2014 SUPPLEMENTAL FOREWORD[1]

"....And as for rivers, I believe it is evident, that they are furnished by a superior circulation of Vapours drawn from the Sea by the heat of the Sun which by Calculation are abundantly sufficient for such a supply. For it is certain that nature never provides two distinct ways to produce the same effect, when one will serve. But the increase and decrease of Rivers, according to wet and dry Seasons of the year, do sufficiently show their Origination from a Superior circulation of Rains and Vapours"... (Keill 1698)[2].

Compare Keill's quotation from 316 years ago with my recollection of a comment in a newspaper by an Idaho legislator in the early 1970s: *"...If God can't guarantee a minimum instream flow, how do you expect us to?..."*

It appears as if human knowledge concerning streamflows had not increased much between 1698 and 1976 (278 years) if solely based on those quotations.

Positive change can be achieved with good science and public comprehension. During the 38 years that followed the 1976 conference, I have been fortunate to observe and participate in immense amounts of positive, productive and protective science based outcomes achieved by state, federal, tribal governmental and private partnerships.

Laws, regulations and programs recognizing instream flow and water level conservation benefits and actions have expanded. This positive momentum has been energized by increased public awareness, comprehension, and participation.

A focal group contributing to this advancement and maintaining its momentum has been the Instream Flow Council (IFC). IFC is composed of representatives from each of the state fish and wildlife agencies in the United States and its territories and the provincial and territorial fish and wildlife agencies of Canada. The seeds for this group were planted before and during the 1976 Boise meeting. An example of a cooperative seed was the fact that the Boise conference was jointly sponsored by the Power Division of the American Society of Civil Engineers and the Western Division of the American Fisheries Society.

Now, instream flow and water level analyses linked to natural hydrologic variability and processes are fundamental to any stream flow and lake/reservoir level project, research study, and water-planning program. Governmental and private sector watershed-planning and subsequent actions rely on scientifically sound instream flow and water level studies.

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[1] *Orsborn, J. F. and C. H. Allman. 1976. Editors. Proceedings of the Symposium and Specialty Conference on Instream Flow Needs: Solutions to technical, legal and social problems caused by increasing competition for limited streamflow. 2 Volumes. Presented by the Western Division of the American Fisheries Society and Power Division of the American Society of Civil Engineers at the Rodeway Inn-Boise, ID. May 3-6, 1976. Published by American Fisheries Society (AFS). Bethesda, MD. 2014* Supplemental Foreword to Instream Flow Council (IFC) e-reprint-with AFS permission.

[2] *Keill, John. 1698. An examination of Dr. Burnet's Theory of the earth together with some remarks on Mr. Winston's New theory of the earth. Printed at the Theater, Oxford, London. Page 148.*

I trust the e-reprint of this conference publication will contribute to those efforts. More people will be able to avail themselves of this historic reference thanks to the IFC and the American Fisheries Society (AFS).

Despite my positive outlook, some that review this publication for the first time may be surprised when agencies and members of the private sector still use the term "*minimum flow*". Others may wonder why some members of the public and agencies still fail to recognize or comprehend there are seasonal life-stage supporting minima. Others might question why there still isn't full consideration and integration of the variety of uses, requirements, and processes meriting recognition and attention beyond those specific to fish. I don't know all the answers. I can only hope this publication will benefit the discussion.

In 1975-6, "*minimum flow"* was considered to be the unused amount *of water* remaining in a water body, after all the impoundment, diversionary, and withdrawal demands (irrigation, municipal and industrial supply, hydropower, etc.) had been met. Certainly we have come farther than this in 38 years. I continue to hope so.

It is an honor to have been bestowed "*Lifetime IFC Membership"* and the 2013 IFC "*Making a Difference Award*". It is even more gratifying and extraordinary this e-reprint will be accessible to current and future generations. This IFC action will help preserve the history of water issues, uses, methods, and values related to instream flow and water level conservation.

It is my pleasure to provide this 2014 supplemental e-reprint foreword to the original 1976 two volume conference publication.

-John F. Orsborn, PE (retired) PhD - May 2014 (orsborn@olympus.net)

INSTREAM FLOW NEEDS

Volume II

A
S F American Fisheries Society

Volume II

PROCEEDINGS
of the
Symposium and Specialty Conference
on

INSTREAM FLOW NEEDS

Presented by the
Western Division of the
AMERICAN FISHERIES SOCIETY
and the
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AMERICAN SOCIETY OF CIVIL ENGINEERS

Solutions to technical, legal, and social problems caused by increasing competition for limited streamflow.

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FOREWORD

The original intent of this conference, as it was conceived in the early 1970's, was to provide a forum and a proceedings to serve as a focal point and a primary reference for persons working on water resource allocation problems. This intent has not changed, though the emphasis on program and proceedings content shifted. Originally the conference was to serve the technical needs of disciplines dealing with methodologies. These needs were thoroughly assessed by a cooperative study, workshop and report prepared by the U.S. Fish and Wildlife Service, Utah State University, and numerous reviewers. Recognizing this accomplishment, the Steering Committee for the Instream Flow Needs Conference revised the original program to emphasize the interdisciplinary aspects of current problems, namely communication and the awareness of legal, social, and technical aspects of preserving instream values and diversionary necessities in emerging areas of conflict.

The success of any conference is, of course, the result of the combined efforts of many people. But the expertise and motivation of the individual contributors is the essence of the endeavor, and their contributions are sincerely appreciated. Also recognized are the cooperation and financial assistance of the following: U.S. Fish and Wildlife Service; U.S. Forest Service; Water Resources Council; Federal Energy Administration; Sport Fishing Institute; Trout Unlimited; State of Washington Water Research Center; and the Albrook Hydraulics Laboratory, Washington State University, where the proceedings was edited. The broad sponsorship reflects the multidisciplinary character of the program and the proceedings.

Papers are arranged in the chronological order of presentation at the conference. Each author prepared his paper camera ready for printing. The papers were reviewed by the editors who assisted with minor corrections or adjustments, but the language of the authors was retained.

We hope that the users of these proceedings will find them to be a valuable reference for instream flow problems.

EDITORS
John F. Orsborn
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Albrook Hydraulics Laboratory
Washington State University
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September, 1976

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THE LEGAL BASIS FOR INSTREAM FLOWS

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ABSTRACT

Water laws are designed to further the interests of the people, and if those interests require instream flows, the law will respond. A surprising amount of current law can be used to protect instream uses.

The law of riparian rights once called for "natural flow" to power textile mills, and today's "reasonable use" rule still preserves living streams and lake levels that add to property values. "Public rights" protect navigable waters now used for recreation. Modern eastern permit laws require minimum flows.

Prior appropriation concepts that recreation is a beneficial use and that not every appropriation requires a diversion can be combined. A dam or diversion that does more harm than good may not be a beneficial use; certainly a permit for one could be denied as against the public interest. Appropriations can be bought and the water left in the stream.

Many model laws exist. Idaho and Colorado permit the appropriation of recreation and scenic flows; Oregon, Washington and Montana accomplish the result by reserving or withdrawing water. Several states spell out the need for environmental protection in the water statutes or general statutes.

No federal project can be built without consideration and avoidance of environmental impact, and no dams can be built on wild and scenic rivers. In some cases, federal navigation laws and federal and Indian reserved rights call for flowing water.

INTRODUCTION

"Aqua currit et debet currere ut currere solebat."[1] Lawyers don't really talk Latin--few of today's law students even qualify for Mr. Justice Holmes dictum that a lawyer should at least have forgotten Latin. But in medieval times the only formal law studies found in universities were of Roman and canon law, and this has left us with a heritage of "maxims," old saws given an air of solemnity and antiquity by their Latin trappings. This one means, "Water flows and ought to flow in its customary manner."

Some maxims are derived from Roman writings, but I can't trace this one back before the early 1800's. Still, that was the formative period of water law as we know it, and it is interesting to note that at the very start the main objective of water law was to preserve the natural flow of water. This rule was once criticized as "non-utilitarian," as allowing the water to "run to waste,"[2] but as the late Jacob Buescher of Wisconsin pointed out, the doctrine was evolved in the early days of the Industrial Revolution and served a very utilitarian purpose as the law kept the water in the streams and passed it down from one mill dam to the next. Water ran the spinning frames and power looms of the early cotton mills and woolen mills, and when that was its greatest value, that the law protected.

This statement sums up my message. The law will protect and foster the greatest values of water. I have been called that rare bird, a legal optimist, for taking the position that the law is what people make it, that if the law doesn't suit you, you may change it. But I have grown tired of hearing that the law is a barrier to wise and good water use, as if the law were some malevolent creature with a life of its own, or as if it were the creation of lawyers whose aim was to complicate transactions and cause trouble between people in order to raise the demand for legal services. Laws are made by people: people with conflicting interests ask the judge to decide which person's interests is to be preferred, people with interests to foster elect legislators who will protect and further those interests. A person who grouses that the law is wrong is either wrong himself or in the minority; if he is right and in the minority he should persuade enough others of his rightness to procure a change. But before we all rush out to buttonhole our legislators or write our Congressmen, let us take a hard look at the laws we have. Some of us may be surprised at how much law presently in existence provides for or can be made to produce instream flows.

RIPARIAN RIGHTS

Most of the emphasis of this conference appears to be on western law, but the conference is national in scope and we should think in terms of eastern states as well. This brings us to the law of riparian rights. Today one might have a tough time trying to persuade a court that the natural flow theory of riparian rights is still good law, that the lowest riparian proprietor on a stream has a right to have it flow as it was wont to flow in nature undiminished in quantity and unimpaired in quality. The modern rule is that each riparian may make a reasonable use of the water. A representative case is Dunlap v. North Carolina Power & Light Co.,[3] in which a riparian complained that a hydroelectric dam interfered with his fishing for pleasure. Relief was denied, the court holding that defendant's use was reasonable and that the claimed right to the natural flow would prevent all sorts of useful employment of the water. But although most American courts have clearly repudiated the natural flow doctrine, they have never given way completely to stark utilitarism. Legal protection is still given to a plaintiff who is not making a use of water as such but who is harmed by an unreasonable use which drys up a stream or lowers a lake. The courts have not clearly articulated a rule for these cases. They have often characterized such diversions or withdrawals as unreasonable and occasionally reverted to natural flow language, but regardless of the form of statement, they have consistently required the defendant to leave a running stream on the plaintiff's property[4] or maintain an acceptable minimum water level in a lake.[5] The decisions recognize that a tract of land through which runs a stream, or one situated on a lake, normally has a greater value than an essentially identical tract without these advantages. The values of the water have been transformed into land values. I recall the University of Pennsylvania extension worker who had once been a farm appraiser; he told me that when he had figured a basic value by multiplying the number of acres by the value per acre, he would add $1,000 if the farm had "living water" on it.

Eastern water law is more than just riparian rules. In some states at least the doctrine of public rights and the existence of a public trust may be called upon to protect flows and streams. The damming of a navigable water way may constitute a perpresture, the illegal blocking of public highway. In those states which recognize the smaller streams as navigable, the canoeists and fishermen now enforce the rights established by the trapper's bateaux and the lumbermen's log drives.[6] Not only must those who would dam streams have state permits under modern law but those who would rather have free running streams may resist the granting of permission.[7]

At least ten of the Eastern states have adopted permit systems which supersede riparian rights or govern their exercise, and four of these adopt some concept of preserving minimum flows.[8] One would think that any minimum flow would be adopted at least in part to preserve recreational opportunities and ecological elements, but some states, New Jersey for example, merely adopt a formula for computing the minimum on a historic basis. In Florida, on the other hand, the criterion for setting minimum flow is the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area.

PRIOR APPROPRIATION

Prior appropriation law is often thought of as one that authorizes the complete destruction of streams. Actually, it offers a number of legal techniques and devices that may be used to keep water in the streams. Some of these are modern inventions and modifications of traditional law, but existing law offers a number of ways in which private persons or groups may protect streams for various purposes. Appropriations are private rights, but they may further public purposes to some extent if they are obtained by a resort which is open to the public or if the public is permitted or is legally entitled to take advantage of the recreational opportunities that often accompany some types of appropriation. The essential element of an appropriation is that the water must be put to beneficial use. There seems to be little doubt that under many circumstances both private and public recreation may be a beneficial use which will sustain an appropriation. As far back as 1913, in the case of Empire Water & Power Co. v. Cascade Town Co.,[9] it was held that water taken for a resort, "a place designed to promote health by affording rest and relaxation,"[9] was put to beneficial use. Several cases have since held that water may be appropriated for the propagation of fish. The Montana court has indicated that a swimming pool was a beneficial use.[10] Cases in New Mexico and Texas have upheld the use of water in reservoirs for fishing and recreation. The New Mexico case involved a multiple-purpose dam, the Texas case an appropriation "for the purposes of game preserve, recreation and pleasure resort." In both the water was open to the public. Today it is very common to include recreation in the list of purposes for which a permit is sought to build a dam.

In most of the above cases the beneficial recreational use was accomplished by diverting or damming the water and an important question is whether an actual diversion is essential to an appropriation. It frequently arose in the early days of the west when pioneers took advantage of natural conditions. Nevada and Utah both have cases holding that reaping the benefits of natural overflow irrigation was not an appropriation of the water,[12] but Oregon held that a water right was so acquired, though the court suggested that as time passed the necessities of economy might require the appropriator to install a controlled system of diversion.[13] Colorado codified this rule in its "meadow rights" statute.[14] Where horses, cattle and sheep do their own diverting, stockmen who regularly and repeatedly pasture the animals on land on which a spring rose or through which a stream flowed were said to have appropriated enough water to supply their herds.[15] In recent years there has been a flurry "vestiges of primitive America", (2) scenic river areas, accessible by road but largely undeveloped, and (3) recreational river areas, readily accessible and partially developed. The Act is in a large measure a land-use control law for protection of the "river corridor" and provides for acquiring ownership of or restricting uses of the land, for control of the location and operation of mines and other activities, and for acquisition of scenic easements. But it prohibits the Federal Power Commission from licensing any dam on a declared river or river under study and no federal agency can construct, sponsor or fund a dam or other project if it would have a direct and adverse effect on the values of the free-flowing river.

Federal dams, however, may augment as well as decrease instream flows. Many now have stream flow maintenance as one of their objectives. The dilution of waste and sewage was the first authorization for this type of water supply but today the 1972 Federal Water Pollution Control Act provides that storage and water releases shall not be a substitute for adequate treatment or other methods of controlling waste at the source.[46]

Most federal water law is concerned with the powers of the United States government and is not like state law that creates rights in water users. But the "doctrine of reserved rights" gives the government its own water rights. When the United States reserves a piece of land for its own purposes, that is, exempts it from the operation of the public land laws and settlement by individuals, it at the same time reserves sufficient water from appropriation to carry out the purposes for which the reservation was made. This doctrine had its start with Indian rights to irrigate Indian reservations, but is has since been applied to other types of withdrawals of land.[47] Some reserved rights may call for maintenance of minimum or natural stream flows. The Paiute Indians have been held to have a reserved right for held in trust for them that entitles them to the maintenance of Pyramid Lake at its present level.[48] In the famous "pupfish case" no pending before the Supreme Court,[49] the United States for preserving a "conservation pool" to prevent the complete destruction of fish and recreation by a total emptying of the reservoir. Additionally, the stored water may be released to preserve or create a minimum flow in the stream below the dam. In such a case, the problem is whether the released water can be protected from a new diversion below the dam. I think it should be, since the beneficial use for which it has been appropriated has not yet been fulfilled. Most states have statutes permitting the owner of a reservoir to use the bed of a stream to carry stored water downstream to the place of use and empowering the water commissioners to see that ditch owners in the intervening stretch of the stream do not pirate the water.[21] These seem to be applicable to the water released for recreation.

Perhaps the most effective use of existing law for stream preservation could be made not by granting appropriations for recreational purposes but by denying appropriations that destroy them. Many a potential dam or large diversion could do tremendous harm to recreational, scenic, biological, and historical values. Many an appropriation is made for only small or marginal values. Does the law give no protection to high instream values in these cases? I think it does. The foundation of an appropriation is beneficial use. This is a term without exact meaning, although sometimes it has been crystallized into absolutes such as "irrigation is a beneficial use." Nevertheless there are many indications that the concept of beneficial use is a relative one,[22] and in proper case, I could conceive of a court saying that a use which did much more harm than it did good was not a beneficial use and would not support an appropriation.

Most states have a better weapon. In all the western states except Colorado an appropriator must apply for a permit, and all of the permit states except Montana and Idaho follow the original Wyoming model which stated that a permit might be denied if the appropriation was contrary to the public interest. This phrase was first construed in a New Mexico case back in 1910, and the court held that the public interest is not limited only to stopping menaces to public health or safety, but the phrase is designed to "secure the greatest possible benefit from [the waters] for the public."[23] This is nothing but the economist's maximization principle, tested by the cost-benefit formula. This power would enable the administrator to deny an application where the total social costs and opportunity costs exceed the benefits to be obtained by the individual, though that individual himself might receive greater benefits than his dollar outlay. The Utah court considering a similar statute subordinated a power project for which application had first been filed to a later permit filed for a multi-purpose project promising greater benefits.[24] This is a recognition of the economist's opportunity costs. The Wyoming Court upheld the denial of a permit for a dam that would destroy a valuable railroad location and interfere with transportation between important parts of the state.[25] Now I am not saying that the state engineers and water officials adopt a cost-benefit approach in every case, but I do say that in a proper case the contest of an application would require the officials to evaluate and weigh the various factors, whether reduced to dollar terms or not, and to deny the permit if the costs exceed the benefits. While in the New Mexico and Utah cases cited above the courts were concerned with the relative merits of different projects, the priniciple applies to a single application.

The benefits and costs are not fixed by law but by people. As the environmental movement shows us, men's ideas of what are costs and benefits have changed. Benefits are those things that people value, and costs are things that people do not like to lose. Perhaps our ancestors, our fathers, we ourselves not too long ago were willing to throw away as worthless some scenic, recreational and environmental factors. Perhaps they were regarded as worthless because of their abundance, but now we realize what is left is far from abundant, that it is scarce, partly because we have already thrown away so much, partly because there are now so many of us that we compete with each other for what is left, and partly because the opportunities for enjoyment have been broadened by the automobile and highway.

No cases directly involving the denial or limiting of water projects in favor of recreational or scenic values have yet come before the courts, but some have been decided by state water officials. An important one is the "American River case" in which the California Water Rights Board, issuing permits for Folsom and Auburn Reservoirs, preserved substantial quantities of instream water. The county of Sacramento has plans for a parkway along the river, a twelve square mile recreational and open space green belt stretching from Folsom Dam to the Sacramento River. The river maintains a number of important fishery resources - salmon, steelhead trout, striped bass and shad. It is also widely used for recreational purposes - swimming, water skiing and motorboating, and the extensive use of canoes, kayaks, and rafts. In its decision the Board required very substantial minimum flows to be left in the river for fish and wildlife preservation and enhancement, and in addition required the reservoirs to release flows for instream recreation in amounts greater than would have existed in the stream in the absence of the projects.

A final aspect of prior appropriation law may be one of the most important measures for the preservation of streams. An appropriation is a property right that may be purchased and put to a new use, under proper regulation to see that no harm is done to others. An example of the use of this feature of the law occurred in the Empire case cited above, involving the use of water for a resort, the first case in which an appropriation for recreation was recognized. One feature of the resort was a beautiful waterfall, but the court said that this could not be saved from upstream appropriation by an attempt to claim the full natural flow, that the resort owner could only insist on enough water to water his trees and park. The case always mystified me because I often visited Cascade as a boy and the falls were still there. Recently I found that after judgment the case was settled by the resort company buying off the power company. Apparently the value of the falls to the resort owner was greater than the value of the water for power purposes, so a private sale was made. Today, in the Mountain states, the Southwest, and in many areas of the West Coast nad Great Plains states, there is no unappropriated water that can be allocated to instream uses, and there will be no more applications for appropriations that can be resisted and denied to protect the streams. New water users such as growing cities and incoming industries must buy out the water rights of existing users. This is the way that new development is taking place in these parts of the west, and this is the route that must be followed if we seek to restore and enhance rather than protect and maintain instream flows. If the economic value of the use of water for recreation, to maintain reservoir levels for fishing and boating, to maintain a minimum flow or restore natural flow in streams for sports fishing, outweighs the value of present uses, then public and private entities may be willing to pay a proper price for the needed water and the owners of the water rights may be desirous of receiving the money. The Isaak Walton League has purchased fishing rights, why not water rights? The Wyoming Fish and Game Commission has powers to buy water rights to maintain fish population and propagation.[26] They have not been exercised beyond the state becoming the owner of water rights appurtenant to lands purchased for public fishing areas, but there is no reason why the water rights may not be operated and maintained for the suitable operation and maintenance of the public fishing area, in other words left in the stream, protected by priority from upstream junior diverters. The Commission could purchase the water rights of an upstream appropriator and transfer it down to a public area that needed water, or it might purchase reservoir capacity for maintaining minimum flows and levels in a public area.

The laws I have described have been with us a long time. However, they do not solve all problems, they do not fill all needs for instream use, and when they do they are not universal, there is conflicting authority and doubt as to their applicability. If it is desired to insure their applicability, to remove the doubts or to go beyond what they allow, new legislation is necessary.

Legislation could take the form of patches applied to the law of prior appropriation to make minor changes in it. I spoke earlier of making appropriations for instream uses, and noted that one countervailing consideration was the danger that everybody would rush out to appropriate his favorite fishing waters. If the opportunity to make such an appropriations is limited to public agencies or officials, this objection may be avoided. The water rights would still be "private rights" although held by a public entity and would be subordinate to private rights and superior to future rights. If acquired for a particular stretch of water, they would protect the specified flow from upstream dams or diversions. This is the technique used long ago by Idaho and recently adopted in Colorado.

In 1925 the Idaho legislature enacted this statute: "The governor is hereby authorized and directed to appropriate in trust for the people of the state of Idaho all of the unappropriated water of Big Payette Lakes or so much thereof as may be necessary to preserve said lake in its present condition. The preservation of said water in said lake for scenic beauty, health and recreation purposes, necessary and desirable for all the inhabitants of the state is hereby declared to be a beneficial use of water."[27] In 1927, similar appropriations were made of Priest, Pend d'Oreille and Coeur d'Alene Lakes.[28] In 1971, the State Park Board was authorized and directed to appropriate, for their scenic and recreational purposes, the waters of a number of identified springs including the famous Thousand Springs. The director of Water Administration was instructed to determine the historical water flow and to grant any future appropriation only above such flow limits and such as "shall not involve any diversion that shall detract from or interfere with the geological interpretative value, historical significance, or the scenic attraction for public use of the waters."[29]

In 1973 the Colorado Legislature overruled the holding of the Colorado River Conservation District case [30] by adopting a new definition of an appropriation: "The application of a certain portion of the waters of the state to a beneficial use." By eliminating the need for a diversion, the new law permits the use of the appropriation technique to preserve and enhance recreational and environmental matters. The statutory definition of the term beneficial use was also broadened to include appropriations of such minimum flows between specific points on natural streams "as are required to preserve the natural environment to a reasonable degree." [31] The law is implemented by granting the Conservation Board the power to appropriate the minimum flow, after receiving the recommendations of the State Division of Wildlife and the Division of Parks and Outdoor Recreation. The state has no preferential rights, but may appropriate the water only in the same manner as a non-governmental water user. The intent seems obvious to restrict such appropriations to those made by the Board under these safeguards, but the grapevine tells me that a number of water districts and other agencies are claiming such appropriations in the Colorado district courts. These have not yet reached the higher courts, so we have no definitive rulings on the question.

Another way of reaching the same result as a state appropriation of the water is by the state withdrawing the water from appropriation by others. This type of legislation has a long history, going back over half a century. In 1915 the Oregon lawmakers took the first step: "The following streams and water thereof forming waterfalls in view of, or near, the Columbia River highway, from Sandy River to Hood River, are hereby withdrawn from appropriation and shall not be diverted or interrupted for any purpose whatever: [naming twenty-three streams and the falls they form]". [32] In 1929, the legislature preserved a fishing stream: "Subject to such water rights as are existing at the time of the taking effect of this act, the waters flowing in the main channel of the Rogue River ... are hereby withdrawn from appropriation; provided this act shall not prevent the appropriation and use of such water for domestic, stock, irrigation, and municipal purposes and provided further that it shall not prevent the appropriation, diversion and use of the waters of any tributary streams."[33] While it looks like the proviso swallowed the provision, the second section made it clear that the statute was intended to prevent the construction of dams in this famous stretch of salmon and steelhead water. The present Chapter 538 of the Oregon Revised Statutes contains a much enlarged list, amendments and additions having been made in 1931, 1935, 1953, 1959, 1963 and 1971.

Another, and newer, form of withdrawal of water from appropriation is found in the Wild and Scenic River Acts of the states, to the extent that they forbid dams or diversions of water that will interfere with the free flowing nature of the streams.[34]

Washington and Montana have taken a broader approach, authorizing the administrative withdrawal of water. In Washington, the Department of Resources may establish minimum flows to protect fish, wildlife, recreational or esthetic values of public waters when in the public interest or when requested by the Fish and Game Department.[35] The Montana statute enables the state, any political subdivision or agency thereof or the United States to apply to the Board of Natural Resources and Conservation for a reservation of waters to maintain a minimum flow, level or quality. No specified grounds or purposes need be shown and the only limitation is that the reservation must be in the public interest.[36]

Another embellishment of prior appropriation would be a statute that insures that the power to deny any permit in the public interest is available when the public interest concerns recreational, scenic and environmental values. There are several models. The Alaska Water Use Act requires that in the issuance of a permit one criterion for determining the public interest is the "effect on fish and game resources and on public recreational opportunities."[37] In 1971 the Utah State Engineer was instructed to reject an application for an appropriation if he has reason to believe that it will "unreasonably affect the public recreation or the natural stream and environment."[38] The new Washington Water Resources Act contains a general declaration of fundamentals for utilization and management of the waters of the state, including the statement that "The quality of the natural environment shall be protected and, where possible, enhanced as follows: (a) perennial rivers and streams of the state shall be retained with base flows necessary to provide for preservation of wildlife, fish, scenic, esthetic and other environmental values, and navigational values. Lakes and ponds shall be retained substantially in their natural condition. Withdrawals of water which would conflict with their width shall be authorized only in those situations where it is clear that overriding considerations of the public interest will be served."[39]

California, in 1965, took steps to make sure that in every case some of these values are considered. Section 1257 of the California Water Code requires an applicant for a permit to appropriate water to set forth all data and informantion reasonably available concerning the extent to which fish and wildlife would be effected by the appropriation, plus a statement of any measures to be taken for their protection.

The Wyoming Water Planning Act of 1973 requires a water resources plan to "identify and specify ... state, regional, and local goals and objectives for management of water resources, including the obtaining of economic efficiency and desirable distribution of income, the protection of the health, safety and welfare of the people, the protection and encouragement of particular industries and activities and the protection and enhancement of the environment." These plans should be employed "to the extent deemed desirable," in determining the public interest in the supervision of the state's water resources, the issuance of water rights permits, and in the regulation and management of water use.[40] To the extent that Wyoming state plans to identify recreational and scenic values of water sought to be appropriated, such plans can give significant data for determining where the public interest lies.

FEDERAL WATER LAW

The historic basis for federal use, regulation and development of water resources was the interestate commerce clause, which gave Congress power over navigable waters used for transportation. In 1890 Congress prohibited the creation of obstructions to the navigable capacity of any waters in respect to which the United States has jurisdiction.[41] This applies not only to dams but to depletions of water, and not only to navigable waters but to their headwaters. Thus an irrigation project in the non-navigable upper reaches of the Rio Grande in New Mexico was held to need Federal permission.[42] But the power is not only to protect navigation, the government may also destroy it. In fact, the United States has built more dams than any other entity in the world. These have always been subject to project review, but the need for instream flows has not kept many from being built. Two modern programs bring a partial reversal of this trend. The National Environmental Protection Act of 1969,[43] and the Principles and Standards for Planning Water and Related Land Resources[44] both require not only that adverse effects of each project be considered, but that alternatives be prepared and one alternative that must be always analyzed and considered is that of no project at all.

Thus every federally built or licensed dam will now be reviewed on a case-by-case basis. On some waters, however, the government has decided once and for all that no dams are wanted. In the Wild and Scenic Rivers Act of 1968, the introductory section states: "The Congress declares that the established national policy of dam and other construction at appropriate sections of the rivers of the United States needs to be complemented by a policy that would preserve other selected rivers or section thereof in their free-flowing condition."[45] The act defines three classes of rivers, (1) wild river areas, purposes of navigation, transport, power production and pollution dilution. The same laws may not serve all of these purposes. The law of instream uses can become as varied and complex as any other type of law.

But a law, or a number of laws, can be found or enacted to serve any one or all of these purposes. The law is a mechanism for getting things done, for accomplishing the purposes of society, for requiring some things and forbidding others. If the people of the United States or of a state desire to keep water in a stream or to put it back in a stream a law can be framed that will do the job. I have tried to show that there is no lack of models -- that somewhere, somehow, the law has done it before.

But if a new law is needed, you will find that law reform is no sport for the short-winded. Water law is a human institution and just as resistant to change as other institutions. Have any of you ever tried to rearrange your school districts into a sensible modern pattern, or the even simpler operation of getting a badly needed new hospital in your community? For an example, I will give you the Wyoming experience. We are making what I believe is normal progress in Wyoming. In 1972, a seminar on wild, scenic and recreational rivers was sponsored by the League of Women Voters, coordinated by the State Recreation Commission and joined in enthusiastically by a number of citizens and their organizations. In 1973, an act was passed that authorized a stream preservation feasibility study and created and funded a study committee. For two years the committee worked diligently and in the next general session of the Legislature produced a very mild bill which would create a permanent council, advisory bodies, set up procedures under which specific streams would be studied and recommended for inclusion by future legislatures into a wild and river system and providing for the appropriation of water by the council and the governor to maintain minimum flows in rivers. Somehow, however, the agricultural interests got the word that they would lose their water rights, they would certainly lose all future development rights, and they would lose control of their lands -- none of which was true. No matter, the bill was killed -- not defeated in session, it never got out of committee. A resounding defeat? No, the beginnings of victory. That same legislature passed an act which reads "In the administration of water rights on any stream and in the consideration of any applications for permits, the State Engineer may require that water be provided to meet reasonable demands for instream stock use."[51] We innoculated them, the germ has been planted. A stockman-farmer dominated Legislature has recognized that for their purposes there are virtues to instream flows. They got theirs -- next time we'll get ours.

FOOTNOTES

1. Black's Law Dict. (4th Ed. 1968) 133.

2. 4 Restatement of the Law, Torts 344 (1939).

3. 212 N.C. 814, 195 S.E. 43 (1938).

4. Collens v. New Canaan Water Co., 155 Conn. 477, 234 A. 825, 1967.

5. Taylor v. Tampa Coal Co., 46 So.2d 392 (Fla. 1950).

6. Diana Shooting Club v. Husting, 156 Wis. 261, 145 N.W. 816 (1914); Elder v. Delcour, 364 Mo. 835, 269 S.W.2d 17 (1959).

7. Meunch v. Public Service Commission, 261 Wis. 492, 53 N.W. 2d 514 (1952).

8. Florida Stat. Ann. §§ 373.081(7)(8), 373.141; Iowa Code Ann. §§ 455A.1, 455A.22; Mississippi Code §§ 5956-02(i)(j), 5956-04, New Jersey Stat. Ann. §§ 58:1-35, 58:1-40.

9. 205 F. 123 (C.A. 8, 1913).

10. Osnes Livestock Co. v. Warren, 103 Mont. 284, 62 P.2d 206 (1936).

11. State v. Red River Valley Co., 51 N.M. 207, 182 P.2d 421 (1945).

12. Walsh v. Wallace, 26 Nev. 299, 67 P. 914 (1902); Adams v. Portage Irrig. Co., 95 Utah 1, 72 P.2d 648 (1937).

13. In re Silvies River, 115 Or. 27, 237 P. 322 (1925).

14. Broad Run Investment Co. v. Deuel & Snyder Improvement Co., 47 Colo. 573, 108 P. 755 (1910).

15. Stiptoe Livestock Co. v. Gulley, 53 Nev. 163, 295 P. 772 (1931).

16. Hunter v. U.S. 398 F.2d 148 (9th Cir. 1967); England v. Ally Ong Hing, 105 Ariz. 65, 459 P.2d 498 (1969).

17. Lamont v. Riverside Irrigation Dist., 498 P.2d 1150 (Colo. 1972).

18. State v. Miranda, 83 N.M. 443, 493 P.2d 409 (1972).

19. Paradise Rainbows v. Fish & Game Commission, 421 P.2d 717 (Mont. 1967).

20. Colorado River Conservation District v. Rocky Mtn. Power Co., 158 Colo. 331, 406 P.2d 798 (1965).

21. Wyo. Stat. § 41-29.

22. Trelease, The Concept of Reasonable Beneficial Use, 12 Wyo. L.J. 1 (1957).

23. Young & Norton v. Hinderlider, 15 N.M. 666, 110 P. 1045 (1910).

24. Tanner v. Bacon, 103 Utah 494, 136 P.2d 957 (1943).

25. Big Horn Power Co. v. State, 23 Wyo. 271, 148 P. 1010 (1915).

26. Wyo. Stat. § 23-15(b).

27. Idaho Code § 67-4301.

28. Idaho Code §§ 67-4302, 4303.

29. Idaho Code §67-4304.

30. Supra n. 20.

31. Colo. Rev. Stat. Supp. 1973 §148-121-3(7).

32. Ore. Rev. Stat. § 538.200.

33. Ore. Rev. Stat. § 538.270.

34. E.g., 82 Okla. Stat. §§ 1451-1458.

35. Wash. Rev. Code § 90.22.010.

36. Mont. Rev. Code § 89-890.

37. Alaska Stat. §46.15.080.

38. Utah Code § 73-3-8.

39. Wash. Rev. Code § 90.54.020.

40. Wyo. Stat. § 41-1.18.

41. 26 Stat. 426, 454.

42. U.S. v. Rio Grande Irrigation Co., 174 U.S. 690 (1899).

43. P.L. 91-190, 42 U.S.C.A. § 4321-4335.

44. 38 F. Reg. 24778 (1973).

45. 16 U.S.C.A. § 1271.

46. 33 U.S.C.A. § 1252.

47. Winters v. U.S., 207 U.S. 564 (1908); Arizona v. California, 373 U.S. 546 (1963).

48. Pyramid Lake Paiute Tribe v. Morton, 354 F. Supp. 252 (U.S. D.C. 1972).

49. U.S. v. Cappaert, 504 F.2d 115 (CA 10th 1974).

50. Tarlock and Tippy, The Wild and Scenic Rivers Act, 55 Cornell L. Rev. 707 (1970).

ADMINISTRATION OF STATE INSTREAM FLOW LAWS

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ABSTRACT

An overview discussion of one state's (Washington) thrust in Administration of existing instream flow laws. Sets forth five principal elements of a state program to ensure that instream flows, as available, are protected to an appropriate level. Activities within the elements set forth are discussed. Results of a "do nothing" course of action are suggested.

INTRODUCTION

I am honored to follow Professor Frank Trelease and believe that my discussion of the administration of state instream flow laws will reinforce several of the points that Professor Trelease has made regarding the legal basis for instream flows.

In the discussions, deliberations, and other exchanges, both at this conference and over the last several years on this subject, I am reminded of the situation depicted in the cartoon (see next page) of the husband and wife out sailing. My wife has this cartoon posted on our refrigerator at home and it can be taken to mean many different things. In the context of multi-disciplined discussions on instream flow needs, one might posit that instead of man and wife, the sailboat contains a biologist and an engineer. With one's head under the water, communication is somewhat difficult and the boat has a hard time sailing very efficiently. It could be suggested, however, that the individual examining the underwater environs is really doing some quite necessary study of surface water conditions, lake level maintenance, or what have you. It might further be suggested that the fellow trying to get the sailboat on an even keel should join his boat mate in such study activity. The results of such an action would either be a capsized sailboat or a sailboat with no one at the tiller. In either case, the sailboat travels rather poorly.

Let us look at the cartoon situation differently. Let us say that it was a bad decision to put all efforts into putting both heads below water and studying the situation. Perhaps both individuals should be hiked out on the

"OOPS.....NOW THE OTHER SIDE, JAN....."

provides for administrative and regulatory agencies to set forth more detailed interpretation of the statutory provisions for the carrying out of the intent of the legislative branch of government.

Administrative Interpretation

The laws setting forth the beneficial uses of water and the ability to protect minimum flows or base flows do not provide the details to accomplish the task demanded. Therefore, in Washington State, paralleling the progression of laws was a progression of administrative "paperwork." That paperwork took several forms, including the simple expedient of making a decision between Fisheries and Game and the water right administrator and then transmitting that decision by letter to an applicant for a permit to use water (1950 through 1970). A lengthy process was followed in arriving at this state's one and only minimum flow determination under RCW 90.22.

The initial thrust under the base flow concept embodied in RCW 90.54 was to administratively set forth a standard criteria to define a point on the recessional limb of a hydrograph considered to represent the "base flow." To individuals who are trained in hydrology, the concept of base flow is understood to mean those streamflows to be expected during periods of little or no precipitation; or basically, that streamflow primarily derived from ground water contributions. The criteria proposed in administrative regulation form was the seven-day, ten-year low flow.

It should be clearly set forth that without some form of instream flow protection, there is the potential for continuing to allow new appropriations of water which may clearly conflict with the undefined instream flow needs. That is, so long as instream needs remain undefined and unprotected, we, in fact, are operating to an instream flow protection of zero cubic feet per second. The concept that an alternative to doing something was to receive no protection has not always been clearly understood.

Several factions believed the criteria proposed was much too limiting and that it was acceptable to have no instream flow protection for the time being, instead of the instream flow protection represented by the seven-day, ten-year low flow. The Department of Ecology decided not to adopt regulations which set forth the blanket criteria.

The program which is being followed at the current time is described in the hand-out entitled, Department of Ecology Streamflow Preservation Program, by Ed Garling. This proposed streamflow preservation program is part of a larger basin management program and is, of itself, not adopted in administrative regulation.

Basin management programs speaking to the allocation of waters in individual hydrologic basins within the state do include allocations for base flows and are implemented by an administrative regulaton to which further water right permitting activities are subject. Both the streamflow preservation program and the basin management program will be discussed later in this session (under the west coast experience).

Criteria for Quantification

Much of this conference revolves about the search, study, and other activity leading to providing specificity to our definition of instream flow needs. We all want that magic number. Many of us think that there is a specific number, which, given enough time, effort, and manpower, will emerge from some formulation or combination of formulations of instream flow need parameters. I would suggest quite strongly that while we are searching for the absolutely correct number, some of us step aside and make the best educated guess that we can, at this time, and set forth some quantification of instream flow needs. We should not believe that the flows "guessed at" are the final answer. Perhaps there never will be a final answer. I do, however, perceive a need for a flow figure different than the zero cubic feet per second which we so often have used in the past.

The State of Washington has proposed and is using a system which basically provides that the agencies entrusted by the public with looking after certain instream functional uses (water quality, fish, wildlife, navigation, aesthetics, etc.) provide a relative rating for the particular reach of stream in question for the several instream flow need functions. A composite rating for each management reach is then applied to a transformation function to be converted to a percent flow duration. That percent flow duration then can be converted directly to a flow on any given day. These base flows are then assessed in light of the overall basin problems, needs and opportunities, and allocations are proposed in a basin management program.

We fully recognize that this course of action includes a degree of subjectivity, but we have not been convinced that any one of the many other proposals being currently worked on provides a better starting point for instream flow protection quantification.

Figure A shows the progression of annual water right filings. Each year, month, or day we delay means further rights granted without recognition of instream flow needs.

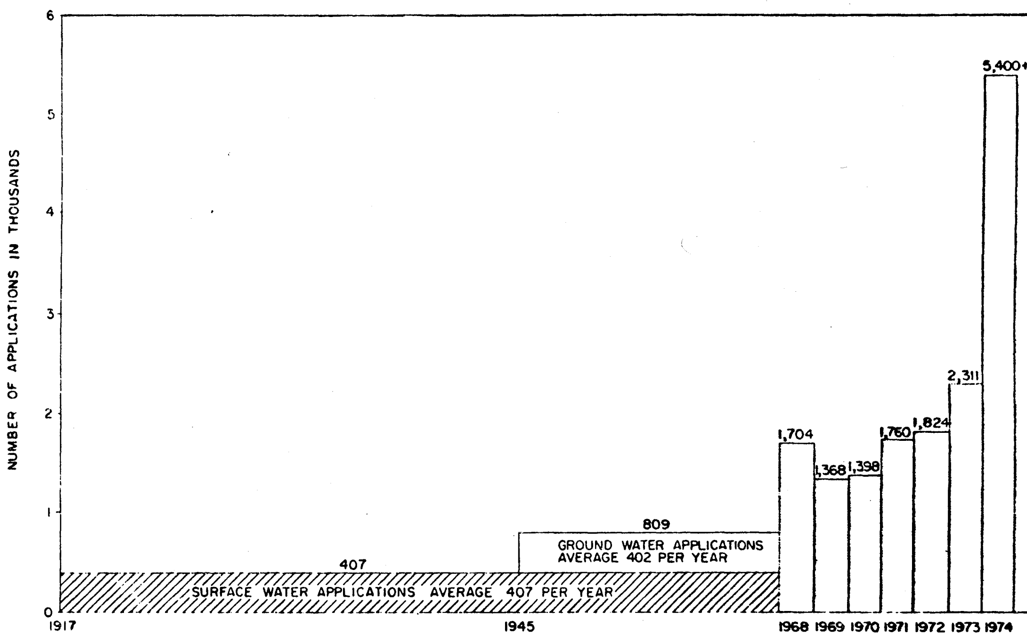

Fig. A. WATER RIGHTS HISTORICAL FILINGS 1917 TO 1974--SURFACE AND GROUNDWATER

Monitoring

Since the state has followed the legal direction through an administrative regulation and set forth specific flows to be protected, the question then becomes: Who does the monitoring of the actual flow conditions in which situations and precisely where?

That question has as many answers as there are management reaches addressed. To date, we have had as many as 31 management reaches in any one basin management program. Each management reach has a designated control point at which monitoring is to occur. Suggested within the basin management program document are specific time frames for monitoring certain or critical stations in the particular basin so that flow trends can be established as early each year as possible. Snow survey data interpretation also plays a clear role here.

Regulation

To ensure that the maximum protection is provided when conflicts arise, regulatory action must be taken. In 1973, the Northwest experienced abnormally low runoff conditions. One case where instream flow needs were protected by a downstream power right, regulation was successfully effected by writing a letter to all users who were to terminate their use. The success of this effort was confirmed by Watermaster field checks.

In Washington State, the story has not been completely written yet on regulation. However, as people better appreciate the fact that "there is no more free lunch," the regulatory situation does become somewhat more easily addressed.

Conclusion

Laws are implemented through administrative action using established criteria with monitoring and regulatory efforts within the local, basin, county, state, and federal political and legal framework. The political framework cannot be ignored.

In 1910, William James wrote an article entitled, "A Moral Equivalent of War," setting forth a concept somewhat similar to legislative proposals by Senator Hubert Humphery and Representative Rues in 1958. The concept was administratively effected by President Kennedy in 1961 by Executive Order. It was called the Peace Corps.

Ladies and gentlemen, I believe that we have a moral imperative to allocate water to provide instream flow protection levels greater than zero. In Washington State the idea has been actively set forth since the late forties. Let us hope, for the sake of our children and grandchildren, that those activites now being pursued are successful before the year 2000.

Let us define clearly our objective, get on the right side of the sailboat and sail on an even keel towards our common destination.

I look forward to seeing many of you in the following session on the west coast experience where I will discuss details more, philosophy less.

7-COURTS CASE--EAGLE COUNTY, COLORADO

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SUMMARY OF THE PARTIAL REPORT

To assist Court and counsel, the Master-Referee has prepared the following summary of this partial report. Since this summary is not a substantive portion of the partial report, any conflict between the summary and other portions of the report shall be resolved in favor of the other portions.

1. Water appurtenant to the various federal reservations involved herein, to wit: national parks, national monuments, national forests, public springs and water holes, and mineral hot springs, may be reserved for use on the reservation to which the water is appurtenant.
2. The United States intended to and did, in fact, reserve waters for use upon the reservations under consideration in this matter.
3. The United States must quantify the reserved right appurtenant to the above reservations and withdrawals.
4. Although the United States is entitled to conditional and absolute water rights for the benefit of the various reserved lands in this matter, the reserved right of the United States must be strictly construed and is not as broad and so extensive as claimed by the government.
5. The reserved water right does not exist or have a priority to serve reserved land prior to the date that such land was reserved, nor to serve any but the purposes of the reservation <u>as they existed at the time that the land was reserved</u>. For example, the reserved right for minimum stream flows and lake levels on national forests bears a priority date as of June 12, 1960, rather than any earlier date of reservation. In addition, all reserved rights on the national forests, regardless of the date upon which such right was established are subject to the terms of 16 U.S.C. §481, which permit the use of all water on the national forests for domestic, mining, milling, and irrigation purposes.

5\. The concept of equitable estoppel may be applied against the United States in this case. Based on the facts herein, the United States is estopped to deny that its reserved water rights are subject to those of the Twin Lakes Reservoir and Canal Company and the Southeastern Colorado Water Conservancy District.

6. The defense of _res judicata_, raised by the Jackson County Water Conservancy District, the City of Fort Collins, Colorado, the Water Supply and Storage Company, the Colorado Cattlemen's Association, and certain individual protestants, is inapplicable and not a bar to the assertion of the claims of the United States in this matter.

TOPIC IV-A.

7-COURTS CASE--EAGLE COUNTY, COLORADO

Summary Discussion

Most questions addressed Mr. White's interpretation of the details of his recent and timely opinion of the case. Mr. White's scholarly review of the evidence produced two points of primary interest to the Forest Service: (1) The Forest Service in its claims for waters within the appropriation system of five Colorado Water Districts, shall have a priority date of 1960. This corresponds to the Sustained-Yield, Multiple-Use Act of 1960 and supports interpretations of the non-recreational nature of the Forest Service upon establishment of instream flow. (2) The interpretation of the intent of the Forest Service to provide for "milling, manufacturing...and municipal...water demands" off the reservation was upheld. This interpretation greatly extends the duty of waters rising upon or flowing through Forest Service lands, and allows municipalities an almost equal appropriative status with the reserved right.

Notes by panel moderator: Charles G. Prewitt
Steering Committee Member

THE RESERVATION OF INSTREAM FLOW FOR FISH IN CALIFORNIA - A CASE STUDY

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ABSTRACT

Forty-five projects that altered instream flows in California were intensively examined to assess the process of acquiring instream flow reservations. Sixty-four percent of those examined have instream flow reservations. Almost all of these reservations were acquired after 1950 and were predominantly achieved to preserve salmon, steelhead and trout. Three reservations were acquired to benefit only non-game species. Technical investigations centered on the spawning and passage requirements of anadromous salmon and steelhead and the summer low flow habitat of trout. Most instream flow reservations were based on general stream surveys and negotiations. Among the specific technical methodologies, the usable width transect method was most common. During the 1960's, the average percentage of the natural flow acquired by reservation for November, February, May and August was 53, 24, 16 and 98 percent, respectively.

INTRODUCTION

Most reports on instream flows for fish have been concerned with technical methodologies used to ascertain the amount of instream flow needed by salmonid fishes. Although such methodologies enter into this study,[1/] it is directed more broadly to the total effort of acquiring Instream Flow (ISF) reservations for fish in California. Through the investigation and evaluation of major flow-altering projects in California, the study objective is to assess:

- Project evaluation processes
- The effectiveness of biological investigations
- The influence of institutional controls
- Constraints on success
- Opportunities for the achievement of adequate ISF reservations

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[1/] U. S. Fish and Wildlife Service, Western Water Allocation Project, Office of Biological Services, Ft. Collins, Colorado, Dr. Harvey Doerksen, project leader (Contract No. 14-16-0008-955).

From the analysis and evaluation of projects and associated historical events, recommendations will be made and directed toward the improvement of both technical and procedural methods.

Since the total study has not been completed, this report conveys preliminary information and data relative to the study objectives. Because of its preliminary nature, the data and analysis given should be considered tentative and subject to change in the final analysis. The scope of the report has necessarily been narrowed and is restricted to several pertinent data observations and conclusions that hopefully will merit discussion in this symposium.

APPROACH

Three major investigations constitute the study approach. During July and August 1975, a survey was made of major projects that altered stream flows in California. Consistent with California's wet and dry seasons, deserts and major centers of population in arid areas, great governmental and private effort is put into water projects that alter stream flows. In addition to power production, the trend is to convey water from areas of high precipitation to arid agricultural and urban areas. Thousands of surface streams have been impounded or diverted from their natural courses. A recent inventory of dams in California gave a count of 1,091;[2/] moreover, 16,000 water rights permits have been issued to divert surface water[3/] and many of these diversions affect fish and wildlife.

2/ Department of Water Resources Bulletin No. 17-67, Dams Within the Jurisdiction of the State of California.

3/ State Water Resources Control Board, Water Rights Division, file data.

Using library research and contracts with federal, state and local agencies, an effort was made to discover major projects susceptible to investigation and evaluation relative to the study objectives. Eighty-seven such projects were reviewed, and 50 were finally selected for intensive case study. These initial screenings are reported in the Jones & Stokes Associates report, Assessment of Effects of Altered Stream Flows on Fish and Wildlife in California, Task I: Inventory of Projects Recommended for Case Study, August 28, 1975.

After the approval of 50 projects for case study by the U. S. Fish and Wildlife Service (USFWS), an intensive effort was applied to learn as much as possible about events connected to the reservation of instream flows. This effort required visits to project sites, the review of published reports, file searches and interviews with persons who participated in projects during their developmental stage. The case studies have been completed with each case appearing according to the following outline: Project Description, Pre-Project Conditions, Project Development, Post-Project, Conclusions, Personal Contacts, and Bibliography. The case studies are described in the second Jones & Stokes Associates, Inc. report, Task 2: Individual Case Study Results and Evaluation, April 30, 1976.

Environmental Orientation

Any discussion of stream flow reservations for fish in California should be considered in light of the many diverse environmental features that influence stream flows. Although this need cannot be adequately covered here, it seems pertinent to illustrate some of the broad features. The major river systems are shown in Figure 1, indicating the locations of projects considered in the study. Figure 2 gives a view of the magnitude of annual runoff which responds to the amount of precipitation and relates to a stream's geomorphology. California's landscape provinces which can be typified by both biological and physical associations are shown in Figure 3. The projects chosen for case study have representatives in almost all of the broad bio-physical categories as indicated in Figure 4.

Institutional Orientation

The agency having principal involvement in almost all stream flow altering situations is the California Department of Fish and Game (DFG), while the USFWS is most heavily involved in federally sponsored projects. However, both agencies appear to coordinate their activities as required along with other federal and state agencies through statutory responsibilities and interagency agreements. Figure 4 illustrates the three most common initiators of stream flow alteration and the corresponding network of agency involvements.

Observations

Although 50 projects were researched as case studies, 45 are retained for continued analysis and evaluation. The list of projects and a consolidation of some of their statistics is in Table 1. The general locations of these projects are in Figure 1. The organization of Table 1 by DFG region reflects the manner in which case studies are being processed. In addition to distributed agency reports, most project data and information is retained in either project or stream survey files in a DFG region. Augmenting sources are other agency files principally in the USFWS (Sacramento), U. S. Bureau of Reclamation (USBR),

Table 1. SYNOPSIS OF CASE STUDY DATA

Case Study Number (Figure 1)	Project	River or Creek	Date of Development	Date of Agreement	Principal Fish	Instream Flow Reservation - Normal Year Feb.	Aug.	Instream Flow Reservation - Pre-Project Flow Feb.	Aug.	Index to Public Concern
	REGION I									
1	Iron Gate	Klamath	1960	1958	KS,SH	1300	1000	0.90	0.83	4.28
4	Trinity Lewiston	Trinity	1963	1959	KS,SH	150	150	0.06	0.60	2.53
6	Ruth	Mad	1961	1955	SS,SH	75	40	0.06	2.0	2.99
71 & 72	Pit No. 6 & 7	Pitt	1965	1961	T	150	150	0.03	0.07	0.90
2 & 3	Shasta-Keswick	Sacramento	1949	1972	KS,SH, OGS	2600	2300	0.18	0.57	3.89
	REGION II									
67A	Oroville-Thermalito	Feather	1968	1967	KS,SH, OGS	400	400	0.05	1.6	4.87
32 & 33	Folsom-Nimbus	American	1956	1972	KS,SH, OGS	1250	800	0.21	1.06	5.87
8	Antelope	Indian	1964	1962	T	10	5	0.1	0.6	1.30
10	Rock Creek	Feather	1950	1950	T	50	100	---No Data--		0.84
26	French Meadows	American	1964	1962	T	8	8	0.1	0.8	1.55
27	Hell Hole	American	1963	1962	T	20	10	0.1	0.2	1.97
28	Loon Lake	Gerle Creek	1963	1962	T	8	8	0.4	0.3	0.90
35	Salt Springs	Mokelumne	1931	1947	T	5	10	0.1	0.1	1.67
36	Spicer Meadows	Highland Creek	1929		T	0	0	0	0	1.30
41	Sand Bar	Stanislaus	1939	1955	T	10	15	0.1	0.1	0.77
75	Lake Tahoe	Truckee	1913	1954	T	50	50	0.6	0.1	2.84
68	Black Butte	Story Creek	1962		KS,SH	0	0	0	0	1.07
	REGION III									
37	Nicasio	Nicasio	1961	1960	SS,SH	14	None	0.1	---	1.7
38	Lagunitas	Lagunitas	1954	1954	SS,SH	---	---	---	---	1.9
13	Scott	Eel	1921		SH	---	---	---	---	2.2
14	Cape Horn	Eel	1907		KS,SH	---	---	---	---	1.1
15	Coyote	Russian	1958	1959	KS,SH, SS,OGS	150	150	0.2	0.8	3.2
59	San Pedro	San Pedro	1973	1967	SH,SS	0.15	0.15	---No Data--		1.8
79	Nacimiento	Nacimiento	1957		T,SH	---	---	---	---	1.9
81	Thelma Adair Keyes	Butano	1967	1962	SS,SH	3.0	1.05	4.67	25.0	1.7
86	Whale Rock	Stony Creek	1960		SH	---	---	---	---	0

Table 1 continued.

Case Study Number (Figure 1)	Project	River or Creek	Date Development	Date of Agreement	Principal Fish	Instream Flow Reservation - Normal Year Feb.	Instream Flow Reservation - Normal Year Aug.	Instream Flow Reservation-Pre-Project - Flow Feb.	Instream Flow Reservation-Pre-Project - Flow Aug.	Index to Public Concern
	REGION IV									
50 & 50A	New Melones-Goodwin	Stanislaus	1914	1960	KS,SH, OGS	125	100	0.05	0.1	1.53
52	New Don Pedro	Tuolumne	1971	1964	KS,SH, OGS	280	3.0	0.1	0.1	1.84
54	New Exchequer	Merced	1967	1966	KS,SH, OGS	200	100	0.2	0.3	1.65
63	Friant	San Joaquin	1947		KS,SH, OGS	---	---	---	---	0.76
64	Pine Flat	Kings River	1954	1964	T	50	50	0.03	0.03	2.82
47	Hetch-Hetchy	Tuolumne	1923	1958	T	35	75	0.1	0.3	2.71
73	Isabella	Kern River	1954		T	---	---	---	---	2.15
55	Snelling	Merced	1910		KS,SH, OGS	---	---	---	---	2.50
	REGION V									
83	Mojave	Mojave River	1971		NG	---	---	---	---	0.41
85	Big Bear Lake	Bear Creek	1912		T	---	---	---	---	0.88
82	Lake Morena	Cottonwood	1894		NG	---	---	---	---	0
84	El Capitan	San Diego	1934		NG	---	---	---	---	0
58	Sabrina	Bishop Creek	1911		T	---	---	---	---	1.25
57	Pleasant Valley	Owens River	1955	1955	T	75	75	0.4	0.2	2.16
56	Rock Creek	Rock Creek	1963	1960	T	15	25	1.0	0.7	2.49
49	Bridgeport	E. Walker	1924	1953	T	8	50	---No Data--		1.62
48	Lower Twin Lake	Robinson	1888		T	---	---	---	---	1.95
80	I. M. Dawson	Unnamed Spring	---		None	---	---	---	---	0
77	Santa Felicia	Piru Creek	1955	1955	T	10	10	0.1	2.0	0.89
76	Henshaw	San Luis Rey	1923		T	---	---	---	---	1.24
74	Casitas	Coyote Creek	1959		SH	---	---	---	---	1.07

LEGEND FOR FISH:

KS	King salmon (Oncorhynchus tshawytscha)
SS	Silver salmon (Oncorhynchus kisutch)
SH	Steelhead (Salmo gairdneri)
T	Trout (Salmo gairdneri, clarki and trutta; Salvelinus fontinalis)
OGS	Other game
NG	Nongame
0	None

U. S. Geological Survey (USGS), State Department of Water Resources (DWR) and the State Water Resources Control Board, Water Rights Division (SWRCB). Table 1 cites the approximate year of instream flow reservation development, or if there is no reservation, the time when it was considered. In a few instances, the ISF reservation occurred sometime after project development. In 11 cases where this occurred, the DFG and USFWS were permitted to reenter the ISF reservation arena because of project alterations, Federal Power Commission relicensing, application for water rights, and/or the proposed implementation of a new project upstream of an existing project.

The ISF reservations achieved may vary seasonally and by water year, i.e., normal year and dry year schedules. To reduce the volume of data, only February and August reservations for normal years are shown in Table 1, because they represent the most divergent cases. To illustrate the achievement of ISF, the ISF reservations for February and August are listed along with the fraction of the pre-project mean monthly flow reserved for fish. The fish populations present, which are considered the stimulus for the acquisition of the ISF reservations, are noted except for non-game species which are ubiquitous. Only one case, I. W. Dawson, No. 80, Region 5, was found to historically have no fish population. Three others presently have no fish because the stream channel was dried after project construction.

The index to public concern in Table 1 was developed from the professional judgment of biologists who have had long-term responsibility for fisheries resources in project streams. This index is used to assess possible public input into the ISF reservation process in lieu of records, which could supply a measure of their concern more directly, but such records are rare. Figure 5 illustrates the relationship between the index of public concern and the fraction of pre-project flow reserved for trout and salmon.

Among the 45 cases, 16 or 36 percent have no ISF reservation. A tabulation of ISF reservation achievement (64 percent) is in Table 2. The ratio of success appears greatest in DFG Regions 1 and 2 which contain the major populations of salmon and steelhead. Regions 3 and 4 have less abundant salmon and steelhead but greater population of trout. Except for the eastern slope of the Sierra Mountains south of Lake Tahoe, Region 5 is to a large extent very arid, with few perennial streams and large urbanized sections. These features, among others, are assumed to have significantly diminished the opportunities for the achievement of ISF reservations in Region 5.

During pre-project conditions, 26 of the 45 projects were principally salmon-steelhead streams. Fifteen or one third were trout streams. Ten were recognized to also have other game species such as striped bass, shad, large-mouth and/or smallmouth bass, sturgeon or what are commonly grouped as warm-water fish. Although 44 of the streams have non-game species cited as possible beneficiaries of ISF reservations (Table 3), three streams had only non-game species. In many case study instances, trout were shown to be beneficiaries in salmon and steelhead streams. Although there are resident trout in some of these streams, they were grouped with steelhead in Table 3. Differentiations between rainbow, brown and cutthroat for the purpose of ISF reservations were rarely discovered in the case studies.

Biologists who had worked on the projects were interviewed and asked to respond as to whether or not a species was considered in the project development stage, vis a vis ISF reservation. Their responses are also tabulated in Table 3. Except for non-game species, they believed that game fish were positively considered even in streams where they were not historically a significant resource.

Table 2

INSTREAM FLOW RESERVATIONS BY
CALIFORNIA DEPARTMENT OF FISH AND GAME REGIONS

		1	2	3	4	5	Total
Projects (case studies)	No.	5	13	8	7	12	45
	%	11	29	18	15	27	100
Projects without instream flow reservation	No.	0	1	4	3	8	16
	%	0	8	50	43	67	36
Projects with an instream flow reservation	No.	5	12	4	4	4	29
Normal year	No.	5	12	4	3	4	28
	%	100	92	50	43	33	62
Dry year	No.	1	6	1	2	0	10
	%	20	46	12	29	0	22
Other schedule	No.	0	0	0	1	0	1
	%	0	0	0	14	0	2

Table 3

DISTRIBUTION OF FISH POPULATIONS AMONG THE CASE STUDIES
AND THE CONSIDERATION GIVEN TO THE POPULATIONS DURING
PROJECT DEVELOPMENT STUDIES AS DETERMINED BY INTERVIEW

Fish Population Category	Number of Identified Pre-Project Cases	Number Considered During Project Development as Determined by Interview
Salmon	14	18
Steelhead	18	19
Trout	15	58[1]
Other game	10	36
Nongame	44[2]	38
None	1	0

[1] Trout fishing in salmon and steelhead streams is considered as fishing for steelhead in the pre-project category. Trout occur in streams not available to steelhead and salmon. In the interviews, smolts were considered trout. No differentiations for cutthroat or sea run brown trout were found.

[2] Three streams contained only nongame species and water was sought to preserve these fish.

Among the categories of information evaluated are some of the life history needs of species considered principal beneficiaries of an ISF reservation. In almost all instances these were king salmon, silver salmon, steelhead trout, rainbow trout and brown trout. The life histories of these fishes are well documented in fisheries literature. Life stage relationships to their physical environment are only partially understood. Accordingly, an interview assessment was made of considerations given to life history and habitat requirements during the original project development and reentry stages (Table 4). Project biologists were more heavily oriented toward considering spawning and passage than other categories. Cover and food supply received less emphasis while competition and predation received very little attention. Although the areas of emphasis remained about the same, greater attention was paid to Table 4a categories in projects reentered for the acquisition of new ISF reservations.

Another category assessed by interview was the perspective for achieving an ISF reservation. Did the biologists consider the ISF reservation? Did the biologists consider the ISF reservation acquisition in terms of extinction, impairment, preservation, enhancement and/or flushing? Were disruptive floods considered? ISF reservations for the preservation of existing fish was the dominant consideration although some projects were seemingly processed with a viewpoint for achieving either impairment or enhancement flows. Flushing and flood flows were peripheral in their considerations. Reentry into projects does not appear to have changed this situation.

Characteristically fisheries biologists' interests center on field investigations that can provide an estimate of the amount of instream flow needed to maintain a desired fishery. (Only recently have the needs of wildlife entered into such investigations in California.) In the case study interviews, an attempt was made to determine how project biologists recalled the types of

Table 4

RESPONSES TO INTERVIEW CATEGORIES CONCERNED WITH LIFE HISTORY CONSIDERATIONS, ISF PURPOSE AND FIELD INVESTIGATION METHODS

	% of 45 Projects Receiving Consideration in Development Stage	% of 11 Projects Receiving Consideration in Reentry Stage
A - Life History Considerations		
1. Life history literature	56	90
2. Standing crop	42	100
3. Spawning habitat	44	100
4. Cover habitat	20	54
5. Food supply	20	54
6. Passage	49	82
7. Competition	9	27
8. Predation	11	45
B - Flow Reservation Objective		
1. Extinction	2	
2. Impairment	16	9
3. Preservation	49	54
4. Enhancement	4	9
5. Flushing	11	
6. Flood control	2	
7. Other	4	
8. No response	12	
C - ISF Reservation Field Investigation Method (more than 1 pre-project used)		
1. Basin plan		9
2. Stream survey	51	45
3. Instream flow study	13	18
4. Usable width	18	18
5. Weighted usable width	4	27
6. Special habitat	4	45
7. Conceptual model of system	4	0
8. Mathematical model	4	0
9. Comprehensive ecological investigation	4	36

investigations used during the project development and reentered project stages. Recognizing that more than one type may have been used for a particular project, no attempt was made to limit the number of choices. Table 4c indicates the percentage of the 45 projects receiving some effort for each type of investigation.

The most common investigation has been the stream survey which relies on general, broad scope data describing the stream environment, e.g., creel census, spawner sightings, ad hoc sampling of biota and unverified opinion. Among the available technical methodologies more closely connected to determining instream flow needs, instream flow studies and usable width transect studies have been used most frequently. Recently, the weighted usable width transect study has come into vogue.

Systems approaches based on conceptual and mathematical models and comprehensive ecological investigations were cited for a few projects, but except for the New Melones project, there is no evidence of such levels of study in the case evaluations. These differences are undoubtedly based in part on opinion. Projects that are reentered for the acquisition of a new instream flow reservation have emphasized special habitat studies as indicated by the rise from 4 to 45 percent. This change certainly seems reasonable when one considers that reentry investigations are based on previous ISF reservation experience for that particular project.

Discussion

Among the cases evaluated, 29 have ISF reservations using 31 different cubic feet per second (cfs) values. Figure 6 illustrates the frequency of occurrence of the 31 cfs values. An idealized curve responsive to these frequencies indicates a tendency for 10 and 100 cfs. Additional analysis of the availalbe data is required to determine the validity of such observations.

An interest in achieving ISF reservations has become intense only since the 1950's. A review of 6,000 water rights permits indicated that ISF reservations did not become common until after the mid 1950's. One hundred seventy-four of the 6,000 permits reviewed had stipulations providing water reservations for fish and wildlife. A few of these applied to watering tanks rather than ISF. No attempt was made to determine how many of the 6,000 permits could have received consideration for ISF reservation as opposed to the 174 receiving a reservation.

Some of the projects altering instream flow pre-date 1900. Among the 44 cases involving fish, the oldest project having an instream flow reservation is the Lake Tahoe Dam (1913), but the ISF reservation was only achieved in 1954. Figure 7 lists projects according to their decade of implementation and ISF reservation achievements. The record for achievement is most complete after 1940. ISF reservations on earlier projects were often implemented sometime after construction. Also, many post-1970 projects are still in process so this decade is not presently well researched; consequently, one must look to 1950-1969 data for the best indication of ISF reservation actions.

Certainly the trend toward achievement of ISF reservation has risen. The case studies indicate that the success ratio has about doubled from the 1950's to 1970. The amount of natural flow reserved for fall, winter and spring has remained about the same; however, the reserved fraction of the pre-project flow for the dry period (August) has risen to an average of 98 percent in the 1960-1969 period.

The mean percentage of the natural pre-project ISF reserved for fish in comparison to three hydrographs, representative of different ecosystems in California (Figure 7), is thought to illustrate an interesting and important historical condition. The case study evaluation indicates that most of the technical work and correlative negotiations have concentrated on achieving

ISF reservations for the low flow summer period and salmon-steelhead passage in autumn. The interview data in Table 4 tends to support this observation. One may conclude that it was expedient to neglect considerations of winter and spring ISF, because at first glance, these post-project flows were usually greater than flows at other times of the year and thus supportive of fish.

At least two situations exemplify the importance of seasonal peak flows: the success of smolt migrations in the San Joaquin River and the physical deterioration of the quality of the Trinity River below Lewiston. Correlation analysis of success of returning king salmon adults and the spring ISF during their out-migration as smolts[4/] illustrates the importance of ISF reservations during April and May. The loss of flood flows in the Trinity River has allowed the channel below Lewiston to fill with decomposed granite and encroaching willows which deteriorates salmonid spawning and passage. In this case the ISF reservation index for February and May is 0.065 and 0.039, respectively. The post-project flow during the winter and spring on the average has amounted to 10 to 20 percent of the natural flow which exceeds the reservation but is still insufficient.

The foregoing observations have represented some of the preliminary findings of the California ISF reservation case study. The principal relationships discussed illustrate an unequal application of the processes and procedures available to achieve ISF reservations in that there has been a concentration of effort on ISF for the dry seasons with a neglect of other seasons. This inequity may have elicited the problems cited, and with further analysis, other problems will certainly be discovered. In the case study review, one

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4/ California Department of Fish and Game, 1972. Report to the California State Water Resources Control Board on Effects of the New Melones Project on Fish and Wildlife Resources of the Stanislaus River and Sacramento-San Joaquin Delta, Region 4, Fresno.

can find evidence that only salmon, steelhead and trout are given serious consideration in ISF evaluation processes and among these fishes, spawning, cover and passage is emphasized for investigation. It is concluded that a narrowness of ecological viewpoint has prevailed which is detrimental to the achievement of adequate instream flow reservations. Furthermore, any evaluation of effectiveness of the ISF reservations achieved is greatly weakened, because there have been no follow-up investigations designed to measure effectiveness.

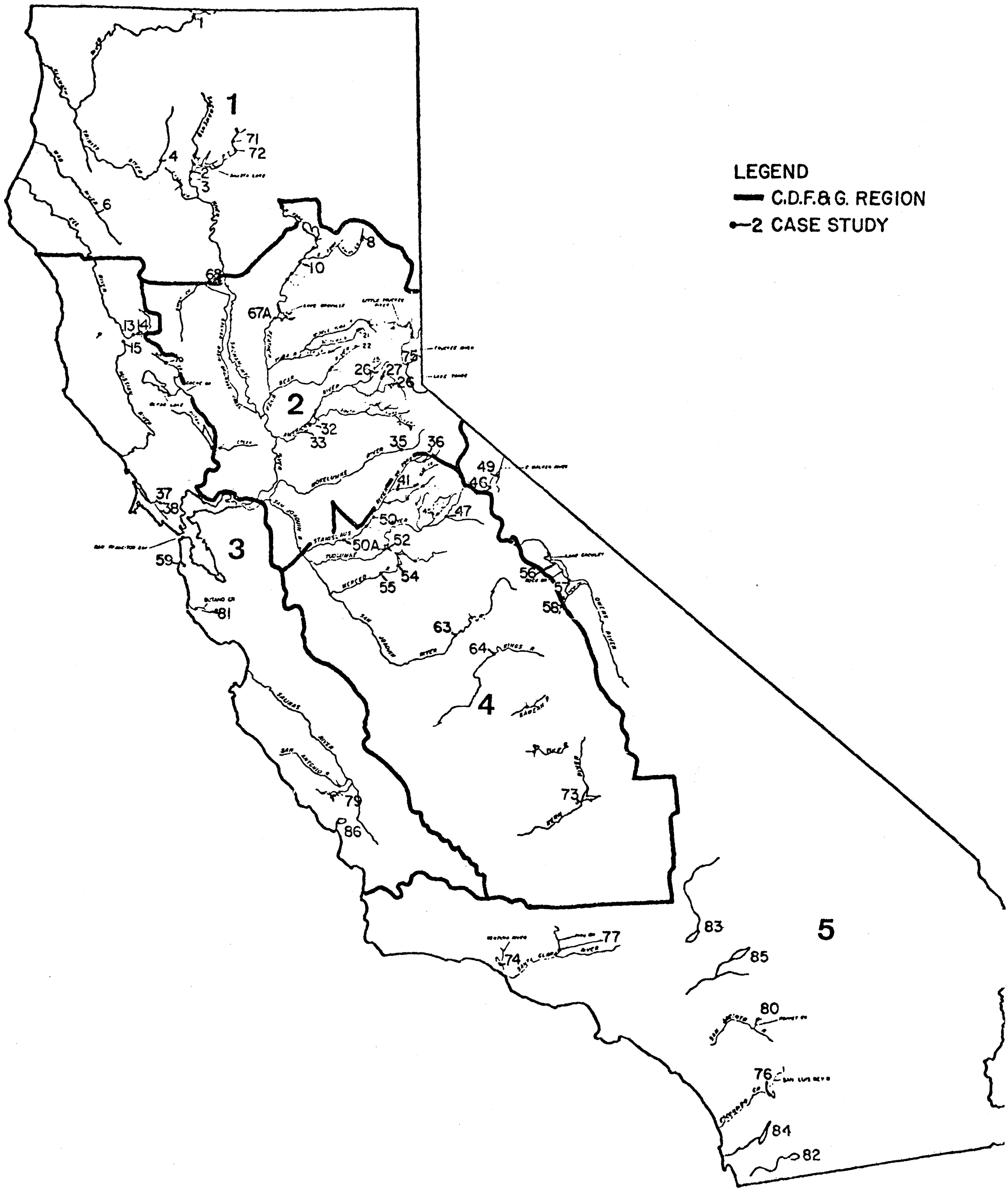
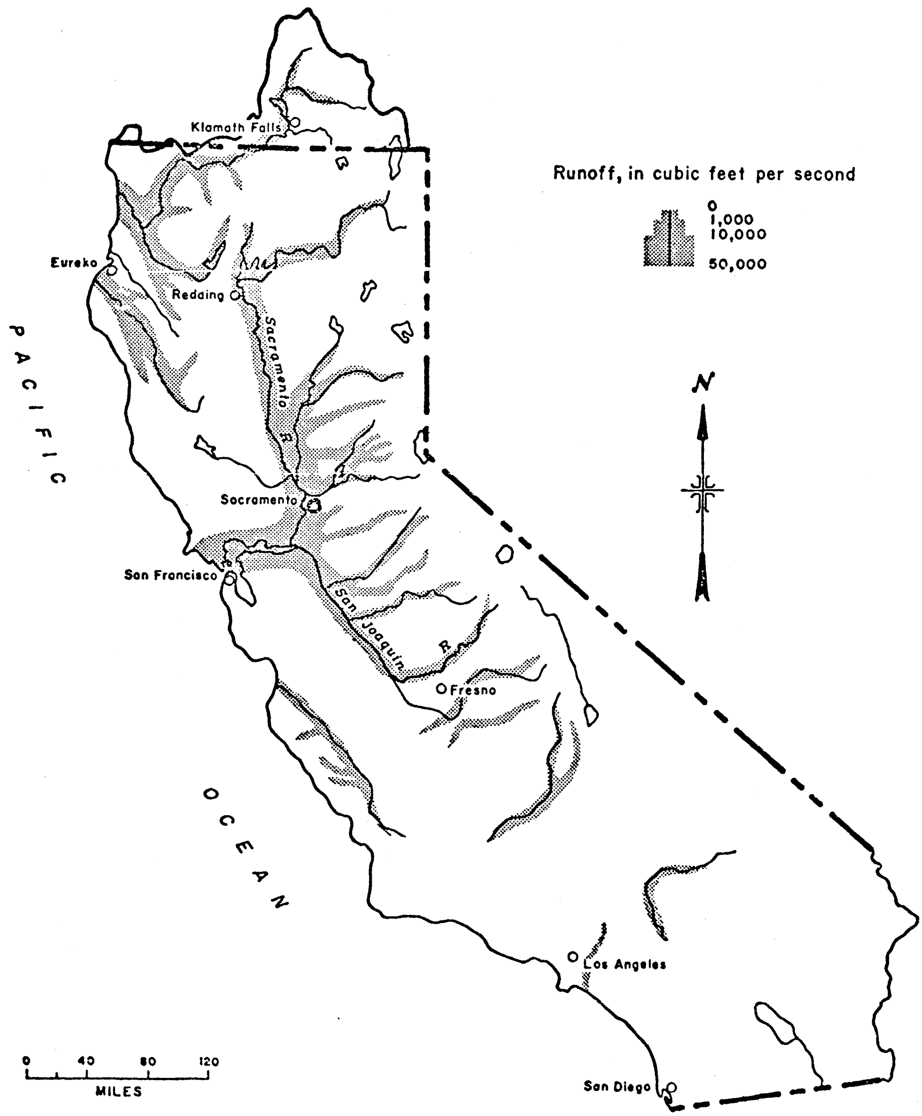


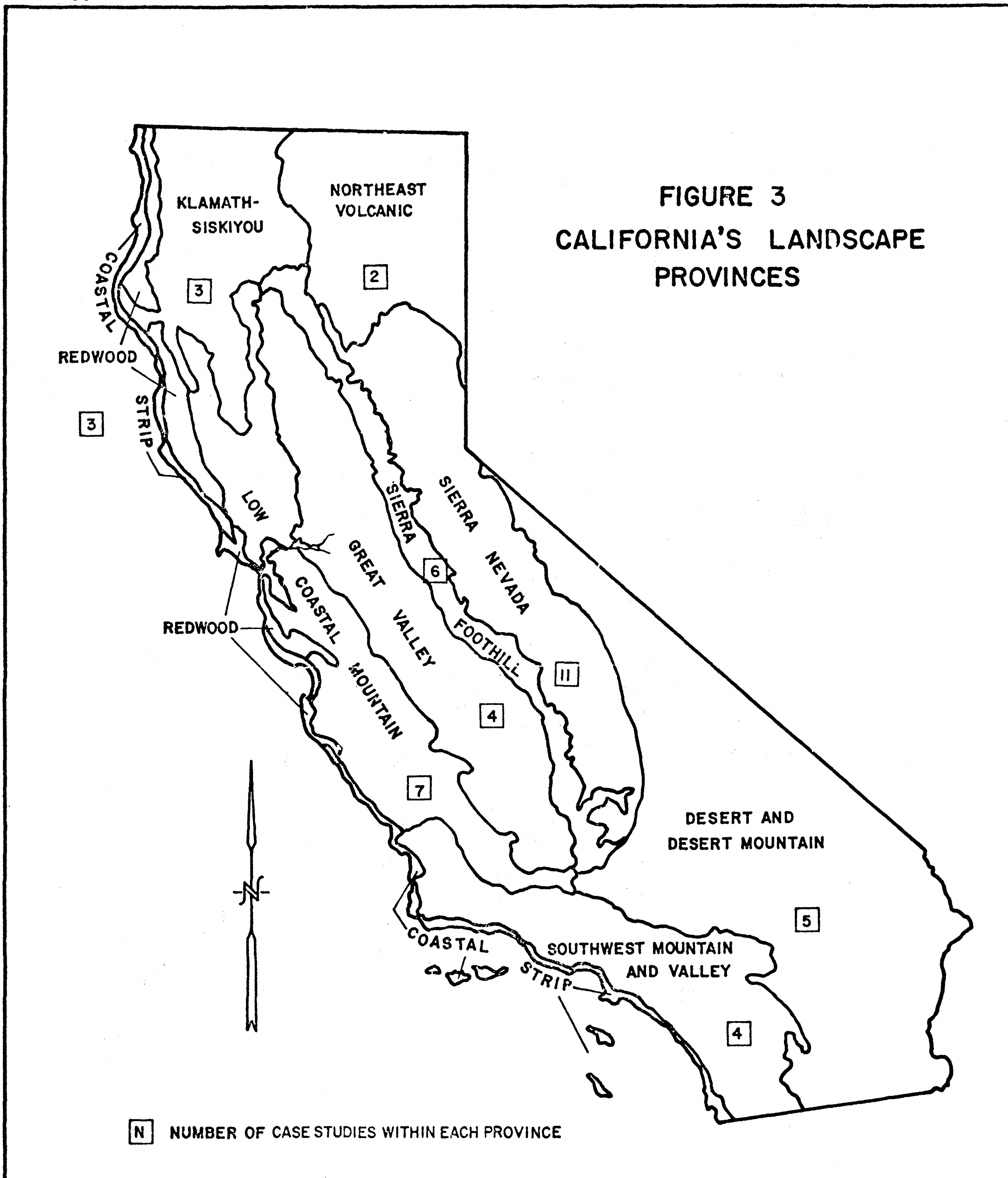
FIGURE I CASE STUDY PROJECT LOCATIONS IN REFERENCE TO MAJOR RIVERS AND DEPARTMENT OF FISH & GAME REGIONS

Figure 2

MEAN ANNUAL NATURAL RUNOFF OF PRINCIPAL STREAMS, 1931-60
California Region



From: Comprehensive Framework Study, California Region (1971).



Modified from Mason (1970)

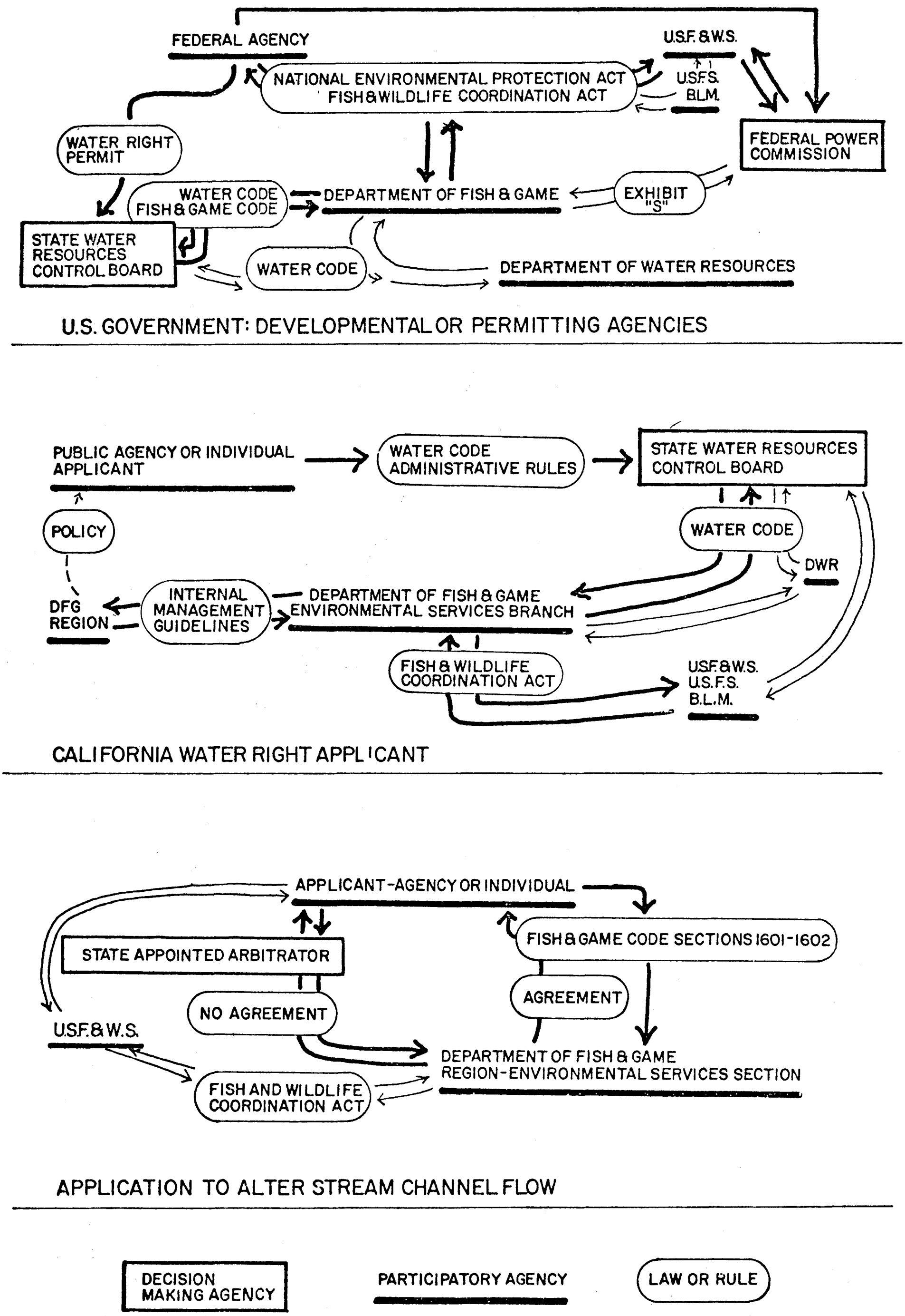


FIGURE 4 INSTITUTIONAL INTERFACES IN THE ACQUISITION OF INSTREAM FLOW RESERVATIONS

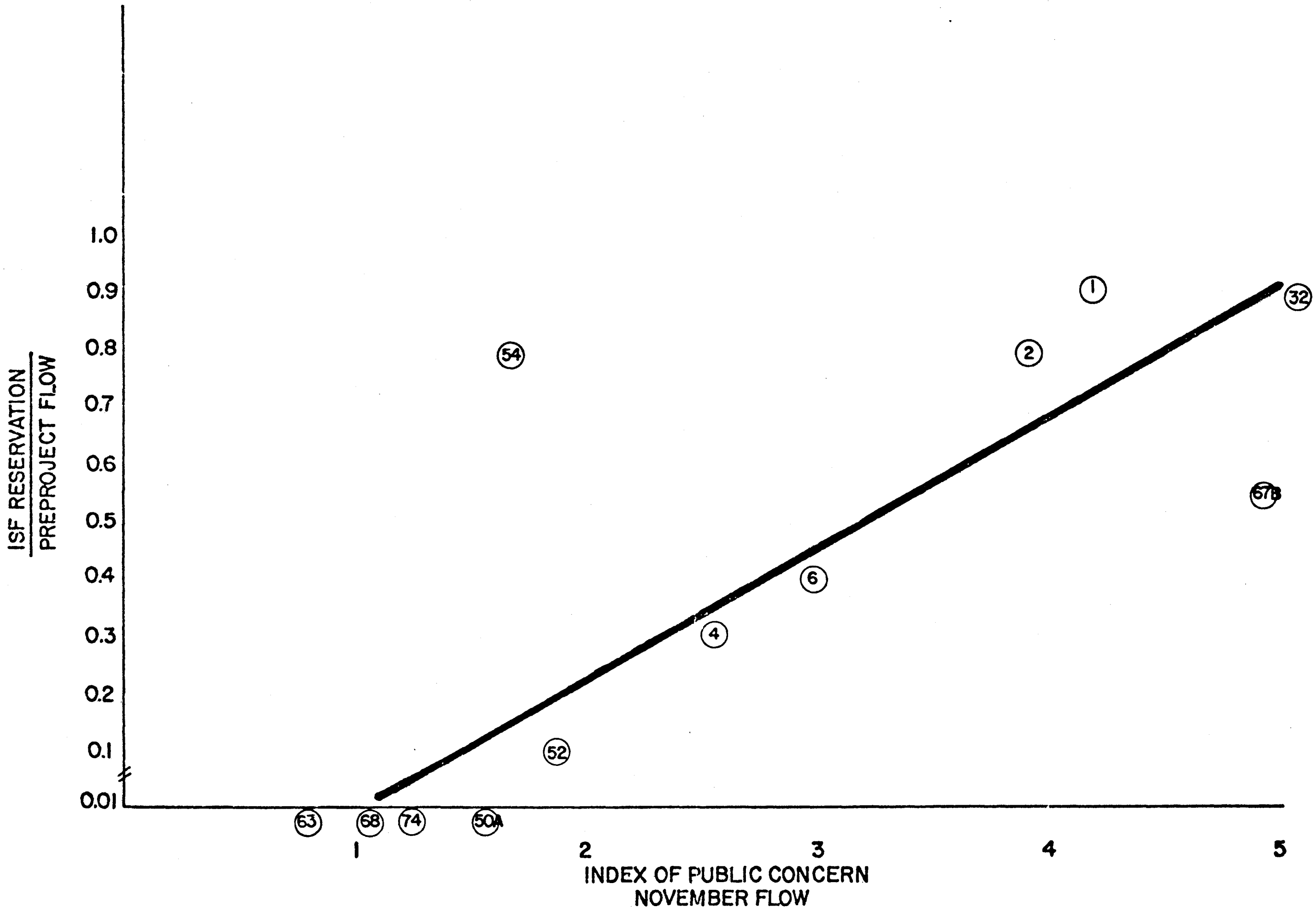


FIGURE 5A SALMON & STEELHEAD STREAMS VS. INDEX OF PUBLIC CONCERN

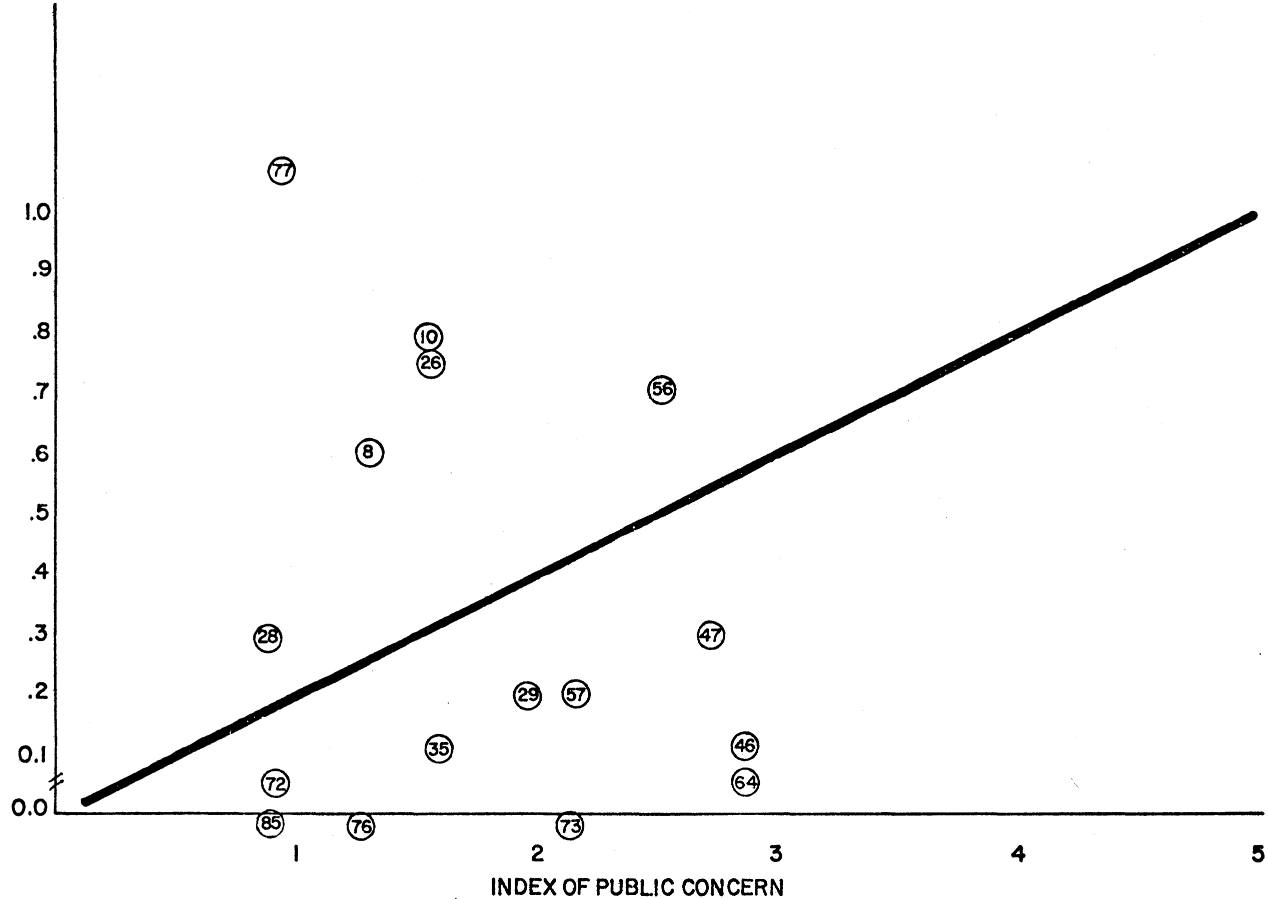
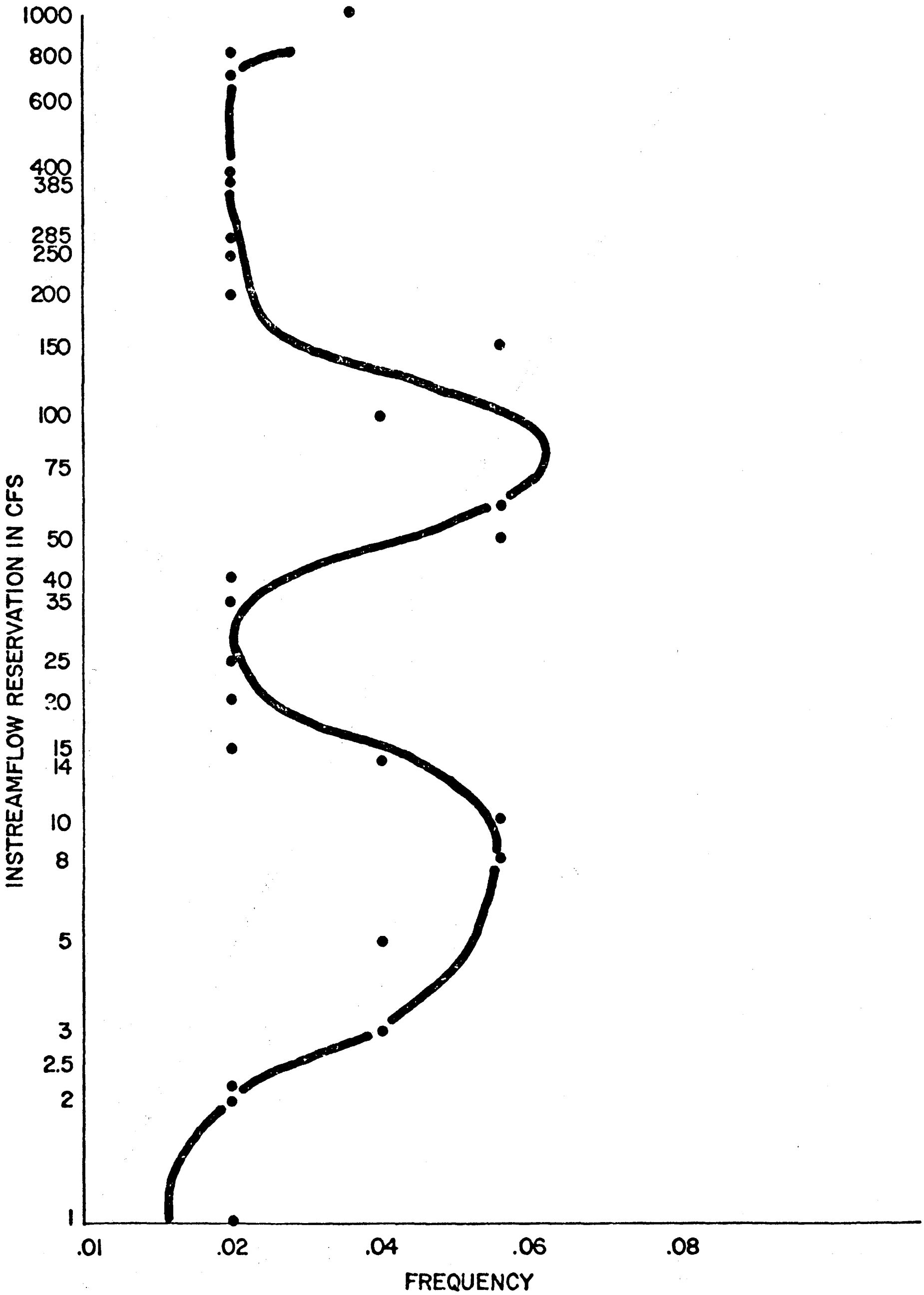
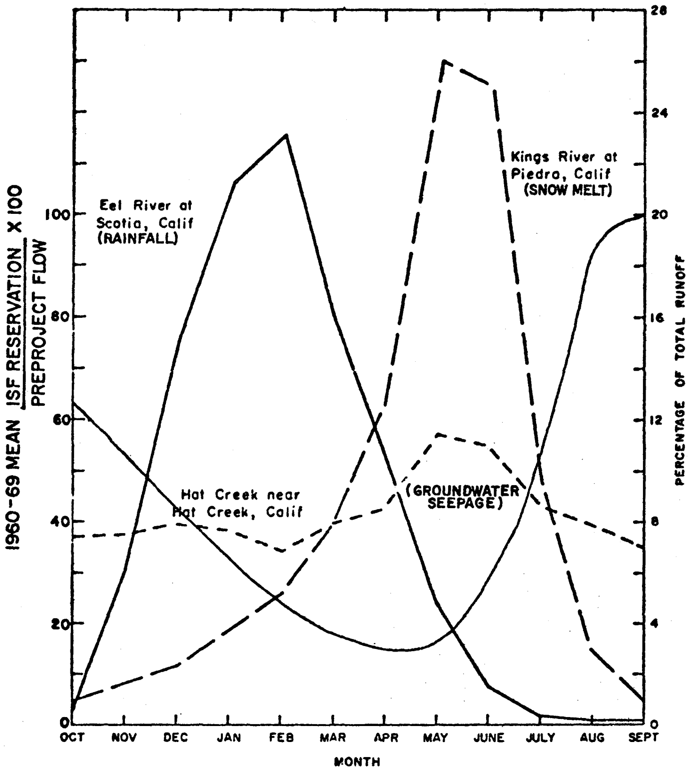


FIGURE 5B TROUT FISHERY STREAMS VS. AUGUST FLOW INDEX OF PUBLIC CONCERN



1000
800
600
400
385
285
250
200
150
100
75
50
40
35
25
20
15
14
10
8
5
3
2.5
2
1
INSTREAMFLOW RESERVATION IN CFS
.01
.02
.04
.06
.08
FREQUENCY

FIGURE 6



MEAN MONTHLY DISTRIBUTION OF RUNOFF AT THREE SELECTED GAGING STATIONS IN THE CALIFORNIA REGION

Decade of Development	Number of Projects	Percent Without Flow Reservation	Percent With Flow Reservation	Not Analyzed	Average Index Flow Reservation Mean Pre-Project Flow Nov	Feb	May	Aug
1909	4	0	0	---	---	---	---	---
1910-19	4	75	25	1	.20	.60	---	.10
1920-29	5	40	60	1	.04	.14	.02	.25
1930-39	2	0	100	2	.06	.02	.01	.03
1940-49	2	50	50	1	.80	.20	.30	.60
1950-59	9	45	55	4	.47	.18	.22	.74
1960-69	15	0	100	14	.53	.24	.16	.98
1970-	3	33	67	1	.55	.12	.01	.01

Modified from: Comprehensive Framework Study, California Region, 1971.

Figure 7

MEAN MONTHLY DISTRIBUTION OF RUNOFF AT THREE SELECTED GAUGING STATIONS IN THE CALIFORNIA REGION

A STATUS REPORT OF THE ASSESSMENT OF EFFECTS OF ALTERED STREAMFLOW CHARACTERISTICS ON FISH AND WILDLIFE: A CASE STUDY APPROACH IN NINE WESTERN STATES

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ABSTRACT

This paper presents, in two major sections, a status report of the "Assessment of Effects of Altered Streamflow Characteristics on Fish and Wildlife: A Case Study Approach in Nine Western States." The introductory section delineates the purpose and scope of the project, sponsored by the Office of Biological Services of the United States Fish and Wildlife Service, and describes the general approach adopted in the performance of the project. The purpose of the project is to develop recommendations for improving methodologies to determine instream flow requirements for fish and wildlife. Case studies have been conducted on 107 instream flows involving 78 projects in Arizona, Colorado, Idaho, Montana, New Mexico, Oregon, Utah, Washington, and Wyoming.

The preliminary findings section presents and illustrates problems and issues which the case studies have yielded. The formulation, bargaining, and implementation of instream flow recommendations are discussed in this section.

INTRODUCTION

This introduction section delineates the purpose and scope of the ongoing "Assessment of Effects of Altered Streamflow Characteristics on Fish and Wildlife: A Case Study Approach in Nine Western States" and describes the general approach adopted in the performance of the project

Purpose and Scope

The purpose of the project is to develop recommendations for improving methodologies to determine instream flow requirements for fish and wildlife. The specific objectives designed to fulfill this purpose are:

- To determine the actual effects of altered flow characteristics on fish and wildlife downstream from a number of dams and diversions;
- To determine the degree to which the various methodologies used were successful in predicting these effects and the instream flow requirements for fish and wildlife;
- To identify biological and nonbiological constraints on the success of these methodologies and the project evaluation processes.

These objectives are being accomplished in four major tasks:

- Selection of candidate projects,
- Conduct of case studies,
- Development of recommendations, and
- Preparation of final report.

The objective of the first task was to select at least 30 major projects involving 50 to 100 instream flows in each of two western regions for in-depth study. The two regions are the Pacific Northwest (Idaho, Oregon, and Washington) and the Rocky Mountains (Arizona, Colorado, Montana, New Mexico, Utah, and Wyoming).

The objective of the second task is to conduct case studies to determine:

- Whether the original project plan for altering the flow regime has been followed;
- The extent of investigations and the methodologies used to predict effects and to determine instream flow requirements;
- The comparative biologic and hydrologic pre- and post-project conditions and the actual effects of the altered flow characteristics on downstream fish and wildlife; and
- The relevancy and effectiveness of the methodologies used to ensure the project's compatibility with fish and wildlife resources.

The analysis task is directed to the following objectives:

- Analyze, evaluate, and summarize the success and effectiveness of the biological investigations, project evaluation processes, and institutional arrangements reviewed during the individual case studies;
- Identify problems, constraints on success, and opportunities common to habitat types, project purposes, sponsoring organizations, and/or methodologies; and
- Recommend procedures which will improve instream flow methodologies and project evaluation processes, and which will guarantee the compatibility of both existing and future water development projects with fish and wildlife resources.

General Approach

In task 1, potential projects were identified for both regions on the basis of information gained from:

- Prior experience[1];
- Review of Water Resources Council map of dams and diversions;
- Interviews with personnel of the FWS, Federal construction and permit agencies, state fish and game agencies, and private companies; and
- Review of FWS and other project reports.

One little-known but valuable source for project identification deserves mention here -- the FWS's KEYSORT project summary system which lists the most important information on approximately 600 projects. Its principal limitations for this effort were the lack of information on the operational status of projects, on Missouri River Basin projects reported after 1970, and on Pacific Northwest projects reported after 1972. Nevertheless, use of the system permitted the concentration of effort on those projects for which the FWS had prepared reports and recommendations on minimum flow and led to the initial identification of some 150 projects. Most of these were eliminated subsequently, on the basis of information obtained from interviews and reviews of project files.

After an exhaustive review of available information, 114 projects and 162 associated flows were found to conform with the minimum selection requirements-current operation and an instream flow recommendation. Of these, 63 projects and 94 associated instream flows are located in the Rocky Mountain region, and 51 projects and 68 associated instream flows are located in the Pacific Northwest region.

To ensure representativeness of projects in terms of distribution by state and region, by biotic and abiotic environment, by main project purposes, and by sponsoring or permit agency, the FWS Project Officer used a random sampling technique to determine those projects on which case studies would be conducted in task 2. In task 2, case studies have been conducted on 107 instream flows involving 78 projects in nine western states. In the Pacific Northwest region (Idaho, Oregon, and Washington), 52 instream flows were studied in-depth, and in the Rocky Mountain region (Arizona, Colorado, Montana, New Mexico, Utah, and Wyoming) 55 instream flows were examined.

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[1] Davis, Robert K., Steve H. Hanke, Gerald C. Horak, Kathleen A. Carroll, and Robert J. Barbera, An Ex Post Evaluation of Fish and Wildlife Mitigation, Rivus, Inc., 46 p., December 1973; Horak, Gerald C., A Preliminary Evaluation of Fish and Wildlife Mitigation in Federal Water Projects, Johns Hopkins University, 39 p., January 1973.

Tables 1 and 2 provide a disaggregation of the instream flow case studies according to state and project sponsor. These two tables illustrate the diverse geographic and institutional distribution of the instream flows investigated.

TABLE 1. LOCATION OF PROJECTS STUDIED

State	No. of Case Studies
Arizona	1
Colorado	27
Idaho	11
Montana	3
New Mexico	2
Oregon	32
Utah	9
Washington	9
Wyoming	13

TABLE 2. SPONSORSHIP OF PROJECTS STUDIES

Sponsor	No. of Instream Flows Studied
Federal	
Bureau of Indian Affairs	1
Bureau of Reclamation	43
Corps of Engineers	15
Soil Conservation Service	2
Non-Federal	
Power Companies (FPC permit)	16
Municipal and Private (BLM permit)	4
Municipal and Private (FS permit)	16
State, Municipal, and Private (State permit)	11

Each case study involved the extensive review of fish and wildlife and sponsoring agencies' records, in-depth interviews of the respective agency's personnel, and a review of United States Geological Survey's and/or State Engineer's hydrologic records. This effort was aided by the development of a questionnaire and interview guide designed to ensure consistency in the type and amount of information being collected for each case study.

Each case study averages eight pages including two graphs. Each case study is divided into the following sections: Overview, Description, Recommendation, Hydrology, Biology, and Analysis. One graph appears in the recommendation section and depicts pre- and post-project low monthly flow extremes and recommended and accepted flows. The other graph, which appears in the hydrology section, depicts pre- and post-project monthly and annual mean flows.

PRELIMINARY FINDINGS

This section presents and illustrates problems and issues which the case studies have yielded. Problems and issues arising in the formulation, bargaining, and implementation of instream flow recommendations are discussed separately in the subsections that follow. However, this discussion is based on a preliminary review of the data and in no way represents an inclusive discussion of the results of the "Assessment of Effects of Altered Streamflow Characteristics on Fish and Wildlife: A Case Study Approach in Nine Western States."

Formulation

The formulation of an instream flow recommendation is the process used by respective fish and game agencies to develop an instream flow recommendation to be offered to a sponsoring agency. Two issues discussed below in relation to the formulation process are earlier detailed methodologies and the type of flow requested.

It is a commonly-held assumption that instream flow methodologies were crude 20 to 30 years ago and have become more complex in recent years. For the most part, this is probably true; however, on two projects between the late 1940's and early 1950's, fish and wildlife agencies used detailed methodologies in determining instream flow requirements.

On the Bureau of Reclamation's Colorado-Big Thompson Project (C-BT) in Colorado, intensive studies were conducted by the FWS before the C-BT dams began operating. Segments of the Colorado and Big Thompson Rivers were studied below the dams under various streamflows, to determine the amount of slow-shallow water, riffles, deep-fast water, and exposed bottom. Changes in the amount of exposed streambed and in slow-shallow areas were noted, because these denoted losses in productive habitat.

On another Bureau of Reclamation project, Hungry Horse in Montana, the Montana Department of Fish and Game with the assistance of the Bureau of Reclamation conducted a stream survey. The survey team identified two instream areas as having all known requisites for spawning of cutthroat trout. These requisites include a moving current and a small-sized gravel or rubble bottom and a minimum of deep holes, sand, or large rocks in the streambed. The shallowest of the two instream spawning areas was chosen as the site from which observations were to be made of the effects of various streamflows.

Streamflows were varied by changing flow releases at the dam. Photographs and measurements of stream depth and width were taken at 12 different streamflows, varying between 135 and 1,610 cfs. This method is very similar to the well-known "Montana Method."

After the biologist has developed an instream flow from a specific methodology, he then usually formally recommends that flow in a report to the sponsoring agency. Two types of flow requests deserve discussion, the "outflow-should-equal-the-inflow" and the "instantaneous" flow recommendations. The first type of request simply states that an outflow from a reservoir up to a certain amount should be equal to the inflow. This type of recommendation is usually requested on smaller projects such as Forest Service, Bureau of Land Management, and State permit projects. However, a request of this nature requires that there be an inflow gauge above the reservoir, a stage-recorder on the reservoir, or an outflow gauge below the reservoir. Any combination of the preceding is required, so that the operator of the dam can compute the amount of water that should be released to comply with the recommended flow.

When power production is the project's primary purpose, the biologist will often request that an instantaneous flow be provided at all times below the dam. This type of flow is requested because the flow requirements of power projects vary; in fact, throughout the course of a day, flows in cfs could conceivably range from zero to the tens of thousands with an average in the thousands. Fluctuating flows on projects such as the Holter Project in Montana cause fish kills, stranding of eggs, and loss of food supply. Therefore, requests for instantaneous flows are well founded.

The United States Geological Survey, however, does not presently compile historical records of instantaneous flows, although gauges below some power dams do record instantaneous flows. If a flow of this type is requested, it is imperative that the biologist also recommend that an instantaneous gauge be installed below the dam and that yearly historical records be compiled.

Bargaining

Bargaining for an instream flow recommendation is the process whereby the fish and game and the sponsoring agencies interact in determining the instream flow which will be provided below a particular dam or diversion. This process may occur before, during, or after the formulation process.

A project in Wyoming illustrates a weakness within the bargaining process. The official joint recommendation by the FWS and the cooperating state fish and game agencies respresented a flow believed by their own biologists to be inadequate for sustaining fishery resources. This low flow was requested because there were substantial constraints on interagency bargaining in formulating the recommendation, influencing the FWS to recommend a flow no greater than the construction agency would offer to guarantee. This flow request represents the capitulation of fish and wildlife interests to the unyielding position of the irrigation interests.

Similarly, in a project in Oregon, the FWS on three occasions, over a 15-year period, evaluated and offered only those recommendations that the construction agency had suggested.

These examples illustrate instances where fish and wildlife agencies accepted and recommended flows offered by the sponsoring agencies and did not report or request preferred instream flows.

In Wyoming, releases for fish and wildlife below the Bureau of Reclamation's Glendo Dam are prohibited by a Supreme Court ruling. This represents the extreme case where bargaining is prohibited by a court ruling. However, other case studies have revealed instances where competing water uses such as municipal and irrigation downstream water rights have been utilized in bargaining to aid acceptance of a recommended flow.

Implementation

Implementation of an instream flow recommendation is the process in which a sponsoring agency complies with an accepted flow regime. Two different types of implementation problems are discussed.

First, instream flows have been requested on ungauged streams on a number of small water resource projects. This creates problems for both the dam or diversion operator and the fish and wildlife agencies. The dam or diversion operator is unable to determine the flow that should remain in the stream, and the fish and wildlife agencies are unable to determine if they are receiving the agreed to flows. This problem is usually confined to small municipal and private projects operating under permits from the Bureau of Land Management, the Forest Service, or a state.

A project in Oregon shows the ineffectiveness of an instream flow containing undefined terms, such as "somewhat lower flow" and "short water years." This project also illustrates the lack of enforcement where an abundant flow was requested to re-establish a trout fishery.

The construction agency did not accept the instream flow recommendation offered by the FWS in 1951, until 1960. At this time, the FWS increased the fishery value of the stretch of river below the project dam 12-fold above the reported 1951 dollar value and agreed to a flow which could fall below the recommended flow in short water years. There was a lag of 10 years between the time of the FWS report and the Bureau of Reclamation's acceptance of a modified recommendation. This lag probably influenced the FWS to accept this modified recommendation, because they probably considered it the best obtainable flow for fish and wildlife.

Additionally, the construction agency and the irrigation district both readily accepted the recommendation with the knowledge that there is no systematic monitoring by fish and wildlife interests. Moreover, there are no penalties for violations, even if discovered.

In fact, the irrigation district has repeatedly reported releasing the agreed to flow to the construction agency, even though United States Geological Survey gauge records reveal serious and consistent violations of the flow during the nonirrigation season. Although the FWS did monitor the status of the project in 1971, the monitoring resulted in a positive change for less than two years, and the project operators were not penalized for violations. Interestingly, the month the FWS follow-up study was published the monthly average flow dropped below the agreed to flow and remained there for six months. Again in 1974, the operator violated the agreement and again agreed to abide by it.

Because of the above circumstances, the state fish and wildlife agency found it necessary to stock fingerling and legal-sized trout to maintain a fishery. This is a costly procedure which would not have been needed had the original FWS recommendation been implemented.

Irregular monitoring by fish and wildlife interests aided the implementation of the recommended flow, but only for short intervals. Fish and wildlife interests were compelled to resort to lengthy and cumbersome procedures, such as presenting the dam operator with substantive findings or working through members of the construction agency, in order to convince the dam operator to release the accepted flow recommendation. No other vehicles were available to persuade the operator to adhere to the recommendation.

This case study raises a number of questions, three of which are:

- What recourse does the American taxpayer have to receive just compensation for violations of agreements in water resource projects?
- Whose responsibility is it to ensure that agreed to flows are being complied with by the operators of dams and diversions?

- How can fish and wildlife agencies monitor flows efficiently and effectively?

Although the first two questions may be beyond the scope of the current study, task 3 of the "Assessment of Effects of Altered Streamflow Characteristics on Fish and Wildlife: A Case Study Approach in Nine Western States" will attempt to provide a workable answer to the third question.

TOPIC IV-B.

DAMS AND MINIMUM FLOW PREDICTIONS

Summary Discussion

Question: How do you measure the public concern or interest shown in your presentation?

Answer: We arrive at a Delphi index--a weighted number based on location and type of fishing and amount of public usage as derived from opinions of experts.

Question: Will data be produced or reviewed to show if instream flows were successful for protection of fish habitat?

Answer: There have not been sufficient follow-up detailed studies in California for giving objective answers. The Task 3 study portion for the Rocky Mountain and Pacific Northwest Regions will present pre- and post-project stream flows wherever available and also the biological effects in those cases where sufficient data have been produced.

Question: Will obtaining such data be part of future plans by the Office of Biological Services?

Answer: It is not in our present plans but if the need is clearly defined, such work might be part of future programs.

Comment by Sport Fishing Institute (SFI) Representative: A review was made for the Army Corps of Engineers of 410 water development projects and only 120 contained predictions for fish habitat. Only 10 of the 410 projects accurately evaluated project effects on fish habitat.

Question to SFI: Isn't it true that detailed studies were largely directed to the reservoirs rather than downstream fish habitat?

Answer by SFI: Yes, that is probably true.

Comment: It would be wise for the earliest request for instream flows to be retained in reports since later compromises often result in requests which are no more than the sponsoring agency is willing to give. The report should present a range of flows along with the probable consequences for fish habitat.

Comment: Enforcement for instream flows, previously arrived at for federally sponsored projects, should be the responsibility of officials high in the sponsoring agency.

Question: Why do such major and long term violations occur?

Answer: Sometimes oversight and sometimes because of real conflict in demand for water; always because there is inadequate monitoring. In California, such violations are rare but may become less rare as the demand for water increases.

Question: How can monitoring be improved?

Answer: Require project operator to install recording gages on rivers and make records available. Average flows are not adequate. Records of reservoir levels can also be used during dry periods when all reservoir inflow is destined for downstream release. Fisheries agencies should make more use of USGS gaging stations or establish programs to read measuring devices regularly.

Comment: Concerning Mr. Horak's statement that gages are needed both above the reservoir and below the dam to insure releases of inflows to the reservoir, it should be observed that a staff gage will tell if the reservoir is rising and hence the upstream gage could be dispensed with if the reservoir elevation is thus monitored.

Response: You are correct that a staff gage will reveal whether water is being stored; however, the staff gage does not quantify the amount of release. To properly measure and monitor for inflow-outflow conditions, an outflow gage would be required. Additionally, if there is no staff gage or adequate records inflow gages would be required on all major tributaries.

Question: Are there advantages from early involvements in project planning by fish and wildlife interests?

Response: The earlier that considerations can be given in the planning process, the better. The time element is important for arriving at reasonable instream flows along with other project uses of water. The role of the biologist and engineer is to present the best case they can for their interest. It is then the role of the regulating agency to decide. Your overall approach is more important than time of entry into the planning process.

Comment: It should be noted that a great danger to instream flows may arise downstream of the dams. Releases, made in agreement with established instream regimen, can be diverted by downstream users.

Comment: I cannot believe that any dam operator would intentionally violate agreed-upon instream releases.

Response: Stream flow data obtained at or near established points of release show that violations have been frequent. The operator should be aware of releases being made from his operated project.

Question: Did you look at pre-project flow conditions?

Response: Yes. As shown on prior graphs contained in our case studies, pre- and post-project mean flows are presented, whenever the data were available.

Comment: FPC reviews stream flows in California and sends a copy of the records to the California Fish and Game Department for review.

Response: California says they do not receive such records.

Question: What has been the most obvious deficiency of past flow releases studied?

Answer: Flows were too low, often far less than recommended by the biologist in the first study.

Notes by panel moderator: Robert P. Hayden
Western Water Allocation Program
U.S. Fish and Wildlife Service
Washington, DC

arrangement has been possible so far only at large Federal, State or municipal projects. Here, project sponsors mitigate for losses to fishlife above their dams by releasing sufficient flow to improve remaining reaches over pre-project conditions. They insure that such improved conditions will exist all the way to the mouths by adding to the releases sufficient water to satisfy all currently valid water rights between their dams and the mouths. Since minimum flows must prevail all the way to the mouths, these water purveyors are held responsible for monitoring flows to see that downstream diverters do not encroach on required flows.

We believe that under limitations of present water law the described arrangement can be very satisfactory, assuming adequate flow levels have been obtained to offset upstream habitat losses. In practice, we have run into very little infraction of mitigative terms in normal and wet years; however, in a dry year such as we are now in, one municipal water purveyor has not only been reluctant to see that others did not encroach on required minimum flows, but has unilaterally violated water right permit terms without contacting the State Board beforehand to make a request for waiver of terms under an alleged water shortage. This example points up that, despite a water purveyor's responsibilities as stated in his water right terms, our Fish and Game Department must be constantly vigilant, especially in a water short year, that the terms are followed. Despite the problems with violations of water right terms in a water short year, it is clear that the described arrangement is far superior for fishlife than that initially described for small diversions.

With that background, in the remainder of my allotted time I will describe a few of the more significant water rights cases that we have experienced in recent years, the benefits for fish and wildlife that have resulted, shortcomings under constraints of existing water law, and the approach we are taking in an attempt to correct the problems.

CASE STUDIES

Sacramento-San Joaquin Delta

The Sacramento-San Joaquin Delta is a 778,000 acre complex of natural and man-made waterways associated with the junction of the Sacramento and San Joaquin Rivers. These rivers drain the great Central Valley and enter San Francisco Bay.

The rivers in the delta serve as transportation routes for the State's largest king salmon runs and second largest steelhead trout runs. The State's largest concentrations of striped bass and American shad live in and move through this area. Large populations of resident warmwater game fish live in the myriad of channels and sloughs. The Suisun Marsh part of the delta is the largest remaining brackish water marsh in the State and serves as an extremely important waterfowl wintering area for the Pacific Flyway.

The U.S. Bureau of Reclamation's Central Valley Project, a complex of storage and water conveyance facilities initiated in the 1930's to irrigate the valley and still being augmented, and our Department of Water Resources' State Water Project, built in the last ten years, convey stored water down the Sacramento and San Joaquin Rivers to the delta. Here, most of the ten million acre-feet of water annually provided by these projects can be pumped to the San Joaquin Valley and, from the State project, to southern California.

These projects have drastically changed flow regimes in the delta. No longer are there the extreme fluctuations in summer flows. A very productive agricultural use has been developed on reclaimed islands. Heavy recreation use, predominantly striped bass and catfish fishing, as well as boating, continues to develop in this area.

During the last 18 years or more, the Board has been considering water rights for the state and federal projects. Several hearings were held and decisions were rendered on the federal project, and in 1969-70 the most recent hearing was held. The decision rendered as a result of this hearing provided for chloride and total dissolved solids criteria at certain reference points to protect fishlife and the aquatic organisms on which they feed, as well as to protect agricultural lands, municipal uses and the Suisun Marsh against salinity. The Board continued to reserve jurisdiction and setting of standards on a number of other water quality and hydraulic parameters and called for further studies and monitoring. Specific Department of Fish and Game recommendations were honored in the decision. The Board required monitoring of fish, benthos, phytoplankton and zooplankton. This has been, and is being, done by the Department so that definitive terms can be formulated and standards set or amended upon hearing and further order.

All in all we in the Department felt quite satisfied with the outcome of the 1969-70 hearing. Last week hearings were resumed, a considerable amount of additional study will be done and monitoring data will be examined, and it is expected that many new standards will be set.

I believe we would be optimistic on the ultimate effect of the delta hearings on fish and wildlife, except for two subsequent events. Following the last decision, irrigators in the San Joaquin Valley sued the Board on the allegation that water supplies contracted to them by the Bureau and the Department of Water Resources would be reduced if the Board's ordered delta standards were met. The suit's outcome is still pending. Secondly, a cloud has come over all Board decisions relative to Bureau of Reclamation projects because of a landmark federal district court decision rendered last fall. More will be said on this later.

American River

The American River is a major tributary of the Sacramento River draining the west slope of the Sierra and joining the latter river at Sacramento. The lower 23 miles of stream, all that remains unobstructed below the Bureau of Reclamation's Nimbus Dam, is the fifth most important salmon producer in the state. It retains this rating by enjoying better than natural flows during the summer and fall and has as effective hatchery. The stream also supports important steelhead, striped bass and shad runs. Because of its metropolitan location, it supports heavy fishing and other water-oriented recreation.

The Bureau's Folsom and Nimbus Dams, constructed 20 years ago, are the first stage of the American River segment of the Central Valley Project. One part of the final stage, Folsom-South Canal, diverts water at Nimbus Dam and will ultimately carry it southward about 50 miles, primarily for irrigation. Its companion feature is Auburn Dam, which will impound a large storage reservoir immediately upstream of the intervening Folsom Reservoir.

The State Board held a water right hearing on the Auburn-Folsom South Unit in 1971. The purpose was to formulate terms and conditions relative to flows to be maintained from Auburn Dam downstream to the mouth of the river for recreational purposes and for protection and enhancement of fish and wildlife.

The Board rendered a decision providing for the flows we had recommended for salmon. These flows would also accommodate the associated species. In response to heavy recreation demand, summer flows were set at a level even higher than that requested for fish. Ordered flows were several times higher than flows agreed to by the Bureau and the Department of Fish and Game 15 years earlier in connection with the Folsom-Nimbus Project. Thus, the Bureau objected to the higher flows and refused to concede that the Board had the authority to set them on the Congressionally authorized project, Auburn-Folsom South.

There continues to be no problem in enforcing the Board's ordered flows, because the Folsom South Canal is not yet completed to take the water stored in Folsom Reservoir. In the meantime, however, ultimate implementation of the Board's decision is under the cloud of the aforementioned Federal court decision.

New Melones Project

The New Melones Project is another unit of the Bureau's Central Valley Project located on the Stanislaus River. This stream is a major tributary of the San Joaquin River, heading on the west slope of the Sierra and joining the San Joaquin a short distance southeast of the aforementioned delta.

The San Joaquin system formerly supported a major king salmon run, but because of dam and diversion projects, only a remnant remains. The remnant run of around 8,600 fish in the Stanislaus, however, is too important to be further reduced as would occur without compensatory measures at this project. Also present are warmwater game fish. The important striped bass and shad fisheries of the lower San Joaquin River and the southeastern delta depend heavily on water contributed by the tributaries.

The New Melones Project is the last hope in the system for major storage of water to be released downstream to the delta. Under our Department plan it would provide several benefits. Stored water would be released to partially restore the salmon runs in the Stanislaus, it would freshen the water in the lower San Joaquin and the delta, diluting cannery wastes in the fall and salts from irrigation return water in the summer and fall, and would help to overcome a flow reversal in the fall in the lower San Joaquin. This flow reversal confuses salmon attempting to ascend to their spawning grounds.

The Board held a hearing in 1971 and rendered a decision in the following year. A limit was placed on storage reducing it to less than half of that proposed by the Bureau. Again the Bureau took exception to the decision, as it had on the delta and American River decisions, and said it could not be bound by new water right terms on a project already authorized by Congress.

In response to this attitude, the State of California filed suit in the Federal district court seeking a declaratory judgement regarding State authority over the Bureau. As a major thrust of its suit, the State referred to Section 8 of the Federal Reclamation Act of 1902. This section says: "Nothing in this Act shall be construed as affecting or intended to affect or to in any way interfere with the laws of any state or territory relating to the control, appropriation, use or distribution of water used in irrigation..."

After hearing State and Federal arguments, the court rendered a decision last October, the highlights of which are:

1. The United States must come to the State Board as a matter of comity (that is, courtesy) for determination of the availability of unappropriated (surplus) water.

2. The State Board must approve the application if unappropriated waters are available.

3. Nothing in Section 8 of the Reclamation Act or any other Federal law allows the Board to condition water right permits for the Bureau.

4. Decision 1422 (New Melones Project) is void where it attempts to condition the Bureau's use of water.

The State has subsequently appealed the district court decision to the Ninth Circuit Court of Appeals, but it is eventually expected to be brought before the Supreme Court. In the meantime, the Board is powerless to set water right terms and conditions on Bureau projects, and conditions imposed by the Board on Bureau water rights permits as affecting the delta and the American River are nullified.

If the Federal government were to emerge victorious in the end, it appears that, if it chose, it could declare null and void all prior terms set on Bureau projects by the Board. This, of course, could have serious effects on fish and wildlife water provided in the past by the Bureau.

Oroville-Thermolito Project

Before I conclude, I would like to describe one more project in which water was provided instream for fish and wildlife under a different Federal law that enhanced the Fish and Game position rather than detracted from it. The project involved is the Oroville-Thermolito project on the Feather River, a unit in the State Water Project sponsored by our Department of Water Resources.

The Feather River is the most important salmon spawning tributary of the Sacramento River, joining that river at a point ten miles north of Sacramento.

In addition to salmon, the river sustains important runs of steelhead trout, shad and striped bass. It is also one of the better smallmouth bass streams of the valley.

The Department of Water Resources applied for water rights permits for this project in the 1950's and the Board held a series of hearings, the last in 1966. The Department of Fish and Game participated in the 1966 hearing and reported it was in process of negotiating with the Department of Water Resources on measures for maintenance of fish and wildlife in the Feather River below the project. We recommended that provisions of the proposed agreement that were within the jurisdiction of the Board be made conditions of any permits issued to Water Resources.

This whole procedure was unique in that the agreement that was shortly thereafter executed, in addition to being honored by the Board, was given added impetus toward successful completion by the authority of the Federal Power Act and Fish and Wildlife Coordination Act, inasmuch as such agreement was a requirement of a Federal Power Commission license issued to Water Resources in 1957 for hydroelectric features of the project.

We feel the agreement adequately provided for compensation for lost upstream spawning areas cut off by the project. In addition to flows to be provided the entire 65 miles to the mouth of the river, an eight-year post-project study to assess appropriateness of project operation was paid for by the licensee. The latter requirement was a provision of the FPC license.

CONCLUSIONS

Through the examples provided by the foregoing case studies, it can be concluded that on individual large projects it is possible to achieve considerable protection for fish and wildlife in California under present State and Federal water law, with the notable exception of Bureau of Reclamation projects while the recent adverse court decision prevails. For small projects, however, we must fight for every short segment of instream water, and always from a defensive posture.

In an attempt to turn the situation around, we are now engaged in a test case with the Board. We have been told by the Board several times in the recent past that we would have no legal standing if we attempted to obtain a water right permit to appropriate water instream for fish and wildlife. We finally decided to test that position by filing an application with the Board to obtain a water right to appropriate water instream on the Mattole River, an excellant, almost completely undeveloped salmon and steelhead stream on the north coast. This application was filed last January through the assistance of our office of Attorney General. Our main basis for filing revolved around the fact that the Board's interpretation of its own authorizing statutes is an administrative construction which carries great weight in the courts in determining the Board's authority, and that nothing in the Water Code prohibits the appropriation of water for instream use.

We intend to pursue this endeavor even if appeal to the courts is necessary. If we are rejected by the courts, we feel we will have a well documented case to take to the legislature to seek relief by enactment of legislation that will finally raise fish and wildlife to their rightful place in apportionment of the State's water. In the meantime, we will be very interested in and hope to profit from the experiences in other States in meeting our own objectives.

THE OREGON EXPERIENCE WITH A MINIMUM STREAMFLOW LAW

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ABSTRACT

Oregon has lost many streams once suitable for summer rearing of salmonids because of flow diversions for out-of-stream uses. Since 1909, 56,000 water rights have been issued in the state, 25,000 of those were issued between 1951 and 1971, representing a rapid growth in demand for all consumptive water uses. Oregon minimum streamflow legislation was enacted in 1955 to protect certain instream uses of water. Since 1955, more than 300 minimum streamflows have been programmed by the State Water Resources Department.

Oregon's experience with the minimum streamflow law and its protection of instream values has been difficult to evaluate. The principal problems with the MSF concept relate to public awareness, enforcement and the continuing appropriation of water rights for uses economically predicated on the availability of water through the low flow season.

Better water management tools include withdrawing over-subscribed streams from further appropriation, classifying streams only for uses with low consumptive demands, or issuing additional water rights restricted to high flow months. "Preventive Management" should replace the MSF concept on streams where population growth and water use demands continue to increase.

As white man settled the Oregon country and exploited the lands and waters to provide the "good life", a loss of fish and wildlife habitat occurred. Several activities most responsible for the loss of habitat have been pollution, depletion of streamflows, logging, road construction, stream channelization, dams, and general urbanization. Public concern and improved technology in recent years have helped reduce some negative impacts. The public is aware of many of the detrimental activities affecting streams. However, less known is the problem of streamflow depletion through over-appropriation of surface waters.

Oregon is blessed with a bountiful supply of water, although it is not always in the right place at the right time nor of the right quality. Because of this general water abundance, policy for its use has evolved over most of the past century as if water had no cost and was unlimited in amount. As demands reach and exceed supply, it becomes necessary to seek new ways to allocate water and increase the efficiency of its use. At the same time, there is concern that water be left in streams for fish and wildlife and the maintenance of an aesthetically pleasing environment.

Fish, especially salmon and trout for which Oregon is noted, thrive only in streams with flows of adequate quantity and quality. Stream environment becomes most hostile to fish during the summer low-flow season. The number of fish produced (a stream's carrying capacity) is largely determined by the amount of streamflow available for "rearing" during summer months. As the flow drops, food, cover, and space for fish decrease and water temperature generally increases. Oregon has lost many streams once suitable for summer rearing of salmonids because of flow diversions for out-of-stream uses.

Water use demand has increased dramatically. Between 1951 and 1971, about 25,000 water rights were issued by the State Engineer. This is more than double the total demand prior to 1951. Water is a finite resource. The supply is renewed annually, but the quantity within each watershed is determined by natural forces and geological conditions. Because of limited supplies and increasing demands, a water crisis has developed. This crisis is particularly evident for those uses such as fish, recreation, and pollution abatement that rely on sustained streamflows. These are called "instream" water uses as contrasted to uses that remove the water from the channel.

Recording of Oregon water rights originated with the early placer miners. They conceived the plan of posting a notice claiming diversion rights for specific quantities of water for use on their mining claims. History tells us that water wars were not uncommon and more than one miner or rancher "slow on the draw" arrived on Boot Hill before his time trying to defend his water use.

Because of the increasing demand for more orderly and uniform ways of initiating and recording water rights, the 1909 Oregon legislature enacted statutes which have become known as the "appropriative" doctrine. Basically, these laws provide that, "all water within the state from all sources of supply belong to the public." The laws provide that all public waters within the state may be appropriated for beneficial use.

However, fish, wildlife, recreation and pollution abatement cannot obtain water rights because the water must remain in the stream rather than be diverted. This means that a water right can be obtained for a fish hatchery because that use requires diversion, but a water right cannot be issued if it is to be left in the channel to provide natural fish production. As a result, under the appropriative doctrine every stream in the state can legally be dried. Many already have been, others have been substantially reduced destroying many public values. Fish need a certain amount of good quality water for spawning and rearing. Consequently, they are at the mercy of the consumptive water user.

The needs of society have changed since the horse and buggy era when basic water law was established. The major thrust of Oregon's Water laws, as well as those in most western states, was to provide an orderly water diversion process to encourage land development and economic growth. Fortunately, Oregon recognized some of the inequities of the 1909 water law long before other western states did. A "blue ribbon" Water Resources Committee recommended major changes in the water code to the 1955 Legislature. A foremost result was establishment of the State Water Resources Board which was directed to develop beneficial water use programs for Oregon's 18 major drainage basins.

The law (ORS 536.300-310) states, in part, "The Board shall proceed as rapidly as possible to study...existing and contemplated needs and uses of water for domestic, municipal, irrigation, power development, industrial, mining, recreation, wildlife and fish life uses, and for pollution abatement, all of which are declared to be beneficial uses...", and "The maintenance of minimum perennial streamflows sufficient to support aquatic life and to minimize pollution shall be fostered and encouraged if existing rights and priorities under existing laws will permit." So beginning in 1955, the state through its Water Resources Board could establish a "public water right" in the form of a minimum streamflow (MSF). Once the state established a MSF on a specific stream, all water rights issued at a later date were subject to curtailment when the streamflow dropped below the established minimum.

Because of this legislation, the Department of Fish and Wildlife became involved in an extensive program to determine minimum streamflows needed to support aquatic life. Initially, the department recommended a single MSF for each stream to create a minimum desirable aquatic environment during the summer low flow season. However, it soon became obvious that consumptive demands for water could create conflicts during seasons other than summer.

In 1961, the department set out to determine by field study specific streamflow requirements of fish life for each season of the year. Because natural salmon and trout production is totally dependent upon certain flows, attention was focused on water requirements of these fish. Specific flow criteria were identified for upstream migration of adult fish, for spawning activities (including incubation and emergence of fry from the gravel) for rearing of juvenile fish, and for outmigration of young salmon and trout. Because of the complex relationship between these biological activities and streamflow requirements, MSF levels have been developed by the department on a seasonal basis by fish species. Oregon pioneered and has published many of these techniques and is recognized nationwide as a leader in the science of instream flow requirements for fish.

Between 1961 and 1974, the Department of Fish and Wildlife at a cost of well over $500,000 made instream flow studies and developed MSF recommendations in more than 1,600 stream locations throughout the state. The Water Policy Review Board 1/ to date has set MSF on more than 300 streams. The majority are in coastal and other western Oregon watersheds, though several have been set on important eastern Oregon streams. The process of adopting MSF requires extensive field investigation by the Department of Fish and Wildlife, complex water availability analysis by the Water Resources Department, and public hearings. This process has taken up to several years to complete a water program for a major river basin. A MSF only applies to water users junior to the date of the program and does not affect valid prior water rights. Time is of essence if any remaining unappropriated water is to be allocated subject to a MSF.

Perhaps the most important issue after 20 years of experience in Oregon is whether the MSF concept is an effective water management tool to protect instream flows and values. Unfortunately, there is not a simple "yes" or "no" answer. The principal problem with the MSF concept is that it is a complex regulation to effectively enforce and evaluate. So complex that my personal opinion is that many MSF have been generally ineffective in preventing flow depletions and overappropriations.

Enforcement is a major problem, both from a practical standpoint and political realities. Currently, there are over 56,000 water rights on record for the 18 districts in the state. Each district has a permanent watermaster

1/ The former Water Resources Board and State Engineer were combined July 1, 1975, into the Water Resources Department which is governed by a seven member Oregon Water Policy Review Board.

and up to 30 seasonal employes are hired statewide to assist the watermasters. Districts range in size from 3,000 to 15,000 recorded water rights. A strong enforcement program is required to assure that water users are complying with MSF. This requires considerable field investigation and with the limited number of watermasters and complexity of regulation, enforcement has not been totally successful.

Watermasters, although doing their best under the circumstances, only have the capability of effectively regulating a limited number of rights in a day. In addition, water users are primarily regulated after a complaint is filed by a senior permit holder. Complaints generally have not been filed by the public when streams drop to the established MSF. In fact, it is difficult for someone to know when the MSF is reached unless they have access to gaging station records. Because many MSF are at points where no gage stations exist, even the watermaster has to calculate the flow (a time consuming job) before he can regulate junior users.

Although there are only 300 MSF points to regulate on Oregon streams, one MSF at the mouth of a moderate size stream may require regulation of several hundred junior water right holders. It does not appear realistic to hope that enforcement of MSF by watermasters will substantially improve or that additional monies will become available to add manpower. What is equally discouraging is the fact that junior water right holders are increasing rapidly, making future regulation more impossible. About 1,000 new water rights are issued annually, making the chore of regulating for minimum streamflows increasingly difficult and creating a volatile political issue.

For example, three hundred and seventy-five permits have been issued in the Tualatin Basin since the program was adopted in April, 1970. In the South Umpqua Basin, 117 permits have been issued since the Water Policy Review Board adopted the program in March, 1974. Two hundred and forty-seven rights in the Luckiamute Basin are subject to the minimum streamflows programmed in June, 1964. Water Resources Department personnel have admitted that during the busy season, minimum streamflow control points not located at gaging stations cannot be adequately monitored.

There has been some regulation of the MSF program. Although the Water Resource Department records are sketchy, on August 14, 1975, six rights totaling 9.7 cfs were shut off in the Luckiamute Basin to maintain a 25 cfs flow. The municipal rights of Falls City and Monmouth were shut off from the Luckiamute River on August 15, 1975 to protect the MSF. There are undoubtedly other examples where the MSF has been enforced successfully.

In certain cases when MSF was enforced on such streams as the Luckiamute, South Umpqua and John Day rivers, the affected water users requested that the Water Policy Review Board temporarily suspend the MSF on those streams. In a highly publicized 1973 incident, the Board responded by allowing continued diversion of water from these critically low-flowing streams. The petitioners generally indicated that they were not aware of existing MSF and that they would suffer substantial economic loss and hardship if not allowed to continue use of the water.

Further forcing the issue, the Polk County Circuit Court issued a temporary injunction stopping Board staff from enforcing the MSF on the Luckiamute River. This court action became moot within a few days when the Board suspended the MSF. To date, an Oregon high court decision has not addressed the legal aspects of the MSF concept. But, it is the department's belief that the state has the statutory right to protect streamflows for instream values.

However, the more important question is whether it is reasonable to assume that seven citizens acting as the Water Policy Review Board can be expected to withstand the tremendous emotional, economic, and political pressures by denying appeals for MSF suspension during critical flow periods. Farmers and ranchers testified that their livelihoods were at stake if crops were lost. City officials made strong appeals that the health, safety, and welfare of their citizens were jeopardized without adequate water supplies. In turn, the Department of Fish and Wildlife, the principal supporter of the MSF, was asked to quantify fish loss in economic terms if the MSF was suspended temporarily.

Although crop loss can be easily estimated in dollars, losses occurring within the aquatic ecosystem are less obvious and cannot generally be quantified in the same terms. The Board has in all cases except one suspended the MSF when water users requested such action. The general public is most often sympathetic to the water users rather than the state which is attempting to "unduly restrict and regulate" a small landowner or community. Thus, the state by enforcement of MSF is placed in the untenable role of an adversary against a growing army of water users that are junior to established MSF.

If the MSF programs are to be effective in protecting the public water for fish, wildlife, recreation and pollution abatement, better public awareness and an increased enforced program are mandatory. Most important is withdrawing streams from further appropriation or classifying for limited uses when flows no longer can reliably serve all needs. This action would stop the issuing of additional water rights for months when streamflow records indicate remaining flows are less than those necessary to maintain MSF. It prevents a costly enforcement program from taking action during times of adversity on citizens who should have been denied a water right initially. It is the contention of the department that conflicts between consumptive and nonconsumptive water users are occurring because water rights are issued on streams already overappropriated and because private investments are being predicated on the availability of water during low flow seasons regardless of the overappropriations.

The Board can classify streams to restrict water uses which significantly reduce streamflows. This water management tool is similar to zoning of land. For example, the lower Deschutes River is "zoned" for fish, wildlife, and recreation, prohibiting all water diversion for irrigation, municipal, industrial, and mining uses. These are generally the major consumptive water uses found anywhere, so the flow of that river section is protected. The Board can modify or grant exceptions to these programs but the requests for modifications are considered on their merit before investments are made by water users. This classification system should be utilized more frequently in future Board programs because experience now indicates that this method is more effective in maintaining certain flows for instream values.

In conclusion, the MSF concept is not always the best legal method available for protection of instream flow values. Stream classification and withdrawal more clearly address the allocation of water before the fact rather than attempting to enforce complex rules after the problem occurs. The MSF program should primarily be limited to streams that have few water users (headwater areas) or where large quantities of water are available for allocation above the amount that is needed to maintain a MSF. This assures that either an unforeseen water use or one major user cannot degrade a stream even though water diversions are uncommon to the area. MSF may also be used successfully in conjunction with a water classification system or other restrictive programs. It should not be used on streams where large numbers of junior users will require frequent regulation.

WASHINGTON STATE'S INSTREAM FLOW PROGRAM ACTION

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ABSTRACT

Presentation is given, with examples, of the instream flow program currently being used in the majority of the small drainage basins in Washington State. Discussion is accompanied by slides which visually depict real life uses of water and the relative stage of several rivers in Washington. A concept to administratively determine whether waters continue to be available for various uses is addressed.

INTRODUCTION

My discussion on this panel will not be repetitious of my discussion presented at the general session this morning. For readers I would recommend reviewing that section prior to reading this section.

This panel can be likened to the sailboat occupants discussed this morning. We have two biologists, the representatives of California and Oregon, and two engineers, the moderator and myself. This is most appropriate; forums such as this do go a long way towards nudging the most reasonable action out of those responsible to represent the public's interest in protecting instream flows, and meeting the needs therefor.

I would commend to the serious reviewer a detailed investigation of Oregon's excellent program. That program has a history of nearly twenty years and was influential in the deliberations of both the Legislature and the administrators in developing the program in Washington. The problem of when the administrator of water rights decides water is no longer available from a particular source and ceases to issue rights therefor has, according to the previous speaker, not adequately been addressed in Oregon. In Washington we have addressed that situation. I will present that concept in addition to the information on our instream flow program.

*Chief, Policy Development Activity

Real World

In my opinion, in the past, often we technicians have gotten ourselves involved in studies for study's sake. I will now present a series of slides that provide visual representation of the several instream flow values we discuss, oft times somewhat abstractly.

(Slides depicting water for fish along with a theoretical production versus flow function (see figure 1), navigation, aesthetics, recreation, wildlife, and water quality.)

On figure 1 it is obvious that there is other than just one particular flow which yields a function of fisheries production. A great deal of this conference is addressed to defining one or more points relating to this particular function. An important concept, about which I may be somewhat redundant, is that if we do nothing to institutionalize protection of our instream flows, they will not receive any protection. The opportunity for zero flow occurring looms much greater.

Let us look at a number of streams throughout Washington State (referenced in the map of figure 2) and see just what a couple of flows look like at the same point of stream in these various parts of the state.

(Slides depicting flows in the indicated rivers at the indicated times found in table 1 are shown.)

(Closing slides addressing the need for action were presented.)

TABLE 1

Location	River	Date	Flow (cfs)
A	Yakima	8/10/72 7/26/72	3,440 1,260
B	Nooksack	7/20/72 9/5/72	2,460 1,010
C	Stilliguamish	7/20/72 9/5/72	832 202
D	Skykomish	7/14/72 7/11/72	6,680 975
E	Humptulips	7/19/72 9/7/72	578 181

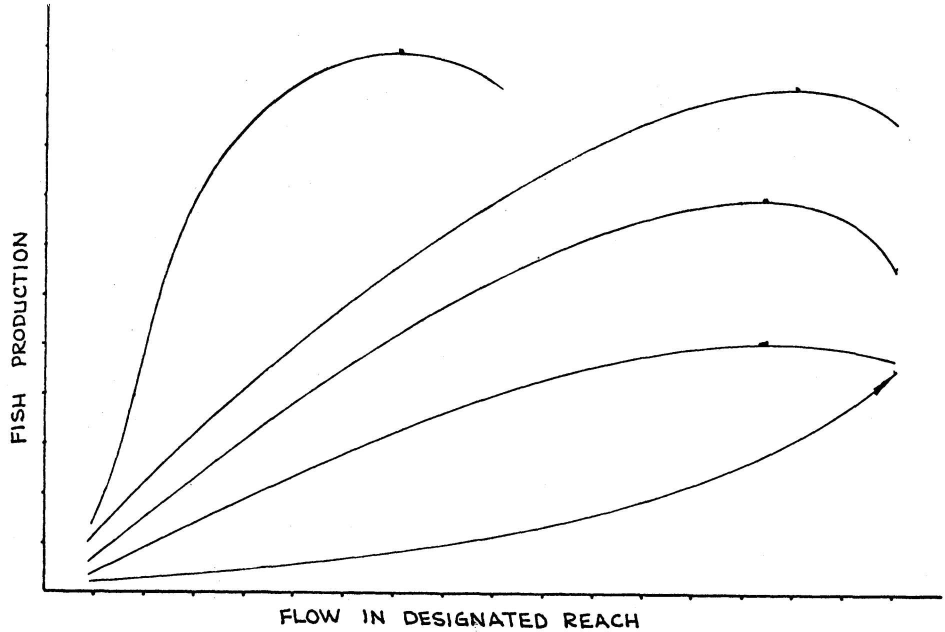

FIGURE 1. THEORETICAL FLOW - FISH PRODUCTION RELATIONSHIPS

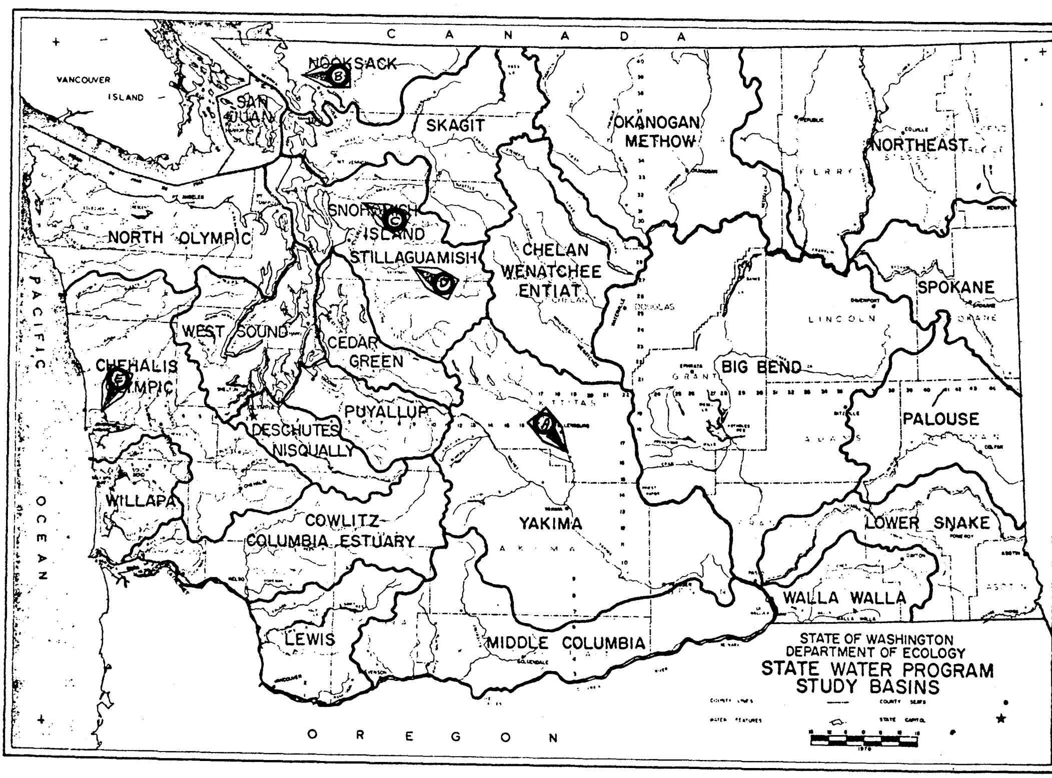

FIGURE 2.

Base Flow Program

Washington State is currently stressing getting instream flow protection on the books for at least the base flow level.

We do not contend the base flow level fully protects instream use potentials; however, we do believe that base flows preserve those instream values for which our state's legislature intended preservation in perennial streams of our state. They do continue to leave the door open to special interests representing instream flow functions to utilize the minimum flow act for obtaining flow which would in fact maintain and enhance that particular interest. It is perhaps a fine distinction, but it is a very important one; that is, getting some flow level protected at this time vis-a-vis further appropriation even if it is not an "optimum" flow, whatever that may be.

You noted from the slides and Table 1 that on the Humptulips River the flow range between July 19th and September 7th was 578 to 181 cubic feet per second. Let us examine the base flow levels recommended for that river in this time period. The base flows range from 265 cubic feet per second in July to 170 cubic feet per second in September. The recommended base flow levels, together with the slides, should communicate the notion that we are in no way trying to protect flows that, in fact, routinely will not actually occur. To be frank, this has been a real problem with many of the instream flow methodologies proposed heretofore.

The question posed earlier in regard to the base flow relationship to the fish production function as presented in figure 1 can now be better answered by indicating that the base flow levels protected clearly are not the "optimum fisheries production flow." The assumption can be made that base flows in nearly all cases will be some value less than the most desired flow from fisheries point of view. I do not believe that the state-of-the-art at this time allows us to say precisely what that relationship is.

For a detailed discussion of our base flow quantification procedure, I refer to Ed Garling's streamflow preservation program document, that you all have a copy of. Let us trace through the determination of an actual base flow number at a given point in time for an acutal control station and a real river. The following steps are taken and can be traced through on figures 3 (summary sheet), figure 4 (transformation function), and figure 5 (duration hydrograph):

1. Determine management reaches and specific control points therefor.

2. Communicate the information on those control points and reaches to individuals in agencies representing the public interest in instream flow values. This group is known as the instream flow rating committee.
3. Tabulate and totalize individual stream flow ratings and note along with the control reach discription and control point on the summary sheet (figure 3).
4. Route the rating through the transformation functions for the high flow and low flow periods of the year as indicated on figure 4.
5. Convert the percent flow duration levels obtained to specific flows for any given day through the duration hydrograph (October 15 and June 15 are noted in figure 5). Selected flow information is also noted on the summary sheet (figure 3).

This system does have a recognized degree of subjectivity to it. However, it allows obtaining variable flow figures as a function of variable instream values for different management reaches in the various basins throughout the state. There are many more details involved in this procedure which are discussed in Ed Garling's paper or that are sorted out by detailed studies in one of our overall basin management program documents.

Basin Management Program

Going through the process to derive base flow figures would be a purely academic exercise were we not able to carry those flows through an implementation process which defines their relationship with other conflicting uses and users. The basin management program is designed to do that. Time does not allow us to get into much detail about the basin management program; however, I think relationships can be seen by using an example. The example selected will be the middle reach of the Okanogan River which is located in north-central Washington State and flows through a prime agricultrual area. Figures 6 and 7 depict two levels of security associated with water availability for this particular management reach when existing uses and their impact, instream flow protection at the base flow level, certain institutional constraints, and potential future uses are considered.

After assessing various "upper-bound limitations" to use as criteria for the decision of when water availability exceeds supply on a reasonable basis, the one-in-two-year flow on a monthly basis was chosen for this particular management reach. In this particular basin, two different "upper-bound limitations" have been selected for various management reaches. Figure 6 depicts

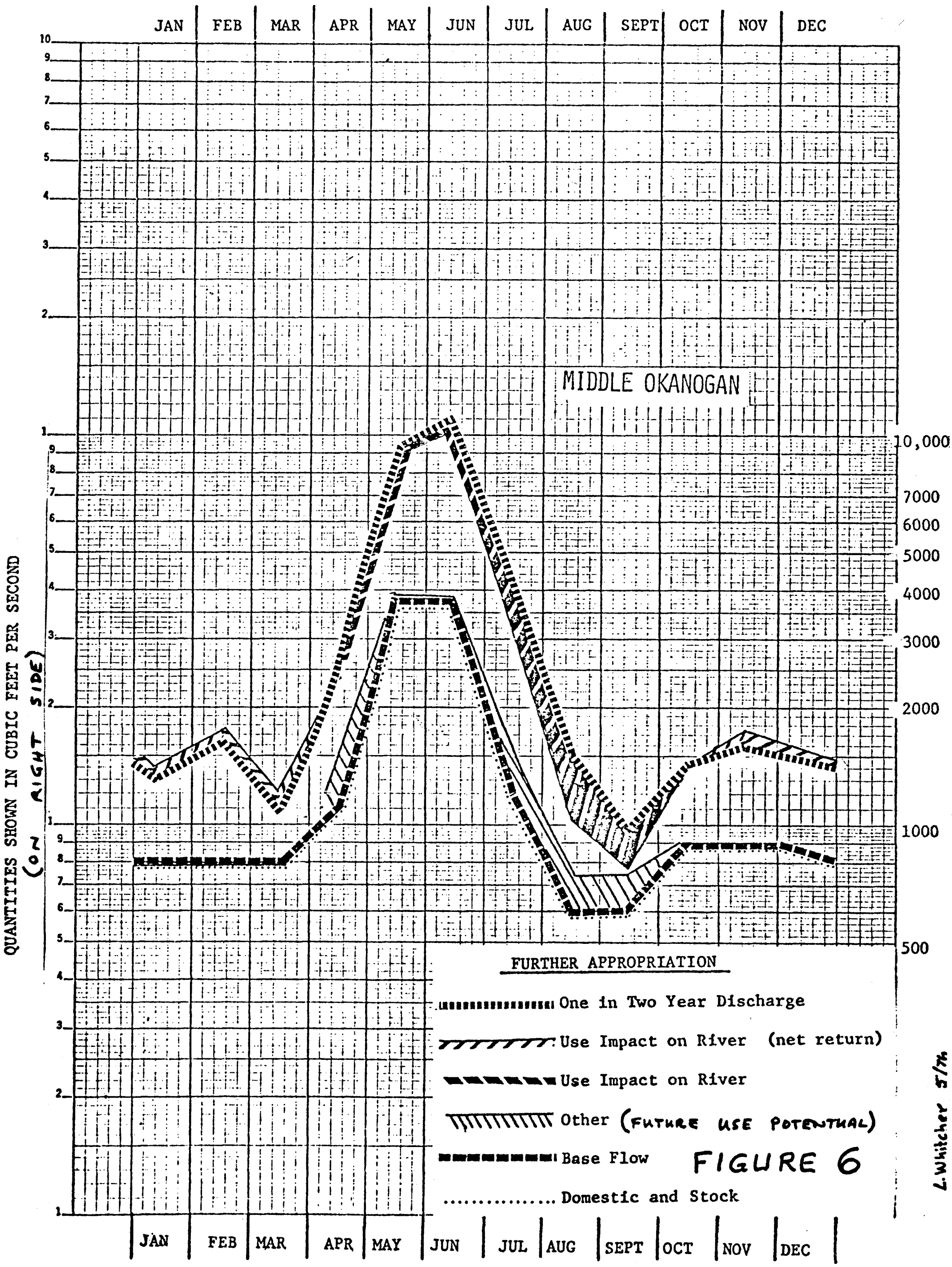
JAN FEB MAR APR MAY JUN JUL AUG SEPT OCT NOV DEC
MIDDLE OKANOGAN
QUANTITIES SHOWN IN CUBIC FEET PER SECOND
(ON RIGHT SIDE)
10,000
7000
6000
5000
4000
3000
2000
1000
500
FURTHER APPROPRIATION
One in Two Year Discharge
Use Impact on River (net return)
Use Impact on River
Other (FUTURE USE POTENTIAL)
Base Flow
Domestic and Stock
L. Whitcher 5/76

FIGURE 6

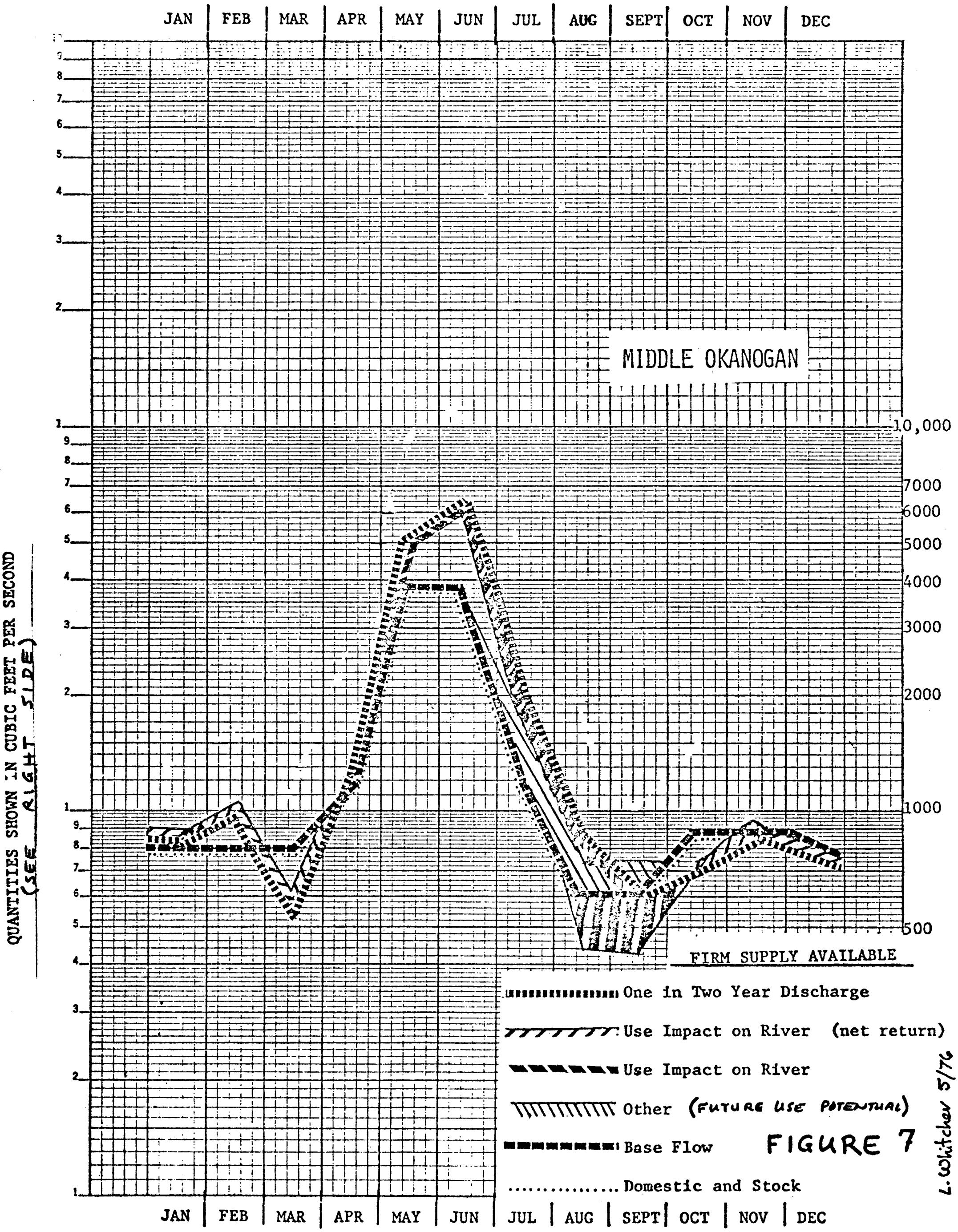
JAN FEB MAR APR MAY JUN JUL AUG SEPT OCT NOV DEC
MIDDLE OKANOGAN
10,000
7000
6000
5000
4000
3000
2000
1000
500
QUANTITIES SHOWN IN CUBIC FEET PER SECOND
(SEE RIGHT SIDE)
FIRM SUPPLY AVAILABLE
One in Two Year Discharge
Use Impact on River (net return)
Use Impact on River
Other (FUTURE USE POTENTIAL)
Base Flow
Domestic and Stock
L. Whitcher 5/76

FIGURE 7

graphically information which is contained in the program document tabularly and shows the relationship of various allocation categories to the upper-bound selected. Allocation categories shown include:

1. Domestic and stock watering uses.
2. Base flow level.
3. Existing use impact.
4. Future use potential.

The upper line is the one-in-two-year flow on a monthly basis. Also shown for assessment purposes is the return flow during certain times of the year. This shows up as a positive use impact. Given the selected upper bound limitation, existing and potential uses, and the base flow, one can draw conclusions as to whether water is available for further appropriation in this management reach and the order of magnitude of the security associated with the water availability. In this particular reach there is water available in excess of potential demand based on foreseeable irrigable acreage.

Now look at figure 7. Figure 7 substitutes for an upper bound the one-in-ten year low monthly flow. One can immediately see the conflicts that arise during the latter part of the irrigation season. The obvious conclusion from figure 7 is that water uses requiring a near 100 percent probable availability could not be allowed for uses subject to instream flow protection. Very simply, in the Okanogan, the conclusion is that water is available for such annual crops as alfalfa and pasture; but, water under existing flow conditions clearly is not available for orchard crops. Therefore, an individual desiring a firm supply of water for orchards must depend upon an assured source of stored water.

In other management reaches in this basin the upper bound criteria when combined with other information available leads to the conclusion that further water rights should not be issued by the state for uses which are inferior to the base flow protection.

The question is raised as to whether or not it would be better to wait until a more perfect instream flow protection figure could be derived. Table 2 provides information comparing requested Fisheries and Game flows (these agencies may consider these flows to be outdated in this point in time) to the base flows for the middle Okanogan reach. The important concept to note is that the base flows, while nearly always less than the Fisheries and Game Department's requested flows, are very significantly greater than zero.

TABLE 2. Instream Flow Comparison (in cubic feet per second)

Month	Okanogan River at Oroville		Similkameen River at Nighthawk		Okanogan River at Tonasket	
	G & F*	Base**	G & F	Base	G & F	Base
January	350	320	650	400	1000	800
February	350	320	650	400	1000	800
March	350	320	650	400	1000	800
April	375	340	875	640	1250	1070
May	825	500	1925	3000	2750	3800
June	550	500	3450	3000	4000	3800
July	375	350	1125	900	1500	1200
August	400	300	600	400	1000	600
September	400	300	600	400	1000	600
October	400	370	600	500	1000	900
November	450	320	800	500	1250	900
December	450	320	800	450	1250	850

*From letter dated June 2, 1970, from Departments of Fisheries and Game.
**Taken at the mid-month point.

Implementation

What does it all mean? Briefly, program document decision recommendations are embodied in an administrative regulation. The program document and the regulation undergo close public scrutiny and, when adopted, provide the basis for action on the granting and regulation of future water rights for the basin and management reach in question.

In the Okanogan Basin example, in excess of 100 water right filings are held pending this decision. As a result of the decision set recommended in the basin management program, sixty of those filings will be able to be acted upon. Fifty other filings are involved in an institutional situation upon which court action is pending.

The principal control station in the Okanogan Basin is telemetered with information being available on a real time basis. Before this discussion, I called Portland and got the flow for this morning which was 5,000 cubic feet per second at the Tonasket station. The base flow recommended for today is approximately 3800 cubic feet per second, therefore regulatory action need not be contemplated for any water rights issued subject to this program. The same conclusion was reached preliminarily last March by reviewing the forecast provided by snow survey analysis.

If action would be necessary, the program document provides for a stepped regulation process.

Conclusion

In my opinion, a do nothing or study forever alternative is clearly unacceptable. Let us make some decisions using the best judgment we can and take action. A base flow of 3800 cubic feet per second for instream flow protection on the middle reach of the Okanogan River is not equivalent to the water there today. Does it need to be? My answer is: very probably not. A flow of 3800 cubic feet per second is very much greater than zero.

Thank you.

TIME TO CHANGE SIDES!

TOPIC IV-C.

THE WEST COAST EXPERIENCE

Summary Discussion

Mr. Fisher of California had commented on the fact that it was necessary for the Fisheries and Game Department to file appeals to the Water Resources Department in order to have any effect on the issuance of water rights. A question was raised on how successful this approach has been. Many times the Fish and Game Department has been effective in reducing the amount of the granted right, but there have been no known instances where the water right had been denied.

California is still recognizing riparian rights. This was questioned in the discussion and it was emphasized that in many areas, small streams with many adjacent properties are significant problems. By the riparian doctrine they have a right to use water as needed for their property.

Is the Department's demands for 75 percent of the flow to be released from a proposed dam on the Stanislaus River reasonable? Due to the conflict, the dam was not built and consequently no flow was augmented. It was felt that the demands were reasonable, necessary and proper, and their agency did not lose out in the long run.

Mr. Rousseau was questioned regarding whether it would be acceptable to charge a higher price to water right applicants so that it would be comparable to the administrative costs involved, to discourage applicants. It was felt that this would be a good idea and has been discussed for some time. The big problem seems to be what the public reaction would be to higher prices. Something of this nature was proposed by the Governor of Washington recently and it met with overwhelming objection. There was publicity that the "State was going to begin to charge for water," so the proposal was dropped.

Mr. Kauffman had described the base flow procedure and was asked to comment on whether base flows were considered to be interim flows. Although the base flows were not interim flows they were subject to revision. The State has a minimum flow statute also that many consider to be generally higher flows than base flows, and on certain streams where the fishery resource is particularly large, minimum flows may be established later than, or instead of, base flows. To achieve these optimum fisheries minimum flows, in many cases it would be necessary to augment the flows by releases.

A definition of base flow was requested. It is more of a method that is used in calculating flows rather than a particular flow. Base flows, by the Water Resources Act of 1971, must be maintained to satisfy the criteria in the Act.

A question was raised on how flows can be kept in rivers that are for a specified use downstream or are augmented flows as a result of an upstream storage project. A concensus was reached that these flows are not subject to use by a senior right holder because this is not natural flow and the senior right holder is only entitled to the amount of water (even less than his water right) that he was accustomed to prior to the introduction of the unnatural flow.

Notes by panel moderator: Jerry Louthain
Office of Water Programs
Dept. of Ecology
Olympia, WA

Table II. SALMON AND STEELHEAD RUNS AT TRINITY RIVER HATCHERY[1/]

July 1-June 30	King Salmon			Silver Salmon			Steelhead	Brown Trout
	Grilse	Adult	Total	Grilse	Adult	Total		
1958-59	878	3,013	3,891	33	583	616	2,880	80
1959-60	2,701	4,549	7,250	26	93	119	2,071	52
1960-61	4,162	2,964	7,126	70	138	208	3,526	82
1961-62	2,899	2,498	5,397	37	318	355	3,243	35
1962-63	6,535	2,916	9,451	9	7	16	1,687	49
1963-64	2,536	4,204	6,740	11	72	83	894	34
1964-65	1,287	5,016	6,303	2	48	50	6,941	145
1965-66	1,521	1,554	3,075	9	3	12	992	100
1966-67	2,786	2,054	4,840	807	218	1,025	135	152
1967-68	1,746	2,870	4,616	59	806	865	232	231
1968-69	873	3,899	4,772	34	4	38	554	170
1969-70	1,130	1,456	2,586	1,711	285	1,996	241	70
1970-71	2,946	1,498	4,444	341	2,806	3,147	67	23
1971-72	928	8,293	9,221	8	39	47	242	7
1972-73	339	11,042	11,381	2,612	58	2,670	271	111
1973-74	1,577	3,635	5,212	486	7,595	8,081	162	39
1974-75	677	7,387	8,064	40	55	95	372	32

1/ All data through 1973-74 taken from annual operating reports of Lewiston Fish Trapping Facilities and Trinity River Salmon and Steelhead Hatchery, Calif. Dept. of Fish & Game, Inland Fishery Administrative Reports; 1974-75 data from Bedell (pers. comm.) are preliminary, subject to revision.

returning to the hatchery during these years. Total numbers of fall-run fish entering the hatchery in recent years have been well below pre-project totals and those recorded in earlier years at the hatchery.

Steelhead declines in the Basin are also reflected in decreased angler harvest. The estimated annual angler catch of steelhead in the river during the period 1956-58 was 8,800 fish (USFWS, 1960). The estimated annual catch a decade later (1968-69) was only 1,062 despite increased fishing effort. See Table III.

The downward trend in total king salmon harvest since project construction indicates that the increases in spring-run numbers have been insufficient to offset fall-run declines. There no doubt has been an adverse impact on the Indian fishery as well as the ocean sport and commercial fisheries and the river sport fishery. There has been an increase in fishing effort in the Trinity River but success and catch are down when compared to pre-project projected levels.

IMPACT ON THE AQUATIC ENVIRONMENT

As a result of Trinity project construction and operation, a number of major environmental changes have occurred affecting anadromous fish populations in the main Trinity River downstream from Lewiston Dam.

The most obvious operational change has been the approximate 90 percent reduction (except for occasional uncontrolled spills) in average annual pre-project runoff past Lewiston. Peak discharges have been reduced significantly. The river is turbid for longer periods over pre-project conditions. During some years this turbidity lasts for several months, the result of storing and later releasing silt laden winter runoff from Trinity Dam.

The temperature regime in the river downstream from the dam also has been altered. Reduced flows result in earlier and more rapid warming of downstream areas than occurred before construction of the project. The impact this

TABLE III. SUMMARY OF AVAILABLE ANGLER-USE AND CATCH DATA, TRINITY RIVER, 1941 TO 1968-69 (Percentages in Parentheses)*

Survey period	Annual effort (angler days) expended				Annual catch			
	Salmon	Steelhead	Trout1/	Total	Salmon	Steelhead	Trout1/	Total
1941 2/	1,385 3/	-	-	-	11,496	-	-	-
1956-58 4/	5,000 (15)	13,300 (35)	19,700 (50)	38,000 (100)	2,600 (5)	8,800 (16)	42,500 (79)	53,900 (100)
1963 5/	16,000	13,000	-	-	6,400	5,200	-	-
1968-69 6/	-	-	-	40,936	1,320 (8)	1,062 (6)	14,141 (86)	16,523 (100)

1/ Includes juvenile steelhead and salmon.

2/ Moffett and Smith (1950).

3/ Figure reported as "anglers" not "angler-days" but probably represented days of effort.

4/ U.S. Fish and Wildlife Service (1960).

5/ California Department of Fish and Game (1965a).

6/ Rogers (1972b). Figures are preliminary, subject to revision.

* Hubbell 1973.

earlier warming of downstream holding and nursery areas is having on salmon and steelhead populations is unknown. However, it is suspected that it may be interfering with the orderly emigration of a significant portion of the smolts destined to go to sea each spring, thereby reducing ultimate adult returns.

Problems of sediment (decomposed granite sand and silt) accumulation and growth of riparian vegetation have developed in the 40 miles of river between Lewiston Dam and the North Fork Trinity confluence since construction of the project. Sediments have filled pools and compacted spawning gravels. Vegetation encroaching on the stream channel has narrowed it in many places, causing changes in flow patterns that have resulted in erosion of riffles. Natural gravel recruitment to the river immediately downstream from Lewiston Dam was halted by construction of the project. Erosion and scouring of riffles in this river section have resulted in further spawning habitat losses. Habitat degradation from these causes is continuing.

King salmon spawning habitat surveys conducted in the Trinity before (1945) and after (1969-70) project construction indicate that available pre-project spawning habitat between the confluence of the North Fork and Lewiston Dam has been reduced by 44 percent (Coots, 1972). An undetermined amount of juvenile salmon and steelhead rearing habitat and adult resting habitat also has been lost.

Fishability of much of the river between Lewiston Dam and the North Fork confluence has been significantly impaired by the development of riparian vegetation and the filling of pools with sediment. The impact has not been quantified. The impact of the Indian fishery on the Trinity River fish resources also has not been identified.

These impacts can be summarized as follows:

1. Changes in streamflow are altering the stream ecosystem, thereby affecting all flora and fauna in the stream.

2. A reduction of living area utilized by anadromous fish with steelhead affected to the greatest degree.
3. Fish habitat affected include spawning riffles, holding pools, and nursery areas.
4. The patterns and timing of upstream migrating adult steelhead and downstream movement of young have been modified by the altered temperature and flow regime.
5. Lower fish populations are resulting in reduced sport fishing activities in the Trinity River Basin and the ocean sport and commercial fishery as compared to pre-project projected levels.
6. Stream setting and scenic quality have been degraded.

DISCUSSION AND RECOMMENDED ACTION

The Trinity project represents California's first experience with trans-basin diversion of a significant part of the runoff in a major river basin. Since project construction, extensive modification of salmon and steelhead habitat within the Trinity basin, and significant declines in anadromous fish resources, particularly steelhead, have occurred. All the causes of these declines have not been fully identified. Some of the factors responsible are now being corrected under the Trinity River Basin Fish and Wildlife Action Program. It is particularly important that the factors, both project and non-project related, adversely affecting fish populations in the Trinity River be corrected so that the perpetuation of these resources can be insured and especially so if they have been brought about by the water export features of the Trinity project.

The minimum flows incorporated into the Trinity River project were originally recommended by the U.S. Fish and Wildlife Service and California Department of Fish and Game in the late 1950's. The actual release schedule was modified in 1968 but did not include additional amounts of water. The past several years of operation lead us to believe that we were wrong; but because of ironclad contracts and operating criteria, neither we nor the California Department of Fish and Game have been able to satisfactorily correct the instream flow situation.

It must be remembered that the Federal Government at this time has a liability on its hands and that in the end, someone is going to be subsidized, either Trinity County or the distant clients -- the water users and power users far removed from the project area.

There is only one choice as far as Trinity River fish resources are concerned; that being the total fish resources must be restored. There is no other logical choice. The various fisheries and their economic spinoff must be restored through a subsidized program using increased flows, a fish resource restoration program including hatchery modernization, and a watershed rehabilitation program.

We believe the only way to approach reassessment of the amount of water required to protect and restore the salmon and steelhead fisheries of the Trinity River is through experimentation and evaluation. Observations indicate that there is a positive relationship between the size of a fish population and the amount of water available at certain times of the year. Thus, in order to yield a measurable increase in the fish runs, significant increases in the amount of water released from Lewiston Reservoir would be required.

In an effort to reverse the declines in steelhead and fall-run king salmon in the Trinity River, the California Department of Fish and Game, in a letter dated October 24, 1973, to the Bureau of Reclamation, recommended releases in the Trinity River be increased from 120,000 acre-feet to 315,000 acre-feet per year. The Department proposed that this initial experimental flow release and associated monitoring program extend for a minimum of three years.

The flow schedule developed is as follows:

Month	Recommended Average Flow 1/	Acre-Feet
January	200	12,000
February	250	15,000
March	300	18,000
April	300	18,000
May	1,750	105,000
June	1,000	60,000
July	300	18,000
August	200	12,000
September	225	13,500
October	250	15,000
November	275	16,500
December	200	12,000

Total - Approximately 315,000 acre-feet/year

1/ Within any given month, flows will vary according to fishery management needs.

It is believed that the higher flows would:

1. Increase survival and out-migration of juvenile steelhead and fall-run king salmon.
2. Provide more spawning area.
3. Provide better attraction flows for fall-run king salmon and steelhead.
4. Provide more living area for holding fish prior to out-migration.
5. Provide lower temperature throughout the upper stream reach -- Lewiston to Douglas City.
6. Reduce vegetative encroachment on the stream channel.
7. Facilitate a higher percentage of out-migrants of hatchery reared fish.
8. Not significantly aid in controlling the siltation problem.
9. Not necessarily satisfy those who desire more water for esthetic and recreational reasons.

The Bureau of Reclamation estimated that increased flows would cost the Central Valley Project about $4 million per year in potential power revenues.

They have also estimated that in the future (when the water is needed) it would cost the project another $2.2 million annually for reductions in the available firm irrigation water supply. They estimated that capital outlay costs of over $200 million would be needed to replace this water.

The problems associated with the Trinity River as a result of water development are not necessarily new; however, the magnitude and complexities are. The problems that plague the Trinity River Project planning and follow-up evaluation are inherent with water development planning in general. These are:

1. Projects are first designed to maximize water uses and yield for non-fish purposes. It must be recognized that critical needs of fish resources must be considered essential uses of water and that protection of such resources should not be included in the benefit-cost ratio. Not all fish resource problems can be solved solely through structural means such as hatcheries or management, but frequently water in addition to that presently allocated is required to adequately protect or maintain habitat conditions.
2. Existing water development projects have been authorized without adequate funding for conducting pre- and post-project baseline - biological - ecological - hydrological and hydraulics studies. This is especially true for post construction evaluation studies. These studies are necessary and the resulting information must be an integral part of decision making processes. Such studies also have to be conducted and funded as an integral part of project cost.
3. Most water contracts and commitments are too inflexible and oftentimes seem to be encased in concrete. Such contracts and commitments must be flexible enough to allow for reallocating water to meet fish resource conservation and protection purposes as they become known through post-project studies.

4. Impacts on fish resources and their environment must be measured by monitoring population changes and not the successful construction and operation of physical facilities. This type assessment only can be done if adequate pre- and post-project studies have been conducted.
5. Unforeseen environmental impacts are always a possibility. When they occur and are further complicated by a project, they should be corrected. Cost for investigating and correcting these problems must be considered a part of the project to be paid for by those benefiting from project water, not the fishing license buyers or the general public, as this would constitute a subsidy to the project and its distant water users.

There is concern that Trinity River water will continue to contribute power benefits, irrigation values, and Delta outflow at the expense of the Trinity River's salmon and steelhead resources. Federal tax dollars are being used to provide water and power to clients far removed from the Trinity River area and at the expense of the area's fish resources. We believe that the waters and the fish resources of the region of origin should be protected first before water is exported. Once distant clients have firmed up their demand and the agri-business has invested its money, it is near impossible to void Bureau of Reclamation irrigation or power contracts and return the flows to the stream of origin.

I believe that fish and wildlife conservation agencies must insist on project plans that include features, operation criteria, and operational flexibility so that measures or features to protect fish resources of the affected area can be incorporated into a project after it is constructed and in operation.

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IS THE TRINITY RIVER DYING?

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ABSTRACT

A brief overview of the Trinity River Division of the Central Valley Project and the dramatic effects of this massive water diversion upon the ecosystem of the river itself are considered from several aspects of the county of origin's point of view.

Social, political and economic impacts upon the county, as the originating watershed, and the implications of growing competitive demands for this water, are evaluated in light of established criteria and also in light of changing values.

The need for ongoing corrective measures to benefit this possibly dying stream (some of which have been initiated, but very few of which have been implemented to date), and also the need for a more balanced weighting of values that will insure realistic recognition of county of origin rights and needs, offer some basis for future management techniques.

INTRODUCTION

Those who pose the question, "Is the Trinity River Dying?" include not merely concerned residents of Trinity County in northern California.

A broad spectrum of voices is raising this question. These voices represent such varying backgrounds of expertise and interests as State and Federal government agency personnel who are evaluating the changing ecosystem of the entire watershed; sportsmen who deplore depletion of the river's once famed anadromous fisheries; local government officials who must cope with socio-economic impacts apparent in growing number since completion of the Trinity River Division of the Central Valley Project in the early 1960's; and also a chorus from concerned citizens in many parts of California as well as visitors from other states. All react with alarm to the cumulative insults and degradation this once-proud river has borne since the dams were placed unalterably across its upper reaches about 14 years ago.

Background of the Project

Upon completion of the Trinity project and component Trinity and Lewiston Dams the resultant massive trans-basin diversion of water produced a dramatically altered streamflow regimen.

Prior to construction, average annual runoff at Lewiston was 1,200,000 acre-feet; present annual flow below Lewiston Dam is 120,300 acre feet, or only about 10 per cent of the historical mean annual runoff. It should be kept in mind that this 1.2 million acre-feet diverted annually is 303,000 acre-feet above the planned design diversion of 897,000 acre-feet.

This 90 per cent diversion carries water from the Trinity watershed via a tunnel through the mountains and through a series of drops to the watershed of the Sacramento River. Here Trinity water is co-mingled with that of the Sacramento for delivery to farmlands and urban areas of the vast central California valleys. Trinity water also contributes heavily to water quality control and desalination in the Sacramento-San Joaquin Delta. Electric power development is also a component of the project's output.

A review of political pronouncements on the project back in 1952, well prior to enactment of the Trinity River Act in 1955, indicate through newspaper records that Congressman Clare Engle and Mr. Arnold Zimmerman of the U. S. Bureau of Reclamation assured the people of Trinity County that Trinity Dam would provide the following benefits: 1)Flood control; 2)Twenty-five per cent of the electrical power generated by the project; 3)No more than 60 per cent of the water would be exported; and 4)There would be no loss of fisheries.

These statements are taken directly from newspaper accounts. Yet the only one even partially effective today might be flood control, and even this the Bureau has denied in recent years as being a legitimate goal of the project operation.

The question here then becomes: How can you divert 90 per cent of a river from its watershed to another drainage system and not kill the river? Incidentally, the Mining Laws of 1872 (supposedly still effective) barred transfer of water from one drainage system to another, and perhaps with good reason as examination of impacts of the Trinity diversion will demonstrate.

General Environmental Impacts

Neither space nor time permit detailed exposition of disastrous environmental and ecological impacts apparent in the Trinity basin today. Most are well documented (in study after study, after study!) but a few general observations follow.

Project construction flooded 20,460 acres of wildlife habitat when the reservoirs filled in 1963. An estimated 8,500 to 10,000 black-tailed deer, dependent upon the flooded critical winter habitat, were ultimately lost. Uncounted other varieties of wildlife either wholly or partially dependent on these lands were also ultimately lost. Dollar value of these losses is exorbitant but has been relatively unconsidered in cost-benefit evaluations.

Trinity River Hatchery was built to compensate for upstream salmon and steelhead spawning areas blocked and lost to construction of the project. It was assumed gravel areas and pools below Lewiston Dam would continue to produce the same runs as existed under pre-dam conditions. Neither hatchery operation or the assumption of the remaining river's capabilities proved correct, with failure of both probably based on the fact that 90 percent rather than 60 or even 70 per cent of the river's natural runoff is exported.

There exists reams of data substantiating the facts of fisheries losses, and it would be a duplication of effort to detail them here. But an example or two is dramatic, and these losses bear close relation to economic impacts on the county. Steelhead returns at the hatchery dropped from a high of 7,000 in 1964-65 just after completion of the dams, to a low of 67 in 1970-71 and in the years since the count has remained similarly depressed. As to salmon spawning habitat, fisheries experts noted that from 1963 to 1967 there was an estimated 28 per cent loss of this critical habitat in the 16-mile stretch between Lewiston and Douglas City, the most heavily used spawning portion of the river. An estimated 50,000 King salmon spawned there in 1963, year of project completion, but due to sediment build-up and riffle degradation habitat for approximately 14,000 salmon had been lost in just four years. Then in 1970 another investigation in the upper river revealed that where a 1956 study noted 44 spawning riffles existed with 529,000 square feet of area, the 1970 survey determined that only 10 riffles covering a mere 81,000 square feet remained---a loss of nearly 85 per cent!

Additionally contributing to adverse impact on fisheries and wildlife, the river's reduced downstream flow has diminished its sediment transport capacity. As a result, tributary sediment and granitic sand continues to enter the river at undiminished rates where it builds up, contributing to even greater potential flood problems. Spawning riffles, nursery areas and holding pools used by both adult and juvenile salmon and steelhead are filled and lost, particularly in the miles of river most immediately below the mouth of Grass Valley Creek. And riparian and aquatic growth chokes the river and its banks for miles, producing both a habitat loss and esthetic impacts that have economic implications through loss of scenic quality, loss of access, and a consequent loss of tourist trade.

Few corrective measures have been attempted since that 1970 spawning area study, though some are being initiated with work projects scheduled to begin this summer. It can only be assumed that continued attrition of the salmon fishery along with a decline in the steelhead resource remains in progress.

But it should be noted that the State Department of Fish and Game and U. S. Fish and Wildlife Service both maintain that---regardless of other mitigation measures that may be attempted---if flow is not increased significantly death of the anadromous fisheries in the Trinity River may become a stark reality in the very near future.

totals would still be 3 million acre-feet per year above contract requirements.

It has been pointed out that 1.2 million acre-feet is diverted annually from the Trinity River basin, 90 per cent of its runoff. By contrast, a 150 cubic-foot-second "minimum" for downstream release for fish preservation has been maintained---in reality, more as the maximum generally allowed flow. This amount was set by agreement in 1959, in spite of the State Fish and Game Department's original recommendation for a 400 c.f.s. minimum to preserve spawning beds and maintain fisheries. In the past two years, extra water has been released on request of the State Fish and Game for department fishery studies; this year, however, due to dry conditions and the Bureau's claim of contract commitments the extra release is not considered possible even though the reservoir will experience a major draw-down for out-of-county use demands.

These downstream releases fail to account for a further provision of the Trinity River Act which states that beyond basic minimums for fishery purposes it is "provided further, that not less than 50,000 acre-feet shall be released annually from the Trinity Reservoir and made available to Humboldt County and downstream water users." Bureau officials have recently revealed an internal agency ruling that states this additional 50,000 acre-feet is not "additional" after all, but is contained within the overall 120,300 acre-feet released for fishery preservation purposes. That is a sleight-of-hand ruling at best, in my opinion. Additional oversight seems to occur, too, in respect to Trinity County's county of origin rights above and beyond the minimum release for fisheries.

At the other end of the faucet, a wide variation exists in CVP prices for delivered water. As examples, $17 per acre-foot to Contra Costa County for irrigation; $61 per A.F. to the same county for municipal-industrial purposes; $3.50 per A.F. to Delta-Mendota water users for irrigation; and $7.50 per A.F. to Westlands Water District, the vast corporate farm interests in the westside central valley whose proposed contract not only obligates the

Bureau to develop new water resources, but also gives Westlands priority on any new water. These values compare to the $17 per A.F. value placed on water released directly into the Trinity (for the fishery study purposes.)

It seems strange, indeed, that it costs $17 per acre-foot to open the gates of Trinity and Lewiston Dams and release additional water directly into the Trinity River, yet that same water can be taken from Trinity Lake and moved 400 miles through the Central Valley Project for a delivered price of $7.50 per acre-foot in the Westlands Water District.

Power generation is an adjunct of the Trinity that bears scrutiny, for benefits vary widely. Power is generated only at peak periods. But although the Trinity River Act specifies that "energy <u>will</u> be furnished the county," it gets none; Redding in Shasta County is a preference customer purchasing at 4½ mills per kilowatt hour (a price under upward adjustment, to be sure); and yet Section 31.2-16 of the Westlands Contract provides <u>free</u> electricity from CVP for pumping water to Westlands. One can only ask, "Why?"

The Need for Changing Values

The whole area of water rights and water use is highly complex, competitive and emotionally charged, as well as being politically sensitive in the controversial State versus Federal rights arena.

Two doctrines in California govern water rights---riparian and appropriative---and they exist simultaneously and more often than not in conflict. But there needs to be a thorough reevaluation of the needs and rights of areas of supply, or origin, and the recipient areas, including all attendant legal implications of water export. There also needs to be a complete reevaluation of any water projects authorized but not yet constructed.

An orderly long-range plan based on supply and demand is needed. Water should not be exported from counties of origin unless provision is guaranteed that their needs will be met, and that exported water will not be wasted or under-valued in its area of delivery and use.

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THE FOREST SERVICE ROLE IN THE TRINITY RIVER BASIN FISH AND WILDLIFE RESTORATION PROGRAM: FUNCTIONING OF A PUBLIC LAND MANAGER IN AN INTERAGENCY FRAMEWORK

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ABSTRACT

As the principal landholder in the Trinity River Basin the California Region of the Forest Service (Region 5) has seen itself as having a major responsibility for land management decisions there. It also recognizes the need for assuming a strong role in developing and implementing an interagency restoration program. This duality of positions has resulted in considerable difficulty for the Region in defining its mission and discharging its responsibilities within the interagency framework.

However, the Forest Service emphatically believes that the interagency task force approach is the only possible way to devise solutions and undertake actions for restoration of the Trinity River Basin fish and wildlife resources. Melding and unifying objectives, responsibilities, goals, and programs is essential. Full, open communication and mutual goodwill are required. Compromise and innovation are key concepts.

The values are too high, and the need for immediate corrective action is too great, to allow provincialism to prevent group success. The California Region of the Forest Service believes the job can and will be done this way. We are developing flexibility in approach and trust in others, and hoping to help our numerous partners to do so also.

This paper discusses some of the mechanics involved, and some of our experiences and observations in the process to date.

INTRODUCTION

As you have already heard the interagency Trinity River Basin Fish and Wildlife Task Force came into being in its present form during the spring and summer of 1974. The new expanded group (nine agencies and entities, enlarged to ten in late 1975) in its 3-level hierarchical organization was a response to awareness of a very broad base of area responsibilities and interests, and recognition of complete Basin and resources involvement. The complexities in scope and charter introducted by these changes, and the necessity for developing different working methodologies, resulted in a period of growth and innovation for the Task Force. The major problem in developing a working body lay in learning to integrate differing agency and individual interests, philosophies, and concerns into a unified group consensus and will.

The principal stimulus to produce an immediate broad program of action arose as a direct result of citizen involvement in the political arena (much of it generated by Basin-area residents). It resulted in a large-scale planning effort accomplished preliminarily by an ad hoc Work Group under a very tight demand schedule, and produced a two-phased program package first funded by Congress in early 1976. That portion thus activated was a refined and modest version of the Immediate Action 3-Year Program phase; the long-range total-Basin phase is still undergoing assessment and development, with final acceptance and implementation still in the future. However, in developing an on-going active program the planning-level Action Group is continuing to recommend more portions of the long-range package for inclusion in the presently funded program.

The current emphasis has been on achieving early correction of obvious resource damage in a readily visible manner. The Task Force is keenly aware, however, of the urgent need to develop long-haul fully integrated planning for the complete Basin resource complex.

Given the diversity of participant positions the working-out of an effective modus operandum for addressing these several complex issues, and producing a total resource management program directed initially at correcting serious old problems, has been a challenging experience. Although we certainly do not have all the answers it was felt that sharing some of the details would have value here.

AGENCY RESPONSIBILITIES AND CONCERNS

There is the implication, often unvoiced, in instituting an interagency body that "all of us can do it better then any one of us." Less readily acknowledged is the corollary admission "....so we've each of us got to submerge our individualism in the community." And of course the concept is more easily grasped than the practice! To rough-in the size and scope of our diversity-problem let me briefly list the entities of the Trinity River Task Force and characterize their traditional positions with some semi-facetious caricature:

USFWS - "Defenders against the world" for all animals large and small (but mainly the consumable ones).
Bureau of Reclamation - The West needs water, and we know best how to get it and use it.
Forest Service - The woods are there to use (mainly as wood), and we've been told to see to it.
Bureau of Land Management - We've got so damn' much land to take care of we're not going to be stampeded into any rash decisions.
Soil Conservation Service - If you want to save soil (and you'd better) we have the answers and the know-how.
California Fish & Game - States' Rights, brother! We're the legal animal-managers; we've been at it longest; and we know the territory.
California Department of Water Resources - Our record speaks for itself: we've done a real professional job on the most ambitious water plan in history, and that's been good for everybody.
Trinity County - It's <u>our</u> area and <u>our</u> livelihood, and we're fed-up with you bureaucrats studying it to death: let's <u>do</u> something!
Humboldt County - We've got a stake in this, too, and we're not going to let outsiders and upstreamers call the shots for us.
Hoopa Council - All of you are talking about <u>our</u> fish and <u>our</u> land - now it's time for us to tell you where it's at.

In addition to these varying points of departure the membership bring with them a whole armor of legal constraints that affect, in greater or lesser amount, the degrees of negotiating freedom of the representatives. A few examples: "organic law" that tells an agency it is <u>completely</u> responsible for managing a particular piece of public geography, and that it cannot relinquish that responsibility; the body of law that establishes and upholds State sovereignty in the matter of keeping and using wild animals and fish; Congressional usage and tradition in the language of appropriating and enabling legislation that permits no flexibility by the administering agency in determining "project purposes" and fund allocations; historic and legislatively established Native American rights; etcetera, ad nauseam.

As if that were not enough burden to bring to a socio-political amalgam, laid on top is the time- and honor-encrusted vast, foggy cloud of agency policy and traditional philosophy and IMAGE! It goes almost without saying that these trappings get in the way of commonality of purpose and effort.

Nevertheless, the cornerstone of constructing and operating an interagency organization is the fine art of practical mutuality. It calls for one of the most delicately balanced acts of atypical human behavior: voluntary self-denial for the common good. Even given the premise that this has been achieved by all participants, the daily practice of determining the balance-point between legitimate agency prerogative/responsibility and essential flexible compromise to attain new goals is immensely and frustratingly difficult. Only those of very good will, considerable patience, and no little vision should attempt it, and they will often fail!! Yet, irrevocably, the commitment must be to mutuality.

Within that somewhat introspective context, how is the U.S. Forest Service in Region 5 (California) managing to find and fit its place and develop its role?

FOREST SERVICE MISSION AND ROLE

At this point, in addition to taking time to acquaint you in some detail with our organization's corporate peculiarities, I should probably make the typical bureaucratic disclaimers and qualifications for what I'm doing; ergo, the verities and absolutes I have favored you with up to this moment of donning the cloak of Federal immunity, and those that will come hereafter, are my own personal views and beliefs, and have not had the full examination and blessing of my employer - I alone accept responsibility for them and for any merit or catastrophic results pertaining thereto.

As most of you probably know the Service has recently been undergoing the catharsis of critical self-examination in the light of rapidly changing views and attitudes of its clientele. Consequently we have just barely gotten over re-defining our mission, and are still in the throes of determining all our roles in our world of flux. Encapsulated, we see ourselves as being Congressionally mandated to so manage the country's National Forests as to produce a continuing optimum supply of goods, services, and amenities under a sustained yield, multiple-use system that recognizes the quintuple partnership of wood-water-wildlife-forage-recreation resources; and, of assisting the States and the private wildland owners to do so also; and, of performing the necessary research functions to adequately support such wise management. Our still-developing galaxy of roles embrace many functions and activities too numerous to catalog here, as one would suppose, but lean quite heavily on the responsibility for providing leadership in the ongoing practical management of the Nation's forested lands.

It might be illuminating to tell you that our role-concept has led us to equip ourselves with geologists, landscape architects, meteorologists, botanists, hydrologists, range conservationists, economists, biologists, sociologists, mining engineers, entomologists, archeologists, artists, cartographers, rural and urban planners, journalists, and so on through most of the recognized disciplines, in addition to the well-known foresters, engineers, and business managers long associated with the organizational image. We are cognizant of our roles in developing resource management leadership in many fields.

One of the factors that has been troublesome for the California Region of the Service in working out its function in the Task Force has to do with jurisdictional parameters. We are still wrestling, not only with National Forest boundary/primary responsibility relationships with the other members, but with delineation of who should have the ball in-house. The decentralized autonomies of our hierarchy, as well as our complex line-staff relationships among the several levels, have called for many on-the-spot adjustments, and our talent for innovation and flexibility has not always been equal to the need! For instance, can an authorized agency representative to the working group level of the Task Force truly speak for the Region in a binding manner on an entirely new issue requiring decision now? And can that Staff person really commit any portion of a District Ranger's funding allocation to an accepted job assignment? Does the California Region actually intend to accept for implementation a decision of the Task Force policy level that,say, 6,000 acres of National Forest land shall be managed primarily for deer production, or that Gualala River steelhead fingerlings shall be planted for three years in the Salmon-Trinity Alps Wilderness headwaters of French Creek?

I submit that we must marshall all our abilities to accommodate, indeed to seek, innovative changes in manners of looking at, and means of dealing with, such questions and issues if we are jointly to effectively address our joint problems. It is not easy for a conservative old-line organization to adapt to this sort of change, but it is being worked at, and we believe it will be done. It must be somewhat akin to giving birth: it hurts like hell at the time, but shortly it is possible to relax and shout proudly, "look what I've done!"!!

DEVELOPING THE TEAM CONCEPT

So far I have dealt mainly in generalities, and indulged a penchant to philosophize in the grand manner. How about some specific coming-to-grips with the basic elements of our operating method. I believe our experience has shown us that there are three primary attitudes essential to the "guidelines to good interagency group practice", viz.:

1 - "Loosening up on the reins"
2 - Modification for common goal attainment
3 - Shaping the product through give-and-take

Let's look at them one-at-a-time.

I suspect that keeping a firm grip on the driving controls is as instinctive with Executive Branch agencies as breathing. And yet this provincial self-centeredness must be abandoned as a first basic step in opening up for group action. The metaphor from horsemanship of "loosening up on the reins" might well be accompanied by the familiar admonition to "ride easy in the saddle" - both speak in homely but direct fashion to the need for relaxing from tight individual control toward integrated team effort.

The next logical move in team development calls for positive, focused effort to modify traditional single-agency postures and aims so that agency action will fit group formats and contribute to group accomplishment. We have found that the key word here is "positive" - merely refraining from bucking-the-tide won't make it. Working for positive contributions to group goal-setting and achievement frequently calls for complete turnarounds by members, and that comes hard without a firm commitment to the team concept.

Finally, development of a productive team (read interagency group, in our case) requires more than willingness and good intentions. As functioning practitioners we have had to learn to forge our new unified programs in the heat of honest, open negotiation that demands the best of give-and-take shaping and fitting. Only in jointly hammering away at the initial castings, bending and trimming, cutting in here and adding on there, in unified interaction, can anything really new and better be fashioned. A familiar simile is the welding of a smooth, disciplined college basketball team from an assembly of individual high school stars.

JOB ALLOCATIONS AND SHARED BURDENS

We've set the stage, described the ground rules, and delineated the mental/emotional (behavioral) conditioning necessary for group action as developed by the Trinity River Task Force. The nuts and bolts of actual practice may also be of interest. We have devised a three-question approach for implementing any action proposed by the group as a primary way of cutting quickly through to job assignment decisions:

1 - Who has the expertise?
2 - Who has the capability?
3 - How can it be most efficiently done?

Running our program/project proposals through this sifting process has nearly always resulted in very quickly getting at answers that are nearly as simplistic as the questions; a rather surprising result. The first two steps tend to shake down pretty rapidly under group scrutiny. The third sometimes requires more specific effort of a trial-and-error or "show-me" nature. In short the characteristics of the interagency group and the process of function I've described almost automatically yield innate targeting toward logical contractors for project implementation.

The problem of meeting individual-member fiscal integrity while still exercising group overview control presents some of the stickiest mechanical obstables. Our basic approach has been an attitude of "can do", and it requires inventiveness and forthright aggressive perseverance. The fact that the Federal system utilizes a lead-agency concept for primary Congressional allocations is a distinct help. But spreading it around internally demands fiscal flexibility and reasonable lead-time planning. Of course the matter of divvying up the actual final funds among projects and contractors gets the group right back to practicing group action under our principles with a vengeance!

In practice we've found that thinking of the business arrangement as a contract between the lead agency (fund administrator) and the "will-do" agency, effectuated by standard cooperative agreements with reimbursement for work accomplished, can make this mechanic fairly simple.

It should be pointed out that a willingness to pitch in and help-out in quasi-unofficial cooperation is often also necessary.

KEYS TO GROUP OPERATIONAL VIABILITY

I'd like to close in on my finish-line by trying to reduce this discussion of one interagency group's learning experiences to a short list of summarizing key concepts. I believe, in view of all that I've exposed you to in sharing our experiences and observations on making such a body work, in this case in dealing with shared responsibility for correcting instream flow problems (among other things), that a simple listing will adequately present the basic idea. Here are those five keys we've found:

1 - Listening versus Lecturing

2 - Wearing the Other Guy's Shoes

3 - Focusing on Results

4 - Hanging Loose

5 - Developing Mutual Trust

Utilizing them takes conscious effort and commitment. They're working for us.

SUMMARY

It may seem I have wandered rather far afield from my assignment of covering the public land manager's role in the Trinity River Fish and Wildlife Task Force operation. It is certainly true that the Forest Service has a very broad charter of responsibility for, and expertise and interest in, total public wildland resource management in the Trinity Basin. And I am keenly aware that the Conference's principal thrust concerns instream flow needs. Nonetheless, I have become increasingly convinced that Region 5 of the Forest Service has both a technical participant role and an expediter-catalyst role in the effective functioning of this interagency group, and that the latter may be the most important. Perhaps it is also the hardest to get a handle on.

Further, I know you've gotten a complete and illuminating exposure to the technical aspects of the Task Force operation and the problems and programs we've addressed. Determination and effectuation of adequate instream flows to meet essential needs has been one of our top priorities. I submit that we could not have attacked the problem at all without evolving a group working mechanic. I have discovered that my agency has a unique challenge to function in that area.

Finally, to dispel any notion that I believe that either I or the California Region of the Forest Service have been especially annointed to bring you any ultimate truths in this area of group interaction I want to clearly re-iterate that I've tried merely to share with you our experiences in a common problem situation germane to the business of this Symposium. It has been challenging for me to focus my thoughts on the matter and stimulating to look at them with you. I hope you have found them of some interest.

WATER RESOURCES DEVELOPMENT AND MANAGEMENT
TRINITY RIVER, CALIFORNIA

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ABSTRACT

This paper presents an overview of the Trinity River Division of the Central Valley Project, California, authorized by Congress in 1955. U.S. Bureau of Reclamation completed construction in 1964 and operates and maintains the Trinity River Division as an integral part of the Central Valley Project.

Since the construction of Trinity and Lewiston Dams, instream fish and wildlife problems have occurred in the Trinity River Basin of a magnitude that were not foreseen in the early planning phases of the project.

Because of environmental concerns taking greater and greater proportions, the California State-Federal Interagency Task Force established the Trinity River Basin Fish and Wildlife Task Force. This latter Task Force has developed a comprehensive action program to identify and solve fish and wildlife problems estimated to cost over $7 million over an 8-year period.

Present and future planning of Federal water resources projects must now include the multiobjective planning procedures promulgated by the Water Resources Council to reflect changing public values which are shifting from economic toward greater recognition of environmental and social values. Planners must now be cognizant of a greater variety of instream flow need factors and recognize their impacts where once these matters were largely ignored. The process is complicated and difficult since "environmental impact" includes many physical and social effects which are not easy to quantify and at times almost impossible to compare.

INTRODUCTION

The water resources of the upper main stem of the Trinity River basin in Northern California were developed and are managed by the Bureau of Reclamation at the facilities of the Trinity River Division as part of the Central Valley Project. These facilities divert surplus water from the basin for use in the Central Valley, as well as making downstream releases for fishery preservation. A hatchery was built to maintain the anadromous fish runs and wildlife mitigation measures were taken.

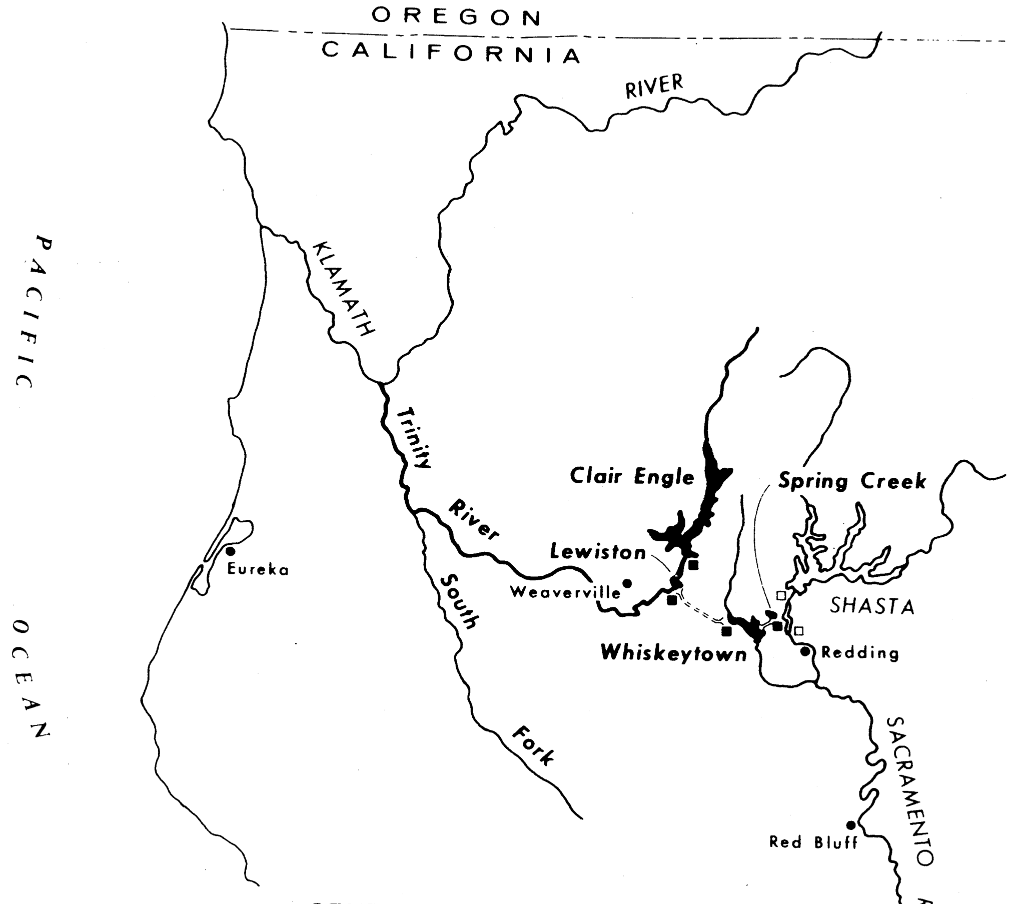
During and following the construction of the Trinity River Division, other developments have occurred in the upper basin including logging, road building, and home developments. Coinciding with these developments, activities have been declining in both the steelhead fisheries and deer populations. To date, the causes for the declines have not been determined.

Because of increasing concerns for the river environment, the Trinity River Basin Fish and Wildlife Task Force was established in 1971 to identify and solve fish and wildlife problems in the basin. In addition, future planning of Federal water resources projects must now include the concept of multi-objective planning established by the U. S. Water Resources Council. Planners must now consider a greater variety of instream flow need factors and determine their impacts.

Trinity River Basin

From its headwaters in Oregon, the Klamath River flows westerly across northwestern California to the Pacific Ocean. The Trinity River is a 130-mile long tributary of the Klamath. The Trinity River Basin encompasses an area of nearly 3,000 square miles located between the northernmost part of the great Central Valley and California's north coastal area. Average annual precipitation in the upper Trinity River Basin varies from about 40 inches near the town of Lewiston to nearly 80 inches at some of the higher elevations. Average annual runoff of the Trinity River at its confluence with the Klamath River is about 4 million acre-feet. The attached plate shows the locations of the Trinity River and the features of the Trinity River Division.

The basin is sparsely settled and its economy is based on lumbering, recreation, mining, and livestock production.



CENTRAL VALLEY PROJECT
TRINITY RIVER DIVISION

Plan of Development

Early planning investigations in the 1950's concluded that the fullest and most economic conservation and use of the water resources of the Trinity River for the widest possible public benefit would be obtained by diverting surplus water from the basin into the Central Valley. The water thus diverted would be put to beneficial use for irrigation without impairing in any way instream consumptive requirements within the Trinity and Klamath River basins. Hydroelectric power essential to the industrial growth of the northern counties and the entire State would be produced by dropping the water some 1,800 feet in the 20 miles between the Trinity and Sacramento Rivers. In addition, the reservoirs created would provide important new recreational opportunities.

The Trinity River Division was authorized by Congress as part of the Central Valley Project in 1955. Construction was completed in 1964.

The Division's facilities regulate the average annual runoff of 1,100,000 acre-feet from the upper 728 square miles of the Trinity River Basin. Trinity Dam, an earthfill structure 537 feet high and 2,600 feet long at the crest, creates a lake that regulates the flow of the Trinity River near the town of Lewiston. From Clair Engle Lake, the 2.4 million acre-feet reservoir behind Trinity Dam, water flows through the 106,000 kilowatt Trinity Powerplant into Lewiston Lake.

Some of the flow is released from Lewiston Dam into the Trinity River, which flows north and west into the Pacific; some is diverted into a tunnel which runs 10.8 miles through a mountain, into the Sacramento River Valley. At the end of this trans-mountain diversion, water is dropped through the 141,000 kilowatt Judge Francis Carr Powerhouse into Whiskeytown Lake.

From Whiskeytown Dam, 282 feet high, part of the water is released to maintain a live stream in Clear Creek; the majority of the flow is diverted through another shorter tunnel into the 150,000 kilowatt Spring Creek Powerplant, which empties into Keswick Reservoir. From Keswick Dam, water is routed to irrigable areas in the Sacramento and San Joaquin Valleys.

Fish Mitigation

The Trinity River is one of California's most famous fishing streams. The river and its tributaries above Trinity and Lewiston Dams provided spawning area for king salmon and steelhead trout. To compensate for the loss of these upstream spawning areas by the construction of Lewiston and Trinity Dams, the Bureau of Reclamation built Trinity River Fish Hatchery. The hatchery has a capacity of about 4 million eggs and is located immediately downstream from Lewiston Dam. In addition, the project plan provided for the downstream release of approximately 120,500 acre-feet annually at Lewiston Dam for fish conservation.

Because the Trinity River is important statewide, both as an angling stream and as a nursery for anadromous fish, fish mitigation procedures were carefully investigated. Prior to construction of Division facilities, the U. S. Fish and Wildlife Service made a preliminary evaluation report on the value of both fish and wildlife affected by the project. The Service, working with the California Department of Fish and Game, prepared a report outlining the fish conservation facilities which should compensate for the loss of the spawning areas.

To maintain the fisheries below Lewiston Dam, 150 cubic feet per second of water is released between December 1 and August 30 of each year. Releases are increased to 200 cubic feet per second during the period of September 1 to October 14, and to 250 cubic feet per second, October 15 to November 14.

Releases for the period November 15 to November 30 are set at 200 cubic feet per second. The higher releases in the fall facilitate natural spawning.

Environmental and Economic Impacts

After the construction of the Trinity and Lewiston Dams, the streamflow regimen changed drastically. The present annual flow below Lewiston Dam of 120,300 acre-feet for fishery purposes is about 10 percent of the historical mean runoff at Lewiston.

After dam completion, the reduced flow downstream diminished sediment transport capacity of the river. At the same time, there was an increase in sediment from other development activities. The result is that sedimentation is filling in spawning riffles and nursery areas for salmon and steelhead, particularly in the 8 miles of river below the mouth of Grass Valley Creek. Due to irregular flows, aquatic vegetation is encroaching upon the channel.

In an effort to reverse the decline in steelhead in the Trinity River, the California Department of Fish and Game recommended in October 1973 that the Bureau of Reclamation release 315,000 acre-feet per year in the Trinity River. These releases, to be made on an experimental basis for 3 years, represented an annual increase of nearly 195,000 acre-feet. These recommended releases would have major economic effects on the operations of the Central Valley Project.

Water diverted to the Sacramento River Basin would be reduced by 195,000 acre-feet annually. With the ability of the Central Valley Project to use return flows and to coordinate its water supply from other sources, this amount is equivalent to a 340,000 acre-foot firm supply of irrigation water.

A reduction of 340,000 acre-feet in the firm irrigation water supply would reduce the amount of money repaid to the project. Revenue losses associated with this yield reduction would vary depending on the service area in which the water would be used. In the San Luis service area, over $2,200,000 annually would be foregone.

Power production would be reduced by about 50,000 kilowatts annually, an equivalent to the power needed to satisfy over 30,000 households. To meet its project pumping load and contractual commitments, the Bureau would need about $4.0 million annually to purchase power.

The Bureau of Reclamation agreed, however, to experimental fish releases of 125,000 acre-feet for 3 years beginning in 1974. Releases were made in 1974 and 1975. Releases have not been made in 1976 because of the effects of a drought year.

Trinity River Basin Fish and Wildlife Task Force

In 1971, a cooperative program between the Federal agencies of the Bureau of Reclamation and the U. S. Fish and Wildlife Service, and the California State Department of Fish and Game was initiated. The primary objectives of this Task Force were (1) to identify factors adversely affecting wildlife and anadromous fishery resources in the basin, especially those arising from construction and operation of the Trinity River Division of the Central Valley Project; and (2) to recommend measures to correct existing problems, restore these resources to pre-project levels, or satisfactorily compensate for losses. All relevant data or proposals were reviewed. A detailed study plan to identify the reason for the decline of the steelhead and salmon populations and to evaluate measures needed to restore these resources was prepared by the California Department of Fish and Game in 1973. Restoration of two spawning riffles was implemented in 1972 and completed in 1973. In 1974, funds were not available for the program.

In 1975, the Trinity River Basin Fish and Wildlife Task Force was expanded to include the following: California Department of Water Resources, Trinity County, Humboldt County, Hoopa Valley Indian Reservation, U. S. Forest Service, U. S. Bureau of Land Management, and U. S. Soil Conservation Service.

This expanded Task Force has developed a 4-year action program costing about $6.1 million. An interim action program developed by the Task Force, including formulation of plans for future action, a fish restoration program, a program to compensate for wildlife damages, and a watershed restoration program, is now underway. The action program will be followed by a 4 to 5 year monitoring program costing about $1.5 million. Congress has appropriated $500,000 to initiate the action program this year. Multiobjective planning procedures will be the primary evaluation guideline for the program.

Multiobjective Water Resources Planning

People have become increasingly aware of the relationship between the development of natural resources and the environment. The U. S. Water Resources Council has incorporated in its planning policy the changing public attitudes on water development. The concept of Multiobjective Water Resources Planning is one in which environmental and social values are weighed equally with economic ones. Today, planners must consider a greater variety of factors, including instream flow need and establish their impacts. To the decision-maker, multiobjective planning procedures offer greater evaluation depth. More readily identifiable facts and figures will be available on the many trade-offs, both measurable and unmeasurable, on instream flow needs than those previously recognized or considered.

Conclusions

The fishery conditions in the Trinity River Basin indicate an urgent need for further studies to develop a coordinated and integrated resource use and management plan adaptable to the capabilities and limitations of the area's natural resources and environment. A comprehensive evaluation of the environmental impact of the Trinity River Division's operation on the Trinity River Basin is needed.

Such studies, however, should not be limited to only fish and wildlife biological aspects, but should include geological, engineering, legal, social, economic, and other interrelationships as well.

Since the Trinity River Division's operation is only one contributor to the changed conditions in the Trinity River Basin, the comprehensive evaluation should include an appraisal of the environmental impact that other man-related activities have had on the area. A multidisciplinary approach to achieving a solution to the problems involved is needed.

This comprehensive investigation will be made by the Trinity River Basin Fish and Wildlife Task Force, using input and participation from other Federal agencies, interested local agencies, and citizen groups as well. Because the Trinity River Division is alleged by many to be the principal cause of most instream environmental problems on the Trinity River, the Bureau of Reclamation will assume a major role in the study effort.

To the decision-maker, multiobjective planning procedures may offer greater evaluation depth than exercised under the more traditional approaches of the past. More readily identifiable facts and figures will be available on the many tradeoffs -- both measurable and unmeasurable -- on instream flow needs than those previously recognized or considered.

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TOPIC IV-D.

THE TRINITY RIVER STUDIES

Summary Discussion

The Trinity River, a 130-mile tributary of the Klamath River, is located in northwestern California. The water resources of the upper river were developed and are managed by the Bureau of Reclamation through the construction of the Trinity River Division facilities of the Central Valley Project in 1964. These consist of a series of dams, tunnels, and power plants which divert as much as 90 percent of the annual Trinity River flow at Lewiston into the Sacramento River Basin for irrigation and M and I uses.

Mitigation measures for fish and wildlife, developed by the California Department of Fish and Game and the U.S. Fish and Wildlife Service, included a fish hatchery at Lewiston with a capacity of 4 million eggs, annual downstream releases for fisheries of approximately 120,500 acre-feet (about 10 percent of the annual historic runoff), and certain wildlife mitigation lands.

Despite these mitigation efforts, which were completely implemented, the run of steelhead as measured at the Lewiston Fish Trapping Facilities, has declined from an estimated annual preproject level of 10,000 to a 1971-75 average of 223 fish. King salmon runs measured at the same point have also declined to an annual average of about 6500 or about one-half the estimated preproject level. The downward trend of King salmon, however, has been reversed in recent years due to increases in the spring run component. Silver salmon, on the other hand, have apparently increased although their pattern is highly erratic.

The impact on the aquatic environment has consisted of increased turbidities, increases in downstream temperatures, siltation of spawning gravels and resting holes caused by the loss of scouring action by winter floods, and fishing and aesthetic impairment caused by the encroachment of riparian vegetation. These effects, while apparent, have not been quantified.

Socioeconomic problems include: the need to zone certain lands as flood plain; the increased burden on community services from shifts or influxes of residents, as well as summer population; other activities brought about by project construction; the impact of the reduced fishing on businesses providing services to fishermen; and the losses incurred by real estate businesses and river front owners when their lands were placed under the stigma of a flood-prone area.

Because the Trinity River project of the U.S. Bureau of Reclamation is only one of the contributors to the changed conditions in the Basin (logging, road building, development of second homes are a few of the others), a multidisciplinary approach to achieving a solution to the problem is apparently needed. The Trinity River Basin Fish and Wildlife Task Force, consisting of ten agencies and entities, was formed in 1974 in response to the need to address the failure of the mitigation measures for fish and wildlife and to fully compensate for the effects of the project and associated causes of problems.

Largely in response to local citizen involvement, a planning effort by an ad hoc work group of the Task Force, operating under a tight schedule, developed an immediate 3-year action program. Funded by Congress in 1976, the program addresses immediate problems in relatively limited but critical area of the upper river. This program will be followed by a long-term, fully integrated plan for the complete basin resource complex.

The application of multiobjective planning procedures by the Trinity River Basin Fish and Wildlife Task Force will offer greater depth of evaluation than the traditional planning procedures. More readily identifiable facts and figures will be available for considering the many trade-offs, quantifiable or not, than those previously recognized or considered for instream flow needs. Largely due to this multidisciplinary approach, the panel views the future of the Trinity River with guarded optimism.

Notes by panel moderator: J. Bruce Kimsey
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WATER MANAGEMENT AND FISH PRODUCTION IN MISSOURI RIVER MAIN STEM RESERVOIRS

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ABSTRACT

The Missouri River reservoirs are managed by the U.S. Army Corps of Engineers primarily for flood control, power production and navigation, but there is enough flexibility in water management during some years to modify water levels or peaking schedules to benefit fish. Recommendations to enhance fish production are developed through a committee of state and federal fishery biologists in consultation with The Reservoir Control Center, Corps of Engineers. The primary biological information needs for each major fish species are habitat types required for reproduction and spawning time and temperature. Modification of water levels and peaking schedules has been shown to benefit northern pike, sauger, walleye, yellow perch, white crappie, bigmouth buffalo and smallmouth buffalo.

INTRODUCTION

The Missouri River Reservoirs are managed as a system by the Missouri River Division, U.S. Army Corps of Engineers (1). Limitations in the control of water management in individual reservoirs to benefit fish include such prime-purpose demands as flood control, power production, navigation or irrigation, and natural variation in runoff. Even with these limitations it is important to understand the relations between water management and fish production for two reasons: (1) It is possible in some years to control water to enhance fish production; and (2) the ability to predict adverse or beneficial effects of various types of water management on fish enables fishery managers to know when to implement other fish management measures. This brief review will discuss: (1) methods for coordination between the Corps of Engineers and fishery managers; (2) biological information needs to implement the coordination; (3) fish reproduction habitat requirements; and (4) fishery management values.

Water management in reservoirs involves the manipulation of water levels, peaking schedules or storage ratios. Water levels refer to mean levels for the entire reservoir. Peaking is defined as the variation in water levels directly below powerhouses during a 24-hour period. Annual storage ratio, also referred to as exchange rate, is defined as the average annual reservoir volume/annual discharge.

COORDINATION METHODS

A Missouri River Basin Coordination Committee meets each April and September to review water availability and operational needs for the system. This committee consists of one representative from each state in the Basin (usually the state water engineer), and one representative from each of the following federal departments or agencies: Agriculture; Health, Education and Welfare; Fish and Wildlife Service; Corps of Engineers; and Environmental Protection Agency. This group has input over operating procedures after the technical aspects of water management are reviewed by the Reservoir Control Center, Corps of Engineers. The member of this committee are supposed to represent all interests in their respective areas and location. Fishery interests were not adequately represented through this committee because state water engineers often fail to maintain adequate liaison with fishery interests. There was no system for relating fishery data to water management. Coordination of fishery interests for the mainstem reservoirs developed through the formation of the Upper Missouri Chapter, American Fisheries Society. The Chapter includes state (Montana, North Dakota, South Dakota, Nebraska) and federal fishery biologists working on the Missouri River reservoirs. A committee from this Chapter meets with the Corps of Engineers prior to the meeting of the Coordinating Committee and develops recommendation's for water management to enhance fish production and to evaluate past programs. The recommendations of the AFS committee are presented to the Coordination Committee through the FWS member.

There are six reservoirs in this system and each has different possibilities for water management (Table 1). Often it is possible to create suitable fish spawning habitat in one reservoir while habitat in other reservoirs must be sacrificed. Trade-offs among states become necessary. In any case, state and federal fishery biologists settle their differences prior to making recommendations to the Coordinating Committee. It should be noted that the size of

TABLE 1. Morphometry at Top of Annual Flood Control Pool and Average Storage Ratio in Missouri River Main Stem Reservoirs

	Fort Peck	Lake Sakakawea	Lake Oahe	Lake Sharpe	Lake Francis Case	Lewis and Clark Lake
Surface area, km^2	967	1489	1449	227	421	113
Volume, km^3	22.3	28.2	27.7	2.13	5.80	0.59
Average width, km	3.22	5.31	3.86	1.93	2.09	3.0
Maximum depth, meters	66	54	62	23	41	17
Average annual water level fluctuations, meters	3.0	3.0	1.5	0.6	10.7	1.2
Storage ratio	3.0	1.4	1.0	0.12	0.5	0.04

these reservoirs prevents the development of a carefully designed experimental program and the progress that has been made in this fish management effort has been developed partially through trial and error.

BIOLOGICAL INFORMATION NEEDS

A knowledge of spawning and nursery area requirements for the major fish species in the system is the most important information need for relating water management to fish productivity. Growth and survival rates reflect the overall fish reproduction success because of predator-prey relationships. A knowledge of time of spawning of each of the major fish species is also essential. Time varies annually because it is directly related to water temperature; each fish species has a relatively narrow range (2-5C) when spawning activity begins. Thus, most of the recommendations to benefit fish are directed at fish reproduction.

FISH HABITAT REQUIREMENTS

A summary of the spawning and nursery habitat types required by the 16 most common fish species in the system is shown in Table 2. Note that such fish species as the walleye and yellow perch may utilize several habitat types while other species (smallmouth buffalo and largemouth buffalo) only utilize a single habitat type.

Some habitat types can be developed through water management procedures while others can be only partially controlled. In Habitat Type A (Table 2) tributary streamflow cannot be controlled because it varies according to natural runoff; sections of river between reservoirs can sometimes be modified by adjusting peaking schedules. The use of Habitats B and D for spawning can be controlled when glacial till, stumps or brush are present only at a specific depth range; it is often possible to schedule water levels to inundate these habitats at the proper time. Habitat C cannot be controlled. Habitat Types E and F require submerged vegetation and the development of these types requires intensive water level management. Aquatic plant development in the Missouri River System is virtually restricted to Lewis and Clark Lake and Lake Sharpe, reservoirs with little water level fluctuation. The development of terrestrial vegetation on exposed reservoir shoreline requires 1-2 years of suitable water levels. Prior to the year of spawning, water levels must be lowered early enough in the summer (about July 1) to allow terrestrial

Table 2. Spawning and nursery habitat types commonly used by 16 major fish species in Missouri River Reservoirs.

	Habitat type	Fish species that use this habitat	Amt. of possible developement by water management
A.	Tributary streams, reservoir areas with heavy current, river sections between reservoirs	Walleye, sauger, channel catfish, white bass, goldeye, river carpsucker	Partial
B.	Wave exposed shorelines where glacial till exposed	Walleye, emerald shiner, white bass	Partial
C.	Open water minimal wave action is	Freshwater drum	None
D.	Shoreline with stump or brush	Yellow perch	None
E.	Protected embayments with aquatic or flooded terrestrial vegetation	White crappie, black crappie, gizzard shad, river carpsucker, yellow perch, carp, Northern pike	Complete
F.	Partially protected areas where terrestrial vegetation is inundated	Northern pike, bigmouth buffalo, smallmouth buffalo, river carpsucker, carp, yellow perch	Complete

vegetation, primarily prairie grasses and forbes, to develop. Suitable soils must be exposed by mid-July to develop heavy growth. For some plant species, two years of summer growth are needed. Extensive studies (3) have shown that the development of various plant communities is complicated because of variations in germination times among species, amount of flooding which various species can tolerate, methods of seed dissemination (floating or sinking), and soil types. The programming of water levels for the development of terrestrial vegetation on reservoir shorelines is an important management technique in the process of being developed. In addition to fishery uses, this vegetation is valuable for aesthetic purposes and for erosion control. After vegetation is established it must be inundated early in the spring (about April 15) and high water levels must be maintained until about July 1 is the majority of the fish species are to have suitable spawning habitat. Thus, the use of water level management to benefit fish requires extensive water level control.

FISHERY MANAGEMENT BY WATER CONTROL

Water level management has the greatest potential value for increasing fish production in the Missouri River Reservoirs and most effort has been directed at water level control. Reduction of peaking has been used only below Lake Francis Case but it has had significant value to sauger. There is virtually no possibility of utilizing storage ratio to manage fish since the general range is established at the time of construction of the dam and annual differences are controlled by runoff. Both the measured effects of the above water management practices on fish production and the intentional use of these practices to benefit fish are discussed below. The importance of tributary stream flow will also be treated.

Water level management --

Most of the major fish species in the reservoirs evolved in rivers; these species spawned during the spring flood period on inundated flood plains. A few of the fish species that evolved in glacial lakes also reproduced during the spring high water peiod. Thus high and constant water levels from April 15 to July 1 have been shown to benefit northern pike, yellow perch, walleye, white crappie, carp, river carpsucker, smallmouth buffalo and bigmouth buffalo (2). Lake Francis Case water levels are the most amenable to control in the entire system and there are 20 years of fishery data on this reservoir. Yellow perch reproduction during this period was positively correlated ($r = 0.80$, significant at 1 per cent confidence level) with spring high water levels and the correlation of walleye and high water levels was significant at the 5 per cent level (4). The probable reason for the high correlation of walleye was the fact that yellow perch are the primary forage for walleye. There is a spawning sequence of various fish species from about April 15 to July 1. Any lowering of water levels during this 75-day period will reduce the spawning success of some fish species. Water levels should be dropped after 1 July to develop vegetation on the shoreline for the following year. There has been intentional management of water levels on Lakes Fort Peck, Sakakawea, Oahe, and Francis Case; in all cases fish reproduction has responded favorably.

Peaking --

Direct control of peaking to benefit fish reproduction has only been attempted below Lake Francis Case. Sauger and walleye move into a spawning area from 8 - 16 km below the dam in late April and early May. Most spawning takes place in water 1m deep and the eggs are broadcast on the rubble bottom. The time of spawning (1800 - 2100 hrs.) coincides the maximum power release period. With normal peaking releases, the eggs become exposed to the air and die during the minimum release period when the water level drops about 2m. The eggs require 18 - 21 days for incubation. By eliminating the daily peaking schedule during May, it was possible to increase the abundance of young sauger up to 10 fold. Although other factors, such as sudden temperature drops during the incubation period, may reduce the effectiveness of the elimination of peaking this management measure has had great benefits to the sauger and walleye populations in Lewis and Clark Lake.

Storage ratio --

Annual storage ratios can usually be predicted early each year from storage and snow melt data. Although storage ratios cannot be controlled it is possible to predict the following from low storage ratio's; (1) heavy losses of young fish through powerhouses; (2) lower zooplankton abundance; and (3) lower water temperatures.

Tributary stream flow --

Although flows in tributary streams are not controlled it is necessary to consider the importance of flow in these streams on fish reproduction in the reservoirs. Although many streams are essentially intermittent, walleye, goldeye, channel catfish, white bass, river carpsucker and several minnow species reproduce in these streams during the spring runoff period. A reduction in the spring runoff cycle in these streams would have severe adverse effects on reservoir fish reproduction. In Lake Oahe, where walleye reproduction has been erratic, a multiple regression analysis indicated that annual variations in the mean flows of tributaries and air temperature accounted for one half of the variability of reproduction between 1965 and 1974. Variation in mean flows alone accounted for 1/3 of the variability of reproduction (4). Mean April tributary flows varied between 3.4 and 48.5 m 3/5. Thus any water management program to divert small streamflow should not disregard the biological value of these streams even though flows may be negligible during most months of the year.

CONCLUSIONS

1. There is enough flexibility in water management in the Missouri River reservoir system to justify close coordination between fishery and other interests on a continuing basis.
2. There should be adequate biological information available to predict the probable effects of any water management program.
3. Evaluation of the effects of different types of water management on fish production should play a significant part of reservoir fishery management.

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CONFLICTS AND COMPATIBILITIES ASSOCIATED WITH REGULATING THE MISSOURI RIVER MAIN STEM RESERVOIR SYSTEM TO ENHANCE THE FISHERY RESOURCE

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ABSTRACT

Six major reservoirs on the main stem of the Missouri River extend from Montana through the Dakotas to Nebraska and form the backbone of the Basin's reservoir system. These reservoirs have been operated for over 20 years to serve flood control, power, navigation, irrigation, water supply, water quality control, recreation, and fish and wildlife. During the reservoir filling period which extended until 1967, the new vegetation horizons which were being inundated each year contributed significantly to the reproduction and survival of many fish species. Since initial fill the reservoirs have operated in an annual cycle which is not as favorable for the development of the fishery resource and the provision of favorable spawning conditions frequently requires special releases or pool-level management. When these special operations conflict with operations for power, navigation, or flood control, judgement decisions must be made as to which will prevail. During the last decade special operations have been scheduled for one or more reservoirs each year to enhance fish spawning. Most of these operations have involved the maintenance of minimum releases for sauger, walleye and paddlefish spawning and the scheduling of steady or rising pool levels to enhance northern pike and forage fish spawning.

INTRODUCTION

The Missouri River is the Nation's longest, extending 2300 miles from its headwaters in southwestern Montana, to its confluence with the Mississippi near St. Louis, Missouri (see Figure 1, Missouri Basin Map). The River drains all or parts of 10 states, with a total drainage area of about 530,000 square miles, 1/6 of the continguous United States. Temperatures and precipitation vary widely through the basin, as well as seasonally. Annual precipitation varies from less than 10" in the lee of the mountains in Montana to greater than 40" in the higher elevations along the western rim of the basin and in the extreme southeastern portions of the basin in Missouri. Temperatures range from well in excess of 100°F to below -50°F. This climatic pattern, coupled with the extended drought of the 1930's and the severe floods of the early 1940's, led in 1944 to widespread support for the Pick-Sloan Plan for development of the water resources of the Missouri Basin by coordinated efforts of the Corps of Engineers and the Bureau of Reclamation.

PICK-SLOAN PLAN FOR WATER RESOURCE DEVELOPMENT

The Pick-Sloan Plan envisioned five major reservoirs on the Missouri River between the existing Fort Peck Dam in Montana and Yankton, South Dakota; over 100 tributary reservoirs; agricultural levees from Sioux City to the mouth; navigation through this same reach; urban levees and floodwalls at major cities, such as Kansas City and Omaha; irrigation of about five million acres; hydroelectric plants at each of the main stem dams; and flood control storage at the main stem reservoirs and most of the tributary reservoirs.

In the past 32 years since this plan was authorized by the Congress in the 1944 Flood Control Act, the main stem reservoirs have been completed, as well as over 50 multiple-purpose reservoirs on tributary streams. Several other reservoirs are under construction; others have been dropped from the plan and are not likely to be built. The navigation and stabilization works, which are designed to protect the banks and provide a 9 foot deep by 300 foot wide open-river navigation channel between Sioux City and the mouth, are essentially complete. Construction is proceeding on the initial irrigation units to be served from the Garrison and Oahe Reservoirs, but water deliveries are not expected for several years. No levee units have been built between Sioux City and Omaha, but about half of the flood plain acres between Omaha and Kansas City have been protected by Federal levees. Many private levees exist below Kansas City, but only a few Federal units have been constructed.

MISSOURI RIVER MAIN STEM RESERVOIRS

The construction of the Missouri River main stem reservoirs has been one of the most important contributions to sport fishing in the Missouri Basin in this century. The reservoirs and downstream tailwaters are very popular, attracting fishermen from many states to fish for record-breaking northern pike, walleye, sauger, and paddlefish. The big reservoirs are producing many more sport fish and commercial fish than the river did before impoundment. However, limited access facilities, the dangers associated with fishing "big" water with inadequate equipment, and the remote location from population centers, have hampered optimum development of sport fishing.

Although the tributary reservoirs have a definite influence on flows in the main stem of the Missouri River, and these reservoirs are frequently regulated to enhance their own fishing resources, this discussion is limited to the main stem reservoir system which forms the backbone of water resource developments in the Missouri Basin. This system consists of six multiple-purpose reservoirs which fill the Missouri Valley for 755 miles through portions of four states, Montana, North Dakota, South Dakota and Nebraska. See Figure 1, Missouri Basin Map. The first reservoir in the chain, Fort Peck, was closed in 1937; the other five were closed at intervals through the 1952-1963 period. The system is regulated to serve eight purposes, flood control, navigation, hydroelectric power, irrigation, water supply, water quality control, recreation and fish and wildlife. The reservoir system has a storage capacity of 75 million acre-feet (maf) and a surface area at normal operating levels of about one million acres.

Storage Zones

Each of the reservoirs contains four storage zones. Figure 2 illustrates these zones and shows the percent of storage allocated to each in the six-reservoir system. The operational zones, and governing criteria for operation in each, are as follows:

a. Exclusive Flood Control Zone. A top zone in each reservoir is reserved exclusively for flood control. The storage space therein is utilized only for detention of extreme or unpredictable flood flows, and is evacuated as rapidly as feasible.

b. Annual Flood Control and Joint-Use Zone. This zone is reserved annually for retention of normal flood flows and for annual multiple-purpose regulation of the impounded flood waters. Storage in this zone will normally be evacuated by about 1 March to provide adequate storage capacity for the ensuing flood season. During the flood season, which generally extends from March to July, water is impounded as required by flood control considerations and in the interest of later use for power generation, navigation, irrigation, and other conservation uses. Except for Oahe, the reservoirs are regulated within this zone more than one-half the time.

c. Multi-Purpose Carryover Zone. This large zone, with 53% of the system's storage capability, provides a storage reserve to service all functions during drought periods. The storage space in this zone is sufficient to maintain an acceptable degree of service to these functions during a drought period of several year's duration, such as the basin-wide drought of the 1930's.

d. Inactive Storage Zone. The top of this zone at most projects is the minimum power pool. The zone also provides sediment storage capacity and serves as an assured pool for recreation, fish and wildlife, and for pump diversion of water from the reservoir.

Operating the completed main stem reservoir system is in many ways a repetitive annual cycle. Most of the year's water supply is produced by winter snows and spring and summer rains which result in rising pools and increasing storage. After reaching a peak--usually between early July and early August--storage begins a decline lasting until late in the winter when the cycle begins anew. A like pattern may be found in release rates from the system, with the high levels of flow required for navigation, or for the evacuation of accumulated flood storage, being followed by low rates of winter discharge from late November until late March, after which navigation releases are resumed.

Water Supply

The water supply which is available for regulation by the main stem system is quite variable and is subject to many man-made influences. These influences include the regulation of streamflow by upstream tributary reservoirs, streamflow depletions by diversions for irrigation and other consumptive uses, and evaporation from reservoir surfaces.

Records of monthly flows and their distribution are available for the period 1898 to date for a number of locations along the Missouri River. During this record period there was a substantial growth in the development of water related resources in the Missouri River Basin. This growth is expected to continue; therefore, for comparative purposes, and for the establishment of consistent reservoir regulation criteria, observed flows have been adjusted to a common water resource development level. The base level of 1949 was selected because it represents a base prior to recent emphasis on water resource development and prior to the time that the main stem reservoir system and many major tributary projects were constructed. The annual streamflow volumes which are available for regulation by the main stem reservoir system under the 1949 level of development are approximately equivalent to the streamflows at Sioux City, as shown on Figure 3. This bar chart illustrates the great variability of annual runoff, the extended drought periods in the 1930's and 1950's and the periodic high flow periods such as have been experienced for the past decade.

Initial Fill of Main Stem Reservoirs

The large ratio between storage capacity and annual runoff (over three to one) and the occurrence of the 2nd worst drought in the basin's history during the intial fill period, made it difficult to fill the reservoir system. This filling period extended from 1953 until 1967 for the system as a whole and required from 6 to 14 years for the major reservoirs (Figure 4). The two smaller reservoirs, Gavins Point and Big Bend, were filled in a one-year period by the appropriate scheduling of releases from the larger upstream reservoirs. The earlier-constructed Fort Peck Reservoir was also integrally involved in the filling process. During the 1953-56 period Fort Peck storage was drafted about 10 maf to assist in filling the Garrison and Fort Randall projects. Therefore, the refill of Fort Peck became a part of the initial-fill effort for the main stem system.

The prolonged initial fill of the reservoirs was beneficial for the rapid and continued development of many fish species in the reservoirs, but resulted in major operating problems for other functions, notably navigation and power generation. For over a decade, from the mid-1950's to the mid-1960's, service to navigation and power was severely restricted. Navigation season lengths during this period were generally 6 to 7 months, compared to a planned normal of 8 months. Reservoir releases were restricted to those that would provide only minimum satisfactory service for navigation, with barge loadings generally restricted to 6 to 7 feet compared to full-service loadings near 9 feet. Power generation was also restricted, with releases during the wintertime period of peak firm power demand averaging slightly over half of the long-term normal. Because of these restricted releases, and reduced power peaking capabilities due to low power heads, firm power contracts were significantly delayed.

The rising pool levels during the initial fill period inundated new vegetation horizons each year and frequently provided ideal conditions for fish spawning and development. Consequently, no special pool-level operations to enhance the sport fishery resource were scheduled until the 1960's. On the other hand, several attempts were made during the fill period to control rough fish populations by temporary reservoir drawdowns during critical spawning periods. The success or failure of these drawdowns was difficult to document and they were discontinued after a few years.

SPECIAL RESERVOIR OPERATIONS TO ENHANCE THE FISHERY RESOURCE

After the reservoirs were essentially filled in the mid-1960's achievement of satisfactory spawning conditions became more difficult and less frequent. Special operations had to be undertaken to assure success in most cases, although the natural sequence of runoff events at times provided the desired pool-level conditions. During this period operations for fishery enhancement were largely in five categories:

a. maintenance of minimum releases during spawning periods to assure continued water cover of spawning beds in the river downstream of projects;

b. scheduling of releases to raise reservoir levels into vegetated areas in early spring to enhance northern pike spawning;

c. scheduling of releases to maintain the peak reservoir level as low as possible to permit vegetation to grow at lower elevations for inundation in subsequent years;

d. scheduling of releases to maintain steady or rising reservoir levels from early spring to early summer to enhance spawning of forage fish; and

e. scheduling minimum releases during week-ends and other selected periods to improve fishing success.

Perennial requests have also been received to reduce the flow-through rates at the small Gavins Point Reservoir during the spring and early summer period to reduce the flushing of eggs and small fish through the project. However, it has not been possible to accommodate these requests due to the overriding requirements for flood control. With the reservoir system filled to normal operating levels, most of each year's inflows are scheduled to be released before winter ice formation limits the downstream channel capacity, so that the system may again be fully prepared to control floods the succeeding spring.

<u>Sauger and Walleye Spawning below Fort Randall</u>

The requests for maintenance of minimum flows for spawning below projects has largely been in connection with sauger and walleye spawning below Fort Randall during the month of May. These requests have been honored for the past 10 years, although at times the requested minimum releases of 15,000-20,000 cfs have interfered significantly with operations for power.

In the power marketing area served by the main stem reservoirs, base-load power demands are met largely by fossil fuel and nuclear plants, whereas oil is used widely for peaking. Thus optimum operation of the main stem hydropower plants involves operating the power plants at full capacity during the peak load periods of each day, then reducing releases to zero or near zero during off-peak periods to maintain the desired daily average releases. Flows of up to 47,000 cfs can be passed through the Fort Randall power plant and used for power generation, but average daily releases during the May sauger spawning period are only about 30,000 cfs. Scheduling minimum releases of 20,000 cfs from this project during off-peak periods severely limits the amount of on-peak generation and significantly reduces power revenues and oil savings.

Northern Pike Spawning

Natural lakes in the vicinity of the main stem reservoirs are fed largely by early spring snowmelt. The weather conditions which melt the plains snow and break up the ice cover on streams in the area also melt the ice in the lakes and raise these lakes into shoreline vegetation. This cycle is favorable to production of northern pike which spawn in vegetated shallows soon after the ice goes out. The main stem reservoirs on the other hand, are fed not only by early spring snowmelt, but by mountain snowmelt in the period from late May to July and by warm-season rains. Thus maximum reservoir levels in most of the reservoirs are reached in July and reservoir levels reached during the early spring northern pike spawning period are normally not high enough to reach into vegetated areas. This problem can be overcome in many years, particularly for the three downstream reservoirs, by careful scheduling of releases from the larger upstream storage reservoirs. This generally involves a two-year operation, however--one year to hold the reservoir level down to permit vegetation to grow, and the next to raise the reservoir into vegetated areas. Such operations tend to limit the flexibility of operations for power and to result in storage imbalances that are undesirable from a flood control standpoint. These and other factors, including several unexplained failures to achieve good northern pike reproduction in spite of ideal reservoir-level conditions, have led in recent years to reducing the emphasis on northern pike spawning in the main stem reservoirs. Since 1972 the emphasis has shifted toward water level management for spawning of forage fish.

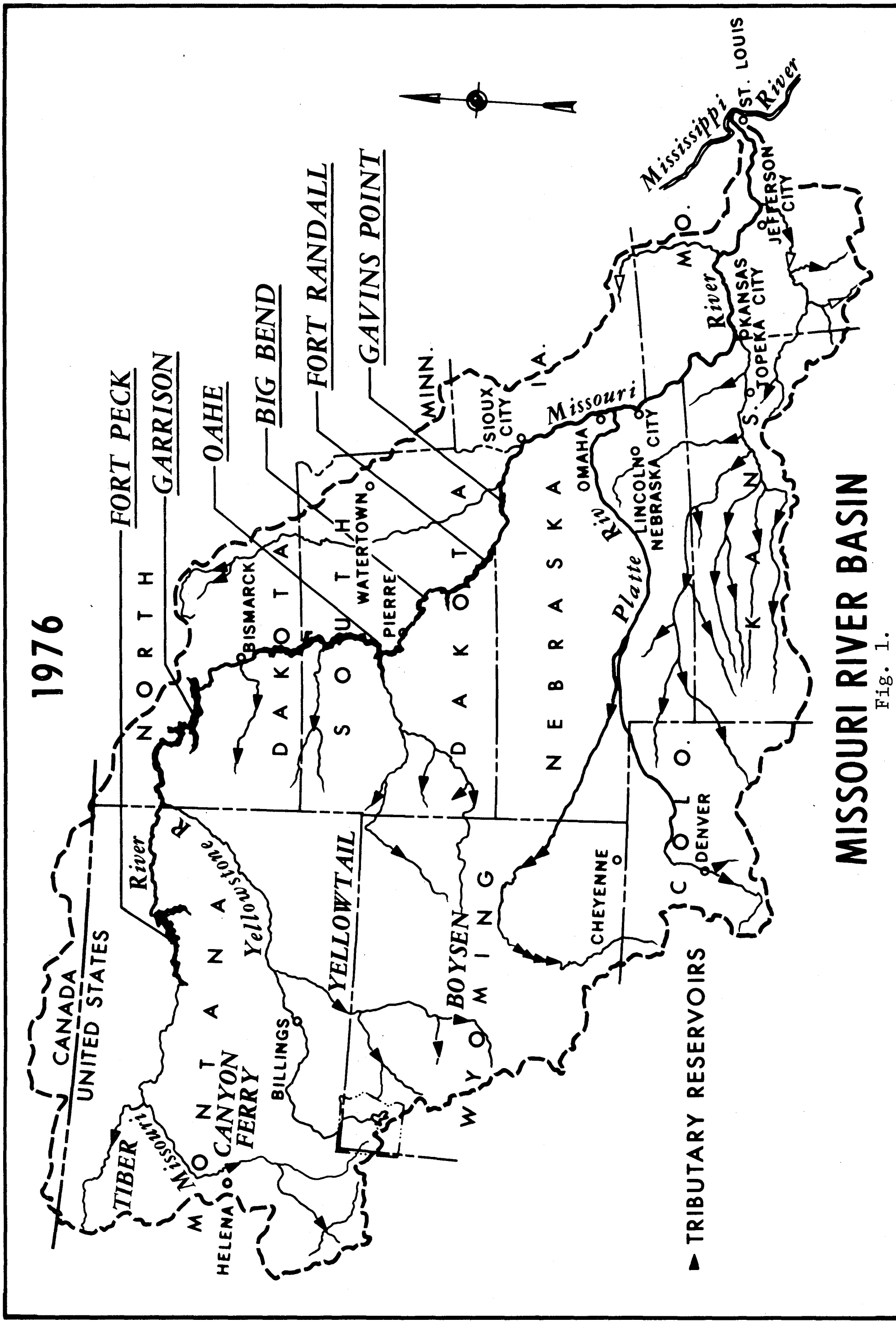
Forage Fish Spawning

Forage fish spawning conditions are not so rigid as for northern pike. Requests for reservoir level management to enhance forage fish spawning have generally specified stable or rising pool levels in the April through June period, but without any inundation-of-vegetation requirement. Since this is the major inflow period to the main stem reservoirs, rising pool levels occur frequently without any special emphasis on regulation for fishery enhancement. However, the lack of a plains snow cover, or dry conditions in the interim between the plains snowmelt and the mountain snowmelt periods, can result in falling reservoir levels unless special measures are taken. In such cases priorities have to be established, since releases which are made for the purpose of maintaining rising levels in a downstream reservoir may result in falling pool levels in an upstream reservoir.

Operations to Improve Fishing Success

Fishing pressures at the main stem reservoirs are at a maximum during summer weekends, particularly on Sundays. On the other hand, power loads are at a minimum on Sundays, with zero releases at some projects the rule, unless special measures are taken. This conflict exists primarily below the Oahe project, where many fishermen maintain that their fishing success in the tailwaters correlates directly with the releases being made from the project. As a result of these complaints and requests, minimum releases of 3,000 cfs during the daylight hours of each weekend during the recreation season are made as a "fish attraction" measure. As in the case of maintaining minimum hourly releases from Fort Randall, these Sunday releases frequently reduce the capability of the Oahe project to meet on-peak power loads and result in reduced power revenues.

Although the special operations to enhance the fishery resource of the Missouri River main stem reservoir system conflict at times with operations for other purposes, these operations constitute an important part of the overall development and management of the water resource potentials of the Missouri River and will be continued as opportunities arise.



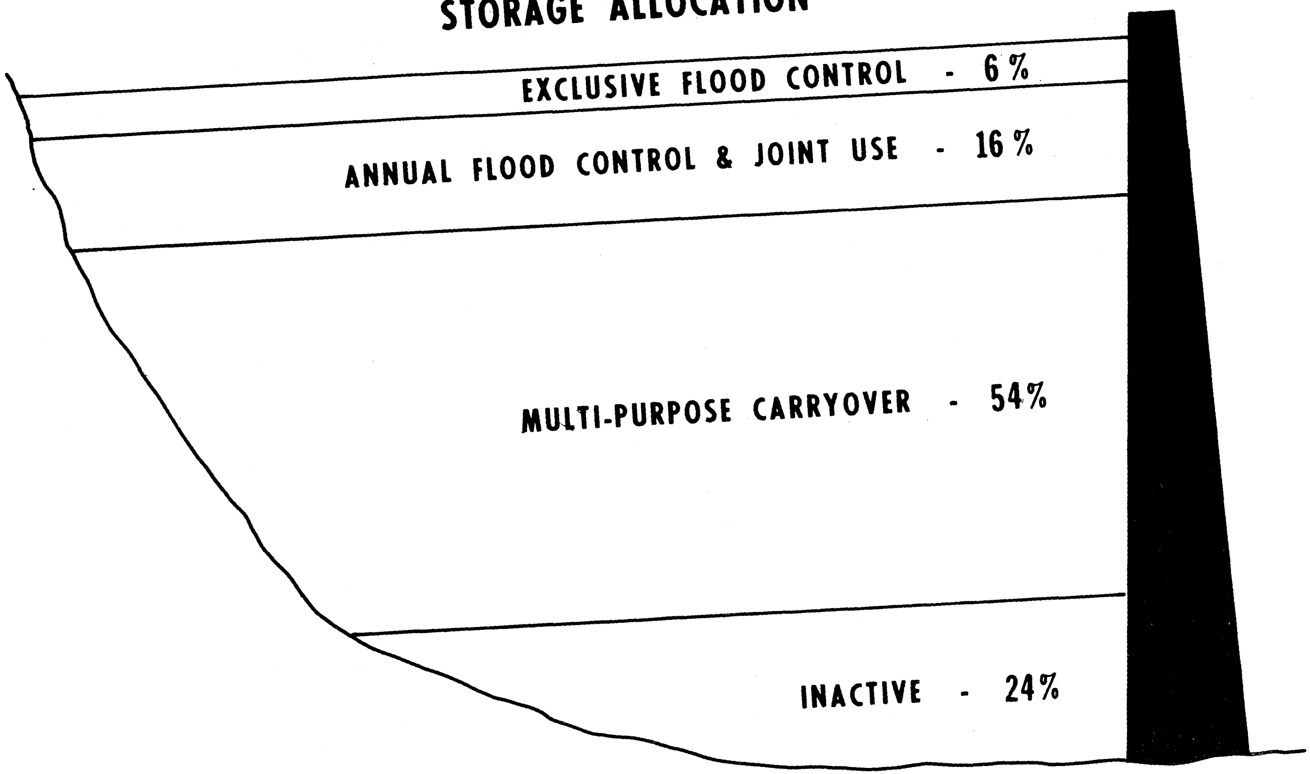
MISSOURI RIVER BASIN

Fig. 1.

Fig. 2.

MISSOURI RIVER MAIN STEM RESERVOIRS

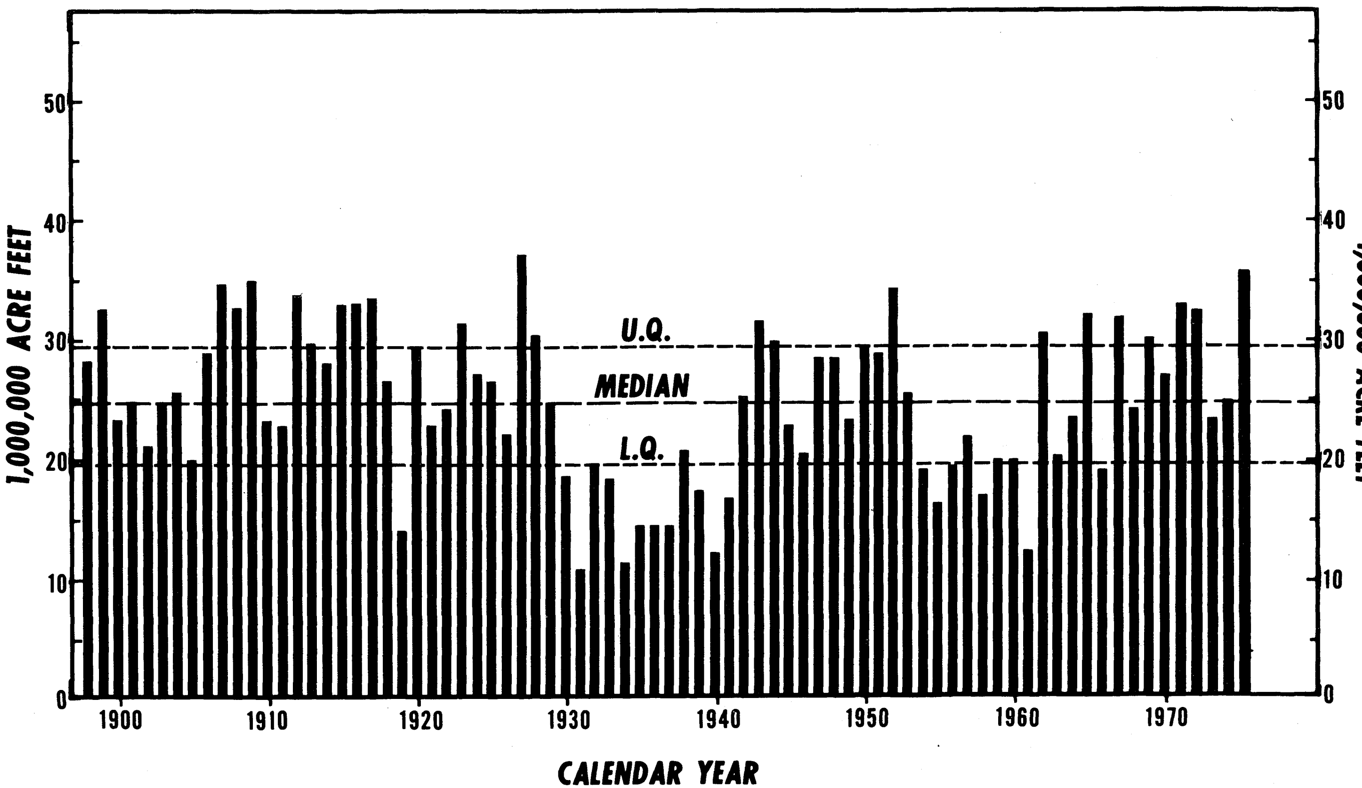
STORAGE ALLOCATION



TOTAL SYSTEM STORAGE - 74.7 M.A.F.

Fig. 3.

ANNUAL WATER SUPPLY
MISSOURI RIVER AT SIOUX CITY



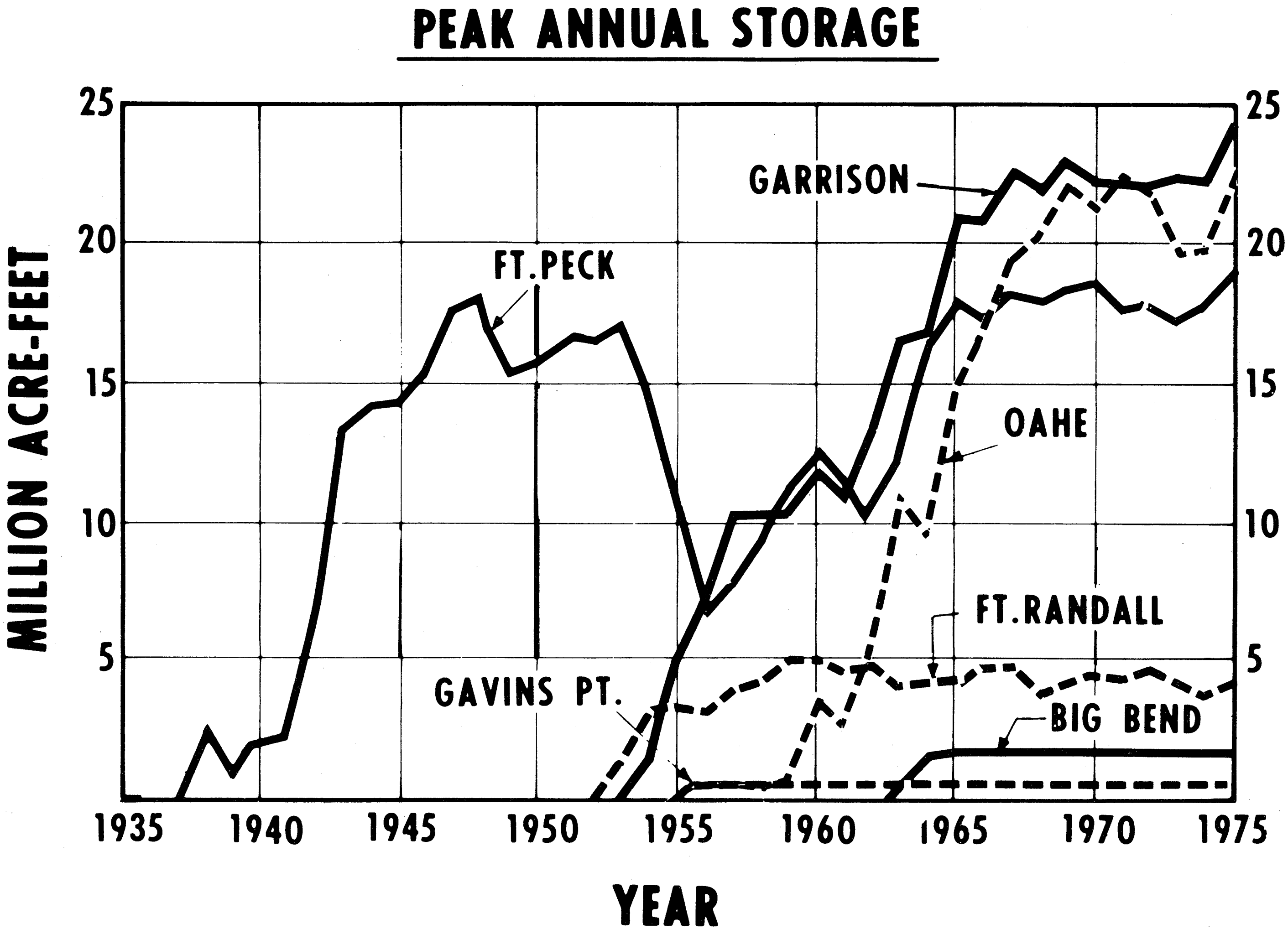


Fig. 4. Peak Annual Storage, Missouri River Main Stem Reservoirs

THE INFLUENCE OF MAINSTEM NAVIGATION DAMS ON WATER QUALITY AND FISHERIES IN THE UPPER OHIO RIVER BASIN

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ABSTRACT

The design and operation of mainstem navigation dams were found to significantly influence a number of physical, chemical and biological parameters. The effect of the mainstem projects on dissolved oxygen was the most dramatic.

Dissolved oxygen stratification can develop in navigation pools during low summer flows. Reaeration was observed downstream of navigation structures during high and intermediate flow periods. However, during low summer flow periods, dissolved oxygen depressions were created downstream of certain projects . Such depressions were noted below gated dams where the outlet sills are submerged in the receiving pool.

The greatest reaeration benefits achieved on the Upper Ohio River, where a dissolved oxygen problem exists, are at a gated structure with elevated sills and where water is discharged over step weirs. The reaeration potential of existing gated navigation structures is dependent on operational schedules during low flow periods.

INTRODUCTION

The first lock and dam projects on the Ohio River were completed in 1830. By 1929 the entire 981 mile length of the Ohio River had been pooled by a series of 46 mostly movable crest, low head navigation dams. In the mid-1950's a program was begun to modernize the lock and dam system. The new system, when completed, will consist of a series of 19 high-lift, gated navigation dams.

The purpose of this study is to evaluate the effect of existing and replacement slackwater navigation structures on water quality and fishery resources.

The Ohio River is formed by the confluence of the Allegheny and Monongahela Rivers at Pittsburgh, Pennsylvania. The study area is limited to the upper 130 mile long reach of the Ohio River and the entire Monongahela River. The Monongahela River is a major navigable tributary of the Ohio River and like the Ohio River, the Monongahela River Navigation System is also in the process of being modernized. In 1974, when the study was initiated, there were 9 navigation dams on the Ohio River Mainstem within the study reach. At present there are 6 dams on the same reach of the Ohio River. On the 129 mile length of the Monongahela River there are 9 navigation dams. All of these navigation structures are under the jurisdiction of the U.S. Army Engineer District, Pittsburgh.

The flow in the Ohio River is extensively regulated and the effects of mainstem navigation projects on water quality is strongly related to flow. In the Pittsburgh District there are a total of 15 flood control reservoirs, 9 of which supply low flow augmentation. The system of Corps of Engineers' water resource development projects in the study area is shown in Figure 1.

Chronic water quality problems in the study area include serious domestic and industrial pollution in the lower Monongahela and upper Ohio Rivers. Acid mine drainage from bituminous coal mining operations is nearly a basin wide problem and previously, the Monongahela River was severely degraded by mine drainage. Considerable progress in pollution abatement has been made, but the amount of pollution from non-point sources in the study area is substantial and will remain a problem in the future.

METHODS

The study plan was to conduct intensive three dimensional sampling surveys of the Upper Ohio River and the Monongahela River during a wide range of flows. Sampling stations were established immediately above and below navigation dams, at mid-length in navigation pools and at other strategic locations, such as above and below major tributaries, cities and industrial areas. There are 53 stations on the Upper Ohio River and 45 on the Monongahela River. Nine of these are transect stations. At the transect stations sampling was at mid-channel, 1/4 point right bank and 1/4 point left bank. All other stations were located at midchannel. Vertical measurements of water temperature, dissolved oxygen, and conductivity were taken at the surface, three feet below the surface, five feet below the surface and then at five foot depth intervals to the bottom. Water samples for all other parameters were collected three feet below the surface and approximately three feet from the bottom.

In order to examine changes in the same approximate block of water as it progressed downriver, the sequence of sampling proceeded in a downstream direction.

Dissolved oxygen and water temperature were the principal parameters of the study. These parameters were measured in the field with a pressure compensated Yellow Springs Instrument Company Model 54 Oxygen Meter, connected by 50 feet of calibrated cable to a combined Y.S.I., dissolved oxygen, thermistor and mechanical agitator probe. Also attached to this probe assembly was a conductivity probe.

These probes were designed for limnological work. They are relatively lightweight and their resistance to even a low Ohio River flow makes accurate vertical sampling difficult. Therefore, it was necessary to adapt this equipment for sampling in flowing water.

Vertical measurements were obtained by lowering the probe assembly to the various desired depths along a plumb steel cable. The steel cable was weighted by a brass torpedo weight (Columbus-type) suspended just off the bottom. The probe assembly was attached to a one-foot long pipe section through which the steel plumbline had been threaded. Allowing some downstream drifting of the survey boat, a 30 pound weight was adequate for the highest flows encountered. Had sampling been conducted from stationary objects such as bridges, experience indicates that a 100-pound torpedo weight would have been necessary to get a plumbline to the bottom during the high flows.

Other parameters, besides dissolved oxygen and water temperature that were monitored in the study, include phytoplankton, aquatic vascular plants, phosphate, nitrate-nitrite nitrogen, Kjeldahl nitrogen, iron, manganese, lead, copper, zinc, chromium, sulfate, filtrable and non-filtrable solids, turbidity, color, conductivity, transparency, hardness, pH, alkalinity, acidity and flow. The results of rotenone sampling of lock chambers conducted cooperatively by the U.S. EPA, ORSANCO, the States of Pennsylvania, West Virginia and Ohio, and the U.S. Fish and Wildlife Service provided the fish data.

RESULTS

The results of this study indicate that navigation dams significantly influence the dissolved oxygen concentrations of the rivers they pool. In the following presentation the degree and nature of this influence under a variety of flow conditions, and how it varies with the design of the projects is discussed.

Figure 2 illustrates surface dissolved oxygen variations along the 130 mile long reach of the Ohio River below Pittsburgh, Pennsylvania at three different summer flows. A two dimensional profile of the low flow survey (10,000 to 13,000 cfs[1] variation along the study reach) is presented in Figure 3. The two dimensional profile shows the development of horizontally stratified patterns of dissolved oxygen distribution at low flow. This stratification was slight or nonexistant at the higher Ohio River flows.

As demonstrated in Figures 2 and 3, Montgomery Dam (Ohio River Mile 31.7) was the most efficient reaeration structure of the navigation dams examined on the Upper Ohio River. At a flow of 20,000 cfs the hydraulic structures of Montgomery Dam add at least 200,000 pounds of oxygen a day to the Ohio River. The direct influence of Montgomery Dam is measurable for more than 15 miles downstream (Figure 3). A less obvious effect of Montgomery Dam is that at low flows the supersaturated discharge is drawn largely from a low dissolved oxygen concentration stratum of the pool.

Montgomery Dam is a gated structure. Because the invert elevation of the outlets (fixed sill elevation 667 msl[2]) is 15 feet below the surface of Montgomery Pool, the stratum of water which is relatively low in dissolved oxygen during low flow stratification is evacuated from the pool. This water is then violently aerated when discharged into New Cumberland Pool (normal pool elevation 664.5 msl) over step weirs. Also, at Montgomery there are reaeration benefits from each overflow weir on either end of the dam plus turbulence from revised gate operations.

The revision of gate operations resulted from field observations at Montgomery Dam to determine the amounts of oxygen which could be added by

[1] cubic feet per second

[2] feet above mean sea level

increasing discharges per gate at low flows by using fewer gates with larger openings. It was found that 1 gate open 2 feet provided 50 percent more oxygen than 2 gates open 1 foot. The additional oxygen was the result of induced turbulence from the gate operation.

The stepped weir configuration below the gates at Montgomery is always submerged except for the top step and probably would have been even more effective had it been constructed higher above the tailwater. A section of Montgomery Dam, along with typical sections of the other principal types of navigation dams in the Upper Ohio and Monongahela Rivers is shown in Figure 4.

As can be noted in Figure 3, another project with an extremely beneficial impact on the dissolved oxygen concentration of the Ohio River is Emsworth Dam at Ohio River Mile 6.2. Emsworth Dam is located in a section of the Ohio River where a sometimes severe oxygen sag is created by the contributions of oxygen demanding waste materials from the Pittsburgh Metropolitan area. Water from a lower stratum of Emsworth Pool is discharged over a sill that is elevated six feet above the receiving pool (Dashields Pool). The discharged water must pass over an apron at the toe of Emsworth Dam with an energy dissipating end sill. Considerable reaeration is achieved at Emsworth Dam, though it is probably not as effective a reaeration design as Montgomery Dam.

Likewise, the fixed crest Dashields Dam oxygenates the Ohio River. Reaeration at Dashields is apparently somewhat increased by a toe apron. Emsworth, Dashields and Montgomery Dams are strategically located. During the 10,000 to 13,000 cfs low flow survey graphically presented in Figure 3 they contributed 65,000, 30,000 and 97,000 pounds of oxygen a day respectively to the Ohio River. Individually and as a system, these three projects have an extremely beneficial effect on the dissolved oxygen concentration of the Ohio River at low flow.

It should be emphasized that while 10,000 to 13,000 cfs was the lowest Ohio River flow surveyed in this study, flows less than 10,000 cfs are not uncommon in the Upper Ohio River. The minimum mean monthly flow of record during the critical warm summer months at Emsworth (August 1930) was 1,284 cfs. Had low flow augmentation from existing storage reservoirs been available at that time, the mean monthly flow at Emsworth during August 1930 would have been 4,205 cfs. At 5,000 cfs dissolved oxygen concentrations can be expected to be considerably lower than those measured in this study.

Dams number 12, 13 and 14 were movable crest or wicket dams that have been removed since the study was initiated in 1974. At higher flows the wickets were down and the river was free flowing. At lower flows when the wickets were up, aeration was only by impact turbulence. While the reaeration potential of impact turbulence alone is not great, dams 12 and 13 were strategically located around the Wheeling, West Virginia area where their limited reaeration was significant.

Reaeration was observed at New Cumberland, Pike Island and Hannibal Dams at high and intermediate flows, but at low flows these projects create downstream oxygen depressions. All three of these dams are gated structures. The discharge from both Pike Island and Hannibal is completely submerged and the sills of New Cumberland Dam are elevated one foot above the normal elevation of Pike Island Pool.

At higher flows, aeration at these projects is achieved by submerged discharge turbulence which creates a hydraulic jump. However this degree of turbulence does not occur at low summer flows, and low dissolved oxygen water from stratified upstream pools is discharged with very little reaeration.

The nine navigation dams on the 129 mile long Monongahela River were also evaluated individually and as one interrelated flow dependent system. Opekiska Dam is the only gated navigation dam with submerged outlets on the Monongahela River Navigation System. As was observed with similarly designed dams on the Ohio River, dissolved oxygen depressions occur downstream of Opekiska Dam during low flow periods.

A low flow (650 to 1,800 cfs) length-depth dissolved oxygen profile of the system of pools and dams on the Monongahela River is presented in Figure 5. As shown in this figure low flow dissolved oxygen stratification is extreme in Opekiska Pool. At higher flows, stratified distribution of dissolved oxygen was not evident in Opekiska Pool, but during the low summer flow survey shown in Figure 5, dissolved oxygen in Opekiska Pool decreased vertically from a maximum of 10.2 mg/l at the surface to a minimum of 0.1 mg/l at the bottom.

This extreme dissolved oxygen stratification was accompanied by well-defined thermal stratification as can be noted in Figure 6. Figure 6 shows

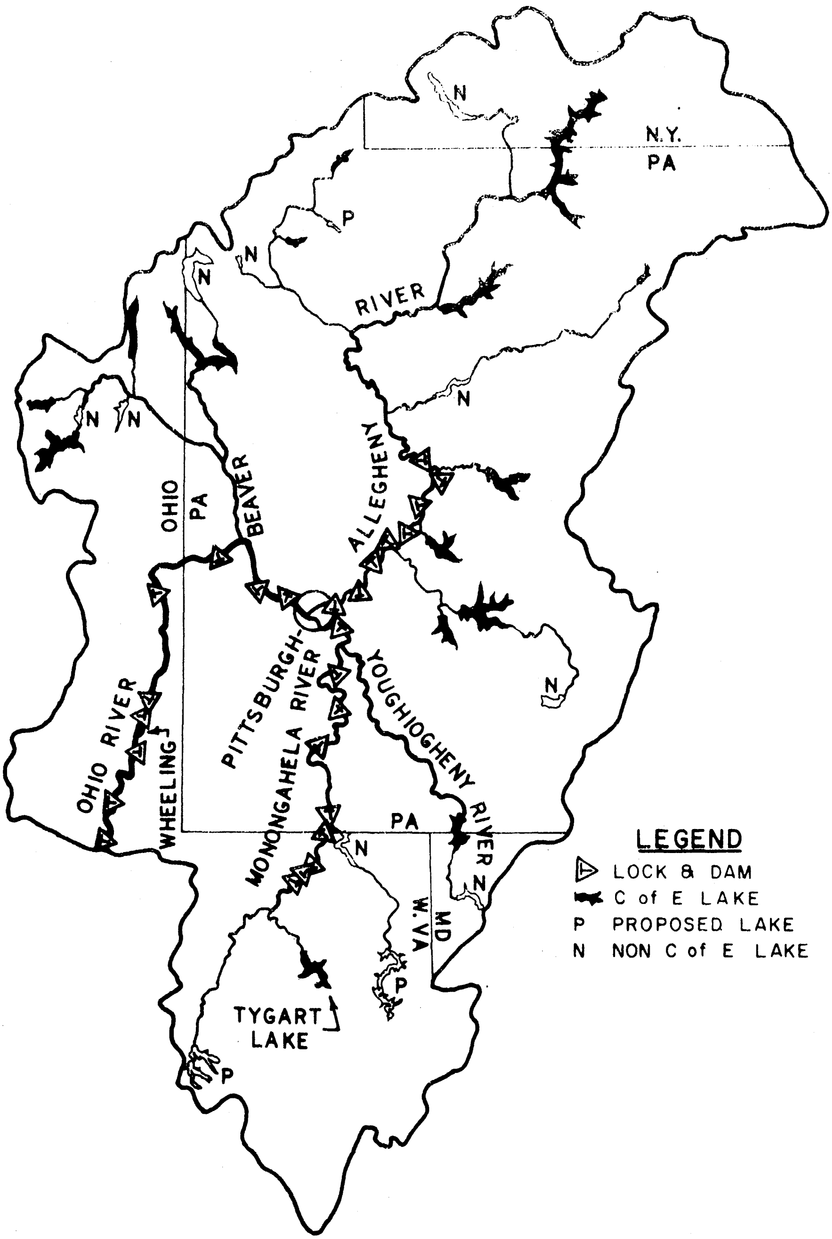

Fig. 1. Pittsburgh District Corps of Engineers System of Water Resource Development Projects

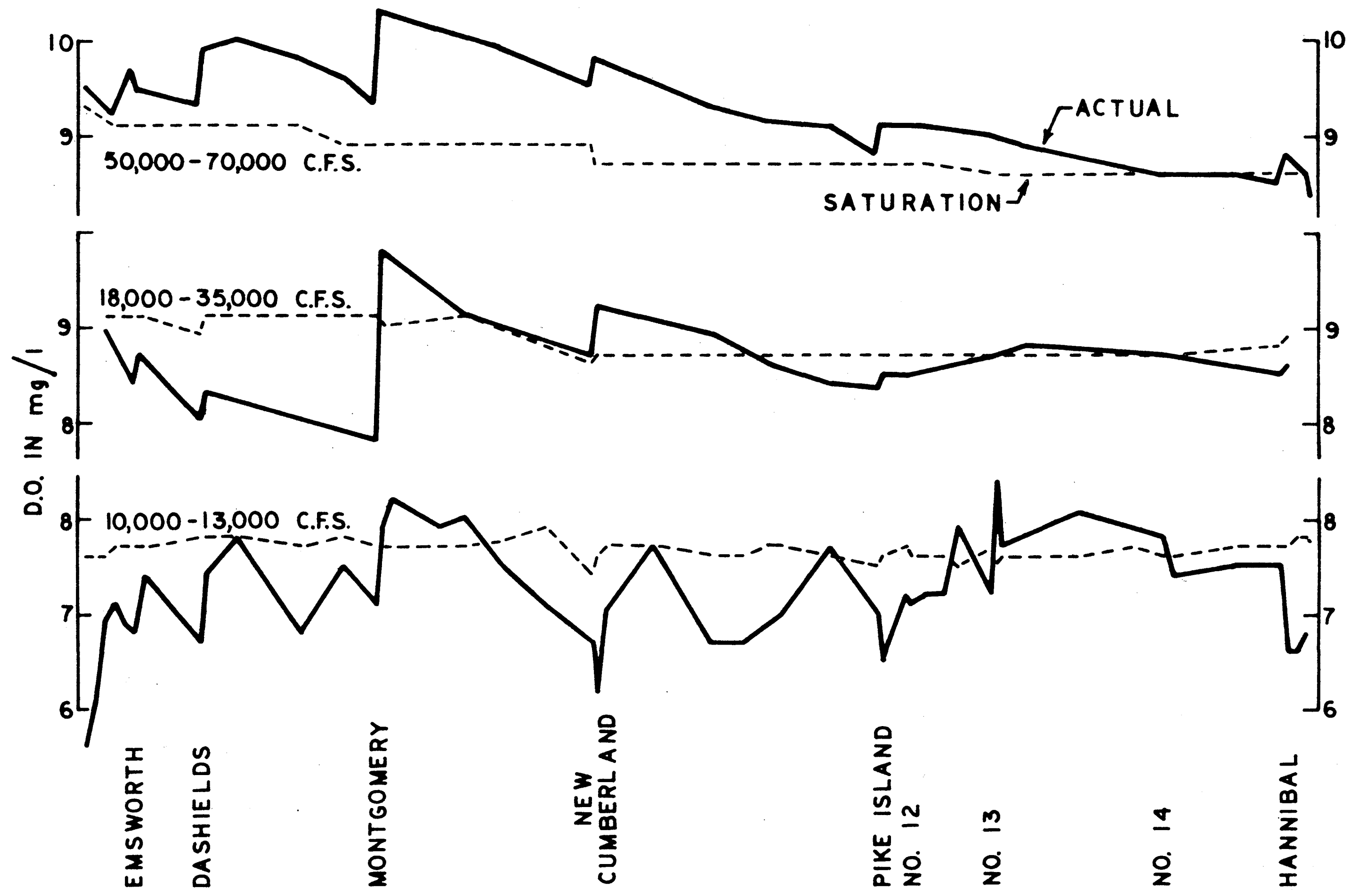

Fig. 2. Dissolved Oxygen Variation in the Ohio River from Mile 0 to Mile 130 at Three Different Summer Flows

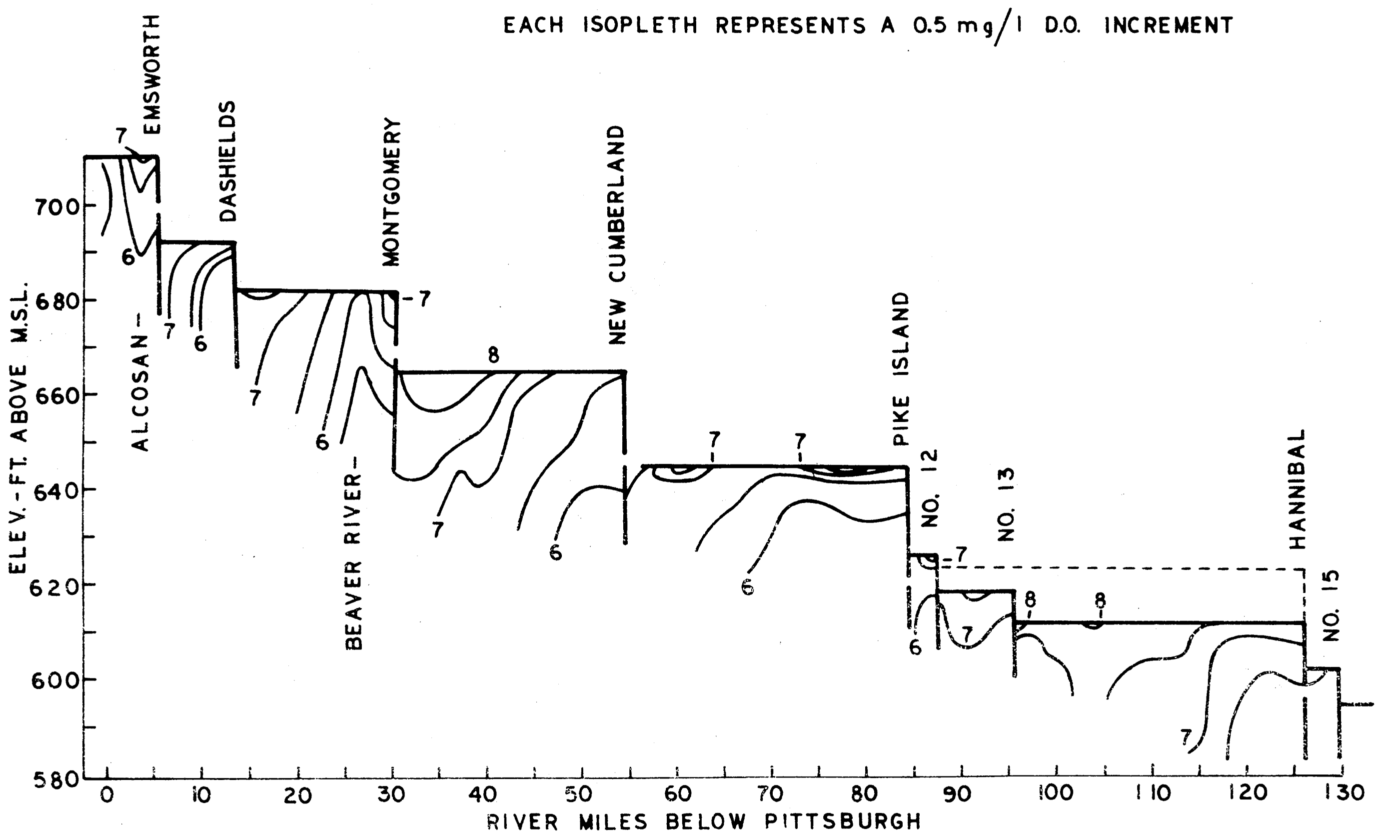

Fig. 3. Length-Depth Dissolved Oxygen Profile of the Upper Ohio River at a Low Summer Flow, 10,000 to 13,000 cfs.

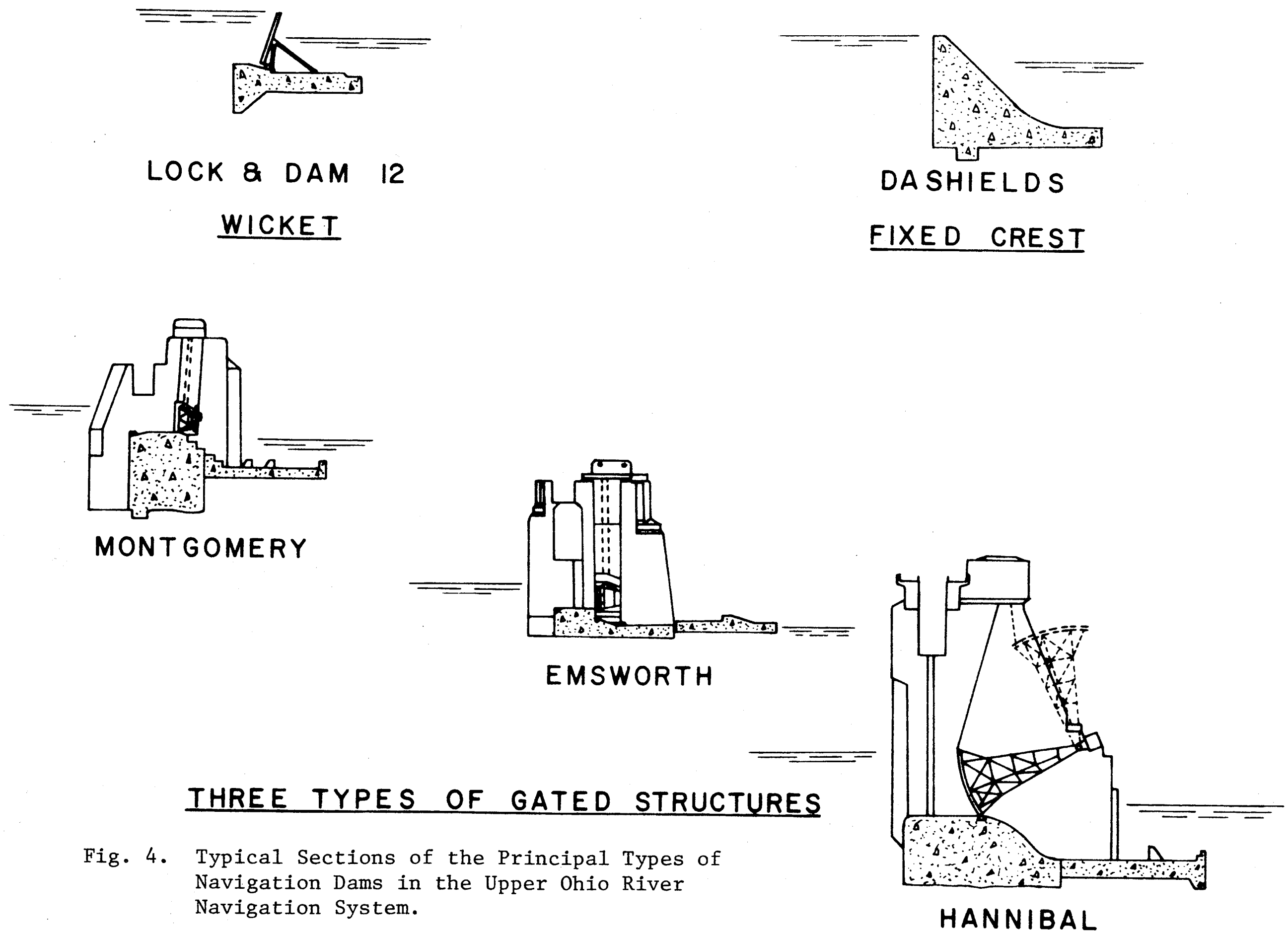

Fig. 4. Typical Sections of the Principal Types of Navigation Dams in the Upper Ohio River Navigation System.

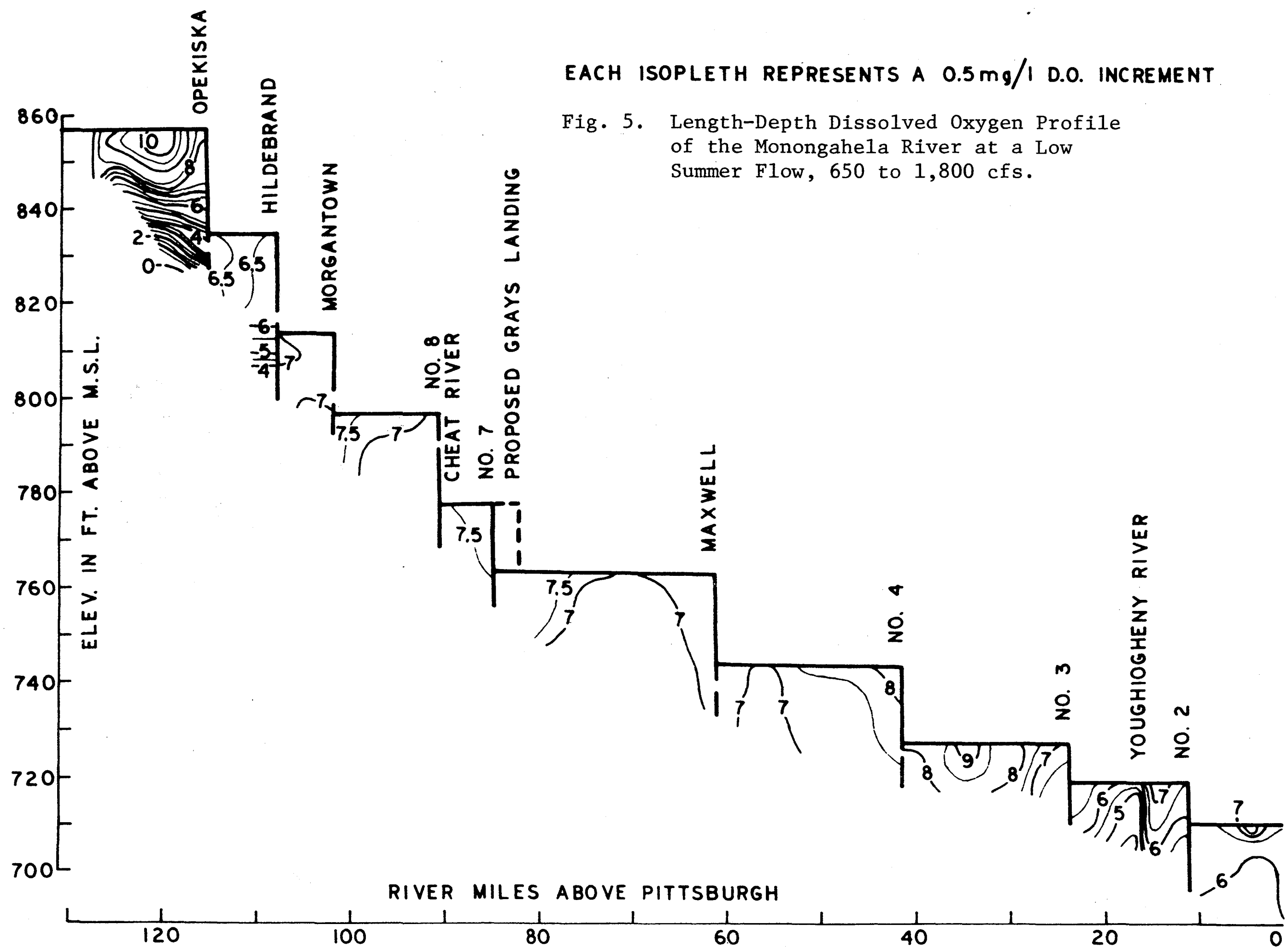

Fig. 5. Length-Depth Dissolved Oxygen Profile of the Monongahela River at a Low Summer Flow, 650 to 1,800 cfs.

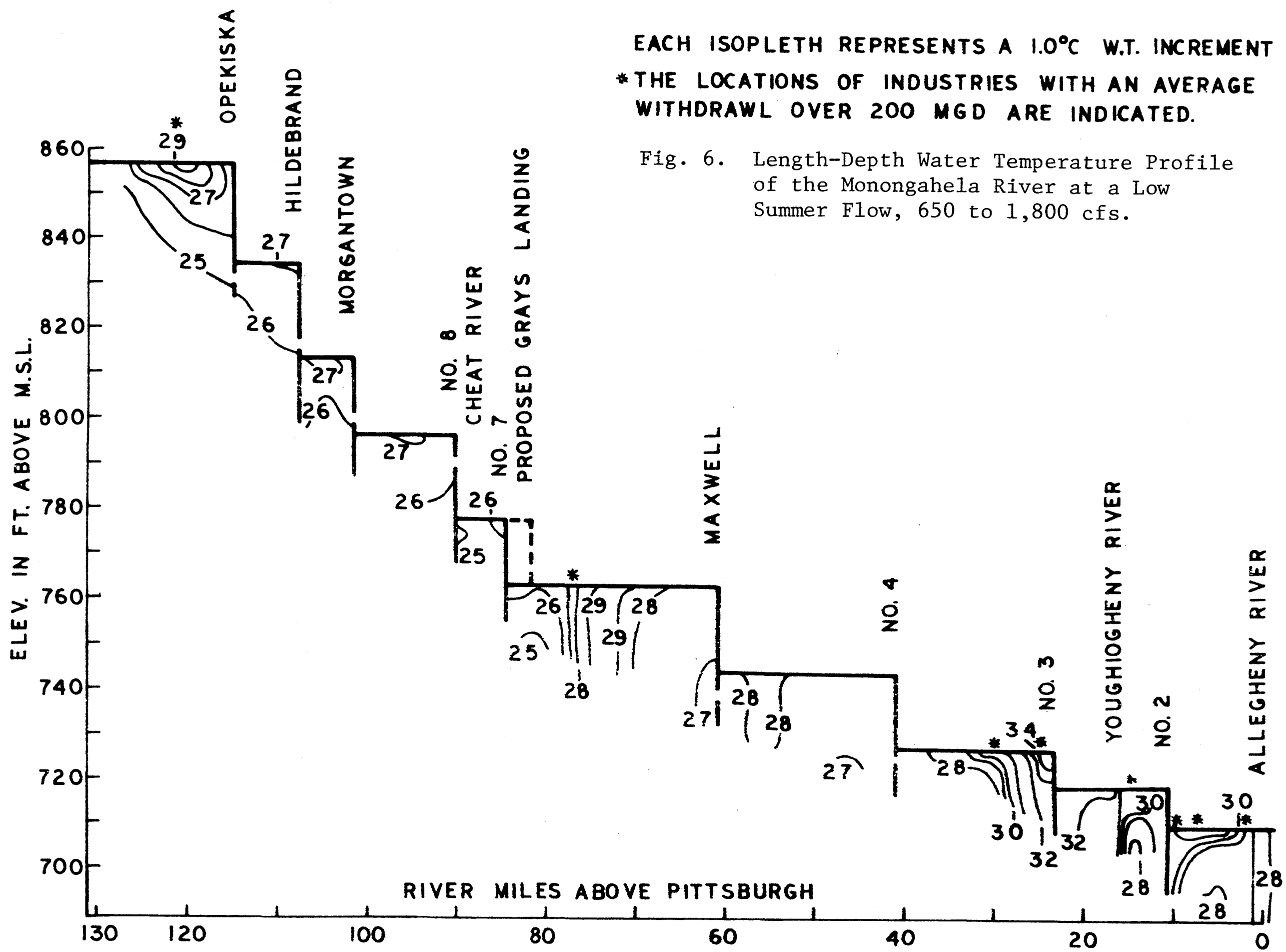

Fig. 6. Length-Depth Water Temperature Profile of the Monongahela River at a Low Summer Flow, 650 to 1,800 cfs.

TOPIC IV-E.

OPERATION OF PROJECTS FOR IFN BENEFITS

Summary Discussion

The operation of upstream and main-stream reservoirs in the Missouri and Ohio River Basins for in-reservoir and downstream benefits to fisheries, wildlife, and water quality was the subject of discussion in this session.

Mr. Koryak discussed the effects of mainstem navigation dams on water quality and fisheries in the Upper Ohio and Monogehela River Basins. This discussion evaluated the characteristics of dissolved oxygen and temperature profiles as they are influenced by structure design.

Mr. McClendon and Mr. Benson discussed the regulation of the Missouri River mainstem reservoir system for fish production. They indicated that modification to peaking operations of facilities have been made in the interest of fishery resources, and with the general knowledge of having a substantial economic effect. However, detailed economic analysis of power production and resource protection has not been completed.

The lack of shoreline vegetation is recognized as a major concern along the Missouri River main-stream reservoirs. Cattle grazing on the shoreline is a problem in maintaining adequate shoreline vegetation. Some shoreline planting has been undertaken but the lack of protective fencing has impared its effectiveness. The extensive mileage of shoreline on the Missouri system presents major problems in effective rehabilitation through these treatment measures. The University of South Dakota is conducting research on this problem.

Notes by panel moderator: Noel Larson
Steering Committee Member

PERMIT SYSTEMS FOR MANAGING WATER QUALITY: AN INFLUENT CONTROL PROPOSAL FOR AGRICULTURAL RETURN FLOWS

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Abstract

The maintenance of instream flows for fish and wildlife preservation and recreational purposes has implied the need to not only consider the quantity but also the quality of the flows. These two characteristics of water resources have been traditionally treated separately by the law in the Western part of the United States. Water quantity has been allocated under permit systems following principles of prior appropriation, with the additional complexity in nine states of also allocating water under the riparian doctrine. Assertion of water quality is by common law remedies for parties whose water "quantity" rights have been adversely affected.

Laws for water quality control have been enacted by each of the Western states. Most of these laws pattern in substance and approach the federal counterpart--The Federal Pollution Control Acts of 1965 and 1972. The 1972 Act created target dates for achieving water quality improvement. Section 402 created the National Pollution Discharge Elimination System (NPDES) permit program which includes "permitting" degraded water discharges from agricultural water uses.

The program has been difficult to implement for agricultural return flows and it is proposed that an alternate approach be adopted. The nature of irrigation return flows stems from the exercise of the water right, and thus control of degraded return flows would best be handled at the source of the problem, not the problem itself. An influent control program is proposed to operate conjunctively with areawide waste treatment management planning agencies set up by the states under Section 208 of the 1972 Federal Act.

PERMIT SYSTEMS FOR MANAGING WATER QUALITY: AN INFLUENT CONTROL PROPOSAL FOR AGRICULTURAL RETURN FLOWS

by

George E. Radosevich

The maintenance of satisfactory in-stream flows requires focus upon both attributes of water quantity and quality. In the West, it is often assumed that most streams, rivers and lakes are of high quality, but the true status must be relative to the needs of both man and aquatic life. We cannot ignore the potential failure of the INF Program by only concerning ourselves with traditional methods of acquiring flows under state water rights laws. It is necessary to explore several legal provisions or lack thereof, for water quality control of stream flows. The focus will be upon specific problems of water quality degradation from agricultural water uses.

NATURE OF THE PROBLEM:

A. Water quality degradation arises from natural and artificial distributions of water.

   1. In the Eastern U.S.A. and humid areas of the West Coast states, there is an abundance of precipitation, often causing excessive runoff and return flows which, through this natural process, contribute to water quality problems.

   2. In the more arid West, agriculture depends upon the artificial diversion (and storage), conveyance and application of water.

B. The problem of degraded stream flows from agricultural water uses is a a result of the allocation method provided for by law.

   1. Under traditional water law in the West, called the doctrine of prior appropriation, a user acquires a right (in the form of a permit in most states) to divert water. The usual elements of this right are: source of supply, maximum quantity divertable under the right, point of diversion, place of application and type of use. A time of use is implicit if for agricultural purposes. The exercise of the right is limited to the conditions of using only that amount of water which can be beneficially used if available for diversion under the priority of the right. The right is perpetual in most states as long as it is used. The quantity originally allocated is protected by diverting the maximum allowed, otherwise it may be lost in part or whole by abandonment or forfeiture.

   2. The problem may begin with the exercise of the right. Water is diverted, conveyed through channels to the lands for irrigation or temporarily

stored in reservoirs before application.

3. The potential for return flow begins with the diversion and may occur at any point in the three components of an irrigation system. These components are: (a) diversion and delivery, (b) application, and (c) removal.

4. The sources of return flow from the irrigation system are (a) seepage from the diversion and delivery sub-system, (b) deep percolation, and (c) tailwater runoff from excessive amounts of water applied. The return flows may become diffused throughout the soil profile and make their way back to the watercourse or be collected in drains and directly discharged.

5. It is not to be implied that all irrigation return flow is a waste or misuse of water nor contributing unreasonably to stream flow quality conditions. The dimunition of water quality occurs from excessive seepage and applications of water which pick up pollutants and have sufficient force to convey them into a watercourse.

6. The types of pollutants which may occur in agricultural return flows that have degrading effects include salinity (dissolved solids), bacteria, pesticides, fertilizers, sediments and debris from soil surface.

RANGE OF SOLUTIONS:

A. Solutions range from do-nothing, to improving the effluent control program, to implementing an influent control program.

B. The "Do-Nothing" approach may be most strongly supported by the agricultural water users as a temporary measure until data and technology have concretely identified the harm caused and consequences of altering the return flow regime, as well as provide economically feasible solutions. I do not accept this approach in toto, but do feel many irrigated areas of the West can best be left undisturbed until it is determined that particular water use practices are causing actual harm and not simply benefiting from the assimilative capacity of the watercourse. That is, pollution control must serve an objective, not be an exercise for control's sake.

C. Effluent control has become the traditional approach to resolving water quality problems associated with discharges from artificial uses of water. Prior to 1972, however, control techniques were not very effective. The legislation provided for research and development, construction grants and the cumbersome "conference system" for pollution abatement. A comprehensive approach focusing upon the totality of water quality control was finally adopted in the Federal Water Pollution Control Act Amendments of 1972.

1. The objective of the Act is to restore and maintain the chemical, physical and biological integrity of the Nation's waters.

2. The Act established several goals relevant to instream flows. They are that the discharge of pollutants into navigable waters be eliminated by 1985 and that where attainable, a water quality necessary to protect and provide for propogation of fish, shellfish and wildlife and recreation

be achieved by July 1, 1983.

3. The objective and goals are to be achieved through the integrated effort of a three-pronged program encompassing:

   (a) construction grants, Section 201 to 207,

   (b) areawide waste treatment management, Section 208 for both point and non-point source discharges, and

   (c) a permit system for discharges from point sources into navigable waters, Section 402, called the NPDES program (National Pollutant Discharge Elimination System).

4. To insure a progressive improvement in water quality, the Act requires point sources to have adopted the best practicable available technology by July 1, 1977 and the best available technology economically achievable by July 1, 1983, except for discharges into publicly owned treatment works and the discharge form such works, Section 301(b).

5. States are encouraged to adopt a pollution control program consistent with the federal provisions. Once accepted by the Environmental Protection Agency, the states shall administer water quality control within their jurisdiction. The majority of Western states have implemented accepted laws and programs.

6. EPA promulgated regulations for implementation of the NPDES program in 1973 which identified agricultural return flows as point sources, but provided certain exemptions. These exemptions in the regulations were challenged in N.R.D.C. versus Train (7 ERC 1881, March 1975) and the Supreme Court held EPA in violation of the Act's intent.

7. Consequently, on 23 February 1976, new regualtions for discharges from agricultural activities were proposed by EPA (41 FR 7963). In brief, these regulations would include in the permit program agricultural point source return flows coming from the "controlled application by any person" and exempt degraded return flows steming from natural courses. Agricultural point source is defined in the regulations as any discernible, confined, and discrete conveyance from which any irrigation return flow is discharged into navigable waters. Irrigation return flow is defined as surface waters, other than navigable waters, containing pollutants which result from controlled application of water by any person to land used primarily for crops on forage growth, forestry or nursery operations. A general permit system would be instituted, but the Agency can issue specific regulations for irrigation return flow (drainage) ditches.

D. A proposed solution for agricultural return flow quality control is a program placing primary emphasis upon influent control and waste water management. As a general proposition, the effluent permit program for all agriculture will not withstand enforcement under judicial scrutiny due to rules of evidence and burden of proof requirements. Further, without a concrete, definable program, increased alienation of the agricultural community against the administrators of control will result. The proposed approach would capitalize upon the "permit" program for water allocation and seek to attack the cause of the problem, not the consequences.

1. State water rights (permits) are subject to beneficial use and conversely non-waste requirements. As long as reasonable practices are followed, there has been little action taken by state water administrative agencies. Further, one of the key ingredients for the economic base in irrigated agriculture is the security and dependability of water rights. But, certain features of state water law compel full use of the rights, even when not essential, in order to prevent partial or total loss through abandonment or forfeiture.

2. Definitions of beneficial and/or reasonable use and waste are not very definite under state laws. It is proposed the state water administration agency prepare standards and implementation procedures for the terms.

3. Incentives in the law need to be provided for irrigators to use their water more efficiently by adopting improved delivery technologies, water application practices, and allow the water right holder to trade, lease or sell excess amounts upon state approval. The Utah financial loan program of interest free money for canal and ditch lining and other such improvements is strongly recommended. Many other states, such as Wyoming and Colorado, have similar provisions in the law or agency programs.

4. The influent control program will attempt to cause only diversion and applications of those water quantities essential for plant growth, thus reducing pollutants in irrigation return flow from tailwater runoff and excessive seepage and deep percolation.

5. The influent control program should be highly coordinated and integrated with the 208 areawide waste management program provided for under P.L. 92-500, the 1972 Federal Water Pollution Control Act.

6. This approach would not cast an undue burden upon the water users without a corresponding benefit. It is hypothesized the result would be:

   (a) to create an awareness by the irrigator of the injury caused from agricultural return flow to instream flows and downstream water water users,

   (b) provide an opportunity for independent decision making on his part as to which practices and technologies to adopt, and

   (c) create a social consciousness in the agricultural water user for his use of the public's resource.

CONCLUSION:

Instream flows are affected by return flows from agricultural water uses, and it is important to take this factor into account when pursuing a program for protection of aquatic life and habitat. The proposed influent control program would partly solve degration to instream flows and assist the state and federal governments in achieving the water quality control objectives of the 1972 Federal Water Pollution Control Act.

USING INTERSTATE COMPARISON TO IMPROVE A PERMIT SYSTEM

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ABSTRACT

The Washington Water Resources Act of 1971 provides that water be allocated in ways that will promote maximum net public benefits. The Act requires that recreational, commercial, and aesthetic values of instream flows be protected. It provides various means whereby these objectives may be accomplished.

Comparison of Washington's system for issuing permits to appropriate water with arrangements in other states indicates some areas where improvements could be made in the Evergreen state. However, most of the recommended changes are administrative in nature, since the basic 1971 legislation appears to be strong compared to the statutory base found in most other states.

Finally, this study seems to support the value of comparative research as a tool for improving the state's system for allocation and management of water.

INTRODUCTION

Sixty years ago the Washington State Legislature adopted a permit system for allocation of water. Beneficial use requirements and provisions for condemnation of water rights for superior uses promoted utilization of water for public benefit. However, instream uses were not recognized as beneficial, and both allocation and condemnation of water were handled on a case-by-case basis. Little consideration was given to general and long-term consequences of particular administrative or judicial decisions.

The past decade has seen a growth of environmental consciousness in Washington. The distributive, case-by-case approach to decision-making has been recognized as inadequate, and a more ecological approach has been advocated forcefully. In 1971 the Washington Water Resources Act was adopted. In this measure the beneficiality of instream values of a recreational, commercial, and aesthetic nature is recognized, and comprehensive planning to assure allocation of water in ways that will promote maximum net benefits for the public in required. Provisions for determination of existing water supplies, rights, and uses are included in the Act; a review of existing rules, regulations, and statutes is required; and the Washington State Department of Ecology is charged with developing a comprehensive state water program.

Achievement of the objectives of the 1971 Water Resources Act requires integration of legislative and departmental rules, regulations, and procedures in a coordinated system. As part of its effort to implement the Act, the Department of Ecology contracted with the Washington Water Research Center in November, 1975, for an evaluation of the state's permit system. A comparative analysis of arrangements in western states was prepared. The design and some results of the study will be presented in this paper, which will conclude with some comments regarding the usefulness of the comparative approach.

STUDY DESIGN

The objective of the Center's study was to identify changes in rules, regulations, procedures, and statutes which would help in the development of an integrated system for promoting maximum net public benefits in the allocation of Washington's water. The study design proposed comparison of arrangements in Washington with those in other states. Profiles of the statutory and administrative provisions and practices of seventeen continguous states in the West were prepared. In addition to these profiles, a conference of experts in water law and administration was held in Portland, Oregon. The profiles provided a number of alternative approaches, procedures, and provisions to those used in Washington. These concrete alternatives were productive of numerous comments and suggestions by participants at the conference.

FINDINGS AND RECOMMENDATIONS

Despite some doubts by officials in the Department of Ecology, it appears that the Water Resources Act of 1971 provides Washington with a relatively strong basis for insuring that water is allocated and reallocated in ways that will promote maximum net public benefits. However, more opportunities for investigation, notice, and hearings are suggested in the study. Other states utilize these procedures as a means of advancing both public involvement and more intelligent decision-making. Strict adherence to time requirements for initiating and completing construction is urged; the need for development and promulgation of criteria to (1) guide conditioning of permits; (2) define what constitutes substantial beginning construction; and (3) identify completion of construction is stressed; and a need for increasing the Department's resources to provide more effective field inspections of water works and applications is mentioned.

The Department has a very strong statutory position from which to protect instream values. Department personnel are preparing a comprehensive state water program consisting of a series of basin plans. The plans will establish base flows for streams. These base flows have been distinguished administratively from "minimum flows," which are somewhat higher than base flows and can be set on request from Fisheries and Game Departments of the State without lengthy planning and hearing requirements.

Reservation and withdrawal provisions provide the Department of Ecology with a number of opportunities for fostering creative arrangements that can promote various public benefits. The state is, for example, promoting regional development of irrigable land in southeastern Washington by assisting in and insisting on a program for building a canal. Another approach which the Department might consider is temporary appropriation of water reserved for other uses. Finally, the Department could investigate establishing moritoria on issuance of permits in areas where significantly more efficient utilization could be achieved through conjunctive use of surface water and groundwater. The possibility also exists of requiring formation of water management districts for such purposes.

EVALUATION OF THE APPROACH

No sophisticated statistical techniques were utilized for comparative analysis of Washington's arrangements with those of other western states. However, description of other states' arrangements, identification of alternative arrangements, and expert evaluation of various alternatives appears to have been fruitful. An official at the Washington State Department of Ecology has given the following assessment:

> Since your report has just been published, we may not realize its full benefit for several years. We do intend to begin by reviewing some of the proposals you made for regulations and administrative procedures. One area where you suggested a regulation be developed, and where I feel we desperately need it, is in construction schedules on permits.
>
> We plan to use your recommendations for legislative action by providing copies of your report to our Ecological Commission and a committee looking at revision of our water laws with the idea of proposing some changes to the next legislative session.

TOPIC IV-F.

PERMIT SYSTEMS FOR WATER MANAGEMENT

Summary Discussion

In response to Mr. Dufford's survey of the evolution of water law and administration in the state of Washington, a member of the audience asked if the state law required a diversion of water. Response was in the negative and, in fact, the State Water Pollution Appeals Board has ordered that one individual be issued a permit for water that was to remain in a stream to allow scientific research to continue. Dufford claimed that the permit granting agency, the Washington State Department of Ecology, was opposed to this appropriation.

A question was asked regarding Washington's attempt to require registration of water rights, and whether this might result in extinguishment of many riparian rights, and consequent release of water for instream flow purposes. The answer given by Dufford was that any increased flow would be advantageous only if guaranteed by state action which established minimum or base flows. Without guarantees the water, which might not have been used by the riparian owners, would be available for appropriation by other prospective users.

Regarding the case of Environmental Defense Fund vs. East Bay Municipal District, Mr. Radosevich was asked if this case meant that there were public rights to water that antedated and conditioned the rights of appropriators. Radosevich expressed the feeling that the decision suggested the existence of public rights which constitute unwritten conditions on permits. Is it likely that future cases would recognize the superiority of implicit public rights over private, vested rights? Radosevich's response was that this would be probable only in cases where important values associated with the stream were threatened with extinction.

Notes by panel moderator: Race D. Davies
Steering Committee Member

QUANTIFICATION OF INSTREAM FLOW NEEDS BY LAW IN COLORADO

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ABSTRACT

The topic of this paper is best described as a review of the status of Colorado Senate bill 97. A review of its history from a legal perspective is necessary in order to familiarize the reader with the necessity for and format of Senate bill 97. The basic concept of Senate bill 97 was to redefine the words of art "diversion" and "beneficial use" to insure that the use of water for preservation of the natural environment would be considered a beneficial use under the law and to insure that an actual diversion from the natural channel of the stream was not required in order to make an appropriation under the Colorado constitution. The State of Colorado through the Colorado Water Conservation Board, with the assistance of the Colorado Division of Wildlife and the Colorado Division of Parks and Outdoor Recreation has made 256 applications to date for the protection of minimum lake levels and 87 applications for the protection of minimum stream flows. Under the Colorado approach, water may be appropriated to preserve the natural environment to a reasonable degree. The possibilities include: recreational uses, scenic values, wildlife habitat and protection of fisheries. The present state of the art for measuring minimum lake levels and instream flows is sufficient to allow an adequate case presentation and the establishment of specific flow requirements. The questions concerning appropriations on water bodies whose present condition has been improved or augmented by man has still not been decided.

INTRODUCTION

A more apt title for this discussion might be "a review of the status of Colorado Senate bill 97." Instream flow needs within the State of Colorado must be viewed in light of that bill and the success or failure of the Colorado program will depend upon the Colorado Supreme Court's interpretation of its constitutionality and legality. Despite the stumbling block of a future confrontation over the constitutionality of the authorizing legislation, the Colorado Water Conservation Board through the Office of the Attorney General and with the assistance of the Colorado Division of Wildlife and the Colorado Division of Parks and Outdoor Recreation is pressing forward in its efforts to make appropriations on minimum lake levels and minimum stream flows across the state. The concern at the present time is to appropriate those stream systems that are presently subject to greatly increased water demands due to development pressures from various sources such as energy development, urbanization, increased agricultural development and recreational developments.

At this point I would like to recognize my indebtedness in preparing this paper to Mr. Dwayne Helton, Chief, Environmental and Water Quality Section, Colorado Water Conservation Board and to Mr. Eddie Kochman, Specialist, Environmental Resources Section, Colorado Division of Wildlife.

The thrust of this paper will be an attempt to briefly review the history of Senate bill 97 in order to explain the reason for the Colorado approach to the quantification of instream flow needs; second, to discuss the basic instream flow needs that can be met through Senate bill 97 and to describe the technical support we would anticipate utilizing to justify an instream flow appropriation; third, to describe in some detail the procedures utilized in Colorado for the quantification of instream flows for fish preservation purposes; fourth, to consider some of the questions that remain concerning protection of the natural environment through the appropriation of water within the State of Colorado; and fifth, to briefly review where the state stands from an appropriation standpoint at the present time. In furtherance of discussion a series of approximately 30 slides will be shown to characterize the manner in which instream filings are made.

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BRIEF HISTORY OF SENATE BILL 97 FROM A LEGAL PERSPECTIVE

The use of water within the State of Colorado has traditionally been governed by the doctrine of prior appropriation. The Colorado constitution in article XVI, section 5 states:

> Waters of streams public property. The water of every natural stream, not heretofore appropriated, within the state of Colorado, is hereby declared to be the property of the public, and the same is dedicated to the use of the people of the state, subject to appropriation as hereinafter provided.

Provisions of section 6 of article XVI state that:

> Diverting unappropriated water - priority preferred uses. The right to divert the unappropriated waters of any natural stream to beneficial uses shall never be denied. Priority of appropriation shall give the better right as between those using the water for the same purpose; . . . .

In the case of Coffin v. Left Hand Ditch Co., 6 Colo. 443 (1882) the Colorado Supreme Court clearly stated that the doctrine of prior appropriation would govern the use of water within the state. The foregoing quotation from section 6 contains within it the basis for the establishment of a water right and coincidentally, the reason for the necessity of Senate bill 97 and the legal problems that arise therefrom. I refer, of course, to the words "the right to divert the unappropriated waters of any natural stream to beneficial uses shall never be denied." While the Supreme Court of the State of Colorado has never specifically set forth a standard for what is required to accomplish a "diversion" or to achieve a "beneficial use" it has certainly given some guidance during the years between its decision in Coffin v. Left Hand Ditch and the present.

In considering the meaning of the term "diversion" the court has recognized that stock watering directly from a flowing stream could be considered a diversion in that the drinking of the water by the animals constituted the diversion necessary to meet the constitutional requirement.

It is also recognized that there is a right to have your land flooded and the beneficial results of such flooding could constitute an appropriation of water within the law. However, in a recent decision, Colorado River Water Conservation District v. Rocky Mountain Power Company, 158 Colo. 331 (1965), the Colorado Supreme Court held that the Conservation District could not appropriate waters for the preservation of fish life within a stream because such an appropriation did not constitute a physical diversion.

Fortunately, the Colorado court has not created similar problems with the definition of "beneficial use." In the case of Denver v. Sheriff, 105 Colo. 193 (1939) it held specifically that the term "beneficial use" is not defined in the constitution and the determination of what would constitute a beneficial use is a question of fact. Between the case law and the constitution a great many uses have been termed to be beneficial within the ambit of Colorado water law. It is certainly evident that at the time of the passage of Senate bill 97 the Colorado constitution and case law did not recognize instream flow needs as either a beneficial use or as a diversion under the requirements of the constitution.

The State of Colorado had two basic choices when it determined that minimum stream flow and lake level protection was in the public interest. The first possibility was to amend article XVI of the constitution to specify that appropriations could in fact be made for instream purposes under the terms of section 6. This approach would have required the expenditure of large amounts of money and would have created a change in the law that few individuals in Colorado had considered. It was the judgment of the supporters of Senate bill 97 that the appropriate way to provide the necessary minimum flows in streams and lakes was through an addition to the statutes that codified the procedures for appropriating and administering water within the state.

Thus Senate bill 97, a two-page act passed by the general assembly of the State of Colorado in 1973, was born. In very simple terms the act amended three definitions contained in the law. First, it removed the requirement, from the definition of appropriation, that a physical diversion be made. Second, under the definition of priority, it removed the word "divert" and substituted the word "use." Finally, the definition of beneficial use was amended to include wording that allowed appropriation by the State of Colorado of such minimum flows between specific points or levels for and on natural streams and lakes as are required to preserve the natural environment to a reasonable degree. The legislative intent setting forth very briefly the manner in which such appropriations were to be made is as follows:

> Further recognizing the need to correlate the activities of mankind with some reasonable preservation of the natural environment, the Colorado water conservation board is hereby vested with the authority, on behalf of the people of the state of Colorado, to appropriate in a manner consistent with sections 5 and 6 of article XVI of the state constitution, or acquire, such waters of natural streams and lakes as may be required to preserve the natural environment to a reasonable degree. Prior to the initiation of any such appropriation the board shall request recommendations from the division of wildlife and the division of parks and outdoor recreation. Nothing in this article shall be construed as authorizing any state agency to acquire water by an eminent domain, or to deprive the people of the state of Colorado of the beneficial use of those waters available by law and interstate compact.

Thus a very simple procedure was established whereby the State of Colorado could insure that the instream flow needs of this state could be protected by action of state officials without setting up special procedures or taking the matter out of the normal methods for acquiring water rights.

Whether or not the foregoing change in the Colorado law will satisfy the constitutional requirements as interpreted by the state supreme court is yet to be decided. There are presently eight cases at the pretrial stage wherein the constitutionality of Senate bill 97 has been challenged and it is inevitable that within the next two years a decision will be reached by the state Supreme Court determining whether or not the manner chosen by the supporters of minimum stream flows was correct under the laws of the state. Clearly, the legislature can determine what constitutes a beneficial use of water within the state. However, there will certainly be extensive argument concerning whether or not the legislature can determine that physical diversion is not required in order to "divert" the waters of the state in accordance with the constitution. It is also very likely that a federal and state constitutional issue will be raised concerning the question of whether or not a minimum stream flow statute such as Senate bill 97 constitutes a "taking" of private property as set forth in those documents. It can be argued that Colorado law does not now guarantee the right to change the place of use, type of use, or amount of use and so the fact that a minimum stream flow appropriation could significantly hinder such changes in use should not constitute a taking as considered in the state and federal constitutions. For the immediate future the responsible agencies in the State of Colorado are proceeding under the assumption that the changes made in Colorado water law by Senate bill 97 are constitutional and that the appropriation of minimum stream flows and minimum lake levels thereunder will in fact guarantee for the people of the state the preservation of the natural environment.

FLOW REQUIREMENTS THAT MAY BE GUARANTEED THROUGH THE COLORADO LAW

The first issue that must be resolved under any statute similar to Colorado's is to decide what will be the basic standard utilized for the determination of the required minimum stream flows. It would appear that there are four basic types of instream flow needs that could be identified and for which water might be appropriated under Senate bill 97. The most obvious one, of course, and the one which has received the most interest at this point in time, is the determination of the amount of water necessary to maintain a viable fishery on a given stretch of stream or in a given lake. That determination must be made by trained biologists who must take into account many factors depending upon the kind of habitat, the type of aquatic life to be protected and the management ends to which the water will be placed. For example, a greater amount of water will be required in a stream that is tributary to a large lake and which is used by large brown trout on spawning runs than will be necessary in a small mountain stream that contains only brook trout. In addition, more water may be necessary in a stream that has a tendency to freeze solid to the bottom in the winter when flows are low than in one that maintains large pools capable of sustaining fish life through the winter.

The second consideration for minimum stream flow protection are the flows necessary to sustain wildlife habitat. Examples of this could include a determination by a wildlife biologist of the amount of water necessary to sustain habitat for reintroduced river otter, habitat necessary to sustain beaver or muskrat, or the amount of water necessary to sustain a viable duck or goose population. Naturally, one would assume that the flows appropriated for fish production would be adequate to sustain wildlife habitat for any of the foregoing, however, circumstances exist where there is no valuable fishery present yet there is extremely valuable wildlife habitat. Such an example is the Arikaree River in eastern Colorado.

The third example of possible uses for minimum flow appropriations are recreational purposes. This would include enough water to allow kayaking, river float trips, tubing and rafting, or body contact water sports. These flows are generally far in excess of any flows that could be justified for either fishery preservation or wildlife habitat and they therefore will require a greater degree of study and consideration before making the appropriations. It may be the situation under present Colorado law that the larger flows required for these activities do not meet the requirements of preserving the natural environment to a reasonable degree and therefore cannot be protected.

The final use to which an instream flow appropriation could be made would be for scenic values. This would certainly be the most difficult to establish from a legal standpoint because it is very hard to quantify the amount of water necessary to produce a vista that is pleasing to the eyes of the majority of citizens. In the case of waterfalls and lakes it may not be difficult, but in the case of an average stream or river it will be extremely hard to establish a rational basis for picking a particular amount of water as that amount necessary to preserve the scenic grandure of an area.

The wide variety of purposes to which a minimum stream flow appropriation could be put will require a broad spectrum of expert witnesses in order to justify the appropriation. Under Senate bill 97, the one individual who will be required to participate in every contested appropriation will be the director of the Colorado Water Conservation Board or his designee who will have to testify concerning the manner in which the appropriation was made, the fact that proper notice was given of the Water Conservation Board meeting at which the appropriation was approved, any discussion held by the board and any reasons that were given by the board for making the appropriation. As the statute does provide a specific statutory body that can make such an appropriation, I would certainly anticipate that this individual will become a standard witness in establishing the proof necessary to successfully acquire the minimum flow right.

Having established the legal basis for the appropriation and that the proper procedures were followed in making it, the next witnesses will depend greatly on the purpose for which the appropriation is made. The spectrum of possibilities includes professionals as well as citizens who have some interest or knowledge of a given area. As an example, one might expect to call both fish and big game biologists to testify to various fish flow requirements and wildlife habitat requirements, landscape architects and local citizens to testify to the amount of water necessary to preserve scenic values or a recreation specialist to describe the flow required for kayaking. It would be expected that all of these various specialists and citizens would supplement their testimony with pictures displaying the before and after situations involving lack of minimum flows on a given stretch of the stream, charts and technical exhibits to display the methods of quantification and the reason a particular instream flow is necessary and even site inspections by the court itself.

At the present time in the State of Colorado the appropriations being made by the Colorado Water Conservation Board tend to take two paths. They are to maintain the natural elevation of high country lakes and to preserve the amount of water necessary for continued fish survival in streams and rivers. We have not made any filings involving scenic values unless they relate to the foregoing nor any filings relating to recreational values separate from fishery preservation. It is also important to note that at this time the State of Colorado has not been required to establish the propriety of its methods nor carry the burden of proof on a particular appropriation. The appropriations that have been made to this time have either been processed by the water court without opposition from other parties and an award of an instream flow has been made as requested by the state or the application has been opposed by various parties and the case has not gotten beyond the pretrial conference stage. The lack of trials is not due to any disinterest on the part of the state but simply the result of crowded court dockets and the inability to get an adequate amount of time set aside so that the matter can be properly heard.

QUANTIFICATION FLOWS NECESSARY TO MAINTAIN A FISHERY

As an example of the methodology that will be utilized, if and when trials are held concerning the applications of the State of Colorado for minimum stream and lake levels, a brief look at the data collection procedures utilized by the Department of Wildlife would be helpful. The method utilized to determine minimum lake levels is very simple and easily described. During recent years personnel of the Colorado Division of Wildlife visited almost every lake within the State of Colorado and conducted a survey of each lake to include measuring the shore line, attempting to determine the average depth and reviewing the water quality and fish population. This survey was not conducted with Senate bill 97 in mind and, therefore, the data is not as complete as one would wish. However, it does give a good summary of the geographic data and a close enough approximation of the volume of the lake to allow the Water Conservation Board to make a filing thereon. The onsite survey is checked against a reconnaissance of both U.S. Forest Service and the United States Geologic Survey maps to double check the elevation of the lake and its location, either by longitude and latitude or by section, township and range. This combination of map reconnaissance and onsite survey has proved successful up to the present time and seems to provide an adequate data base to justify the filings that have been made.

Most of the lakes in Colorado that are under consideration for appropriation pursuant to Senate bill 97 can best be described as high country lakes. The opposition by water users to the appropriations is very low as the natural level of the lake is controlled in great degree by the rock structure that empounds the waters and is not susceptible to any significant decrease in elevation. The one major question that remains and as of this date is unanswered is whether or not the appropriation by the Water Conservation Board of a minimum lake level can be utilized to prohibit the future use of that lake as a storage reservoir. This would normally be accomplished by the addition of a dam at the lake's outlet and the artificial storage of water on top of the natural lake. It would appear at the present time that such an artificial increase in the storage capacity of the natural body is not prohibited by the law and probably would not be prohibited by the present terms of Senate bill 97. Naturally, the question will require additional study because the construction of a dam and the resultant fluctuating water level on the lake has a destructive effect both on the fish population and on the scenic environment.

In making appropriations to guarantee minimum stream flow protection for fishery purposes the Division of Wildlife and the Colorado Conservation Water Board utilize a system of on the ground inspection and stream survey in conjunction with computer analysis of the data thus gathered. The procedure involved has undoubtedly been discussed at numerous times at this convention, but I will reiterate it briefly for those who are unfamiliar with the procedure. A team of two men is dispatched to the stream in question for the purpose of collecting date on certain critical parameters. The team initially inspects the stretch of stream to be surveyed and attempts to pick two points: one near the upstream end of the stretch and one fairly close to the downstream end of the stretch that in their judgment represent critical flow areas. These critical flow areas are generally considered to be the riffles above and below the quieter ponds in the stream where the water flow is rapid and the depth is relatively shallow. Once a site has been picked for the foregoing characteristics a steel tape of a known weight, referred to as a sag tape, is stretched across the stream perpendicular to the channel and with the use of a spring balance is held in place at a known tension. The two individuals then proceed to measure the depth of the stream bed with relation to the tape at foot intervals and to measure the velocity of the water at the same foot intervals. These figures are then placed on a chart similar to the one that is attached to this paper as exhibit A. In performing this task a Gurley flow meter, rated by the United States Geological Survey, is used as well as a depth measuring device. The team then determines the slope of the stream at the point of measurement with a hand-held abney and normally will conduct fish shocking to determine size, number, type of fish specie present. Finally, the members of the team should take some photographs for purposes of any future trial indicating the locations where the flow measurements were taken both upstream and downstream, the nature of the terrain, weather conditions, amount of water flowing in the stream and the like.

The information that is obtained is then returned to the Denver office of the Division of Wildlife where it is keypunched into the computer which will provide a stream profile from which the biologist can determine exactly how much water is necessary to provide an adequate fish habitat. This determination then forms the basis for the appropriation of the minimum stream flow by the Colorado Water Conservation Board.

It is anticipated that at the first trial which considers the appropriateness of an application for minimum stream flows the state will utilize four or five witnesses to establish its case. The first witness would be the director of the Colorado Water Conservation Board or his designee who would testify to the actual statutory determination to appropriate and that all of the necessary procedural requirements had been met. A fishery biologist would be needed to testify that the amount of water appropriated was not grossly in excess of that necessary for the purposes for which the water had been appropriated, such as for fish passage, a necessary fish spawning habitat, maintenance of a continuing reproducing fish culture in the stream itself or numerous other purposes. The biologist would probably describe the fish species involved, the nature of the recreational benefits derived by the people in the state, and their relationship to the amount of water appropriated. The team chief of the survey team would be called to describe the technique for obtaining the information that the computer utilized in establishing the stream profile. He would authenticate and identify the pictures taken and describe any physical factors that needed to be placed in evidence. The computer operator would be called to describe how the computer had been programmed and how the inputs from the survey team were utilized in arriving at the stream profile used by the biologist in computing the minimum flow required. The final witnesses that might be called would be local fisherman or officials from sportsmen's organizations who would testify to the value of the fishery to them as representative of the community as a whole.

It appears at this time that the weakest point in the proof of the appropriation will lie with the team chief of the survey team because of the judgment factor involved in choosing the measuring points from which the entire minimum stream flow appropriation is derived. It is clearly a matter of judgment and judgment alone on the part of the survey team that determines which portion of the stream constitutes the most representative location to take the flow measurements. By choosing the wrong position on the stream the section chief can radically affect the values that will then be assigned by the fishery biologist as necessary to maintain the fish population as a whole.

UNRESOLVED QUESTIONS UNDER SENATE BILL 97

Even as the State of Colorado proceeds to appropriate the water necessary to preserve the natural environment through the establishment of minimum lake levels and minimum stream flows, there are a series of questions that remain unresolved. There are numerous lakes within the state whose natural condition has been altered in the past by man made structures which are utilized to control the lake level and to provide additional storage capacity. These structures are usually used in conjunction with other water development projects and significantly alter the natural condition of the lake. The question of whether or not these lakes are available for appropriation by the state is unclear, because in many cases the entire volume of the lake has been appropriated already by the individual or organization that built the level control structures. At the present time the state has taken the position that it will not attempt to file on these altered lakes thus avoiding the problem until all of the lakes that remain in their unaltered natural condition have had their levels assured by appropriation.

A similar situation exists in the case of numerous streams throughout the state that contain water flows that are not native to the particular stream system. These streams are utilized by water users to transport transmountain diversions to their place of use or are streams that collect and drain seepage water that results either from the transportation of irrigation water or from the actual irrigation of cropland. The issues that arise are whether or not the streams that have augmented flows can be appropriated for mimimum flow purposes and if they are so appropriated, can any of the out-of-basin water be included in such an appropriation. It would seem to be the general consensus of the legal community that this form of appropriation would not be appropriate or possible under the present law. The same would appear to be true for the appropriation of water in streams which results from seepage from water transportation structures and from cropland irrigation. While it is undoubtedly possible to make an appropriation for minimum stream flows in such a situation, it is not possible to require the continued irrigation practice or water transportation practice that resulted in the seepage. Therefore, the minimum flow appropriation is very much dependent upon the continued diversion and use by the agricultural user to guarantee the continued minimum flow. The state of Colorado as of this time has stipulated in one case to include language that will allow the irrigation company to change its pattern of use at some time in the future should that be its desire.

The question of the preservation of the marshlands and swampy areas also presents some rather significant problems under Senate bill 97. The law itself specifies that it is designed for the protection of minimum stream flows and minimum lake levels, and in the case of marshes and swampy areas there is generally very little measurable flow and certainly no discernable channel so that one might consider it to be stream flow under the law. On the other hand, it is very difficult to consider a marsh to be a lake within that portion of the law and they therefore appear to be without the ambit of Senate bill 97. This is very unfortunate from a wildlife standpoint because the marshes and swampy areas are very important for duck habitat and breeding purposes as well as for the propagation of many other forms of wildlife and fish.

Because the requirements of Senate bill 97 simply authorize the State of Colorado to file as of the present date on minimum stream flows, the problem of overappropriated streams that are already subject to periodic dewatering cannot be addressed. In a stream system where a priority date of 1890 does not guarantee a full water supply, the priority date of a minimum stream flow appropriation of 1976 clearly does not give the state very great control over instream flow conditions. While Senate bill 97 is a useful tool in the high mountain regions and the underdeveloped regions of the state, it will have very little effect upon some of the more overappropriated stream systems in the state. The preservation and rehabilitation of these overappropriated streams will depend far more on the purchase of water rights by both the state and private parties for the purpose of maintaining those rights in the stream under their original priority dates than it will upon any specific filing under Senate bill 97.

The final question that is confronting the State of Colorado at the present time involves the almighty dollar. While Senate bill 97 appears to be one of the most innovative and advanced instream flow statutes in the United States, the legislature has not seen fit to fully fund the effort necessary to rapidly protect a great majority of the streams and lakes within the state. As described above, it requires approximately 3 or 4 hours for a two-man party to physically measure the flows in a given reach of a stream or river. Without a specific appropriation this expenditure of time and man hours is extremely taxing on the budget of the Division of Wildlife and on the Water Conservation Board. Because of the lack of funds the Division of Parks and Outdoor Recreation has been unable to cooperate in any meaningful way in the program, this is reflected by the lack of appropriations for recreational uses on the streams within the state. At the present time the State of Colorado has measured and run through the computer 200 cross sections on 100 streams within the state at an approximate cost of $800. Simple mathematics indicates that this cost breaks down into about $4 per cross section or $8 per stream segment. As there are literally thousands upon thousands of stream segments within the state that should be subject to an appropriation for minimum flows the question of who will pay and when will they pay becomes very significant. If appropriate financial arrangements are not made by the state the impact of Senate bill 97 may not be as great as was once thought.

PRESENT STATUS OF SENATE BILL 97

At the present time the Office of the Attorney General, on behalf of the Colorado Water Conservation Board and the people of the State of Colorado, has made application for or received an appropriation on 256 lakes within the State of Colorado and on 87 stream segments within the State of Colorado. In addition, the Colorado Water Conservation Board will consider recommended applications for minimum flows and levels on 73 lakes and 21 streams at their next meeting.

As a final note I would give an example of one of the interesting benefits derived from the making of appropriations for instream flow protection. The Water Conservation Board will soon consider a proposed application for a minimum stream flow on Ricardo Creek in Las Animas County, Colorado. Ricardo Creek originates in the Culebra Range of the Sangre de Cristo Mountains of Colorado about 40 miles west of Trinidad and flows south to the Vermejo River in New Mexico which is in turn tributary to the Canadian River and the Arkansas River in Arkansas. The drainage of

Ricardo Creek is located on the Maxwell Land Grant which is wholly owned by the Colorado Fuel & Iron Co. CF&I has obtained a conditional water right to divert up to 45 cfs. from Ricardo Creek across the divide into the drainage of the Purgatory River for industrial use. In considering the possibility of recommending a minimum stream flow appropriation on Ricardo Creek the Division of Wildlife discovered that the stream was currently inhabited by a relatively rare and pure strain of the Rio Grande Cutthroat trout of which no pure populations are known in public waters. As a result of this discovery the Division of Wildlife and the Colorado Conservation Board are extremely interested in obtaining an appropriation for 4 cfs. to preserve the habitat of these relatively rare fish with hopes of utilizing them for a reintroduction program in other parts of the state.

The Ricardo Creek experience has convinced those of us closely associated with the instream flow program in the State of Colorado that the program must receive high priority and must proceed with all diligence to survey and appropriate the necessary waters throughout the state before the crunch of energy development, urbanization and second home development causes the rich, natural, aquatic resources of the state to be permanently damaged or destroyed.

SAG TAPE PROGRAM - INSTREAM FLOW DETERMINATIONS

COLORADO DIVISION OF WILDLIFE

Page 1

A. CROSS SECTION PLOT

1. Location (Card One-Title Card) Cols. 3-80 as needed

   Date: __________ (45... ...53) Mil. Time: ____ (55 58)

   Observers: ________________ (60.. ...75)

   Watershed Name: ____________________ (3.... ...22)(Col. 23 Blank)

   General Transect Location: ____________________ (24... ...43)(Col. 44 Blank)

2. Location State: __________ (24... ....33) County: __________ (35... ...44) Township: ____ (45.. 48) Range: ____ (0...53) Section: __ 55 56 Qtr. __ 58 59

3. Sag Tape Data: Card three-Data Cards Cross Sect. No: ___ 1 2 3 Tape Wt. ____ 4 . . 7 Tape Tens: ___ lbs. 8 9 10

11 14 Dis-tance	15 17 Depth	18 21 Dist.	22 24 Depth	25 28 Dist.	29 31 Depth	32 35 Dist.	36 38 Depth	39 42 Dist.	43 45 Depth	46 49 Dist.	50 52 Depth	53 56 Dist.	57 59 Depth	60 63 Dist.	64 66 Depth	67 70 Dist.	71 73 Depth

Note: Use following letter designation for Water line: W, and Grassline: G, inserted above distance data in appropriate block. Enter 999 in Dist. Col. and 999 in Depth Col. to denote end of cross section.

Remarks: ____________________

Fish Collected:

Species	Length

DISCHARGE MEASUREMENT NOTES

	B	C	D	F	G	H	I	J	K
Dist. From Initial Point	Width	Depth	Observation Depth	Revolution	Time in seconds	At Point	Mean in vertical	Area	Discharge
A									
E									

Dist. From Initial Point	Width	Depth	Observation Depth	Revolution	Time in seconds	At Point	Mean in vertical	Area	Discharge
A									
E									

Gradient Ex. 6% = .060 __________

No. photographs taken __________

Ave. Rock Size __________ in.

Air _____ °F Water _____ °F

Type Meter: __________

Recorder: __________

Flow cfs: __________

E.R.S., 7/75

(continued from page 1)

DISCHARGE MEASUREMENT NOTES

	B	C	D	F	G	H	I	J	K
Dist. From Initial Point	Width	Depth	Obser-vation Depth	Revo-lution	Time in seconds	At Point	Mean in vertical	Area	Dis-charge

Recorder: ______________ Air ______ °F Water ____ °F

Flow cfs: ______________ Type Meter: ______________

STEP A Continued CROSS PROGRAM

4. (Card 4 - See Instruction Sheet 6600-4)	
5. (Card 5 - Control Data. Col. 1 - 10 Blank)	
Distance in feet from "O" Point to last Depth Measurement (at pin) (Col. 11-15) Identified as "Max. measured width."	11 _ _ _ . _ 15
Total Length of Tape used to span cross section. (May be same as above) (Col. 16-20)	16 _ _ _ . _ 20
Manning's "n". Roughness Coefficient. Use hypothetical value of .055, or select value from Ref. Book, USGS. (Col. 21 - 25)	21 _ . _ _ 25
Slope (or gradient) of Stream Channel in percent. i.e. : 6% = .060 (Col. 26 - 30)	26 _ . _ _ 30
(Tells computer a "plot" is to be made) (Col. 31 - 35)	31 _ _ _ 9 9 35
Set Scale for X axis. Divide "Max. measured width" by 8. Round up to next whole number, and enter. (Col. 36 - 40)	36 _ _ . _ 40
Set Scale for Y axis. Divide "Max. measured Depth" (Tape to Stream Bottom) by 6. Round answer up to next whole number, and enter. (Col. 41 - 45)	41 _ _ _ . _ 45
6. Card Six. See 6600-4 (EOF)	
7. Card Seven. See 6600-4 (EOF)	

TOPIC IV-H.

INSTREAM FLOW PROBLEMS OF THE BOISE RIVER

INTRODUCTION

David H. Fortier
Canyon Development Council
and Ada/Canyon Waste Treatment Management Committee
Caldwell, Idaho

The Boise River and its development has been the major factor of growth in the Boise Valley in Ada and Canyon Counties in Idaho. Irrigated agriculture has changed this area from a semi-arid desert to a productive valley. With the present urban growth in the valley, additional needs and concerns in relation to the Boise River and its flows are being expressed.

The Boise River system has been reviewed and studied many times but instream flow needs have only recently become a major consideration. Presently, instream flows are being evaluated in the Boise Valley, Idaho, Regional Water Management Study, a U.S. Army Corps of Engineers urban studies program by the Walla Walla District in cooperation with the local planning agencies, Ada Council of Governments and Canyon Development Council. The study is examining a range of water resource management alternatives and developing early action and long range plans for the Boise Valley. These study efforts are the primary reason that this panel group presentation has been put together to express some of the information which has been developed and to discuss some of the foreseen problems of instream flows of the Boise River.

Another program presently ongoing considering instreams flows is an Area-wide 208 Waste Water Management Program by the Ada/Canyon Waste Treatment Management Committee, a joint effort by the Ada Council of Governments and Canyon Development Council. This program is an effort to develop local water management plans to improve and protect the water quality of the area by local planning and public participation as set forth in section 208 of the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500). The primary effort in relation to increase flows will be a contract to follow up and expand upon the institutional and implementation needs of instream flows in the Corps study. This panel presentation is an effort to present information about instream flow needs and to gain input from technical resource agencies and the public as to the needs, desires, and direction that instream flows can implement.

Instream flow needs are a concern in the Boise River presently because of low flow conditions due to primarily the seasonal diversion of water for irrigation and the infrequent shutoff of flows at Lucky Peak Dam. It is necessary to shut off all the discharge from Lucky Peak when maintenance is required on the single outlet tunnel at the dam. The flow reduction from Lucky Peak has a great impact on the 30-mile reach from Lucky Peak to Star where the irrigation and groundwater drains start to provide considerable flow to the river. These low flow conditions cause problems in relation to recreation activities, aquatic needs, and water quality conditions. These low flows cause a water quality condition requiring the Boise Metropolitan area to have a high level of wastewater treatment. The demand for the water for irrigation purposes presently diverts most of the flows during the summer months altering the flow regime such that below Eagle and Star a warm water fishery exists.

The main points which we have found in relation to instream flows for the Boise River which we want to present include the character of the Boise River and the need for instream flows; the hydrology and water quality presently foreseen by modeling techniques; the water rights and administration problems; and the operation of the dams in the river system. The character and needs of the Boise River will be illustrated and described as seen by the local Idaho Fish and Game supervisor. The hydrology has been studied in the Corps of Engineers study as the availability of flows and the alternatives for Lucky Peak. The hydrology studies and water quality modeling of the Boise River have been done by the Idaho Department of Water Resources and Corps of Engineers and will be addressed by the chief of the urban studies program of the Corps of the Walla Walla District. The water rights of the Boise River's natural flow are fully appropriated and the administration of instream flows will be affected by this factor. The Idaho Department of Water Resources and Idaho Water Resource Board in their state water plan has recommended instream flows for the Boise River. Some insight into the Department of Water Resources involvement will be presented by the chief of the Technical Studies Bureau of the department. Since the river storage system plays a key role in the flows of the Boise River, we have the project supervisor with the U.S. Bureau of Reclamation to describe the operation of the river system for the multi-purpose demands including instream flows.

We are hopeful that this presentation will provide information to you as to the Boise River instream flow needs and what is being done. Also we hope to get input to aid us in being able to continue to improve the Boise River quality.

RECREATIONAL VALUES AND INSTREAM FLOW NEEDS OF THE LOWER BOISE RIVER, IDAHO

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ABSTRACT

The lower 59 miles of the Boise River, Idaho is controlled by three major flood control and irrigation storage dams.

During summer, a number of irrigation diversions deplete flow releases to near zero at river mile 34. The 25 mile upper section supports a cold water fishery year around and water oriented recreation in the summer.

Waste water return flows in the lower 34 miles of river are warm and silt ladened and together with point sources of pollution the river supports a rough fish population and catfish and bass.

Based on evaluations of area wetted by various flows and flows needed for pollution control, minimum flow recommendations of 240 cfs in the upper area and 380 cfs in the lower area are made.

A high quality trout fishery is possible with these flows, however, the thermal and silt pollution of the lower river must be corrected to achieve a good fishery.

High, stable flows in the 4,500 cfs range are needed in early March to maximize goose production and minimize nest flooding.

Because of the proximity of this 59 mile long river section to 25 percent of the state's population, the river and its flood plain have a high recreational potential. Efforts to obtain minimum flows, control pollution, and secure public access on the Boise River should have a high regional planning priority.

HYDROLOGY OF LOWER BOISE RIVER

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ABSTRACT

Boise River is regulated by three headwater reservoirs with a storage capacity equal to half the average annual runoff. Below these reservoirs, in the Boise Valley, there are numerous diversions and return flows mainly for irrigation. For water quality purposes the one-in-ten-year low flow for the Boise River has been developed for November, February, April, and August.

INTRODUCTION

Good morning. It is certainly a pleasure to have an opportunity to participate in this symposium on Instream Flow Needs. For my part of the panel discussion on the Boise River case study, I am going to briefly describe the Boise River Basin, review the basin hydrology, discuss the development of flows used in determining allowed pollution discharges (waste load allocation) and briefly review how we plan to evaluate the impact of various wastewater management alternatives on Boise River water quality as part of the Boise Valley Regional Water Management Study. In this discussion, emphasis will be placed upon the lower river.

BASIN DESCRIPTION

The drainage basin (viewgraph 1) divides into two areas on the basis of topography, with Lucky Peak Dam forming a convenient dividing line. Below Lucky Peak the basin is characterized by river bottom land, terraces and low rolling hills. Above Lucky Peak the watershed is composed of steep mountains with highly dissected pattern of V-shaped valleys. Total drainage area is about 4,200 square miles with 2,650 square miles above Lucky Peak. Elevations range from near 11,000 feet to about 2,200 feet. The principal water courses flow in a westerly direction from headwaters on the eastern slope of the Sawtooth Mountains about 200 miles to join the Snake River. Note the three major storage reservoirs, Arrowrock and Anderson Ranch constructed by the Bureau of Reclamation and Lucky Peak built by the Corps of Engineers. These three reservoirs have a combined storage capacity of about 1 million acre-feet.

Natural runoff is characterized by this Summary Hydrograph (viewgraph 2) which shows low flows in the fall and winter, with increasing flows in March and highest flows generally in the April, May, June period. However, the pattern of flows in the lower river is substantially modified by the upstream reservoirs which have a capacity of approximately one-half the average annual runoff.

Moving into the lower basin (viewgraph 3) we find the Boise River flows through an area that contains about 25 percent of the state's population, the capitol city, and serves a variety of needs although irrigation is the major water user. There are about 260,000 acres of irrigated agriculture in the area outlined on the viewgraph. From Lucky Peak Dam to the Snake River the river is approximately 65 miles long.

Some key locations along the river are Lucky Peak Dam, Diversion Dam, Boise, Eagle Island, Star, Caldwell, and Notus. At Diversion Dam, New York Canal with a capacity of about 3,000 cfs carries water for irrigation around to Lake Lowell. Another major canal is the Ridenbaugh which diverts water out of the river just below Barber Dam. A major diversion downstream of Boise is the Phyllis Canal. This canal is significant because it is one of the most downstream canals that gets water directly from Lucky Peak rather than irrigation return flows.

In the irrigation of Boise Valley, the major irrigation return flows start to drain into the river just above Caldwell. Much of this water has been intercepted and reused several times before it gets back into the river. In addition, there are also several diversions between Caldwell and the mouth of the river where the water gets additional reuse. Between Lucky Peak and the mouth of the river there are some 40 to 50 canals and drains either diverting or returning water to the river.

Another source of water to Boise River is groundwater. Throughout most of the irrigated area, there is a rather shallow groundwater table which is intercepted by various drains and also feeds directly into the river. This groundwater is recharged annually by irrigation and 5 to 10 feet of fluctuation in groundwater elevations are common. High ground has caused problems in the sewage collection systems of Meridian, Nampa, and Caldwell.

In summary, then, the Boise River system is highly regulated and extremely complex. Three on-stream reservoirs, Lucky Peak, Arrowrock, and Anderson Ranch, and an off-stream reservoir, Lake Lowell, are utilized in the regulation of the Boise River. This regulation is for irrigation, flood control, fish and wildlife maintenance, and recreation. Flow, at any time in any segment of the Boise River in the 65-mile stretch below Lucky Peak, is a function of Lucky Peak release, tributary flows, irrigation diversions and return flows, and numerous unknown or unidentifiable surface and subsurface losses and gains. Lucky Peak release, irrigation diversions, and return flows are highly influenced by water use, available water supply, and the season of the year.

ECOLOGY MODEL CALIBRATION

The major reason for the Corps involvement in the details of hydrology of the Lower Boise River is the Boise Valley Regional Water Management Study being conducted jointly by the Corps, the Ada Council of Governments, and Canyon Development Council. This study covers the Boise River below Lucky Peak Dam and one of the major study elements is wastewater management for both municipal and agricultural flows. In order to evaluate the impacts on Boise River from various wastewater management alternatives, a computer model developed by Dr. Carl Chen was calibrated to the conditions of Boise River. This calibration involved a knowledge of both the quality and quantity of flow in the Boise River. The major calibration data were obtained in a multiagency data collection in August 1972 when information was collected on both the drains and the Boise River. Another major data collection period on the lower Boise River was in November 1971 when flows from Lucky Peak Dam were shut off for more than a week. These November data are reported in a December 1974 report of the U.S. Geological Survey entitled, "Characteristics of Streamflow and Ground-water Conditions in the Boise River Valley, Idaho." In addition to providing basic data for model calibration these two periods also provided the basis for developing the flows for waste load allocation.

HYDROLOGY FOR WASTE LOAD ALLOCATIONS

One of the major uses of the Ecology Model has been as a tool to help the Idaho Department of Health and Welfare develop waste load allocations for the various communities discharging effluent from their sewage treatment plants into Boise River. One of the basic considerations in developing these waste load allocations is the flow in Boise River. For this purpose, it was determined that the one-in-ten-year low flow was to be used. The period used as a basis for developing these flows was the 1955 to 1972 which represents present operation of the Boise River since Lucky Peak was completed in 1954. The flows that were developed are shown on viewgraph 4.

For water quality considerations, there are four critical periods on Boise River: (1) November, (2) February, (3) April, and (4) August. Following are the reasons for these periods being considered critical:

(1) November was chosen as the month representative of the period when flows from Lucky Peak to Boise would be at a minimum. Following the irrigation season, almost every year flows at Lucky Peak are shut off for maintenance and inspection of the single outlet at that structure. This shutdown period varies from on the order of one or two days up to ten days or so. Further, if it were necessary to make major repairs, there could be an extended period of flow shutdown at Lucky Peak. The Corps is seeking funds to construct an additional outlet to alleviate this problem. Below Star, river flows are increased by groundwater return flows. These return flows are near a high in this period because the groundwater table is still at a high level this soon, following the irrigation season.

(2) February is critical because it represents the latest time in the winter when certain vegetables are still being processed in the Nampa-Caldwell area. It is probably a more critical time in Indian Creek than on Boise River. Also, by February, in a series of dry years the releases from Lucky Peak may be reduced to less than 50 cfs and by February, the groundwater return flow is significantly less than in November.

(3) April. In April there is a transition period when irrigation is starting. Flow releases from Lucky Peak are high but successive diversions reduce flows downstream. The water table is at a minimum stage, thus, groundwater flow to Boise River is minimal, and surface runoff from irrigation has not yet started so that return flows to the Boise River are at a minimum.

(4) August. This period was taken to represent the summer conditions. Releases from Lucky Peak are high but diversions are also high. It is in this period where mid-reach flows reach a minimum, the mid-reach being that portion of the Boise River in the vicinity of Star just above the locations where return flows are again picking up the river flow. Also, in August, water temperature is at a maximum, tending to maximize biological activity.

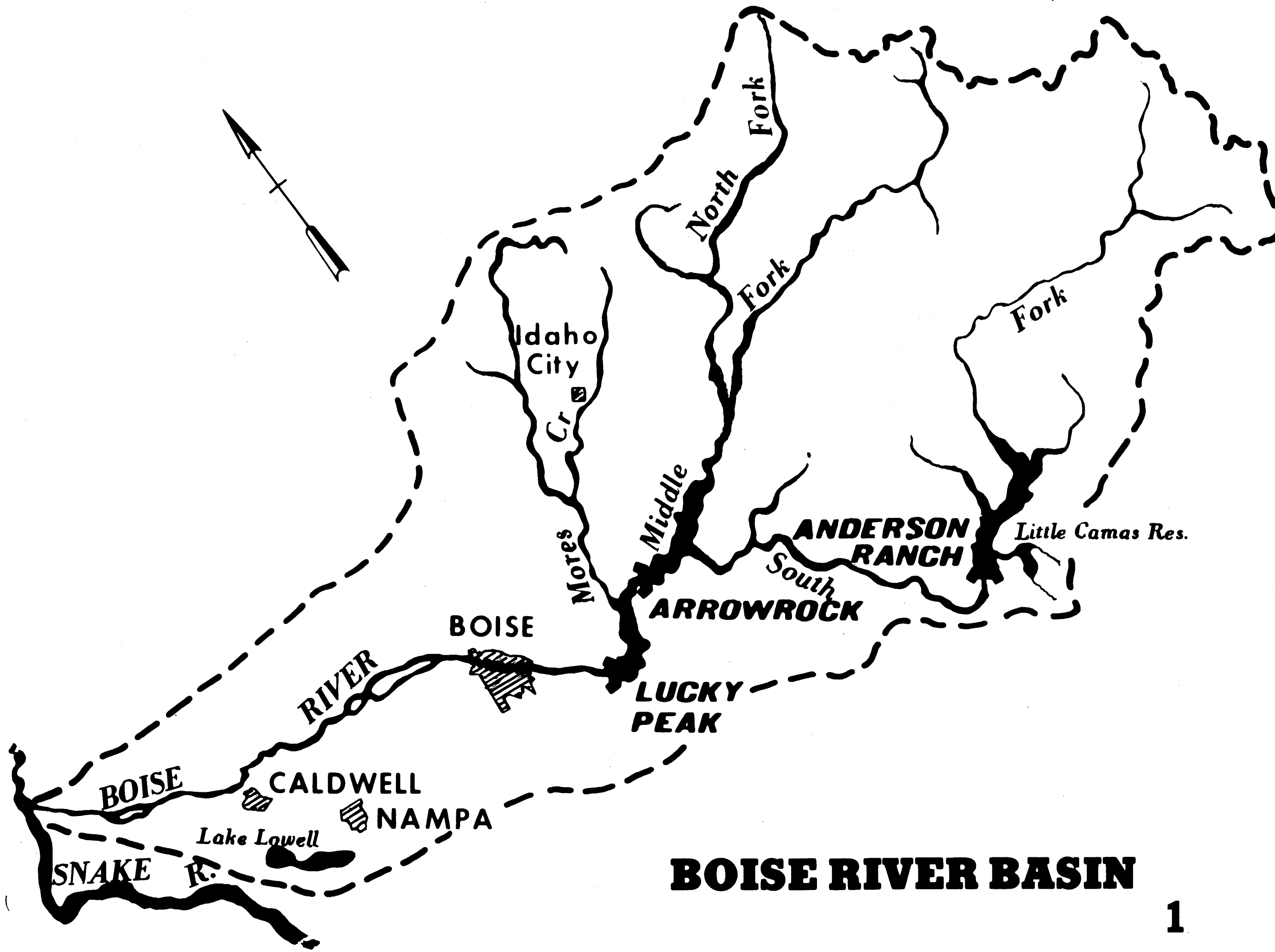
While the Corps took the lead in developing this flow information for Boise River, it should be noted that it was done with considerable assistance from both the Idaho Department of Water Resources and the Bureau of Reclamation.

EVALUATION OF WASTEWATER MANAGEMENT ALTERNATIVES

The Ecology Model referred to previously will be used to evaluate the effect on water quality impacts from various wastewater management alternatives developed in the Boise Valley Regional Water Management Plan. The August and February one-in-ten-year low flow conditions are going to be used as a base condition. These two conditions were chosen because it is anticipated that low flow conditions in November in the upper river will be alleviated by an additional outlet at Lucky Peak. August was chosen as being representative of the summer irrigation season.

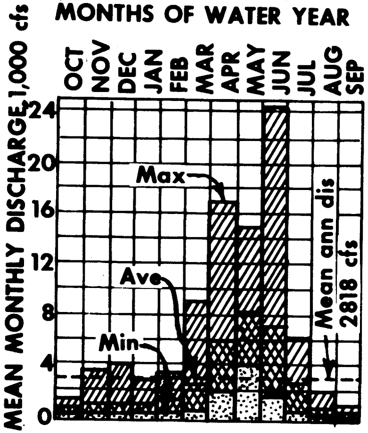
In this evaluation, the water quality impacts from treatment facilities planned for Boise, Nampa, and Caldwell to meet 1983 requirements of Public Law 92-500 will be considered along with zero discharge plans that remove the discharge from Boise River and go to land treatment. For the Boise Valley Regional Water Management Study, zero discharge was essentially defined by the Corps as the water quality necessary to have water equivalent to unpolluted releases from Lucky Peak combined with groundwater.

For urban storm runoff, we can evaluate the impacts from three levels of treatment: settling ponds, settling ponds and high rate filtration, and systems that meet zero discharge requirements. For irrigation return flows, three levels of treatment will also be considered. The treatment processes are similar to those for urban storm runoff with treatment of the flows at the mouths of major drains. The other irrigation return flow treatment alternative being considered is on-farm management practices such as settling ponds. On-farm controls could result in reducing the sediment in the drains as well as in the river. The anticipated water quality, if the total Boise Valley were irrigated with sprinklers, will also be evaluated.

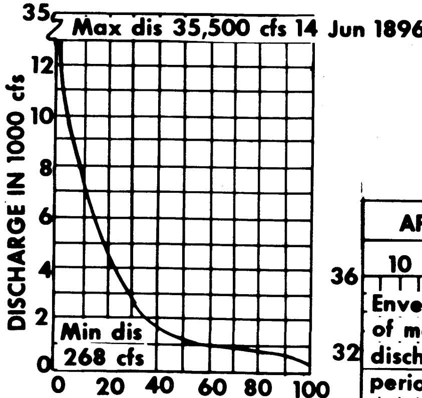


BOISE RIVER BASIN

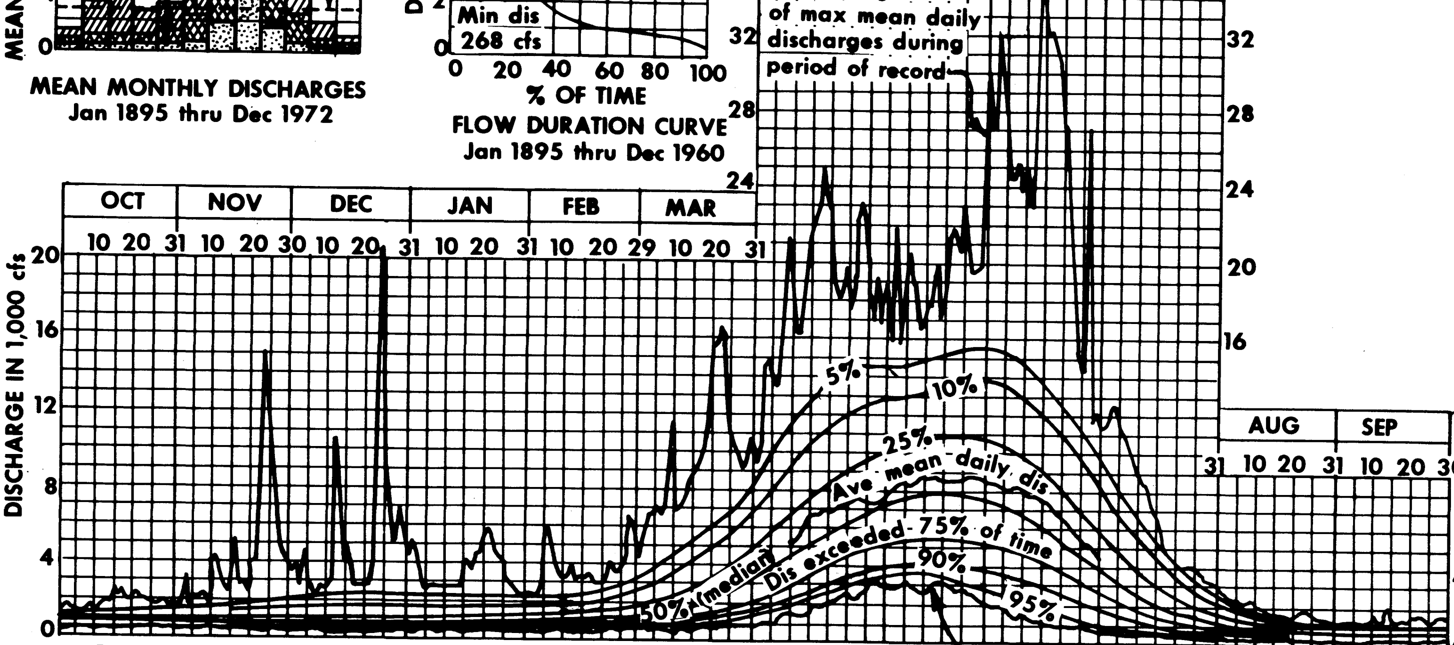
1



MEAN MONTHLY DISCHARGES
Jan 1895 thru Dec 1972



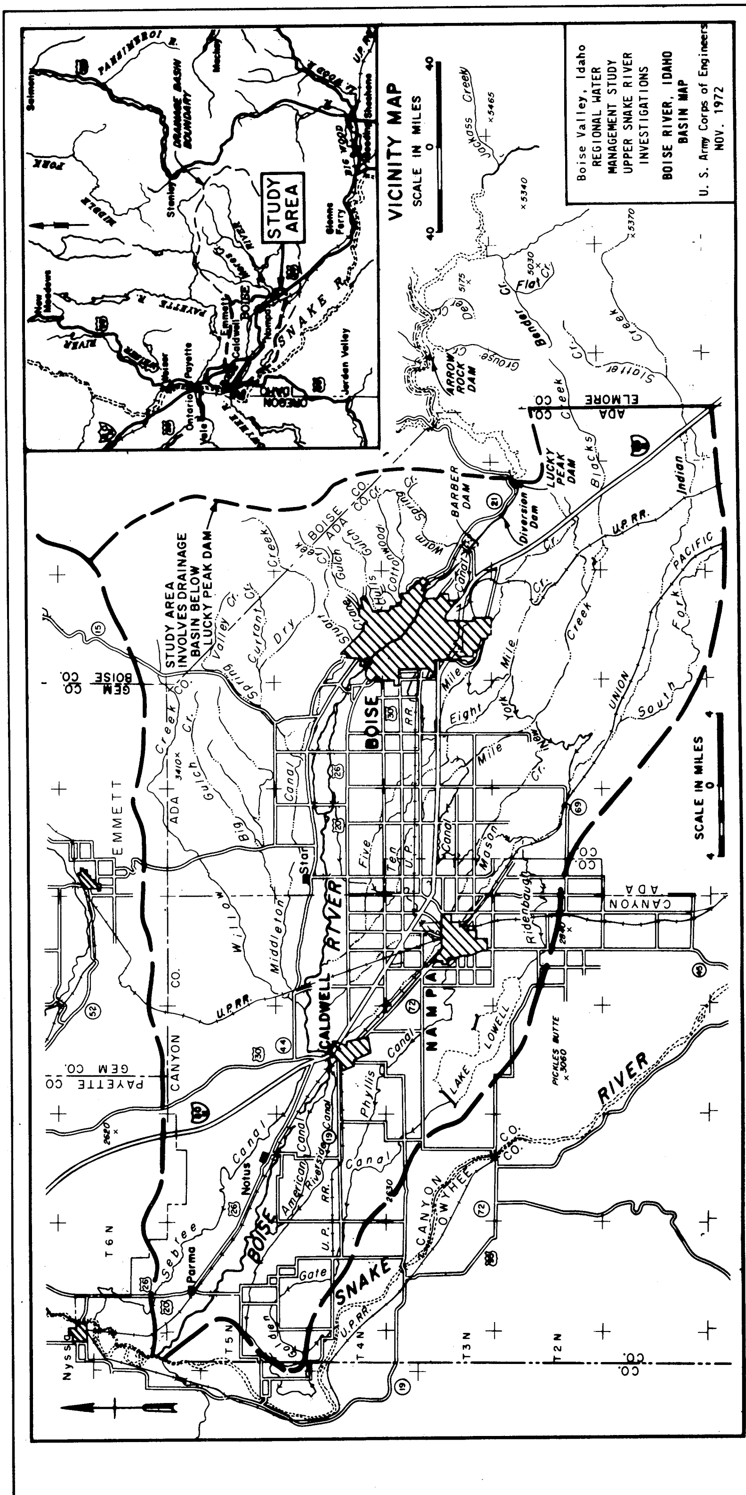
FLOW DURATION CURVE
Jan 1895 thru Dec 1960



PERIOD OF RECORD JAN 1895 THRU DEC 1960
COMPUTED NATURAL DISCHARGES BOISE RIVER AT DIVERSION DAM

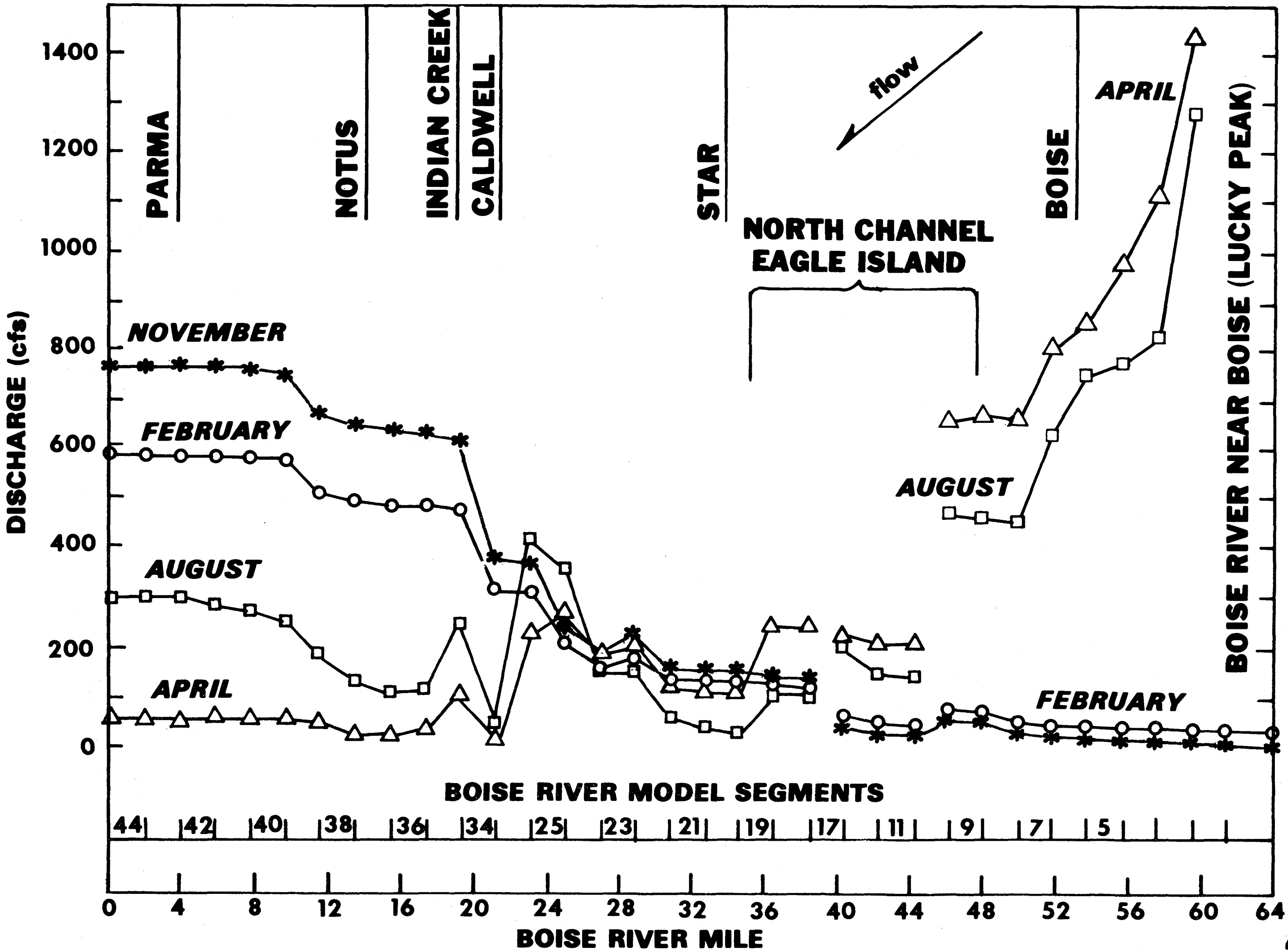
2

3



Boise Valley, Idaho
REGIONAL WATER
MANAGEMENT STUDY
UPPER SNAKE RIVER
INVESTIGATIONS
BOISE RIVER, IDAHO
BASIN MAP
U. S. Army Corps of Engineers
NOV. 1972
VICINITY MAP
SCALE IN MILES
40 0 40
STUDY AREA
STUDY AREA INVOLVES DRAINAGE BASIN BELOW LUCKY PEAK DAM
ARROW ROCK DAM
LUCKY PEAK DAM
BARBER DAM
Diversion Dam
BOISE
NAMPA
CALDWELL
EMMETT
Star
Notus
Parma
Nyssa
BOISE RIVER
SNAKE
RIVER
PAYETTE CO.
GEM CO.
BOISE CO.
ADA CO.
CANYON CO.
ELMORE CO.
OWYHEE CO.
T6N
T5N
T4N
T3N
T2N
LAKE LOWELL
PICKLES BUTTE
U.P.RR.
UNION PACIFIC
SCALE IN MILES
4 0 4

LOW FLOW HYDROLOGY OF BOISE RIVER, ONE IN TEN YEAR



4

ADMINISTRATION OF THE BOISE RIVER

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ABSTRACT

The Boise River system is highly controlled with three on-stream reservoirs and one off-stream reservoir with a combined active storage of 1,157,000 acre-feet. At the present time, there is a storage allocation of 50,000 acre-feet in Lucky Peak Reservoir which is allocated for instream flows. This is not adequate, however, to meet the needs. No unallocated natural flow is available, and Idaho law does not provide a means of allocating natural flows for instream use. It may be possible to provide additional instream flows from unallocated existing storage, new storage, or developing groundwater in the Boise Valley and exchanging this for upstream water rights. Any method of developing additional instream flows on the Boise River will require a source of funds and the cooperation of all parties concerned.

INTRODUCTION

The Boise River system is one of the most highly controlled and administered river systems in Idaho. The first water right in the Boise drainage was established in 1863 for irrigation purposes. Since that time, water rights have been obtained to the full, dependable, natural flow of the Boise River system. Water rights total in excess of 6145 cubic feet per second. There are 327,000 acres (not including storage rights) of associated irrigated land. Most of the water rights have been defined by the so-called Stewart and Bryan decrees of 1906 and 1929. At the current time, there is no water available for additional natural-flow water rights during most years, particularly during the irrigation season.

Under present operation, there are two critical reaches with regard to flow of water below Lucky Peak. The first reach is between Lucky Peak Reservoir and the city of Boise and is affected primarily during the non-irrigation season and during periods when the single outlet at Lucky Peak

Reservoir has to be closed for maintenance purposes. During those periods of time, the only water in the channel is a small amount, contributed by side tributaries and groundwater inflow. The second reach is near Star where waterflows are very low during some periods of the year. This reach is affected primarily during the irrigation season, at which time the Canyon County and Caldwell Highline canals divert essentially the entire river.

During the irrigation season, flows in the Boise River are fairly substantial in most reaches. Groundwater inflows below the city of Boise contribute substantial amounts of water. Return flows from irrigation also contribute considerable amounts of water to the river below Caldwell.

Flows in the Boise River system are administered by a state watermaster who operates under the direction of the Department of Water Resources. It is his responsibility to deliver the natural-flow water rights and water held in storage to those who are entitled to its use. Water in the Boise system is measured at points of diversion from the river.

HOW CAN MINIMUM FLOWS BE ESTABLISHED IN THE BOISE RIVER

Currently, Idaho law does not have any provision to establish water rights from natural flows for instream flow purposes (other than power) where there is no physical diversion. Such legislation has been before the legislature on several occasions and has been discussed previously at these proceedings. However, instream flows can be established when based on water stored in a reservoir for release downstream. Current storage rights on the Boise River system include 50,000 acre-feet of space to be used for fish and wildlife. This water is to be released from Lucky Peak Reservoir at the request of the Idaho Department of Fish and Game. Past practices of the Department of Fish and Game have been to call for the release of that water to maintain a flow in the reach through the city of Boise. In the fall after irrigation releases are stopped, about 100 cfs is released at Lucky Peak from this space. This discharge is maintained until the next irrigation season unless: (1) flood control operations require a greater release, or (2) the amount of water that is available from this space has been entirely used.

The question of whether instream uses are beneficial under Idaho law has been a cause of much discussion. This generally stems from the failure of the Idaho constitution to mention these uses, while referring to other uses including domestic, agriculture, mining and manufacturing. The IDWR has determined, however, that this is a settled question, and that the answer is that instream purposes are beneficial under Idaho law. Such an interpretation is based upon legal opinions by the attorney general and by inferrence from past court decisions.

WHAT WATER IS AVAILABLE FOR INSTREAM FLOWS IN BOISE RIVER

We have previously indicated that there is no water available for the establishment of a new water right for instream flow purposes based upon appropriation of natural flow during short water years or during the summer irrigation season. During these periods of time, established rights demand all the available water. There are, however, some opportunities to provide water for instream flows through other mechanisms. At the current time there is 116,000 acre-feet of storage space which has not yet been allocated for use from Lucky Peak Reservoir. Our studies indicate that the space would probably provide 28,000 acre-feet of water per year through the critical period of record. However, the present water right permit on Lucky Peak Reservoir does not authorize the use of water for instream flow purposes except for the 50,000 acre-feet already designated. In order to use the unallocated space of Lucky Peak Reservoir, Idaho law requires that before such change can be authorized, legal notice must be given to give affected parties an opportunity to provide input. Based upon past experience, such an application to change the nature of use may be controversial.

Arrowrock Reservoir, the next reservoir in the Boise River system above Lucky Peak, also has some storage space that has been previously allocated but not used. Approximately 23,000 acre-feet of space was originally allocated to the Hillcrest unit, an area south of Boise. However, that unit was never constructed, and the allocation has not been changed. Since the Arrowrock space fills virtually every year, this space would be a much more effective source than would Lucky Peak space.

Another source of water would be the construction of additional storage space in the Boise system. Our studies have shown that in order to provide the minimum flows identified by the Department of Fish and Game in the critical period, more than 500,000 acre-feet of storage space would be required. The Corps of Engineers has discussed their studies considering the enlargement of Lucky Peak Reservoir to provide water for instream flow purposes. There are also other possible storage sites in the system. Arrowrock could be raised to provide a substantial amount of new storage, and the Corps of Engineers has previously investigated construction of a dam and reservoir at the Twin Springs area on the Middle Fork of the Boise River. However, the state has not supported the Twin Springs project.

Another possibility for providing instream flow is through the exchange and conjunctive use of groundwater and surface water. Idaho law has a provision where use of one water source can be exchanged for the use of another water source under existing water rights. For instance, in the lower Boise River it may be possible to develop substantial amounts of groundwater under new rights. It may then be possible, if agreement could be reached, to exchange the use of groundwater in those areas for surface water that is now diverted from the Boise system. If the exchange could be made, then surface water would be available from either natural flow or storage for use as instream flow. Such an exchange would require an agreement with those holding the surface water rights. The department has calibrated a groundwater simulation model, and we plan to begin studying the potential for groundwater exchange in the lower Boise River system in the near future.

WHAT CRITERIA WOULD BE REQUIRED TO DETERMINE THE AMOUNT OF WATER THAT CAN BE ALLOTTED FOR INSTREAM FLOW PURPOSES

In this conference there has been a considerable amount of discussion of the amount of water which is required, or can be justified, for instream flow purposes. On the Boise system a particular situation has arisen with respect to instream flow purposes other than fish and wildlife where the department has stated a position. In 1975, the Department of Water Resources was asked by the Corps of Engineers if an instream flow for the purpose of diluting effluent from the Boise City treatment plant would be considered a beneficial use of water. The department responded by indicating that such a use of water may be beneficial, but the department's position was not to favor such an action in an area with critical water supply where there is another alternative to the solution of the problem. The department further stated that it would be in favor of the instream flow if it were justified on the basis of water for fish and wildlife purposes rather than dilution of the effluent from the treatment plant.

One of the big problems in establishing the amount of water for instream flows will be in defining the level of the resource that will be maintained with the instream flow. In order to define the flow, the fish and wildlife agencies will need to identify what type of fishery they wish to maintain and at what level.

The instream flow eventually established must recognize hydrologic reality. In other words, there must be water available to provide the flow in a specified period so that a benefit can be derived.

Other specific items which will be needed in the future for the establishment of minimum flows were included in the legislation submitted by the Administration during the last session of the Idaho Legislature pertaining to the establishment of instream flows.

SUMMARY

In summary, there are not water rights at the present time which provide adequate instream flow in the Boise River system. The 50,000 acre-feet of water currently authorized for such use out of Lucky Peak can provide only about 100 cfs during the nonirrigation season. There is, however, water available in the Boise system, particularly if surface and groundwater are used conjunctively to establish the instream flow. In order to make this water available, however, the cooperation of both those who hold existing and new water rights would be required. Establishment of such flows will have a considerable cost and their reality will depend to a great extent on whether or not sources of funding can be found. The realization of instream flows in the Boise system will necessitate changes in attitudes both by those who now use water from the surface and groundwater systems and those who seek to establish instream flows. Instream flows will not be satisfactory unless both sides work together in a cooperative manner.

TOPIC IV-H.

INSTREAM FLOW PROBLEMS OF THE BOISE RIVER

Summary Discussion

A large reservoir, commonly called Twin Springs, has been proposed upstream from the Arrowrock reservoir on the middle fork of the Boise River. This reservoir or other upstream storage could be a source of supplying instream flows since the natural flow water rights have been more than fully allocated. It was pointed out that a reservoir even larger than Twin Springs would be needed to maintain the 240 cfs instream flow recommended in the State Water Plan during the historical critical flow period. The reservoir could not be filled with any regularity but would make flood operations very simple. The reservoir could add the flexibility to the system to provide stability to the lower reservoirs for economic power generation and better recreation usage. The new reservoir would be costly and who would pay for it? There would be serious environmental effects with the loss of important deer habitat and the loss of that segment of free-flowing stream habitat.

Another possibility of storage presently being examined by the Corps of Engineers is the raising of Lucky Peak reservoir with about one-quarter the storage yield of Twin Springs at a much lower cost. This will also destroy some important wildlife habitat in the lowlands along some of the tributary valleys which are also good fishing areas. The raise would back water up the face of Arrowrock Dam.

The fish and wildlife people commented that they would not necessarily like to see another reservoir because they feel changes in the operation of the existing system can accomplish much in the way of instream flows. The existing operation was characterized as a fill and spill operation due to fall and winter storing water and then in the spring the reservoirs are evacuated for flood control based on the existing forecast system. Possibly a more long-range forecast system could be used starting in the fall with stream flow, precipitation, and temperature data. There are new and better weather forecasting and monitoring methods and an extensive existing data base which could be used. It was pointed out that the river operations manual is presently being reworked and a more continuous forecasting system is being developed, but new long-range forecast methods will have to be developed to cause any significant change. The Bureau of Reclamation is starting an upgraded system to obtain real time data with remote sensors, but the priority and money availability is not allowing this system to move ahead significantly at this time.

One of the main problems is that the operations are based on the assumption that we are entering the historical critical low flow situation. The historical critical low flow period is three low flow years in a row. This may be a very extreme case, but what would be a better flow condition upon which to base the operations? Also, if these conditions did occur, would those who have the storage rights and need to use the water allow another less critical flow? For these two questions, no easy answers exist.

Why not allocate the unallocated storage space in Lucky Peak to instream flows? It could be allocated for that purpose, but it would be of low priority and not always available in a particular year. It was pointed out that this is the source for present instream flows.

The Bureau of Reclamation is conducting a Southwest Idaho Study which is examining the possibilities and benefits of the water uses of Boise River waters. The study will address possible changes in operation, instream flows, agricultural and municipal water demand and potential usage, interbasin transfer or exchange, power generation, and other possibilities to explore future directions.

There are many possibilities concerning instream flows in the Boise River. In the near future we can see another outlet at Lucky Peak eliminating maintenance shutdowns, better forecasting data, and new operating procedures. There are options to be examined further such as: long-term forecasting and operation planning but with higher risks; new upstream storage but with significant upstream habitat impacts; and obtaining existing storage but either costly or of low priority. The future holds some important decisions on questions such as: what future water usage will be allowed; how can one administer instream flows and protect existing rights; is saving the lower Boise River worth the cost of another upstream reservoir; and are revised operating changes enough if adequate flows can only be supplied less than nine out of ten years?

Notes by panel moderator: David H. Fortier
Canyon Development Council,
Canyon Waste Treatment Management Committee, Caldwell, ID

DEVELOPMENT AND APPLICATION OF A TROUT COVER RATING SYSTEM FOR IFN DETERMINATIONS

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University of Wyoming
Laramie, Wyoming

ABSTRACT

This paper discusses the use of a trout cover rating system which has been developed from data collected on smaller, predominantly brown trout streams in southeastern Wyoming. Based upon such parameters as water depth, substrate size, overhanging bank cover, wetted surface area, length of stream section, and trout "preferences" for different cover types, cover ratings can be used to compare available habitat between different flow levels for the same stream reach or between different stream reaches at relatively the same flow level.

INTRODUCTION

When making an instream flow recommendation, the biologist or hydrologist may face the problem of "quantifying" the habitat gains and losses which occur between various discharge levels. One important parameter which lends itself to such quantification is the availability of cover or resting areas, a prime component of rearing habitat. Over the past several years, Wyo WRRI (with funding provided by the Wyoming Game and Fish Commission and the Office of Water Research and Technology, U.S.D.I.) has been active in defining trout cover criteria, developing a system for quantifying cover and testing the ability of this system to estimate the trout carrying capacities of various stream sections under varying flow conditions.

The purpose of this paper is twofold:

1) To describe the development of trout cover criteria on Wyoming's smaller, predominantly brown trout streams and the use of these criteria in a cover rating system, and,

2) To discuss the application of these ratings as a habitat "quantifier" for instream flow needs determinations.

DESCRIPTION OF STUDY AREAS

Field studies were conducted from 1972 to 1974 on one or more sections of the following streams (11 study sections total) located in the North

Platte River basin of southeastern Wyoming:

1) Douglas Creek
2) Hog Park Creek
3) Deer Creek
4) Laramie River

The following ranges are presented to briefly describe the reaches studied (see Wesche, 1974[1] for additional information):

Elevation - 5300 feet above MSL (1615 m) at Deer Creek up to 9300 feet (2835 m) on Douglas Creek.

Average Discharge - 27 cfs (0.76 cu m/sec) at Hog Park Creek up to 105 cfs (2.79 cu m/sec) for the Laramie River.

Length of Study Section - 750 feet (229 m) on the Laramie River down to 250 feet (76 m) at one of the Douglas Creek sites.

Wetted Width of Study Section - down to 8 feet (2 m) wide at Hog Park Creek and up to 68 feet (21 m) on Deer Creek.

Substrate - All sites were primarily coarse gravel, rubble and boulders, with the exception of the Laramie River, where sand and fine gravel predominated.

METHODS

Since 1972, data have been gathered at three Douglas Creek sites and at the Hog Park Creek study areas to define the cover preferences of trout. Sampling was conducted by means of electrofishing at discharge levels ranging from 100 percent down to 11 percent of the average discharge. For each trout captured, the following information was recorded: 1) water depth, to the nearest 0.05 feet (0.0152 m); 2) water velocity at the point location used for cover (i.e., below a boulder, underneath an undercut bank) as determined by a Stevens Midget Current Meter; 3) the type of cover being utilized (instream rubble-boulder areas, overhead bank cover); 4) for rubble-boulder areas being used, the substrate diameter was measured and for overhead bank cover, the width of the overhang was measured; and 5) the length (nearest 1.0 millimeter), weight (nearest 1.0 gram) and species. When time allowed, mean water velocity at the cover location was

[1]Wesche, Thomas A. 1974. Relationship of discharge reductions to available trout habitat for recommending suitable streamflows. Water Resources Series No. 53. University of Wyoming. 71 p.

also measured, using a Price current meter.

At each of the eleven study sites, the lengths, widths and associated water depths of all overhead bank cover were measured and the substrate types and associated water depths were mapped by the transect method. The length and surface area of each section was also measured. This allowed trout cover ratings to be made for each stream reach studied.

Investigations at the eleven study sites were also conducted to determine the reliability of the cover rating system as an indicator of the standing crops of trout present. At each site, the DeLury Removal Method for population estimation (DeLury, 1947[2] and 1951[3]) was used to determine the standing crop.

RESULTS AND DISCUSSION

Trout Cover Analysis

From 1972 to 1974, the cover preferences of 1,160 trout have been analyzed at three Douglas Creek sites and at the Hog Park Creek study area at discharges ranging from the 100 percent down to 11 percent of the average discharge. Of the total sample, 884 (76.2 percent) were brown trout, 235 (20.3 percent) brook trout, and 41 (3.5 percent) rainbow trout. Subcatchables (less than 6.0 inches, 152 mm in length) comprised 64.8 percent of the total, while 35.2 percent were of catchable size. Table I summarizes the cover data obtained for the sample of 1,160 in regard to cover type, water depth and point water velocity. Mean water velocity data are also presented for a sample of 479 trout. As shown, between species, the data are quite similar for a given size class. However, between size classes, differences do appear, primarily in the cover type utilized.

Two primary types of trout cover were available in the study areas, overhead bank cover and instream rubble-boulder areas. The principal type of overhead cover was undercut banks with lesser amounts of overhanging vegetation (logs, willows, brush jams, etc.) being present. As these two were often found in association with each other, they were combined in the overhead bank cover category. For subcatchables, 51.6 percent of all

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[2] DeLury, D. B. 1947. On the estimation of biological populations. Biometrics. 3: 145-167.

[3] _____. 1951. On the planning of experiments for the estimation of fish populations. J. Fish. Res. Bd. Canada 8: 281-307.

TABLE I

SUMMARY OF TROUT COVER DATA

UCB = Undercut bank
OHV = Overhanging vegetation

Species	Cover Type		Water Depth (Ft)				Point Velocity (FPS)		Mean Velocity (FPS)			
	Rubble-Boulder	UCB & OHV	<.50	.5-.99	1.0-1.49	≥1.50	<0.50	≥0.50	<0.50	0.50-0.99	1.0-1.49	≥1.50
Brown												
<6.0" (<152 mm)	298	269	52	235	173	107	560	7	152	61	39	15
≥6.0" (≥152 mm)	78	239	22	87	98	110	314	3	89	52	24	11
Brook												
<6.0" (<152 mm)	76	82	13	50	56	39	151	7	4	0	0	0
≥6.0" (≥152 mm)	30	47	5	19	28	25	73	4	4	1	0	0
Rainbow												
<6.0" (<152 mm)	14	13	5	6	3	13	24	3	5	9	4	3
≥6.0" (≥152 mm)	3	11	0	5	4	5	14	0	3	2	0	1
Totals												
<6.0" (<152 mm) (%Total For Size Class)	388 (51.6%)	364 (48.4%)	70 (9.3%)	291 (38.7%)	232 (30.9%)	159 (21.1%)	735 (97.7%)	17 (2.3%)	161 (53.7%)	70 (26.1%)	43 (14.0%)	18 (6.2%)
≥6.0" (≥152 mm) (%Total For Size Class)	111 (27.2%)	297 (72.8%)	27 (6.6%)	111 (27.2%)	130 (31.9%)	140 (34.3%)	401 (98.3%)	7 (1.7%)	96 (51.4%)	55 (29.4%)	24 (12.8%)	12 (6.4%)

1.0 inch = 25.4 millimeters
1.0 foot = 0.3048 meters
1.0 foot per second = 0.3048 meters per second

trout sampled were found in rubble-boulder areas, while 48.4 percent were taken from overhead bank cover. For catchables, 72.8 percent utilized overhead cover and the remaining 27.2 percent were found in rubble-boulder areas. No fish were sampled in areas having a substrate size of less than 3.0 inches (7.6 cm) in diameter or in overhead bank cover of less than 0.30 feet (0.0914 m) in width, although such areas were present at the study sites.

Of the 1,160 trout sampled, 91.6 percent were found at locations having water depths of at least 0.50 feet (0.1524 m). For the remaining 8.4 percnet, most were sampled at low flows (12.5 percent and 11 percent of average discharge), when from 51 to 65 percent of the surface area of the study sites was composed of water less than 0.50 feet (0.15 m) in depth.

Ninety-eight percent of all trout cover being utilized was found in association with point water velocities of less than 0.50 feet per second (0.1524 m/sec). Such low velocities were a direct function of the ability of the cover to minimize the force of the current, thus forming a resting area for the fish.

Mean water velocity data show that approximately 80 percent of all trout samples were taken at locations where velocities were less than 1.0 fps (0.3048 m/sec). As shown on Table I, virtually no differences were found between catchables and subcatchables. At the flow levels sampled, from 59 to 80 percent of the surface areas were composed of water having mean velocities less than 1.0 fps (0.3048 m/sec). Additional sampling at higher flow levels when greater amounts of fast water areas are present will be necessary to determine if preferences are being exhibited by trout for the slow water areas or if the results found are only a function of the surface area composition at the flow levels sampled.

Trout Cover Rating System

Using the data presented above, the following basic equation has been devised allowing for the comparative cover rating of the same stream section at different flow levels or different stream sections at the same level of flow:

$$\frac{L\ obc}{T}(PF\ obc) + \frac{A}{SA}(PF\ a) = CR \qquad (1)$$

where,

L obc = length (ft. or m) of overhead bank cover in the stream section having a water depth of at least 0.5 feet (0.1524 m) and a width of at least 0.3 feet (0.0914 m).

T = length (ft. or m) of thalweg line through the stream section.

A = surface area (sq. ft. or sq. m) of the stream section having a water depth of at least 0.5 feet (0.1524 m) and a substrate size of 3" (7.6 cm) in diameter or greater.

SA = total surface area (sq. ft. or sq. m) of the stream section at the average discharge.

PF obc = preference factor of trout for overhead bank cover.

PF a = preference factor of trout for instream rubble-boulder areas.

CR = cover rating of stream section for trout.

In the application of the system, if measurements cannot be made at the average discharge, the following guidelines would apply in regard to the total surface area (SA): 1) for comparisons of two separate stream sections, measurements should be taken when both sections are at relatively the same flow level (i.e., the same percent of the average discharge); 2) for comparisons of the same stream section at different flow levels, the surface area value used should be that value at the highest flow for which a cover rating is being made.

The preference factor for trout greater than or equal to 6.0 inches (catchables) for overhead bank cover is 0.75 (i.e., approximately 75 percent were found utilizing overhead bank cover). For smaller trout (subcatchables), the factor is 0.50. For instream rubble-boulder areas, the preference factor for catchables is 0.25, while for subcatchables, 0.50. The term "preference factor" has been applied because at each flow level, as far as could be determined, unutilized sections of overhead bank cover and rubble-boulder areas were available. Gibson and Keenleyside (1966)[4] and McCrimmon and Kwain (1966)[5] have stated that the value of cover is probably related to security and the photonegative response of trout causing them to seek cover. All sampling was done at mid-day, when, due to this photonegative response, the fish would most likely have been in the stream areas normally used for cover.

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[4]Gibson, R. John and M. H. A. Keenleyside. 1966. Responses to light of young atlantic salmon (Salmo salar) and brook trout (Salvelinus fontinalis). J. Fish. Res. Bd. Canada 23: 1007-1024.

[5]McCrimmon, Hugh and Wen-Hwa Kwain. 1966. Use of overhead cover by rainbow trout exposed to a series of light intensities. J. Fish. Res. Bd. Canada 23: 983-990.

The difference among preference factors between the two size groups would appear to indicate a stronger preference for rubble-boulder areas by the subcatchables. Competition for favorable stream locations and territoriality, as were shown to exist in salmonid populations by Kalleburg (1958)[6] and Newman (1956)[7], are certainly possible explanations. However, unused cover, of both types, was available at each flow level, as far as could be determined.

Application of Cover Rating System

The following example, comparing available trout cover for catchables at one of the Douglas Creek sites at 100 percent and 11 percent of average discharge illustrates the use of the system:

$$\frac{L\ obc}{T}\ (PF\ obc) + \frac{A}{SA}\ (PF\ a) = CR \tag{2}$$

At 100 percent AD:

$$\frac{181'}{827'}\ (0.75) + \frac{17{,}315\ ft^2}{41{,}736\ ft^2}\ (0.25) = 0.2679 \tag{3}$$

At 11 percent AD:

$$\frac{126'}{827'}\ (0.75) + \frac{5{,}273\ ft^2}{41{,}736\ ft^2}\ (0.25) = 0.1459 \tag{4}$$

The cover ratings obtained show that for catchables, available trout cover was reduced by nearly 50 percent in the flow reduction from 100 percent down to 11 percent AD, with the greatest reduction being the dewatering of instream rubble-boulder areas.

One application of the system is to compare the amount of available trout cover present in a stream section at various discharge levels to aid in determining a suitable streamflow to be maintained in reaches where flow is regulated by upstream water development projects. Wesche (1974) found that the greatest decrease rate for available trout cover at two Douglas Creek sites and at Hog Park Creek occurred as flow was reduced from 25 percent AD to 12.5 percent AD.

Figure 1 compares the reductions in available cover at these sites with

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[6]Kalleburg, H. 1958. Observations in a stream tank of territoriality and competition in juvenile salmon and trout (Salmo salar and S. trutta). Inst. Freshw. Res. Drottningholm. 39: 55-98.

[7]Newman, Murray A. 1956. Social behavior and interspecific competition in two trout species. Physiol. Zool. 29: 64-81.

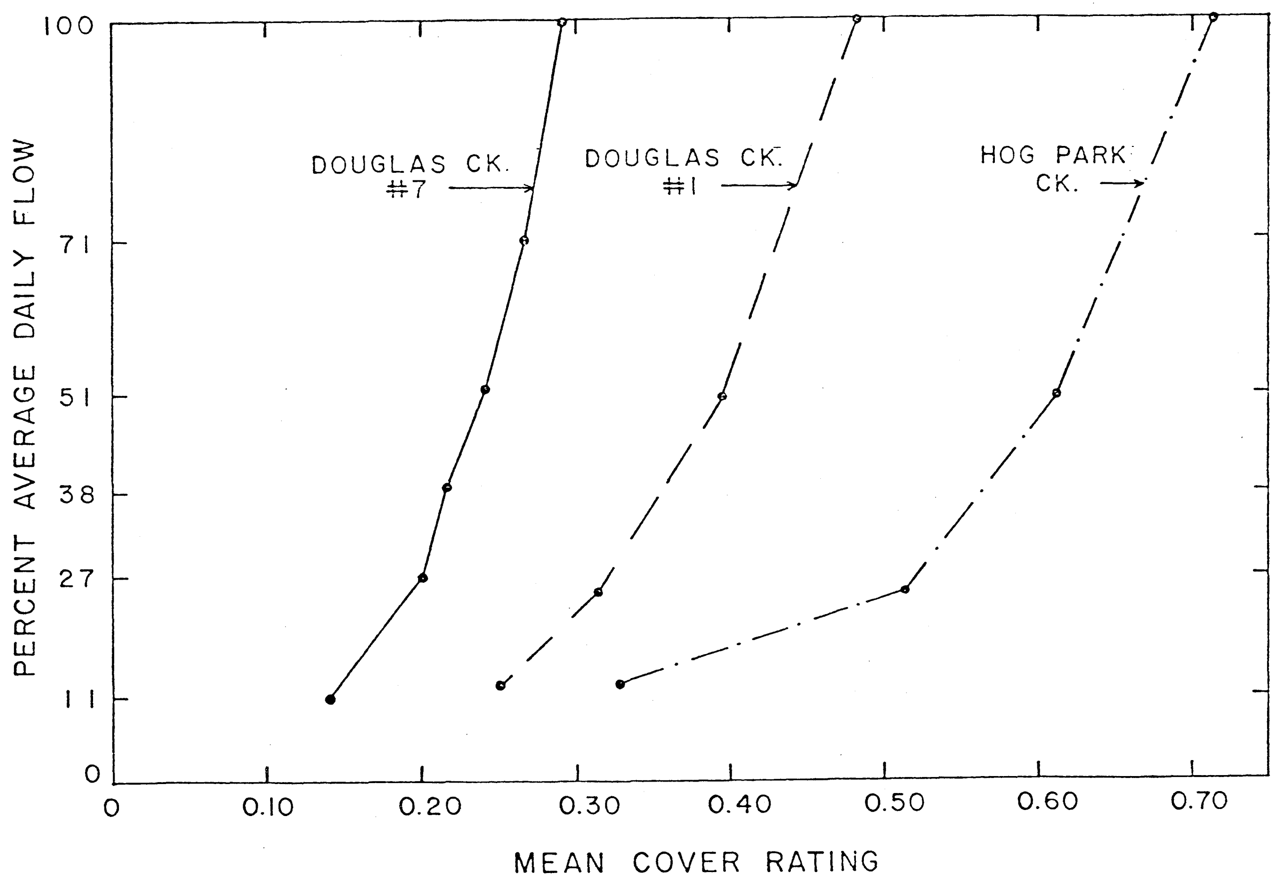

Fig. 1. Changes Observed in Mean Trout Cover Ratings as Flow Was Reduced at Three Study Sites

reductions in discharge. If the biologist or hydrologist is faced with the problem of determining a streamflow to recommend and is concerned with incremental analysis (the quantity of habitat lost in relation to a given flow reduction), it is apparent that such a plot would be of benefit.

To begin to determine if a relationship did exist between the cover rating numbers and the standing crops of trout present in the stream reaches, cover ratings and population estimates were made at the eleven study areas. Figure 2 presents these data. When these points were plotted on an arithmetic scale, the resulting function appeared exponential in nature. To straighten the line, a semi-logarithmic transformation was used. The regression equation was:

$$\log Y = 0.0204 + 5.338\ X, \qquad (5)$$

where,

X = mean cover rating (average of the catchable and subcatchable ratings).

Y = standing crop of trout (pounds per acre).

Testing of the significance of the regression coefficient led to the conclusion that a linear relationship does exist between the two variables at all levels of significance tested. From Figure 2 it appears that the mean cover rating values do serve as a relatively good indicator of the standing crops of trout present in various stream sections. Of course, discrepancies do occur between the measured standing crops and the estimated values determined from the linear regression equation. This is as expected however, because the availability of trout cover is only one factor limiting a population. The rating system does not take into consideration such factors as water chemistry, water temperature, the availability of spawning and food producing areas, the flow regime through the sections and angler-caused mortality. However, this work does represent an initial attempt by the author to begin to "tie" the physical effects of stream dewatering to the potential biological ramifications of such impacts in terms of the trout carrying capacities for given stream reaches.

CONCLUSIONS

1) From the analysis of the cover utilized by 1,160 trout (primarily brown trout), it has been found that in smaller streams a preference is exhibited for water having a depth of at least 0.50 feet in association with overhead bank cover or instream rubble-boulder areas. Larger trout ($\geq$ 6.0")

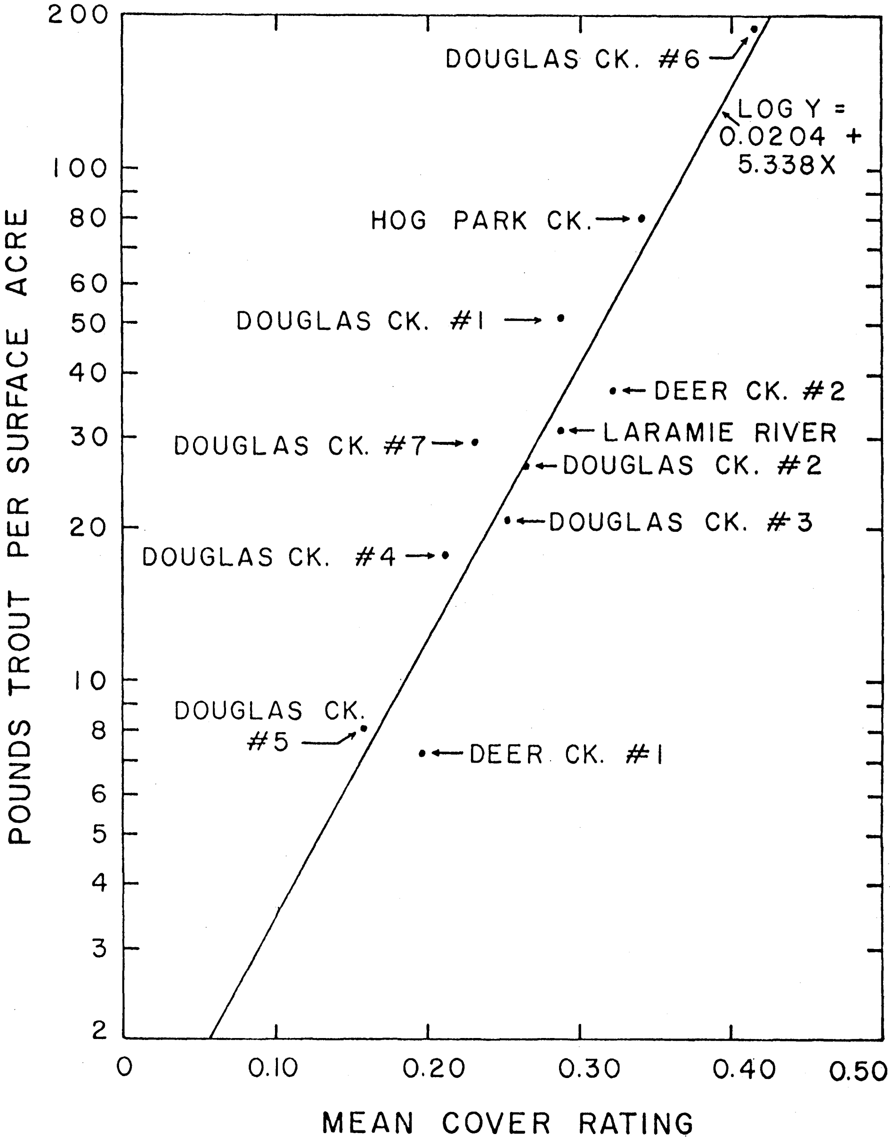

Fig. 2. Relationship Between Mean Trout Cover Ratings and the Standing Crop Estimates of Trout at the Eleven Study Sites

tend to have a stronger preference for overhead bank cover than do smaller individuals, although competition and territoriality may explain this difference.

2) The trout cover rating system which has been developed is a habitat evaluation tool which can be used to quanitfy the loss of available trout cover as flow is reduced. Also, work has been initiated to define the relationship between the mean cover rating for a stream section and the standing crop of trout present. For the eleven stream sections investigated, a linear relationship was found to exist between available cover and standing crop. Continued work in this area is needed to allow the fisheries biologist to better quantify the biological significance of dewatering in regard to the trout carrying capacity of various stream reaches.

EFFECTS OF FLOW PATTERNS BELOW LARGE DAMS ON STREAM BENTHOS: A REVIEW

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ABSTRACT

The variously modified flow patterns below dams are considered in relationship to the effects on ecological factors of importance to the benthic communities of receiving streams. Species composition and diversity are considerably modified by upstream impoundments. Benthic standing crop may be enhanced or reduced, largely depending on the flow regime. Daily flow fluctuations, if not too severe, may be associated with dense benthic populations as long as a relatively constant seasonal flow pattern is maintained. Little is known regarding subtle, sublethal effects of dams on life cycle phenomena and biotic interactions and more data are needed on current preferenda of important fish food species. Any flow regime which significantly reduces habitat diversity should be avoided. A diverse substrate with silt-free interstices will considerably reduce deleterious effects of periods of reduced flow, fluctuating flow and high current velocity. In establishing flow criteria for benthos, each dam must be considered individually.

INTRODUCTION

The productivity, diversity and composition of the stream benthic community is extremely important to the total functioning of the stream ecosystem. Besides providing a major source of food for stream fishes, macrobenthos may be the best indicators of past and prevailing ecological conditions. They are not as mobile as fishes and do not present nearly the taxonomic difficulties as microorganisms (in which congeneric species often have widely divergent ecological requirements). In addition, a diverse benthic community is able to process relatively large amounts of organic matter. The term "benthos," as used in this paper, refers to the benthic macroinvertebrates of streams.

Until recently, most studies of biota below dams in North America considered benthos only parenthetically and only in direct relationship to fish populations. In the past few years several investigators have concentrated their studies on benthic communities below dams, and their work has provided additional insight into the conditions prevailing in these modified environments and the effects of these conditions on the structure and function of the stream ecosystem.

It is the purpose of this paper to review and synthesize work relating to effects of variously modified flow patterns below dams on stream benthos and to elucidate interrelationships between discharge and other abiotic and biotic components important to the benthic community.

GENERAL EFFECTS OF CURRENT

In discussing effects of current speed on stream benthos several factors must be kept in mind. Of primary importance is the fact that many stream invertebrates are highly adapted to conditions in running water, and a large number are confined to lotic environments (rheostenic) because of inherent current requirements often associated with their respiratory physiology or feeding mechanisms (1). Certain caddisflies are able to tolerate much lower oxygen concentrations in flowing than in still water (2). Some lotic species are restricted to running water because they have lost the ability to move their respiratory structures in the absence of current. Other organisms have feeding mechanisms which depend upon current. Blackfly (Simuliidae) larvae, which have cephalic fans for filtering suspended organic particles from the water, are unable to feed below certain current velocities (3). Net-building caddisflies have preferred current velocities in relation to net construction, and some species will not spin nets below a certain current velocity (4). Other benthic organisms are tied to certain current regimes because of their requirements for certain types of substrates (5).

It was first suggested by Ruttner (6) that running water was physiologically richer than still water, and both algae (7) and invertebrates (8) may, within limits, increase their metabolic rate as current increases.

Stream organisms vary widely in their current preferences (9), and this is generally, but not always, related to their ability to maintain their position against the current (10). Chutter (11) emphasizes the importance of separating effects of current and depth when studying current preferences of stream benthos.

It must be emphasized that many stream invertebrates, to a much greater degree than most fishes, may not be exposed to appreciable current even though they reside in a rapid stream. Jaag and Ambühl (8) have shown that even in areas of rapid current, there is a thin zone, the boundary layer, above all solid surfaces in which there is negligible current. The thickness of this "dead water" zone, which varies according to velocity, viscosity and turbulence, is a few mm. There are other dead water zones behind objects and, of course, in the interstices between substrate particles. Morphological adaptations of stream invertebrates, such as flattening and streamlining, enable them to avoid the current by being cryptic or by residing in the boundary layer.

The mosaic distribution of the benthic fauna of stony streams has long been recognized and is the primary reason it is so difficult to obtain certain types of field data with a high degree of statistical validity. The mosaic distribution of the benthos results from the microdistribution patterns of current, substrate type, and food. The multitude of microhabitats allows a rich and varied benthic fauna to exist in stony streams. Conversely, anything which acts to reduce habitat heterogeneity will tend to reduce the number of niches and consequently the benthos.

EFFECTS OF DAMS ON STREAM BENTHOS

Effects dams have on the benthic fauna of the receiving stream depend upon the type of dam (water storage, hydroelectric, etc.), which in turn determines the flow pattern; the reservoir depth from which water is released; the characteristic stream benthos of the region under consideration; and a myriad of other factors relating to the geochemistry, topography, and meteorology. The trophic status, depth, retention time, temperature profile, extent of drawdown and other limnological conditions obtaining in the reservoir are of utmost importance. Characteristics relating to the physical nature of the stream below the dam, such as channel morphology, may also be of critical importance in determining effects on stream benthos. However, within temperate regions, temperature and flow regimes and their ramifications are often the factors of major importance to the benthos below dams.

Effects of the temperature pattern below dams have been considered in detail by the writer elsewhere (12,13), and the only thermal factors to be considered in the present paper are those influenced by the flow pattern. Due to space limitations, discussion will be confined to research published in scientific journals, and only selectively to processed technical reports and other unpublished works. Since Isom (14) recently reviewed pertinent studies containing information on effects of impoundments on benthic macroinvertebrates in the Tennessee Valley, only limited reference will be made to that region. Special influences, such as organic pollution or the release of toxic substances from the reservoir, will not be considered here.

Diversity and Standing Crop

Table 1 summarizes the effects of dams on the diversity and standing crop of benthos in the receiving stream. Although only flow-related causes are listed, most authors indicated that other factors may also have had an influence on the benthic community. However, all authors except Lehmkuhl (15) considered the flow regime to exert an important, if not major, influence on the benthos.

Whereas diversity, if indicated, was invariably reduced, benthic standing crop may be either enhanced or reduced in streams below dams. The effect on standing crop is mainly dependent upon whether the dam results in a more constant or more fluctuating flow pattern. Increased flow constancy, in all cases indicated, resulted in an enhanced benthic community.

Apparently increased seasonal flow constancy may have a beneficial effect on standing crop even if associated with short-term fluctuations, providing these are not too severe. Thus Pfitzer (16) reports an enhanced benthos below TVA dams despite great daily fluctuations in current velocity and discharge. Hoffman and Kilambi (17) also report enhanced density of benthos below hydroelectric dams in Arkansas compared with natural streams, despite daily fluctuations in current velocity and discharge. This they attribute to a more stable substrate resulting from controlled water releases. A lower standing crop in a newer tailwater is explained by the fact that the substrate has not had adequate time to come into equilibrium with the new flow regime. Pearson, Kramer and Franklin (18) reported an enhanced (although unstable) benthic community below Flaming Gorge Dam, Utah. Despite great daily flow fluctuations, a relatively stable substrate occurs below the dam, and this they attribute to increased seasonal flow constancy.

Other investigators (19,20,21,22) report reduced benthic faunas below hydroelectric dams.

Flow reductions (19,23) and increased discharge (20) may also result in decreased standing crops below dams.

Differences in standing crops (whether enhanced or reduced) may be considerable. Powell (19), for example, found densities of aquatic insects 3.5 times higher and biomass values 49 times higher above than below a hydroelectric reservoir.

Effects on Composition

The composition of the benthos of the receiving stream is often greatly altered when compared with unregulated streams.

TABLE 1. Effects of flow patterns below dams on stream benthos in North America north of Mexico[a]

Effect[b]		Probable flow-related cause	Reservoir		Location	Reference
St.Crop	Diversity		Type[c]	Release[d]		
I	NI	constancy	(CS)	L	California	28
NI	D	constancy	(R)	L	Wisconsin	24
I(?)	D	constancy	C	L	Ontario	25
I	D	constancy	S	L	Colorado	12
D	D	low flow	IH(S)	L	Colorado	23
D	D	fluctuation[e]	H	L(?)	Massachusetts	21
I	D	controlled release	HCSR	L	Arkansas	17
D	D	NI	HIS	L	Saskatchewan	15
I	D	seasonal constancy	HI	L	Utah	18
I	NI	NI	HCR	L	Tenn.Valley	16
D	NI	fluctuation low flow	HI	L	Colorado	19
D	NI	fluctuation high veloc.	H	L(?)	Alberta	20
D	D	fluctuation	S(H)	U(?)	Maine	22

[a]All published (and selected unpublished) works known to the writer in which effects of dams on benthic macroinvertebrates comprised a major portion of a study of some duration.

[b]D=decrease, I=increase, NI=not indicated (compared with unregulated streams, sections above reservoirs, or sections farther downstream).

[c]From Toran and Mermel. 1973. World Register of Dams (symbols in parentheses derived from reference cited). International symbols are: I=irrigation, H=hydroelectric, C=flood control, N=navigation, S=water supply, R=recreation.

[d]L=water released from lower levels of reservoir, U=from upper levels.

[e]Diversity and density decreased along a transect from the low water mark to the high water mark.

Dipterans are generally favored by the altered conditions below dams (15, 23). Blackflies (Simuliidae) are frequently enhanced below dams (16,18,24,25) as are Chironomidae (12,15,16,17,18,24,25,26). Blepharoceridae, however, may be reduced or absent (22,26).

Several authors report an enhancement of oligochaetes (17,18,23,27), amphipods (12,16,17,18,25,26), and gastropods (12,16,26) below dams.

Trichoptera have been reported as enhanced (16,25,28) or reduced (12, 17,20,22,23,24,26) below dams. Filter-feeding species, so abundant below natural lakes, may be enhanced or reduced in streams below reservoirs.

Mayflies (Ephemeroptera), depending on the taxa, may be either favored or reduced below dams. Heptageniids and other species with holdfast organs may be the predominant species in streams with rapid current velocities (20), but may be reduced or absent under other conditions (22,25,26). A general reduction in the importance of mayflies below dams has been reported by several investigators (15,17,23,24,28).

Plecoptera (stoneflies) seem most severely affected by conditions below dams, and are greatly reduced or absent immediately below reservoirs (12,16, 19,22,23,25,26,28). While modified thermal conditions may sometimes be responsible for elimination of stoneflies, flow-related effects are also important.

EFFECTS OF THE FLOW REGIME

The flow regime below dams, relative to effects on the benthic community, may be considered under four headings (Fig. 1). These are (1) seasonal flow constancy, (2) reduced flow, (3) increased flow, and (4) short-term flow fluctuation. A receiving stream may be characterized by more than one of these categories. Seasonal flow constancy, for example, may be associated with increased diurnal flow fluctuations as previously indicated. Likewise, reduced flow is not necessarily associated with flow constancy.

Seasonal Flow Constancy

Seasonal flow constancy results from reservoir storage during peak run-off periods, the release of stored water during periods of normally lower flow, and the dampening of the effects of spates.

Flow constancy leads to bank stability, which in turn favors the establishment of riparian vegetation. In addition to providing oviposition and resting sites for aerial adults, streamside vegetation provides an important

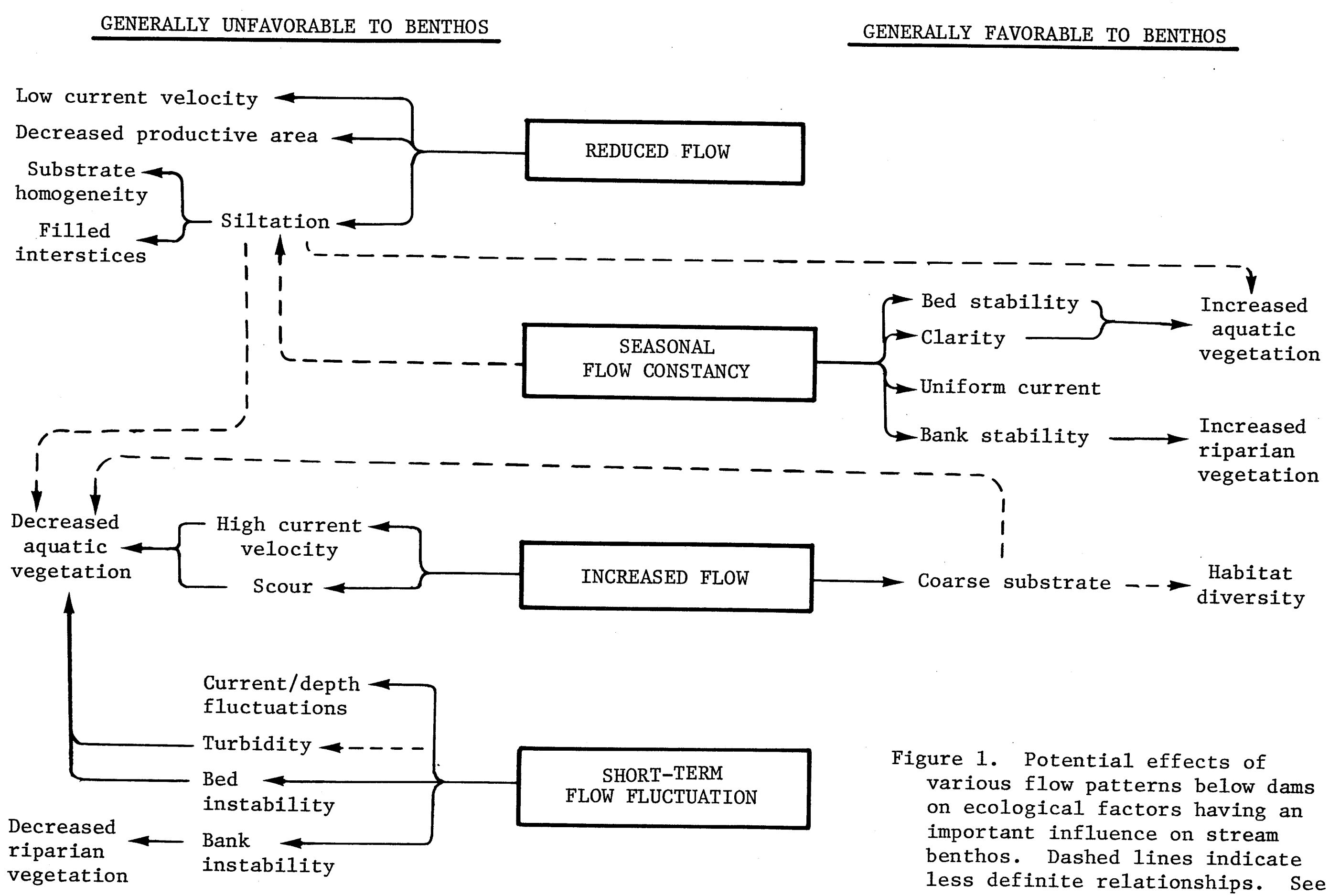

Figure 1. Potential effects of various flow patterns below dams on ecological factors having an important influence on stream benthos. Dashed lines indicate less definite relationships. See text for discussion of specific effects on benthic community.

input of allochthonous organic matter into the stream in the form of plant litter and associated terrestrial insects. Chapman (29) estimated that 25% of the annual net production of coho salmon in a small Oregon stream was from consumption of aquatic insects utilizing terrestrial energy inputs and another 33% was indirectly derived from terrestrial plants through terrestrial consumers which served as prey for the fishes. Only 6% was based upon aquatic insects which fed upon aquatic plants. The remainder (35%) was derived from animals of uncertain origin or unknown food habits. Leaf packs and their microbial communities provide food and spatial niches for a variety of large particle detritivores. Following breakdown, finer particles are utilized by filter and deposit feeders (30). Enhanced riparian vegetation thus enhances the food base and provides additional niches for benthos. In certain regions, however, an excessive input of terrestrial leaf litter may create an oxygen demand deleterious to the fauna. Another adverse effect which may result from a combination of constant and reduced flows is the encroachment of riparian vegetation to the extent of channel modification (31). Indirect effects, which may have considerable influence on the benthos, such as reduced temperature extremes (32), may also result from shading by increased riparian vegetation.

Increased bed stability and reduced turbidity enhance the production of attached algae and macrophytes, providing additional food and niche diversification. Increases in macrophytes (12,24,26) and algae (12,16,18,25,26) have been noted below dams. Beds of macrophytes and mats of algae both offer considerable shelter from the current and from any current fluctuations which occur, thus allowing establishment of species otherwise unable to maintain a population. Pfitzer (16) described the false bottom created by dense stands of *Cladophora crispata* below dams in the Tennessee Valley and noted the large populations of chironomids and amphipods contained within. Spence and Hynes (25) indicated that increased algae may, by trapping detrital material, make this important food source more available to benthos. However, too much epilithic algae may eliminate forms which require clean rock surfaces to effectively utilize their holdfast organs (26) and may create an oxygen depletion below algal mats at night (25).

Long periods of uniform flow, and thus uniform current, may occur below dams not used for power generation (26). This not only creates conditions which favor algal and macrophyte growth resulting in the ramifications discussed above, but has direct effects on certain components of the benthic community. Increased benthic productivity may result as less energy is utilized in maintaining position. Filter feeders are favored, providing there is an adequate supply of suspended organic particles (33), since filtering mechanisms function most efficiently where turbulence is reduced. Major seasonal variations in abundance of benthos and epilithic algae may be partly a function of flow fluctuations, although the flow history of the immediately preceding period may be more important than the instantaneous flow at the time of sampling (12). Downstream persistence of plankton from the reservoir closely follows the discharge, and thus its availability to benthos is dependent on the instantaneous flow (33). Certain benthic groups are poorly adapted to resist current and may be restricted to streams with relatively uniform current, or at least to streams having refuges (e.g. beds of macrophytes) from current fluctuations. This is the case for amphipods which are an important food for stream fishes and which are available year round (unlike some univoltine insects which may be unavailable to fishes for a large part of the year).

Life cycle phenomena may be regulated by or be dependent upon the flow pattern, although little work has been done in this regard. Hayden and Clifford (34) found that upstream movements of a mayfly nymph (*Leptophlebia cupida*) into small tributaries are associated with the spring rise in water level and postulate that this allows this species, which is poorly adapted to resist current, to maintain a population in lotic environments. Amphibious invertebrates, such as certain lumbricid earthworms, may colonize the stream under conditions of uniform flow and become an important component of the benthos (27).

It has been hypothesized by Ward (13,26), however, that relatively constant and predictable conditions below some dams, especially when associated with abundant food, increase biotic interactions and lead to a reduced species diversity despite the factors which lead to niche diversification. In some instances, thermal effects may exert the major influence (12,13,15).

Siltation may result from a seasonally constant flow regime which lacks the cleansing action of occasional periods of high discharge. This is especially true if unregulated tributaries enter the stream below the dam and if flow constancy is associated with reduced flows as a result of diversion. Specific effects of siltation will be considered under the heading of reduced flow.

Assuming that excessive siltation and severe daily flow fluctuations are absent and that no adverse chemical conditions prevail, the stream below a deep release dam with a seasonally constant discharge pattern will likely contain dense benthic algae and macrophytes and a rich benthic fauna with low diversity. Chironomids, amphipods, oligochaetes and snails will very likely be present. Certain mayflies may be very abundant, but those utilizing holdfasts will be absent. Stoneflies will probably be absent immediately below the dam. Surface release will modify the fauna somewhat by enhancing filter-feeding benthos (35).

Short-Term Flow Fluctuation

Flow below hydroelectric dams exhibits various diurnal patterns, but typically maximum discharge occurs during the day with reduced flows at night and on weekends. Pearson *et al.* (18) noted that, within an hour, it was not uncommon for flow to decrease from 70 to 10 m^3/sec below Flaming Gorge Dam, Utah. Trotsky and Gregory (22) reported daily low flows of less than 8.5 m^3/sec associated with daily maxima averaging 170 m^3/sec below a hydroelectric dam in Maine. The river at low flow consisted of a riffle and pool pattern not dissimilar to a nearby unregulated stream, but at high discharge is described as "one uninterrupted stretch of swift flowing water."

Some of the results of flow fluctuation are opposite to those discussed for seasonal flow constancy (bed and bank instability and associated turbidity), but additional factors must be considered. The sometimes overriding importance of the seasonal flow pattern on substrate stability and benthos has already been alluded to. Much depends upon the severity of the fluctuation and the configuration of the channel.

Species restricted to pools as well as those requiring rapid water may be eliminated by current and depth fluctuations below hydroelectric dams. Large areas may be alternately dry and flooded. Trotsky and Gregory (22) found 19 genera of aquatic insects in areas where bottom current fluctuated from 0.5 to 0.9 m/sec, but only 4 genera occurred where the fluctuation was from 0.1 to 0.5 m/sec. A positive relationship was demonstrated between current velocity during the low flow period and both the diversity and standing crop of benthos.

The efficiency of food collection in net-spinning caddisflies varies with current speed in some species, which restricts them to certain sites in a stream (4). Presumably, short-term flow fluctuations would eliminate or severely reduce species requiring relatively narrow ranges of current velocity for efficient feeding.

Brusven, MacPhee and Biggan (36) found considerable taxonomic variation in stranding suseptibility and tolerance to exposure among aquatic insects below Hell's Canyon Dam, Idaho. Mayflies were particularly suseptible to stranding and were relatively intolerant of exposure. Chironomids exhibited negligible mortality after 24 hours of exposure during cool spring air temperatures. Higher air temperatures greatly increased mortality of all groups. Trichopterans and lepidopterans also exhibited considerable tolerance to exposure. *Cladophora* mats provided protection from desiccation for most groups, but mayflies often became entangled in algal filaments near the edge and desiccated. Denham (37) found that several mayfly nymphs and hydropsychid larvae actively migrated when water levels receded in experimental pans, but that many chironomid larvae and oligochaetes did not.

Kroger (38) concluded that large numbers of invertebrates were destroyed below Jackson Lake Dam in Grand Teton National Park, Wyoming, each time large drawdowns occurred. He emphasized that large fluctuations may destroy the food base (algae and macrophytes) of benthos as well as directly decimate the benthic fauna, and postulates that even when water levels rise, the previously exposed bed may not be suitable habitat for fish food organisms.

Fisher and LaVoy (21) found that the benthic community is able to tolerate brief periods of exposure. Whereas great reductions in diversity and standing crop occurred in areas below a hydroelectric dam which were exposed for 70 and 40% of the time, there was little difference between areas always submerged and those exposed 13% of the time. Unionid molluscs were especially intolerant of exposure. Chironomids were most tolerant of exposure and were about the only insects in 70% exposure areas. Only two mayflies (*Stenonema* sp. and *Ephoron* sp.) and two cased caddis (*Molanna* sp. and *Lepidostoma* sp.) were restricted to completely submerged areas.

The discharge below a power dam in Colorado fluctuated as much as 52 m^3/sec in a one-minute period (19). The severe reduction of all orders of insects except Plecoptera was attributed to alternate submergence and exposure of large areas of stream bed (14 to 75% in different sections) below the dam. Stoneflies were observed to actively migrate as the water level dropped, and seven nymphs (species not indicated) placed in a pan of dry sand in the shade were alive and in good condition 32 hours later. Aquatic insects classified as "quality trout food organisms" were over four times more abundant above than below the reservoir, and trout collected above the reservoir had nearly 15 times more food in their stomachs.

Drift of stream organisms is highly correlated with discharge, and numbers of organisms in the drift may increase with both increasing and decreasing discharge (39,40). It is thus conceivable that short-term flow fluctuations below dams may decimate the fauna even without stranding.

Daily temperature-flow relationships may have considerable influence on the benthos, but have been little investigated. Summer tailwater temperatures below deep release dams in the southeastern U.S. may fluctuate 6 to 8°C as power releases peak and wane, and this may occur two or three times daily (41).

Reduced Flow

There are several reasons why reductions in discharge (compared to historical flows) may occur below dams. Water may be diverted from the reservoir for domestic or irrigation use, or carried by conduit to a downstream powerhouse (42). Weber (23) reported that water released from Granby Dam, Colorado, averaged only 11% of the historical average yearly flow. Reduced flow need not be associated with diversion. Since construction of a power dam in Colorado and subsequent modification of the flow regime, minimum discharge has been more than four times lower than historical minimum flows (19). Minimum flows occurred more frequently and were of greater duration.

Physical changes associated with reduced flows include decreases in wetted perimeter, depth, surface area and current velocity. Current velocity is most affected (42,43).

Lowered current velocity may affect the benthos in several ways. As previously mentioned, many stream invertebrates have an inherent physiological need for current and depend completely on current to renew the water around their respiratory surfaces. Others are unable to procure food below certain current velocities, and certain trichopterans fail to construct nets if the water is flowing too slowly. High current velocity (within limits), in regions with heterogeneous substrata, increases the number of current microhabitats and allows a diverse benthic community to exist. Conversely, reduced flow reduces the number of microhabitats and the benthos.

Sedimentation, which is often associated with reduced flow below dams, decreases substrate heterogeneity, fills interstices with silt, and may severely reduce algal populations, in addition to directly affecting the benthos. Reduced flows following closure of Granby Dam, Colorado, were inadequate to remove silt deposited during construction activities (44), and some slow shallow areas below the dam had silt deposits 30 cm thick (23). Whereas the benthos consisted mostly of small dipterans and oligochaetes below the dam, a larger standing crop consisting primarily of mayflies, stoneflies and caddisflies occurred farther downstream where current velocities were greater and sedimentation was less severe.

The necessity of silt-free interstices for the incubation of salmonid eggs has long been recognized. Recent research has shown this hyporheic habitat to also be of great importance for benthos (45,46,47). Many stream organisms spend their early stages deep within the stream bed, and some species complete their entire lives in this biotope. In some rivers the majority of the benthic fauna may reside well below the surface. The hyporheic zone may serve as an important refuge against drought, floods, anchor ice and periods of high temperature; and the fauna contained therein may serve as a reserve when surface populations are depleted (48). A flow regime should be maintained which will insure that this special microhabitat remains suitable for fish eggs, fry and benthos.

Neel (49), among others, has emphasized that, as flow is reduced, the most productive benthic areas are the first to become exposed. The percentage of the stream bed below Granby Dam considered quality habitat for production of fishes and benthos was calculated to be 59, 43, 31, and 18 percent, respectively at flows of 2.8, 2.1, 1.1 and 0.6 m^3/sec (23).

Reduced flows result in more extreme water temperatures, and while some increase in temperature may increase benthic productivity, many stream species are cold stenotherms for which high summer temperatures are unfavorable (48). Slight elevations in summer temperatures may conceivably disrupt life history patterns and change outcomes of competition, resulting in altered community composition. Low discharge in winter may also be detrimental in cold climates by making already adverse conditions more extreme. Low flow in winter enhances the formation of anchor ice which may severely reduce the benthos.

Riparian and aquatic vegetation may increase or decrease depending largely upon the degree of constancy associated with the reduced flow. Powell (19) noted reduced algae associated with a reduced, but fluctuating, flow regime below a power dam. Deposition of fine sediment may eliminate macrophytes by smothering or indirectly by preventing reproduction (50). When a large portion of the water of the Trinity River, California, was diverted, changing it from a large highly fluctuating river to a small, stable stream, riparian vegetation and macrophytes were enhanced (31). The presence of dense beds of macrophytes further reduces current velocity, which leads to additional deposition.

Increased Flow

Increased discharge may result from an alteration of the flow pattern or by addition of water diverted from another drainage area.

Radford and Hartland-Rowe (20) found that flows below a hydroelectric dam in Alberta were higher in autumn and winter and exhibited greater summer peaks than unregulated streams. During periods of increased flow, the stream was very turbid and algae were adversely affected by scouring. Three species of mayflies especially adapted to torrential conditions comprised the majority of the benthos. Although high current velocities, within limits, result in coarse substrata such as rubble with its associated habitat diversity, the high current velocities (>2 m/sec) in the Kananaskis River swept away leaf litter, eliminating important spatial and food niches. Trichopterans comprised less than 1% of the benthos compared to 15% in a nearby unregulated stream. This was attributed not to high flow, but to disruption of feeding in some net-spinning species under conditions of fluctuating current velocities. The three torrential mayfly species accounted for only a small portion of the drift in the Kananaskis River despite the fact that they comprised the majority of the benthic fauna. It is apparent that only organisms highly specialized for torrential conditions are able to maintain large populations in streams with rapid current velocities.

Temperature-discharge relationships below dams may have important effects on benthos. The higher winter and lower summer temperatures below deep release dams may extend considerable distances downstream under high flow conditions. During a year of exceptionally high runoff, summer water temperatures in the first 12 km below Flaming Gorge Dam were depressed to the extent of being responsible for the nearly complete failure of the summer generation of a formerly dominant mayfly species (18). Macan (51) describes an amphipod which is able to maintain its position in current only in the summer, whereas it is swept downstream to slower reaches during lower winter temperatures and must regain lost ground the next summer. If controlled release results in higher than normal winter flows, organisms such as amphipods which are poorly adapted to resist current may be eliminated from the fauna.

CONCLUSIONS

In attempting to define flow criteria below dams, it must be recognized that ultimately each river, indeed even different sections of the same river, must be considered individually. A reservoir will have quite different effects on a stream flowing through a low relief area underlain by sedimentary bedrock than on a mountain stream flowing through a granitic canyon. The structure and functioning of streams of different order in the same watershed, even in similar surroundings, may be quite different and therefore affected in quite different ways by impoundment.

This is not to say that generalizations cannot be made, but only that many factors must be considered when making them. It must be realized that rivers with different substrata, channel configurations, thermal regimes, floral and faunal communities which occur below reservoirs having different limnological conditions will be differentially affected by a given flow pattern.

More research is needed on subtle, sublethal effects of dams on life cycle phenomena and biotic interactions. More data are needed on current preferenda of important fish food species. Very little is known of the long-term effects of floods on the total ecology of a watershed.

The best minimum flow criterion for benthos may be the lowest discharge which maintains not only an absolute minimum current speed, but in addition, a specified range of bottom current velocities. Exact values would depend upon the composition of the benthic community.

Rates of change of discharge should be gradual so that (1) migrating benthos are able to keep up with receding water levels, and (2) drift losses are minimized.

It is important to maintain a heterogeneous substrate with at least some large rocks to provide a variety of microhabitat and current regimes. The presence of coarse substrate particles (rubble and boulders) decreases the risks to benthos of both flooding (48) and stranding (36). The practice of straightening the channel and removing large rocks from stream sections below dams should be discouraged. A relatively natural seasonal flow regime should be maintained including releases of large volumes of water to eliminate accumulated sediment and cleanse the interstices between substrate particles. A diverse substrate with silt-free interstices will do much to reduce deleterious effects of periods of reduced flow, fluctuating flow and high current velocity.

Specific flow criteria should be established for each dam through the cooperative efforts of stream ecologists, fisheries biologists and hydrologists.

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A METHODOLOGY FOR EVALUATING THE EFFECTS OF DIFFERENT STREAMFLOWS ON SALMONID HABITAT

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ABSTRACT

Stream resource managers need to be able to determine the relationships between flows and various fish habitat parameters in order to evaluate the effects of a present or proposed project which can alter flow regimes. A technique was developed which uses field measurements and a digital computer to quantitatively express the relationships between streamflow and available food producing, spawning, resting microhabitat, and cover areas for trout. Changing a few weighting factors can adapt the program to various species of salmonids. An example of a plot of study results utilizing this methodology is presented. A discussion of the benefits from application of the methodology to release flow evaluations is given.

INTRODUCTION

Increasing storage and diversion of water over the last half century has resulted in altered flow regimes in many rivers and streams. In order to best evaluate the effects of a present or proposed project which can alter flow regimes, stream resource managers need to be able to determine the relationships between flows and various fish habitat parameters. In order to accommodate this need, a methodology has been developed and used in the analysis of a number of trout streams in northern and central California. The purpose of this paper is to describe that methodology.

In 1960, the California Department of Fish and Game proposed a method for investigating the flow required by trout below dams[1]. This method considered that the basic requirements of trout included food, spawning area, and shelter. Binary depth, velocity, and bottom substrate criteria for each of these requirements were established in order that the changes in each could be quantified with direct observation and measurement of a stream section at different flows. Steps toward the adoption of this approach, which has served as a basis for the methodology described herein, were initiated

[1]Kelley, D. W., A. J. Cordone, and G. Delisle. 1960. A Method to Determine the Volume of Flow Required by Trout Below Dams: A Proposal for Investigation. California Department of Fish and Game.

at a California Department of Fish and Game training session at Taylor Creek in 1960.

By the mid-1960's there was still little standardization of methodology for recommending appropriate streamflows below impoundments. Those of us working on the subject recognized that professional stream resource biologists and managers should place the emphasis of their flow analysis work on determining the quantitative relationships between streamflows and various habitat parameters, over a range of flows for which there are reasonable management alternatives. When all parties concerned agree on the objective relationships, organization recommendations based on the relationships and other relevant factors can then be made.

A change in flow results in a change in the physical characteristics of all microhabitats of all fish species present, their predators, their competitors, and the food organisms down through the food chain upon which they depend. For each organism category, at different life history stages, there are microhabitat requirements for upstream and downstream passage, reproduction, egg and larvae rearing, resting, feeding, and cover, including escape cover. Each microhabitat requirement can be defined by water depth, water velocity, and bottom substrate. Hence we have the basis for a model.

METHODOLOGY

Described below are the steps, materials, techniques and analytical methods followed in a typical streamflow study using our methodology.

Preliminary Planning and Field Work Preparation

Representatives of all organizations cooperating in the study meet to agree on which section(s) of stream will be studied, which release flows will be studied, how release flows will be verified, when the study will occur, the number and locations of stations and transects, the spacing of measuring points along each transect, the identity of individual field workers, the location of photographic stations, and other related matters. It is agreed that each cooperating organization will receive a copy of all original field data sheets with which to do anything it wishes, independently of an agreement to share results of the analysis resulting from the computer program described later in this paper.

On some streams a preliminary field review is undertaken to observe typical sections under several flows. These observations, possibly documented by photography, may then be used as a basis for selecting study stations and release flows.

If more than one crew of workers will be involved in data collection, an attempt is made during the planning phase to balance the capabilities of each crew after considering such factors as employer organization, experience on studies of this type, logistic support (if it covers a large geographic area), and which days people are available. For continuity, it is desirable to have the same personnel available for all days of the study. In particular, if cover is included as a study parameter it is imperative that the same worker does the subjective evaluation each day.

The number of stations per stream section, the number of transects per station, and the distance between measuring points along each transect will depend on the variability in stream types (cascades, runs, riffles, pools) and mean stream width. Based on past experience with stream habitat variability and practical logistics problems, around 600 measuring points per stream section are generally selected. A three-person crew with one meter should be able to collect at least 300 point measurements per day, and a five or six-person crew with two meters should be able to collect at least 600 point measurements per day. These work budget figures include consideration of average travel time, normal accessibility, and a normal workday. Table 1 gives guidance as to the number of measuring points which various combinations of stream width, measurement interval along transects, and total number of transects would indicate.

Table 1. Number of measuring points resulting from various combinations of stream width, measurement interval along transects, and total number of transects. Transects are divided evenly between stations, usually two or three stations.

If mean stream width at highest test flow is (ft):	And measurements are taken at intervals of (ft):	At a total number of transects of:	The number of measuring points will be:
0- 15	0.5	18	0-540
16- 20	0.5	12	380-480
21- 30	1.0	18	380-540
31- 40	1.0	12	360-480
41- 50	2.0	18	370-450
51- 75	2.0	15	380-560
76-100	4.0	18	340-450
101-150	5.0	15	300-450
151-200	5.0	12	360-480
201-300	10.0	15	300-450

Station locations are selected to be representative of the stream section in question. Major pool areas are avoided because they are not habitats where significant ecological changes occur with changes in flow. However, if resting habitat is likely to be a limiting factor, slow water areas may be given special consideration. Ease of access is a consideration in station location selection only when the representativeness of the final locations selected is assured. If uncontrolled accretion is significant in a stream section, stations should be spaced to include the range of accretion flow conditions that exist.

After station locations and the number of transects per station have been determined, the ends of transects are identified with stakes firmly installed above the water line of the highest flow studied. The distance between transects (commonly 20 to 50 feet) depends mostly on the length of stream available at the station. Stakes are located on one side of the stream by measuring the fixed pre-determined interval along the streambank. Stake locations for the ends of the transects on the opposite streambank are selected by eye such that the transect is perpendicular to the flow at that point in the stream, even if this results in adjacent transects not being parallel.

Field Data Collection

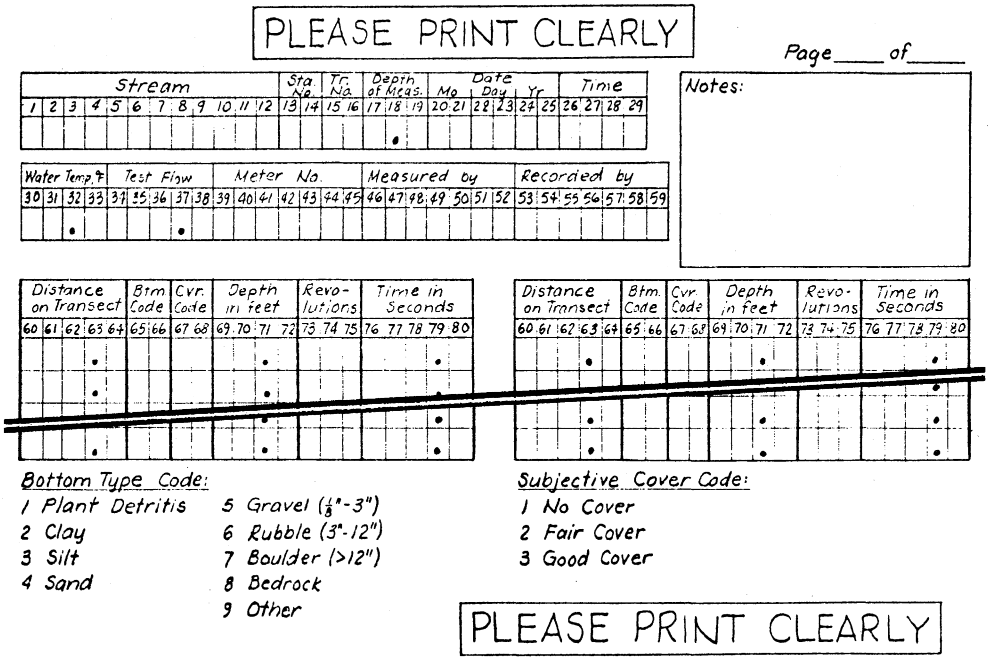
Prior to the initiation of field measurements, all participants should meet to review individual responsibilities, resolve any questions, stress the importance of a standard systematic approach to all aspects of the field study, and inventory equipment and review its use.

A typical equipment list, which would be duplicated with multiple crews, includes: backpack; Gurley Pygmy flow meter(s) with spare parts; measuring tapes (non-stretchable); stop watches; extra transect stakes; data recording forms; clipboard(s); pencils; tape clamps and/or pullers; chalk board; chalk; thermometer; plastic flagging tape; maps; camera and color film; first aid kit; snake bite kit; rope; suntan lotion; and felt soled shoes. Flow meters should be calibrated before and after the study to assure that the calibration did not change.

An example of the field data recording form is given in Table 2, and the general instructions for using it are given in Table 3.

Upon arriving at a transect, crew members stretch the tape tightly between the two stakes. At this point, it is especially important to have the zero end of the tape exactly over the base of the stake. The zero has to

Table 2. Example of streamflow evaluation field data recording form.



PLEASE PRINT CLEARLY

Page ____ of ____

Stream												Sta. No.		Tr. No.		Depth of Meas.			Date Mo		Day		Yr		Time			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29

Notes:

Water Temp. °F				Test Flow					Meter No.							Measured by							Recorded by							
30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	

Distance on Transect					Btm. Code		Cvr. Code		Depth in feet				Revo-lutions			Time in Seconds				
60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

Bottom Type Code:
1 Plant Detritis
2 Clay
3 Silt
4 Sand
5 Gravel (1/8"-3")
6 Rubble (3"-12")
7 Boulder (>12")
8 Bedrock
9 Other

Subjective Cover Code:
1 No Cover
2 Fair Cover
3 Good Cover

PLEASE PRINT CLEARLY

be at the same place for each study flow. The zero end of the tape is always on the study access side of the stream.

The highest flow to be studied is released first, immediately confirming that transect stakes have been placed appropriately in relation to water elevation. Study participants are then able to fill in columns 60-64 of the field data recording forms (distance on transect) in advance for all subsequent (lower) flows to assure that all required depth, velocity, and substrate data are collected. Actual release flows are verified, as well as the actual flows existing at the stations (release plus accretion). Flows are allowed to stabilize before any measurements are made. Usually this is done by having only one study flow per day, with releases set late in the afternoon of the previous day. On uncontrolled streams, study participants must attempt to obtain differing flows as they occur naturally, even if this requires long time periods between field study days.

Velocity measurements for our salmonid stream studies are taken at 0.2 feet above the substrate. The data analysis takes this into account to the extent possible. Substrate type (bottom code) is recorded as that which best typifies the substrate at the given point along the transect and is recorded

Table 3. Instructions for filling out streamflow evaluation data recording form.

Note: Always print clearly with medium soft pencil (No. 2 or 2-1/2)

Columns	Recorded Information
1-12	Name of stream. Be as specific as possible as to location. Use AB=Above, BL=Below. Use abbreviations when necessary (e.g., NFKINGSABWIS = North Fork Kings River above Wishon).
13-14	Station number in the section of stream being tested, 1-99.
15-16	Transect number at the station, 1-99.
17-19	Depth of measurement. Usually held constant at 0.2 feet.
20-25	Date. Use normal sequence of month, day, year.
26-29	Time. Military time approximately half way through transect.
30-33	Water temperature in °F to nearest 0.1° if taken.
34-38	Test flow in cfs to nearest 0.1 cfs. This is the release flow that exists at the time of the study. Do not record intended test flow. Record only after actual release flow is verified.
39-45	Meter No. (right adjusted). If more than seven alpha-numeric characters long, use last seven.
46-52	Measured By (left adjusted). Name of person who does all or majority of metering. Use sequence of first initial, second initial, last name. If more than five letters in last name, record only the first five.
53-59	Recorded By (left adjusted). Same instructions as Measured By.
60-64	Distance on Transect. The point along the tape in feet where the measurement is taken. Skip all dry areas that occur at the first (highest) flow.
65-66	Bottom code (right adjusted) using the key at the bottom of the recording form. This only has to be recorded once, and is done at the lowest test flow for convenience in evaluating substrate type. It has to be recorded for all points at which any measurements are taken on any day of the study, even if that point is dry on the day it is recorded.
67-68	Subjective cover code (right adjusted) using the key at the bottom of the recording form. Recorded only if this option is to be included in the study.
69-72	Total water depth to nearest 0.1 feet at point of measurement. If substrate is dry at the point on that day, record as 0.
73-75	The number of complete revolutions counted after the revolution noted when the stopwatch is started. Flow meter is set at depth indicated in Columns 17-19. Epic counter may be used.
76-80	Elapsed time to the nearest 0.1 second (minimum of 30 seconds) from when stopwatch started until it is stopped at a completed revolution of the flow meter. Record as 30 seconds if no depth or too shallow to get a velocity (revolutions) reading. Epic counter may be used.

analyses was based on a review[2] of all available sources of information which related physical characteristics (substrate, velocity, and depth) of trout habitat to habitat parameters (resting, food production, and spawning). Steps to determine weighting factors for a particular stream and its biota (some of which may require new research) are given in the discussion.

The computer program, which is written in PL/I and used on an IBM 370 Model 168 with Calcomp plotter support, provides the following data in tabulated form for each habitat parameter for each stream studied:

1. Total relative units for each series of transects within each station, including a station total.
2. Total relative units for each series of stations within the stream section under study, including a stream section total.
3. Tables from 1 and 2 in mean relative units.
4. Standard deviation of values in tables from 3.
5. 90 percent confidence limits of values in tables from 3.
6. Relative distribution of different categories of bottom substrate.

The program can also provide results in plot form, an example of which is given in Figure 2. This can be provided for each habitat parameter by station, and for all stations combined in the stream section under study. These plotted results are the most usable product of the program, in that they show the relationship between the magnitude of the habitat parameter of interest (as a dependent variable) and release flow (as the independent variable). The plots provide a tool that biologists and others can use when evaluating the potential effects of different release flows below impoundments, recognizing the constraints mentioned in the discussion.

Plotting results with only relative units on the vertical scale should suffice if there is only one section of one stream involved in an evaluation, since knowledge of relative changes is all that is probably desired. In order to compare values from one stream to another, or from two or more sections of the same stream, the mean relative units can be multiplied in the program by actual streambed area included in the study to get the equivalent number of optimum quality ft^2 (or m^2) of the habitat parameter for each, as shown on the area unit scales.

The program utilizes control cards to enable the user to specify the fol-

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[2] Hooper, Douglas R. 1973. Evaluation of the Effects of Flows on Trout Stream Ecology. Dept. of Engineering Research, Pacific Gas and Electric Co., Emeryville, CA. 97 pp.

lowing (Existing limits are shown in parentheses):

1. Name of stream section under study.
2. Number of stations (3 per stream section).
3. Number of transects per station (9).
4. Measurement interval along transects (100 measurements per transect).
5. Length in feet of stream section under study.
6. Percentage of stream length under study that is represented by the study (from aerial photographs or field reconnaissance if area unit scales are desired on the plots).
7. Number of study flows (5).
8. Whether or not subjective cover is included in the study.
9. Whether or not relative unit plots are desired.
10. Whether or not area unit plots are desired.

The weighting factors are accessed from a file at the time of program and data submittal to the computer.

DISCUSSION

Interpretation of Results

The plotted results (Figure 2) should not in themselves be construed as making recommendations for a streamflow release regime. Rather, they represent relationships that have been determined in as quantitative and least

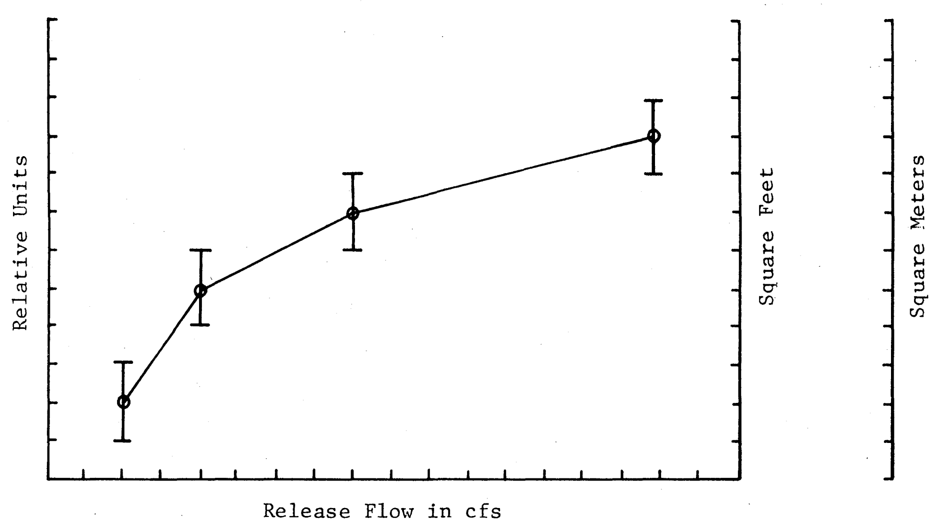

Fig. 2. Representative Example of Plot Showing Relationship Between Relative Units of Habitat Parameter and Release Flow. Ninety Percent Confidence Intervals Are Shown.

subjective manner as possible. They also depict relationships which all interested parties can agree to as representing the best judgement of professional fisheries biologists, prior to any interdisplinary evaluation of their application to the final resolution of the release flow regime under consideration. This leaves flexibility for interpretation and consideration of management alternatives based on all relevant factors, including fisheries management needs, comparisons with natural unimpaired flows, water rights, economics, conflicting recreational uses, safety, esthetics, and other interdisciplinary interests.

From the fisheries management standpoint, the limiting factor concept should be utilized in using the plotted results in a recommendation/decision making process. For example, the importance of the relationship shown in a spawning curve is primarily during the spawning and egg and larval rearing season. Attention should be given to this relationship if spawning success is likely to be a limiting factor to fish production in the stream. Curves can be determined for different species of fish in the same stream, and be applied to flow recommendations during different seasons. An example of this would be different spawning curves based on slightly different weighting factors for rainbow and brown trout, which would be applicable in the spring and fall, respectively. Another example would be if a stream receives heavy use and is managed on a put-and-take basis, the curves for resting microhabitat and food production may be given greater consideration than the curve for spawning, whereas the reverse may be true in a stream managed as a wild trout fishery or one managed for the preservation of a unique or endangered species.

In some cases, some of the plotted curves should not be considered in evaluating flow needs at all. An example of this would be on a stream with much slow and deep water, in which resting microhabitat and possibly subjective cover could be dismissed as not being possible limiting factors, and attention would be given only to the other habitat parameters.

The relative importance of the limiting factors that can be controlled by flow releases is also affected by other fisheries management considerations such as real and potential fisherman use in the stream section, fishability by fishermen at different flows (including access and safety), and the relationship between streamflow and water temperature regimes. It is also possible that other fisheries management programs, such as the eradication of predator or competitor species, stream channel alterations, management of overhead cover, or planting fish where it is not possible or practical to get enough natural production, may be more cost effective and productive to the fishery than relying only on changes that are possible with changes in flows.

An ideal trout stream might have the following percentages of its wetted area available for providing the following habitat parameters:

Cover (shelter)	10 Percent
Resting Microhabitat	15 Percent
Spawning Area	60 Percent
Food Production	80 Percent

There is considerable overlapping of bottom area for these habitat parameters in the same area of a stream. Comparing this to what is available or even possible in a study stream by looking at the relative distribution of bottom substrate materials and other study results, fisheries managers and others might conclude that it is desirable to consider other management alternatives, such as those listed above, in addition to or in conjunction with a controlled flow program.

Improvements in Using this Methodology

In addition to the previously described advantages of utilizing this methodology which are primarily based on not having to rely on subjective evaluations of the relationships between streamflows and fish habitat, another advantage is that users can alter and improve the weighting factors as the results of new applicable research become available, without having to do additional field work. The field measurements will always represent the stream, barring any major morphological and/or hydraulic changes. Field measurement efficiency can, however, be improved with the use of a direct readout current meter.

A primary research need to enhance the value of this methodology for application to a specific stream situation is investigation to establish the most appropriate weighting factors for the depth, velocity and substrate values that best describe spawning, resting microhabitat, and food production in the specific stream.

To carry out this research, the following steps should be followed:

1. Identify the specific stream section in question.
2. Identify the species of fish and important fish food organisms that can be most significantly affected by changes in flows.

3. Identify those habitat parameters (e.g., spawning, resting microhabitat, food production) of importance to the fish species that can be most significantly affected by changes in flows.
4. Identify those physical characteristics of the habitat [substrate, velocity (at what point in water column?), depth] that define the habitat parameters.
5. Develop weighting factors for ranges of the physical characteristics relative to each habitat parameter.
6. Fill in voids on weighting factors, and use in the model.

A second research need to improve on this methodology is to conduct long term ($\geq$3 years) evaluations of the responses in streams where controlled flow regimes have been changed in order to compare results to those predicted so that the predictive model can be modified if necessary.

A third research need could be to establish a coding system of stream types in order to eventually utilize results from studies in some streams to other streams of similar characteristics. This is a longer term research priority which would only follow much experience and verification of the physical and biological characteristics used as a basis for such a coding.

ACKNOWLEDGEMENTS

I would like to acknowledge the cooperation of biologists employed by the Pacific Gas and Electric Company, the California Department of Fish and Game, the U.S. Forest Service, and the U.S. Fish and Wildlife Service in the development of this methodology. Appreciation is also extended to Barry L. Landsman who handled the computer programming which allowed biological thoughts to be quantitatively expressed and displayed.

VALIDITY OF METHODOLOGIES TO DOCUMENT STREAM ENVIRONMENTS FOR EVALUATING FISHERY CONDITIONS

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ABSTRACT

Studies were conducted from July 1970 through September 1972 of (1) the relationship of the physical structural components of aquatic environments to each other, (2) the relationship between stream structure and fish populations, (3) the importance of multiple variables in controlling fish populations, and (4) the validity of using present methodologies to evaluate fishery productivity. A 397-square-mile area in the upper South Fork Salmon River watershed was evaluated for aquatic environment-fishery relationships by analyzing data from 2,482 transects in 38 streams for physical aquatic and streamside environments, with 291 areas for fishery conditions.

Certain valid interpretations could be made concerning aquatic variable control of fish populations, but the overall observed variation was low. In-stream conditions controlled the density of fish populations and the composition of fish species. Control was not isolated to any one variable. Stream depth, width, and the elevation of the stream channel were the most important evaluated variables controlling fish populations.

INTRODUCTION

Most aquatic-fishery methodologies now used to provide land, water, and fisheries managers with information and analysis for decisionmaking have been based mainly on opinion, intuitive thinking, and relationships of variables derived empirically. Seldom has any aquatic methodology been tested to determine if the data are reliable and provide the basis for a valid analysis.

Managers often are apathetic to aquatic environment studies or use them ineffectively because (1) it is presently difficult to relate aquatic methodologies to fishery resources, (2) the manager has a difficult time meshing these data and analyses with those of other disciplines, (3) the masses of data do not offer an analysis to fit decisionmaking needs.

Difficulties arise in developing valid methodologies because of the problems encountered in quantitatively describing the true state of an aquatic system. A stream is dynamic, changing from day to day and especially from year to year. Aquatic scientists usually collect data during the warmer months

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of the year (from June through September), when access, streamflow, and water quality are optimum for aquatic observation. Aquatic conditions thus are seldom measured during periods of floods, annual high flows, extreme low flows, channel icing, ice flow scouring, and debris jam breakups. Because many limiting factors, whether imposed within the system or by the surroundings, will usually exist during periods of no observations, the true (changing) state of the system over time has not been determined. A valid understanding of the environmental mix usually escapes us. Thus, the value of observed physical, biological, and chemical variation that should predict fishery conditions is low.

Past studies do demonstrate correlations and interadjustment between parts of the aquatic system and also with the surroundings, but not the correlation between the environmental variables, the environmental mixes, and fish populations.

Structural Correlations

Leopold and Maddock (1953), in quantitative studies, showed a correlation and interadjustment between stream discharge, sediment transport load, gradient, width, and depth. Leopold and Miller (1954), Morisawa (1962), and Lubowe (1964) compared inter-aquatic structural variables with the surroundings and stated that stream gradient, stream width, length of stream, area of stream drainage, water discharge, shape of drainage basin, and relief have consistent relationships among themselves and with stream order within the same drainage complex.

Von Vertalanffy (1950) expressed the idea that systems in their responses to the surroundings may be dominated by one type of external variable. The trend, however, has been toward recognition of multivariable control in geomorphic systems (Weber 1958). The literature amply demonstrates that the structural environmental components of a stream are influenced by the surroundings.

Biological-Structural Correlations

Researchers differ in their findings as to what variables are the most important in controlling fish populations, and the differences appear to depend partly on the condition of the environments they studied. Cummins' (1966) extensive literature review found that no single factor has greater biological significance in the stream than the physical nature of the channel substrate. Schuck (1945), Inger and Chin (1962), and Ruggles (1966) found that stream depth significantly affected trout populations. Saunders (1965), McNeil and

Ahnell (1964), and Hall and Lantz (1969) associated low standing crops of trout with increase in fine channel sediments. Burns (1971) found only living space correlated significantly with biomass. Saunders and Smith (1955) found that cover was the dominant factor in increasing standing crops of brook trout. Hunt (1971), in conflict with Chapman (1966), noted that the carrying capacity for trout was poorly correlated with the surface area, but that an increase in permanent bank cover increased fish biomass. However, Ruggles (1966) found that silver salmon fry avoided shaded areas and their density decreased when artificial cover devices were added. Needham and Jones (1959), however, demonstrated that rainbow trout strongly preferred sheltered areas.

Reid (1961) stated that the choice of physical factors to be analyzed is difficult because environmental variables in streams are typically correlated and confounded with one another. Later studies lent credence to Reid's thinking on multivariable control of fish populations. Lewis (1967) measured six physical characteristics of 19 pools and found they accounted for 77 and 70 percent of the variation in number of brown and rainbow trout, respectively, in pools. Stewart (1970) analyzed 15 physical aquatic structural characteristics and found mean depth was the single variable of first importance; in addition the combination of several categories of hiding and protective cover proved to be highly correlated with the distribution and density of brook trout, but not rainbow trout. Lewis (1967) concluded that surface area, water volume, average depth, average current velocity, and percent of cover accounted for variations in numbers of trout.

The literature demonstrates the complexity to be faced in the development of a valid methodology. When the multivariable controls on the aquatic system from its surroundings are combined with in-stream controls and then combined further within the different aquatic types that can change the importance of any given variable, it is understandable why a methodology of high validity to determine aquatic-fishery relationships has not been developed.

The study summarized here provides some information from mountainous aquatic environments, in specific geomorphic settings, that can be used to examine the validity of a methodology to evaluate quantitatively the aquatic conditions and their control of fish populations. There also may be an influence from chemical conditions, but it was not addressed in this study.

STUDY AREA

The study area is in the southern portion of the Northern Rocky Mountain physiographic province and located entirely within the Idaho Batholith.

Approximately 397 square miles along the upper 52 miles of the South Fork Salmon River drainage in west-central Idaho were included in the analysis. Data were taken for 38 tributary streams, from 2,482 transects for aquatic and streamside environments, and from 291 areas for fishery conditions.

Fishery

The drainage has historically contained the largest salmon run in Idaho composed entirely of summer chinook salmon. Steelhead trout, fluvial cutthroat trout, rainbow trout, Dolly Varden, brook trout, mountain whitefish, sculpin, and dace also occupy the study streams (Table 1). The study streams often have gradients that are too steep for high production of salmonids. However, salmonids have adapted to almost all streams in the study area.

Members of the Salmonidae family have been present since the Miocene--28 million years ago (Berg 1947). Consequently, salmonids have adapted their life cycle to survive under a dynamic, complex stream environment. They are well adapted to meet natural stress, but require certain conditions in their environmental niches to produce viable populations. Our methodology must be able to quantitatively describe these environmental niches over time and relate these environmental conditions as to their control on fish populations. Once the environmental niches can be accurately described and evaluated, then the effect of streamflows on these niches can be predicted with validity.

The study streams receive insignificant fishing pressure because of poor access and better fishing in surrounding areas. Thus, fish mortality is due almost entirely to natural causes, and standing crops thus provide a measure of fish populations under natural conditions, yielding unbiased estimators of the quality of the aquatic environment.

Rainbow trout were the dominant species, possibly because the area contains both anadromous (steelhead trout) and resident species. Chinook salmon were second in numbers and made unexpectedly heavy use of the small tributary streams for rearing their young. Dolly Varden were third, followed by westslope cutthroat trout. Brook trout were fifth, approximately equaling the sculpin. Mountain whitefish were seventh in numbers, and dace were found only in one stream.

Study Streams

The average elevation of study streams is 5,653 feet and stream elevations range from 4,370 to 7,407 feet within 12 geomorphic types. An example of geomorphic types present is land where alpine glaciation has created cirques or amphitheaters, stream gradients stairstep, and winter conditions are severe.

Table 1. List of Fish Species Present in the Study Area with Population Abundance Rating

Common Name	Scientific Name[1]	Population Rating Abundant	Common	Low
Cutthroat trout	Salmo clarki Richardson		x	
Dolly Varden	Salvelinus malma (Walbaum)		x	
Rainbow trout	Salmo gairdneri Richardson	x		
Mountain whitefish	Prosopium williamsoni (Girard)		x	
Chinook salmon (summer chinook)	Oncorhynchus tschawytscha (Walbaum)		x	
Steelhead trout	Salmo gairdneri Richardson		x	
Brook trout	Salvelinus fontinalis (Mitchell)			x
Northern squawfish	Ptychocheilus oregonensis (Richardson)			[2]E
Suckers	Catostomus spp.			E
Redside shiner	Richardsonius balteatus (Richardson)			E
Dace	Rhinichthys spp.			x
Sculpin	Cottus spp.			x
Pacific lamprey	Entosphenus tridentata (Gairdner)			E

[1]Scientific names according to the American Fisheries Society (1970) list of common and scientific names of fishes.
[2]E = estimate only.

In another geomorphic type, valley glaciers created U-shaped canyons with high-gradient streams and broad streamside buffer zones. Here large valley glaciers intercepted and undercut smaller tributary glaciers, creating hanging valleys with some stream sections being almost vertical. At lower elevations, glacial deposits contain larger streams with less channel gradient. In the fluvial lands, streams have formed narrow V-shaped canyons. Streams with relatively low channel gradient occur in water-formed depositional materials.

The study streams offer a wide spectrum of aquatic habitat types representative of mountainous streams in the Batholith for testing validity of the methodologies used. The study streams are in natural or near-natural condition and contain water of uniform quality and low in mineral content (60 p/m total dissolved solids) because of the granitic bedrock, therefore eliminating these conditions as a bias when comparing aquatic habitats.

AQUATIC ENVIRONMENT EVALUATIONS

The streamside and aquatic environment documentations used the general methods outlined by Herrington and Dunham (1967) with some modifications. The modifications were made to increase sample sizes in small drainages and to quantify additional physical conditions as described later.

The aquatic methods satisfactorily quantified most of the variables, as water depths rarely exceeded 48 inches and water velocities were never excessive for in-stream work. The clear water with low flows (July-November) offered excellent conditions for observation and measurement. The studies were conducted from 1970 through 1972.

Stations

The environmental condition of the 38 major tributaries within the study area, totaling 135 stream miles, was documented by using an average of one transect for every 93 yards of stream. Stations were located randomly along all study streams from mouth to headwaters (where the stream became ephemeral). Each stream contained a minimum of six stations regardless of stream length.

Each stream area (station) to be physically analyzed was selected randomly, marked on an aerial photograph (1-15,000), and then located and marked on the ground. The first transect of the five grouped transects (at 50-foot intervals) making up each station was located 100 feet upstream from the photographic location to avoid any bias resulting from the tendency of field personnel to establish the actual point where access may be easiest.

Transects

A transect (channel cross section) is defined as an imaginary line running perpendicular to the centerline of the stream. The following measurements and conditional factors were recorded:

1. Stream, pool, and riffle widths.
2. Four stream depths at equal intervals across the stream.
3. Ratings, locations, and features of pools.
4. Stream channel surface material classifications.
5. Cover, conditions, and types of streambanks.
6. Channel elevations and gradients.

7. Stream order.
8. Fish species, fish numbers, and fish lengths.

Channel Materials

A given transect crossing the stream channel was divided into 1-foot intervals, and the dominant streambed surface material determined the classification of each 1-foot division (Table 2).

Table 2. Size Classification of Channel Materials

Particle Diameter	Classification
12 inches or over (304.8 mm or over)	Boulder
3 to 11.9 inches (76.1 to 304.7 mm)	Rubble
0.19 to 2.9 inches (4.7 to 76.0 mm)	Gravel
0.18 inch and less (less than 4.7 mm)	Fines (Sand)

Evaluations of Pools and Riffles

Stream areas were stratified as either pool or riffle. The pools were then classified as to their suitability as a fish environment (Table 3).

Streambanks

The conditions and type of each streambank were rated using the total streamside area between each transect in accordance with Table 4. Streamside types refer to habitat types at the intersection of each transect with the banks.

Elevation of Streambed

Station and transect elevations were read from a hand-held "Thommen" altimeter that was set each morning at an official USGS elevation marker. Transects in areas mapped to 40-foot contours were checked against the altimeter readings for any needed adjustment. The estimated elevation error per station is within ±40 feet.

Gradient

Channel gradients were recorded at each station with a hand-held clinometer and equaled the average gradients over each entire 200-foot channel section.

Table 3. Pool Quality Rating Guide for Streams in the Study Area

Quality Class No.	Length or Width	Depth	Shelter[1]
1	greater than a.c.w.[2]	2 ft or deeper	abundant[3]
	greater than a.c.w.	3 ft or deeper	exposed[4]
2	greater than a.c.w.	2 ft or deeper	exposed
	greater than a.c.w.	2 ft	intermediate[5]
	greater than a.c.w.	2 ft	abundant
3	equal to a.c.w.	2 ft	intermediate
	equal to a.c.w.	2 ft	abundant
4	equal to a.c.w.	shallow[6]	exposed
	less than a.c.w.	shallow	abundant
	less than a.c.w.	shallow	intermediate
	less than a.c.w.	2 ft	intermediate
	less than a.c.w.	2 ft or deeper	abundant
5	less than a.c.w.	shallow	exposed

[1]Logs, stumps, boulders, and vegetation in or overhanging pool, or overhanging banks.
[2]a.c.w. = average channel width.
[3]More than 1/2 perimeter of pool has cover.
[4]Less than 1/4 of pool perimeter has cover.
[5]1/4 to 1/2 perimeter of pool has cover.
[6]Approximately equal to average stream depth.

Table 4. Numerical Ratings Used to Classify Streambank Environments

Cover[1]		Condition[2]		Type[3] (Examples)	
forest	2.0	excellent	2.0	sod, root, log	2.0
brush	1.5	good	1.5	brush, rubble	1.5
grass	1.0	fair	1.0	grass, gravel	1.0
exposed	.5	poor	.5	fines, road fill	.5

[1]Type of vegetation dominating the streambanks.
[2]Stability of the streambank to water flows.
[3]A habitat type that can be composed of a single material or combination of materials.

Width and Depth

Stream width values refer to surface water widths measured perpendicular to the flow of the stream. Average transect depths were obtained from four equal-distance measurements.

Order

Stream order was determined by methods originally developed by Horton (1945) and later modified by Strahler (1952, 1957).

FISH COLLECTION

The low concentration of total dissolved solids (60 p/m) in stream waters meant that more reliable fish population samples could be obtained with explosives than by using electrical fish collecting equipment. A total of 2.75 miles of stream were sampled at 291 stations, using 4 miles of explosive prima cord.

A 0.125- or 0.225-inch mesh net was stretched across the stream to block fish from moving out of the sampling area prior to the explosion. The net and the effectiveness of prima cord assured an unbiased collection of 100 percent of the fish population within each sample area. All collected fish were identified and measured from tip of snout to end of longest lobe of the caudal fin.

COMPUTER ANALYSIS

The CUMDIS (cumulative distribution) statistical program (package 52) was used to generate cumulative frequencies, means, and standard errors about predetermined variables. All confidence limits were calculated by using t values at the 95 percent level. The STAPTPAC/LIBRARYA unit at Utah State University was used to run an inverted matrix multivariate analysis.

FINDINGS

Only selected data appear in this report. If the reader wishes to review complete information concerning the relationships between aquatic variables, the relationship between aquatic variables and fish populations, and multivariable control of fish populations, the author can provide a report titled "Geomorphic and aquatic conditions influencing salmonids and stream classification--with application to ecosystem classification." The work was supported by the Forest Service SEAM (Surface Environment and Mining) Program.

Effect of Channel Materials on Fish Populations

Many authors have demonstrated that excessive fine sediment is detrimental to aquatic life (for example, Cordone and Kelly 1961, Phillips and Campbell

1962, Koski 1966, and Vaux 1962). In this study, however, when fine sediment was considered as a single variable influencing one area at one time the results differed from those of other authors who compared the effects of the increased fine sediment as it affected the same area over time.

As fine sediment increased in the stream channel, stream depths, pool quality, and percent pool ratings increased, while channel gradients and elevations decreased. These variables usually equate with increased fish numbers and could bias or hide any effects the increases in fine sediment may have. The multivariate analysis, however, also indicated that the amount of fine sediment in the channel has no effect on any observed variations in fish numbers (Fig. 1). Although no trend developed between increasing fine sediment and the means of total fish populations, rainbow trout decreased as fine sediment increased, and brook trout appeared to increase. Dolly Varden and brook trout were the only species found in transect areas of stream channels containing over 70 percent fine sediment. No clear trend was identified between total fish populations or individual fish species with percent of rubble, although rubble was the only streambed material class that had explained variation (2 percent for total fish numbers).

Diversity of fish species was reduced in areas of streams having more than 50 percent fine sediment, but reduced diversity was not the case in channel areas with more than 50 percent rubble and boulder. Fish numbers, fish lengths, and fish species did not correlate with percent of boulder or gravel in the stream channel.

Effect of Channel Gradient on Fish Populations

As channel gradients (based on the average channel gradient over the complete 200-foot sections) increased from 2 to 4 percent, mean fish numbers per stream length increased. As channel gradients increased above 4 percent, fish numbers declined steadily; no fish were collected when the average gradient was above 25 percent. Fish accumulative length ratings per sample area did not always follow the same trends as fish numbers, in some cases increasing with increasing channel gradients.

Young-of-the-year chinook salmon, utilizing the lower stream segments, peaked at 4 percent channel gradient. In contrast, cutthroat trout, mountain whitefish, and dace did not appear in sampling until 4 percent was reached. Rainbow trout numbers peaked at 5 percent gradient. This may have been due to steelhead trout spawning higher in the streams than chinook salmon. Cutthroat trout, which utilize higher elevation areas, did not peak in population numbers until about 10 percent channel gradient.

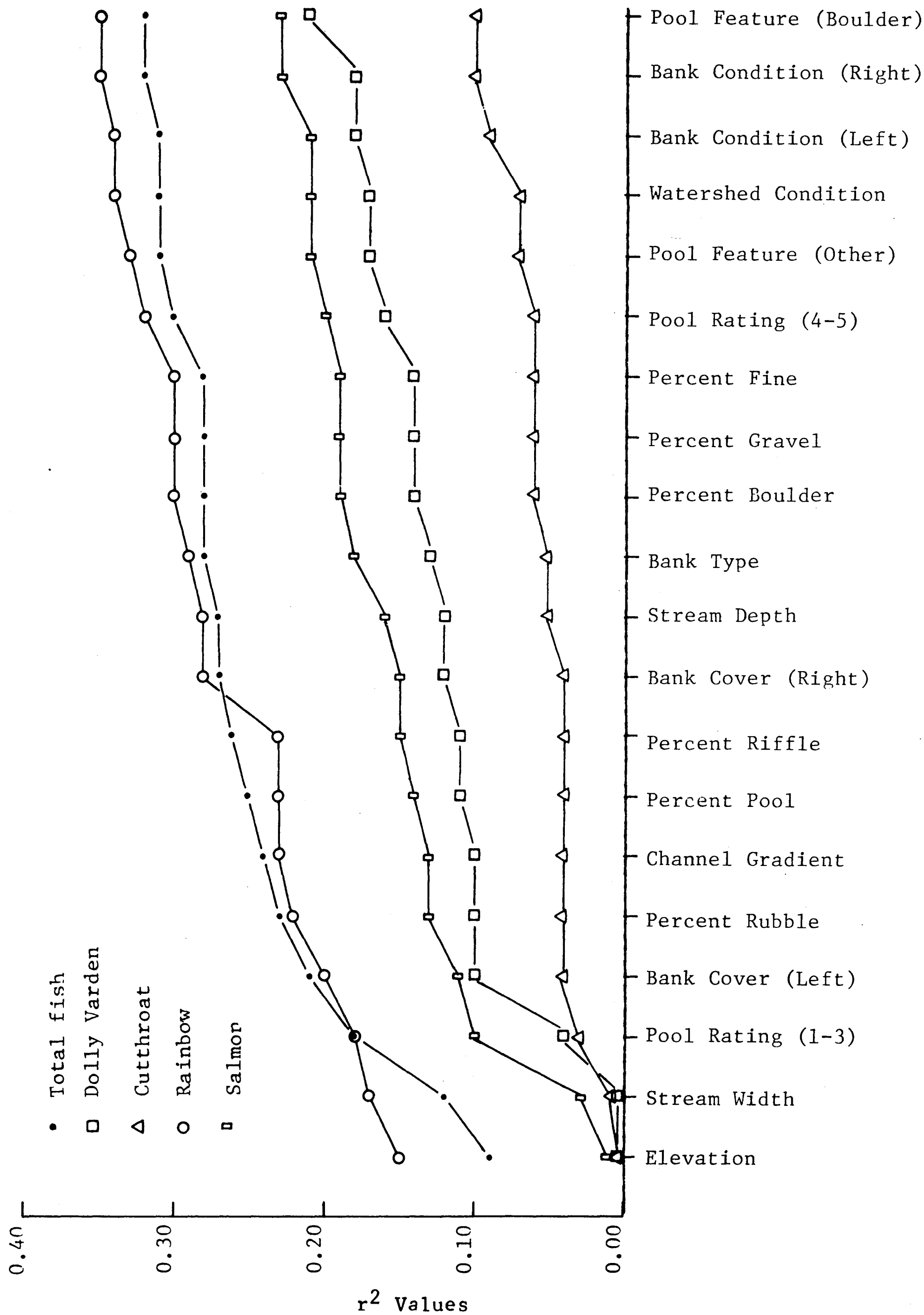

Fig. 1. Explained Observed Variation Between Stream Descriptive Variables and Fish Species Numbers

Dolly Varden numbers peaked at gradients between 6 and 9 percent--a range in which rainbow trout populations were declining. Brook trout and sculpin numbers peaked at 3 percent gradients, and their populations declined as gradients increased above 4 percent. Dace were the first fish and mountain whitefish were the second to disappear from the environment as channel gradients increased. Chinook salmon were not found where channel gradients were over 10 percent because they only utilize streams at the lower elevations.

Brook trout and cutthroat trout were not found in stream areas with channel gradients above 17 and 14 percent, respectively. Although cutthroat trout populations were higher at higher elevations than rainbow trout, rainbows were found in stream areas with gradients almost twice as high. Rainbow trout were the only species analyzed for which gradients accounted for some explained variation. For unknown reasons, rainbow trout appeared to be better adapted to a higher and much more extensive range of channel gradients than were any of the other fish species.

Relation of Channel Elevation to Fish Populations

The lower the channel elevation, the higher the fish population per unit of stream length. The average total length of all fish collected per sample, however, did not follow this relationship. About 80 percent of the fish collected (84 samples) were in streams between 3,600 and 5,200 feet in elevation and 20 percent of the fish collected (207 samples) were taken from streams between 5,200 and 8,400 feet in elevation. Physical stream conditions (depth and width) and water temperatures in the lower elevation areas are more favorable for fish. Elevation was the most influential among the variables in accounting for explained observed variation in total fish numbers.

Dace were the first to disappear from sample collections as elevation increased, and chinook salmon and sculpin followed. Mountain whitefish were not found above 6,000 feet, brook trout were not taken above 6,400 feet. Areas of streams with elevations about 6,800 feet produced only cutthroat trout and Dolly Varden. Surprisingly, rainbow trout inhabited a wide range of channel gradients but disappeared from the samples once channel elevations exceeded 6,800 feet.

Streamside Environment and Fish

Fish populations based on population means, were higher in streams having grass and brush habitats. Chinook salmon, Dolly Varden, brook trout, sculpin, mountain whitefish, and dace had higher population means along grass-dominated streambanks. Rainbow trout populations were higher in stream areas having streambanks dominated by brush. Rainbow trout used open areas more than cutthroat trout, which tended to utilize areas where timber dominated streambank cover.

Populations of young-of-the-year chinook salmon were highest in the more open channels and lowest in channels where tree cover dominated banks. This is partially due to chinook salmon favoring the lower segments of tributaries (close to the river), which had larger areas of water surface per length of stream and lower channel gradients. Streambank cover explained 4 percent of the observed variation in total fish densities.

Streambank condition ratings had no detectable influence and accounted for an insignificant amount of the explained variation of total fish population. Chinook salmon, cutthroat trout, Dolly Varden, sculpin, and mountain whitefish had about the same population means in areas of streams having unstable banks as in areas having stable banks. Densities of rainbow trout increased with increasing streambank quality, but brook trout decreased.

Pool and Riffle Relationship to Fish Populations

Pool Quality--Pools of excellent quality had the highest population means and the greatest fish lengths per sample area. The higher population density was due, in part, to young chinook salmon utilizing the higher quality pools. Pool condition accounted for 8 percent of the chinook salmon's explained observed variation.

Population density of rainbow trout and pool quality related inversely, as rainbow trout tended to occupy riffle areas that were combined with shallow pools. Dolly Varden, brook trout, sculpin, mountain whitefish, dace, and chinook salmon increased in population densities as pool quality ratings increased. Pool condition was second in importance in accounting for explained variations in total fish numbers.

Pool Formation--Population means and explained observed variation demonstrated that pool formation factors were not significant determinants of the ability of a pool to support fish populations. The physical conditions of the pool itself exercise the more important influence.

Pool-Riffle Ratios--Densities of fish populations in relation to pool-riffle ratios were lower than the often quoted optimum density at a pool-riffle ratio of 50/50. The highest total fish population densities occurred in areas of stream having 30 to 50 percent of the stream in pool. Study streams naturally contain infertile water and a lower pool-riffle ratio could be conducive to higher fish populations, as it would increase the proportion of the food-producing areas. Chinook salmon populations steadily decreased as percent of pool increased, because they required relatively larger streams in close proximity to the river that had lower percent pool.

Rainbow trout had lower population means in areas having either a high or a low percent of pool. Their highest population densities occurred in conjunction with a 50/50 pool-riffle ratio. Dolly Varden was the only species to demonstrate a definite mean population increase as percent of pool increased. Cutthroat trout, brook trout, sculpin, and mountain whitefish did not show any marked trends. Pool and riffle only accounted for 2 percent of the explained observed variation and ranked seventh and eighth in importance.

Effects of Stream Depth and Width on Fish Populations

In the multivariate analysis, width was important in explaining variations among fish numbers per length of stream. Increasing depths and widths did not, however, have the same effects on all species. Cutthroat trout, Dolly Varden, brook trout, mountain whitefish, and dace had lower population means in the larger streams, which were dominated by rainbow trout and chinook salmon. Dolly Varden were the only fish found in the smallest streams, and cutthroat trout were collected only in stream areas less than 25 feet wide. Dolly Varden and cutthroat trout did not increase in numbers as stream widths increased. Brook trout were found in the average width channels (6 to 9 ft), but not in smaller or larger than average stream channels. Chinook salmon, cutthroat trout, and sculpin numbers showed no relationship to changing depths. Stream depth was not significant in explaining variation in total fish populations.

Relation of Stream Order to Fish Populations

As stream order increased, available water space and total fish populations increased. As stream order increased, numbers of chinook salmon, rainbow trout, sculpin, and total fish increased per length of stream, and cutthroat trout and Dolly Varden populations decreased. Streams classed as order 4 contained the most species. No species occupied all stream orders, although inadequate sampling in stream order 1 could bias this. Order 1 streams tended to be ephemeral and those with perennial flows were so small (average width 7 feet and depth 4 inches) that they were not sampled. Orders 4 and 5 contributed about 75 percent of the fish population in the study streams, but only made up 19 percent of the stream mileage.

Classifying streams in granitic lands as to their "order" and frequency of occurrence can give the land manager information for an approximation of populations of fish species.

DISCUSSION

Aquatic systems in isolated areas may be dominated by one type of external variable such as glaciation, but multiple external variables usually determine stream conditions. The status of fluvial trout populations is determined mainly by the internal quality of the aquatic environment.

In this study, the physical variables--stream elevations, widths, depths, pool ratings, channel gradients, and streamside cover--substantially influenced fish population densities and species composition. Elevation could be less a factor than it appeared to be superficially because decreases in elevation were so closely associated with increasing stream width and depth. The study data infer that increasing water space, which is associated with decreasing channel gradients and increasing water temperatures, had more influence on increasing fish populations than did other factors.

Fish species preferred certain habitat types, but some species occupied certain types of environments because they were limited in competitive ability. This is exemplified by cutthroat trout and Dolly Varden, which occupied sections of streams that did not have high populations of chinook salmon and rainbow trout. Total fish populations were highest near the grass-brush habitat types because the two dominant fish species centered on these environments. Chinook salmon dominated the grass type areas and the rainbow trout dominated the brush type areas. Cutthroat trout numbers, however, were at their highest in channels with dominant tree cover on the banks. Some species were adapted only to certain ranges of stream gradient, and certain species usually peaked in population density at different channel gradients.

In my work, erroneous interpretations of the effect of one variable on fish populations could have involved gradients, elevations, fine sediment, and pool-riffle ratios. For example, if I had considered fine sediments alone as a dominant controlling variable, the conclusion would be that increasing amounts of fine sediment in the channel would cause increased fish populations. In analyzing the combination of variables, however, as fine sediments increased in the stream segments, stream widths and depths, pool quality ratings and percent pool evaluations increased and channel gradients decreased. All of these conditions, except possibly fine sediment increases, tend to cause an increase in fish populations, thus masking the true effect of fine sediment. In analyzing any aquatic environment, all environmental variables and their interactions must be considered.

In evaluating the inventory procedure as a predictor of fishery conditions, flaws became apparent. The multivariate analysis demonstrated that while

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A HABITAT-DISCHARGE METHOD OF DETERMINING INSTREAM FLOWS FOR AQUATIC HABITAT

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ABSTRACT

A habitat-discharge method of determing instream flows for aquatic habitat has been developed and applied by the Intermountain Region of the Forest Service. The method relates stream habitat loss to reductions in stream discharge and is based on the assumption that suitable aquatic habitat will meet the requirements of the biological components of the ecosystem. Habitat characteristics are determined at a measured index flow and used as a reference to relate discharge changes to a retention or loss of aquatic habitat. The transect method of quantifying habitat variables is used.

Studies of Intermountain Region streams have shown that adequate habitat preservation requires an instream flow equal to no less than 80 percent retention of the index flow habitat values. Recommended flows are therefore at or above the 80 percent retention value and are correlated with the species and life cycle needs associated with each stream. The addition of a General Aquatic Wildlife System (GAWS) computer program in 1976 will provide greater versatility to this methodology.

INTRODUCTION

The Forest Service's responsibility to manage the aquatic habitat in a manner that maintains or improves it is part of their larger mandate spelled out in <u>The Multiple Use and Sustained Yield Act</u>, Public Law 88-517 (74 Stat. 215). "...It is the policy of the Congress that the National Forests are established and shall be administered for outdoor recreation, range, timber, watershed, and wildlife and fish purposes..." However, the need for a reliable method to measure the impacts of reduced stream flows on the aquatic habitat goes back many years before this law was passed.

A technique for sampling general fish habitat characteristics of streams was investigated in 1960 and reported for use in 1967 by Herrington and Dunham of the Intermountain Region of the Forest Service[1]. The procedures were developed through the combined expertise of biologists, hydrologists, and engineers. This technique is now referred to as the transect method and has been used to determine instream flows needed for water development projects, land use planning and water adjudication proceedings. One of the most intensive applications of the transect methodology to instream flow needs was done on streams to be affected by the planned Central Utah Project and reported by Chrostowski in 1972[2]. Some of the more recent applications have been on streams involved in water adjudication proceedings; a need that will undoubtedly increase as the competition for water increases. Refinements to the original technique were reported by Dunham and Collotzi in 1975[3].

METHOD

Preinventory

This method of habitat inventory requires that preinventory work be done to locate stations within selected strata as outlined by Herrington and Dunham (1967) and Dunham and Collotzi (1975) for random gradient and valley bottom stratifications. Statistical measure of dispersion, confidence intervals, variance and deviations are described and exampled in the reference papers.

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Field Work

The field crew locates the points on streambanks that coincide approximately with sample stations marked on maps and/or aerial photos during preinventory. Possible bias on the part of the field crew in locating the sample station is eliminated by having the crews establish transects beginning exactly one hundred feet upstream from the point first identified on the ground. Each sample station contains five transects located at 50-foot intervals proceeding upstream from the first sample point. A photo is taken of the stream at each station for later reference of habitat characteristics and general stream appearance.

The transect is a habitat sampling procedure using cross-channel tape measure lines along which to quantify habitat variables. This is done by tightly stretching a tape measure across and above the water surface at right angles to the direction of streamflow. The tape measure forms the line underneath which habitat features of water and streambottom are identified. It is then a matter of quantitatively stating the habitat in lineal measurement figures (i.e., feet of intercept) in appropriate columns of the field form. Streambank habitat is measured at the cross-channel line's exact streambank point of live water contact.

Channel cross sectioning is the procedure by which discharge is measured and a channel profile recorded. The profile is the channel configuaration shown in Figure 1 and from which hydraulic geometry features are calculated. Average velocity, depths, width, area, and wetted perimeter are key hydraulic variables of each water stage which are tabulated for analysis of habitat retention. It may be necessary to offset upstream or downstream a few feet from the cross section transect for discharge measurements when a less irregular cross section is needed for reliable discharge metering.

Discharge is measured using a current meter. Computations are completed in the office and the resulting flow is called the index discharge. It is the rate of flow in cubic feet per second at the sample station at the time of habitat survey. The index discharge information is used to compute estimates of flow at additional water stages by solving Manning's formula for the n fraction: $V = \frac{1.486}{n} \times r^{2/3} \times S^{1/2}$. "N" thus calculated is then used in computing Q=AV discharge at other water level tracings above and/or below index discharge water level.

Office Work

For evaluation purposes, a profile is measured along a transect line. Horizontal and vertical distance measurements are taken horizontally along the tapeline and downward to ground level. The profile extends between high watermarks at each bank. The existing water level is noted and depth readings are recorded. The profile is then plotted on cross section paper for use in computing rates of discharge and hydraulic geometry. After plotting the profile, the index discharge water level is drawn on the paper. Other water level lines then are drawn above and below the index discharge as in Figure 1 and the investigator calculates discharge and tabulates hydraulic geometry features at the various water levels.

A hydrograph flow duration curve is also prepared from data which is available for gauging stations on the stream course or directly correlated with the study site. Discharge can then be compared with the flow duration curve to determine the percent of time the recommended flow would be attained.

A graph is then prepared for each representative cross section as in Figure 2. Points are plotted which represent percent of field measured value for water surface width, wetted perimeter, maximum depth, velocity, and area

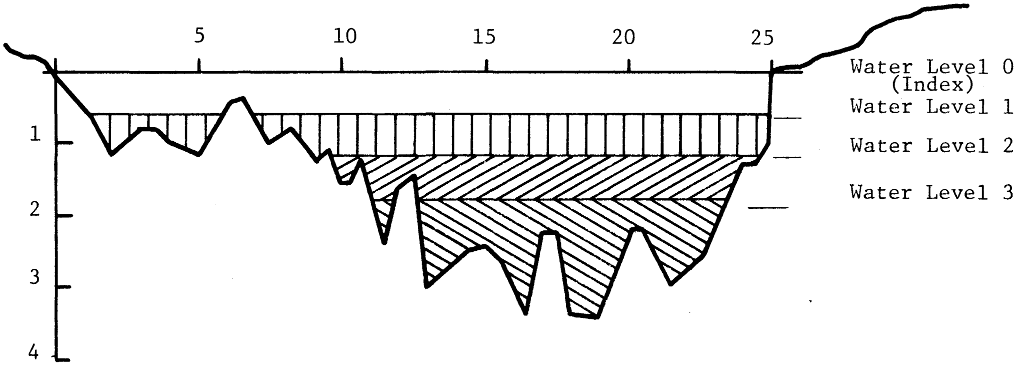

Fig. 1. A Channel Profile Showing the Measured Index Discharge Level and Other Selected Discharge Levels

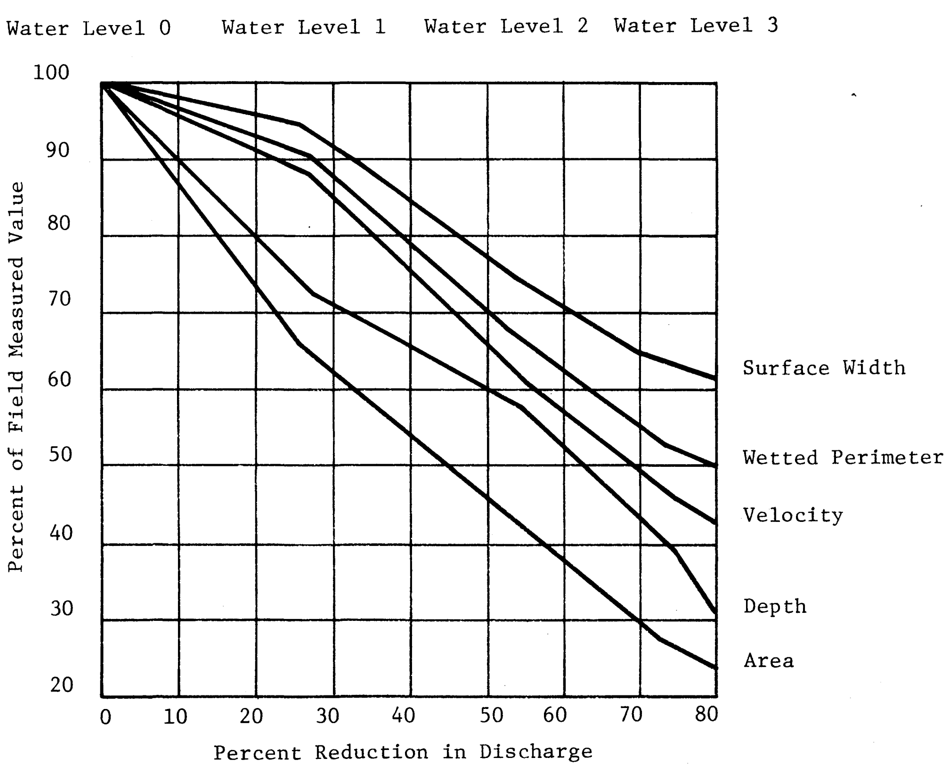

Fig. 2. Hydraulic Variables at Index and Other Selected Discharge Levels

for the water stages drawn on drafted cross sections. The graph is a desirable step to visually show intervals between point discharge estimates and the several data points.

The investigator now has before him the results of the habitat survey and analysis, the index discharge, a channel profile tracing, and a tabulation of hydraulic geometry and discharge at several other water levels. It then remains for the biologist to interpret the relationship among and between the several hydraulic variables and to estimate the habitat retention using percentage increments at the several discharges, and to show the data points on graphs as in Figure 2.

DISCUSSION

The Region 4 Forest Service methodology relates stream habitat loss to reductions in stream discharge. It is based on the assumption that the availability of suitable aquatic habitat will meet the requirements of the biological components of the ecosystem. The method determines a discharge-habitat relationship for a base flow and then relates flow reductions to a retention or loss of the existing and inventoried aquatic habitat. Although the transect method is being used by several biologists in the Intermountain Region, it is not the only method being used and where time, species, season or water constraints appear, a different inventory and analysis method may be applied.

The basic assumption in applying the line intercept type of habitat inventory is that physical features inventoried, i.e., water, streambottom, and streambanks, contain those key habitat variables related to aquatic organism production. It is clearly recognized that production is also strongly influenced by other things such as species composition, age class distribution, chemistry, water temperatures, and extreme climatic events. It is also recognized that variation is a fact of life and that physical features within and between streams will exhibit greater or lesser variation. The transect method can be used to quantify this variation.

Results provide acceptably precise habitat and hydraulic feature estimates. Factors such as stream length and width, surface area, pool area, pool cover features and channel locations, riffle area, depths, and streambank composition as well as the stability and vegetative cover of the streambanks can be related to what we know as requirements for successful fish life during seasons of the year. Discharges which meet velocity, depth or cover levels for migration, spawning, or rearing periods can be computed.

Analysis of this data shows that there is a general rate of reduction in habitat quality with a reduction in discharge. However, a distinct change in this rate occurs at a point within the 0-50 percentile range of reduction from field measured discharge (Fig. 3). A further reduction in discharge beyond this point results in an accelerated rate of habitat quality loss.

Study of numerous streams in USFS Region 4 has shown that this inflection point is more evident for those streams with rectangular shaped cross sections. On those streams with saucer shaped cross sections, the discharge-habitat relationship is very nearly linear representing a constant rate of loss with decreasing discharge. The distinct sharp breaks have been found to occur along the habitat axis above the 80 percentile values. Habitat values below these sharp changes along the discharge-habitat curve are interpreted as habitat significantly degraded from field measure values. Chrostowski states "habitat preservation requires a minimum flow equal to no less than 80 percent retention of low base flow habitat value." The necessity of retaining an 80 percent

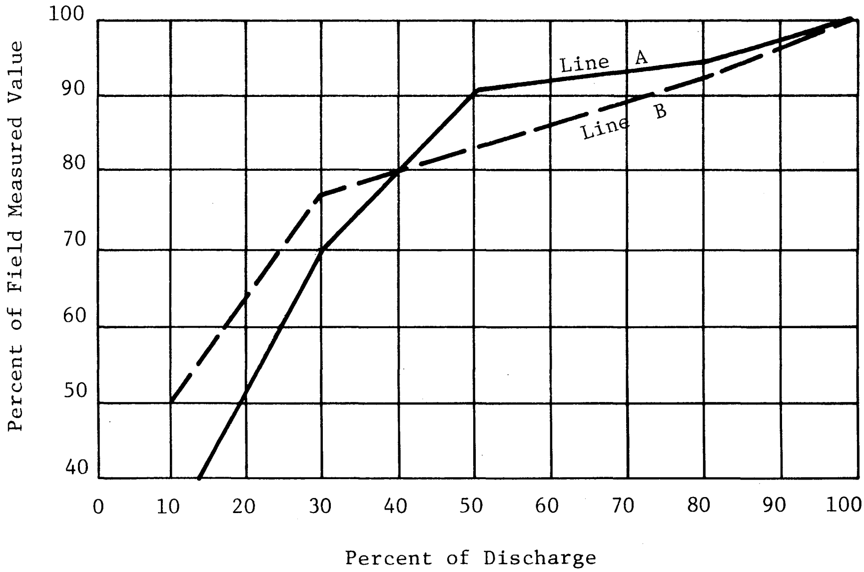

Fig. 3. Estimation of Minimum Flow by the Graphic Representation of Habitat Data

habitat value is a primary assumption of the Intermountain Region methodology. Recommended preservation flows for habitat maintenance are therefore set at or above the inflection point of the discharge-habitat curve for higher quality, steep sided streams. For those more degraded sloping banked streams, the recommended preservation flow is set at or above the 80th percentile habitat value. Flow recommendations from analysis of habitat data along shallow-sloping curves requires some judgment to be exercised by the biologist.

Two habitat trend lines are shown in Figure 3. These lines represent two stream habitats and they are the average condition for several cross sections along the two stream courses. Such averaging may be done where there is little or no gain or loss in streamflow along the channel. The field measured habitat value is assigned 100 percent and is the point on each line at the graph's upper right hand corner. For line A, at 50 percent of discharge, habitat is estimated as equal to 90 percent of the field measured value. For line B, at 50 percent of discharge, habitat is estimated as equal to 85 percent of the field measured value. The estimated minimum flows for habitat lines A and B are 50 and 40 percent of discharge, respectively. These were determined as follows.

For line A, the estimated habitat value ranges between 90 and 100 percent of field measured value for discharges between 50 and 100 percent. At 40 percent of discharge, habitat is estimated at 80 percent of field measured value and at 30 percent of discharge, habitat is estimated at 70 percent of field measured value. Therefore, the absolute minimum flow is at 50 percent of discharge, equal to 90 percent of habitat value because of the sharp fall off in value after the 90 percent value.

Line B has uniform slope between 80 and 100 percent of field measured habitat value. Therefore, the most desirable minimum flow is at 40 percent of discharge, equal to 80 percent of habitat value. Discharge equal to 80 percent of field measured habitat value was considered the lowest acceptable rate of flow, although final determination also took into account the rate of change in habitat for percentage units of discharge.

The Intermountain Region is presently developing a General Aquatic Wildife System (GAWS) computer program[(4)]. One of the program's outputs will provide the predicted values for hydraulic parameters at different discharges. This will considerably shorten one of the more time consuming stages of this method. The program is scheduled for completion and testing during 1976.

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SUMMARY

This methodology is not one that can be done with little effort in a short time. It is an intensive approach that consequently yields more accurate results than some short, quick methods. It is not practical on large rivers as presently set up but could be adapted for use and is in fact very similar to several techniques being used on larger rivers by other agencies. The addition of different parameters could also make it applicable to streams containing non-cold water fish species.

This method has proven to be a reliable technique to determine instream flows on small rivers and streams containing cold water fish species. It considers the total aquatic habitat for each stream evaluated and provides a satisfactory index to this habitat. An evaluation on a considerable number of stream situations has shown that the 80 percent habitat retention figure is a realistic and adequate value necessary to preserve the aquatic habitat.

With the increased competition for water that is certain to come, reliable methods for determining instream flow will become even more important. We feel the Region 4 technique combined with the versatility of a computer program is a reasonable and dependable method to use in determining the instream flows needed for the aquatic habitat.

HISTORY OF FOREST SERVICE INVOLVEMENT IN INSTREAM FLOW NEEDS

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One of the primary responsibilities of the Forest Service is to manage nearly 187 million acres of National Forest System lands and the renewable resources on these lands within sideboards prescribed by Congress. This includes protection of water quality and quantity. As the people assembled here very well know, there is increasing demand on all our resources--this demand for and utilization of the resources has a direct effect on both quality and quantity of water produced from the land. Activities on a watershed can influence turbidity, sediment loads, temperature, chemical composition, biota, and amount and timing of water flows.

The Forest Service is directed by the Congress "to develop and administer the renewable surface resources of the National Forests for multiple use and sustained yield of the several products and services obtained therefrom." With this kind of direction, it is obvious that we must carefully design our programs so as to protect and perpetuate soil, water, and other resources.

Not only is there increasing demand for the land-based resources and uses on the watersheds, but there is also increasing demand for the water resource itself. Over the years, we have seen more and more water diverted from the natural flows of streams. In the early days, most of the impoundments and large diversions were located in the lower country where large volumes of water were available. More recently, with improved technology and less available water, the impoundments and diversions have moved up the mountain. Today we are feeling the effects even at very high elevations on National Forest System lands. Trans-basin diversions have been known to deplete flows in some channels while overtaxing the capacity of other channels. The intensified competition for water has caused us to take a look at the quality and quantity of water left in our streams. This is not new--it has been going on for years.

Another reason we are looking at instream flows is because of our comprehensive land use planning program. It became obvious many years ago that there would not be enough land, water, and other resources to meet the various product and use needs of the American people unless some careful planning was accomplished. This includes an inventory of the resources on hand, suitability of the land and water for various uses, determining capability of the land to produce various products, and devising a scheme of achieving balanced management to meet those needs. Instream flow determination still needs a great deal of attention and refinement in our planning process.

A third reason for our deep interest in instream flows is the adjudication of water rights. In the West, a vast majority of the National Forest System lands were reserved from the public domain for National Forest purposes. When these lands were reserved, there was also reserved a bundle of rights, including the right to use the amount of water needed to meet the purposes of the reservation. I'll not go into the long list of purposes, but will mention a few for illustration. One purpose which requires instream water, which is of great interest to this group, is a viable fishery. In managing this resource we work cooperatively with the States, recognizing their responsibilities and authorities for managing the fish, while we have a responsibility for managing the habitat. In this cooperative venture, we are deeply concerned that adequate water of sufficient quality be sustained for a continuing quality fishery. Instream studies constitute an important ingredient of maintaining healthy fish populations. Other important purposes for which we claim instream flows include, but are certainly not limited to, recreation uses, esthetics, vegetation, and aquatic animals.

Most of the early work directed towards instream methodologies in the Forest Service was done by our fisheries people. We didn't have many fish biologists on the payroll in the mid-Thirties, but some Civilian Conservation Corps projects at that time were directed toward improving fish habitat. To improve the habitat, some guesses had to be made about the amounts of water required. Because of some of these small projects, flows of water have been maintained through the years which still support fish populations. These are important in places like the arid southwest.

For the most part, during the Twenties and following, efforts by developers were more directed toward diverting and impounding water rather than preserving flows. Several large power-generating projects were built in the early days in California and Oregon which paid little or no heed to instream needs below the diversions or impoundments. At the time, there were other places people could go for fishing, recreation, and other water-oriented pursuits. During this same period, large and small reclamation and other projects came on line which materially altered the regimen of streams throughout the West. Some of these projects directly affected streams within the National Forests. Others had indirect effects.

Following World War II, recreation impacts on National Forest lands began to grow by leaps and bounds. Float-boating, fishing, and other water-oriented activities grew even faster. With increasing demands on the diminishing resource, it became obvious that some techniques had to be developed to figure out how much water, and for what reasons, had to be left in our streams. Again, on a piecemeal basis, the fisheries people made numerous studies in an effort to restore damaged areas, minimize impacts, or mitigate losses from projects. Usually, within broad regional guidelines, individual biologists "did their thing" area-by-area. In the case of the Central Utah Project, the Forest Service conducted a multi-year study to determine instream needs on the

South Slopes of the Uinta Mountains. Numerous methodologies or modifications of methodologies were emerging.

At about the turn of the present decade, the State of Colorado began adjudicating all the waters in the State. The Forest Service is a party to the adjudications in every water division in Colorado. We were also involved in numerous other adjudications throughout the West. In attempting to quantify our claims for the courts, it quickly became evident that we needed a methodology which could be described and applied with some precision.

In the spring of 1973, we decided this problem needed National attention. A great deal more information than we then had was needed. We need specific facts about what is in the stream now, and what tradeoffs would occur at various levels of flow. We need to know about the fish, the esthetics, the plants and animals, and the recreation. This is not a job for one man. It requires an interdisciplinary approach. So we pulled together a team of experts in Reno in April 1973 to try and develop a methodology. We made it a joint effort by the Forest Service, Fish and Wildlife Service, and Geological Survey. State people were invited to participate, but they declined. Disciplines included on the team were fish biologist, hydrologist, landscape architect, forester, recreation specialist, watershed specialist, and economist. After two solid weeks of concentrated effort, we came out with a very rough draft proposal.

The first effort was given wide review. Numerous holes were discovered which needed plugging. A second team effort on a smaller scale was made in Washington, D.C. during the winter of 1973-74. After another review, we concluded that one methodology would not apply to all situations. It should be pointed out, however, that common needs should be met in any methodology for our purposes:

1. Flows must be quantified so as to satisfy the needs for various reaches of stream. It does no good to satisfy a flow at a given point if certain reaches are dried up below or above that point.

2. We must be assured that all appropriate uses are identified in the various reaches of stream, and needed flows are quantified for all.

3. The various uses and optimum flows must be displayed for analysis. Quite often, because of prior rights or for other reasons, we must settle for something less than optimum flows.

4. We must be able to measure and analyze the tradeoffs at various levels of flow.

5. It must be admissible in court and capable of presentation in such a way that it can be understood.

On National Forest lands, we are dealing heavily with first, second, and third order streams. Most development of methodologies by others appears to have been done on larger streams. In the Northwest, most attention has been given to anadromous fisheries. We have major concerns, as previously pointed out, with all sorts of other instream needs, as well as with a variety of fisheries.

Because of some shifts in personnel, our 1973-74 effort slowed down considerably, but is once again picking up steam. Although one methodology will probably not meet all situations, we believe we now have enough information to develop one or more which will meet the criteria I outlined earlier. You will be hearing about some of the current activities from other speakers during this symposium.

UNITED STATES FOREST SERVICE
STREAM SURVEY PROCEDURE - NORTHERN REGION

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ABSTRACT

Region One has employed an aquatic habitat survey procedure, briefly described herein, since 1968. The procedure appears to have merit for measuring physical aquatic habitat parameters on small streams and rivers. Correlation between aquatic habitat parameters and biological output is needed.

INTRODUCTION

The Northern Region (Region One) of the United States Forest Service (USFS) has employed a standard stream survey procedure since 1968. The survey is similar to a Region 4 procedure, which was developed a few years earlier. Survey efforts consisted of establishing transects perpendicular to stream flow, the reading of habitat parameters associated with each transect, and writing a narrative to describe habitat and management conflicts. Most surveys were conducted on streams subject to some type of land disturbance activity; the most common activity was timber harvest and its associated road building.

In 1972, the survey procedure was significantly modified and put into use on the Colville, Kaniksu, Kootenai, St. Joe, and Coeur d'Alene National Forests. The primary modifications were the development of an ocular survey component and the establishment of levels of survey intensity. The ocular component is concerned with the subjective interpretation of habitat conditions; levels of survey intensity refer to the survey effort required to justify its completion. Approximately 5,000 miles of stream in Region One have been surveyed employing the transect and/or ocular components.

SURVEY PROCEDURE

The procedure is concerned with inventory and analysis of physical habitat characteristics of wadeable streams and rivers. A considerable amount of detail is not included in this paper: detailed survey procedures may be found in the following publications and manuals: Herrington and Dunham (1967); Anonymous (1973); Anonymous (1975).

Two levels (I and II) of habitat sampling inventory may be employed. A level I survey is employed on streams that are directly affected by an activity which may require habitat monitoring or a reasonably accurate assessment of aquatic habitat; for example, litigation purposes would require a level I survey. A level I survey requires the establishment of transects and is statistically reliable at the 80% confidence level. A level II survey is employed on streams that do not require monitoring or statistically reliable figures; the establishment and reading of transects normally is not undertaken.

I. Office Preparation

A considerable part of the survey procedure involves office preparation.

A. Stream Identification - The stream system is identified and other data gathered from State, Federal, or other records. Items to be recorded include: survey unit, State, County, multiple use zone, etc.

B. Survey Maps - A one-inch or preferably a two-inch scale planimetric map or a USGS topographical map is required as part of the survey records.

C. Delineation of Survey Units - The stream system will be subdivided into individual survey units; e.g., West Fork Spokane River, East Fork Spokane River, etc.

D. Plotting Station Locations - Stations are reference points. Station locations will be marked on the survey map and aerial photographs. The station will be based on one mile intervals for those streams 30 miles or less in length and two mile intervals for those streams over 30 miles in length.

E. Watershed Condition Report - Each survey unit should be described by a short narrative report. The report should contain information on past, present, or future activities or happenings which have influenced or could influence the present status of the habitat. Some items to include are: range condition, recreation use, mining activity, timber sales, water quality, road construction, wildlife uses, flood history, etc.

II. Field Procedure

Field habitat surveys shall be conducted during periods when pool and water quality are critical, generally base flow periods. Base flow periods usually correlate with clear water periods which facilitate collection of stream channel measurements and provide the most safe working conditions. Sometimes an additional effort is necessary during high water to measure spawning habitat conditions.

A. Locating Stations and Transects - Once the station is located in the field, the field person will measure upstream a given distance to locate the first and succeeding transects.

B. Determining Number of Transects - Statistical reliability to the 80 percent confidence level is a requirement for habitat factor measurements associated with a level I survey. Normally, ten transects per station are sufficient. Accuracy can be increased and transect numbers decreased by computing habitat condition for stream stretches with similar geomorphic and hydrologic conditions. For example, a stream often consists of a steep upper section, a moderately steep middle section, and a relatively flat lower section. To increase accuracy, a separate set of habitat figures is computed for each section.

C. Locating Camera Points - Color photographs or slides are taken to record the type of bottom materials, streambank stability, discharge levels, and bank vegetation occurring at a particular transect. As a minimum requirement, one camera point should be established for each 10 transects and/or two stations and whenever geomorphic or hydrologic conditions change significantly.

D. Measurement of Habitat Factors Along Transect - The cross-section measurements will be made along a line projected at right angles to the stream bank.

1. Stream Width - The channel width and water column width will be measured to the nearest foot.

2. Riffle Width - Riffle width is the difference between the water column width and pool widths.

3. Average Depth - Average depth is measured along the tape 1/4, 1/2, and 3/4 the distance across the stream. Depth is measured to the nearest tenth of a foot.

4. Pools - Pools intercepted by the transect are rated.

a. Pool Quality Rating - Each pool will be rated as a class 1,2, 3,4, or 5 pool. A quantitative method for classifying pools is based on the following numerical ratings for pool size, depth, and cover.

(1) Size - Rate 3 if pool is much longer or wider than average stream width within 50 feet above and below the transect. Rate 2 if pool is about as long or wide as average stream width within 50 feet above and below the transect. Rate 1 if pool is much shorter or narrower than average stream width within 50 feet above and below transect.

(2) Depth - Rate 3 if deepest part of pool is greater than 3 feet. Rate 2 if deepest part of pool is between 2 and 3 feet deep. Rate 1 if deepest part of pool is less than 2 feet deep. Deepest part of pool does not have to be under transect line.

(3) Pool Cover - Rate 3 if pool has abundant cover. Rate 2 if pool has partial cover. Rate 1 if pool is exposed. Pool cover

refers to hiding places for fish, such as undercut banks, logs, boulders, choppy water surface, water depth exceeding 3 feet, etc.

b. Pool Class - Pool class is based on the total number of quality points for all three quality factors as follows:

Total Rating	Pool Class
8 - 9 points	1
7 points	2
5 - 6 points	3
4 - 5 points	4
3 points	5

The total of 5 points for a class 3 pool must contain 2 points for cover.

c. Pool Width - The width of that portion of the pool under the transect line is measured to the nearest foot.

d. Pool Location - Pool location is recorded as either right bank (R), left bank (L), or center (C).

5. Aquatic Vegetation - Aquatic vegetation is classified as either rooted (R) or clinging (C).

6. Stream Bottom Materials - Bottom materials are classified as either: organic debris, organic musk, clay, silt, sand, fine gravel (0.1 to 1.0 inches), coarse gravel (1.0 to 3.0 inches), small rubble (3.0 to 6.0 inches), large rubble (6.0 to 12.0 inches), and boulders (over 12 inches), or bedrock.

7. Bank Cover Rating - Streamside vegetation will be recorded for both banks extending 50 feet above and below each transect. Vegetation numerical ratings are:

a. Forested (2 points) - Stream bank is medium to heavily covered and shaded by tall trees and/or dense riparian vegetation.

b. Brush (1.5 points) - Stream bank is bordered or shaded by tall brush. Trees are not a dominating factor.

c. Grass and Low Brush (1 point) - Stream bank is medium to heavily covered with tall grasses and/or low brush.

d. Exposed (15 points) - Scattered low grasses or brush.

8. Bank Stability Rating - Bank stability is recorded for both banks by observing a distance of 50 feet above and below each transect. Bank stability numerical ratings are:

a. Bank Totally Stable (2 points) - No evidence of accelerated bank erosion.

b. Bank greater than 50% Stable (1.5 points) - Light erosion taking place during high flows on less than 50 percent of bank.

c. Bank Less Than 50% Stable (1 point) - Moderate to heavy erosion taking place. Conditions do not allow for bank recovery to proceed to 50% stability.

d. Bank Totally Unstable (.5 point) - Heavy erosion occurring over the majority of the bank length.

9. Gradient - Gradient shots are taken at least once per station stretch.

10. Velocity - Normally, one velocity measurement is taken per station.

11. Temperature - At least one temperature measurement per station is taken.

12. Ocular Component - Habitat factors which are not associated with a transect are observed and the information recorded. The ocular survey is conducted by observation of the whole stream length, including its tributaries. All streams rurveyed require an ocular survey. Factors to be recorded are:

a. Channel Obstructions - Migration barriers are marked on the survey map.

b. Channel Debris - Debris location which threatens to create migration blocks, or which may cause excessive erosion, are marked on the survey map.

c. Pollution - Type of pollution and its source are described and locations marked on survey map.

d. Potential and Active Erosion Sources - Contributing or potential contributors of sediments are marked on survey map.

e. Loss of Streamflow - Location and length of dry sections should be recorded.

f. Turbidity - Streams will be classified as clear (little or no suspended materials), milky (slight to medium turbidity), or muddy (heavy turbidity).

g. Beaver Activity - Locations and status of ponds (deserted or active) should be recorded.

h. Fish - Field notes concerning numbers, size, and species observed should be recorded.

i. Pool Quality - Figure 1 presents a guide for coding pool habitat. The code applies to all stream stretches observed or measured.

j. Trout Spawning Habitat - Figure 2 presents a guide for coding trout spawning habitat. The code applies to all stream stretches observed or measured.

k. Stream Bank and Channel Stability Characteristics - Stability characteristics should be gathered for the full length of a stream to determine stretches sensitive to changes in water flows. A Stream Reach Inventory and Channel Stability Evaluation Form is used for recording stability data. For a detailed description and explanation, refer to the 1974 publication, "Hydrologic Effects of Vegetation Manipulation, Part II" by USDA Forest Service, Missoula, Montana.

ANALYSIS OF DATA

Transect field data are divided into two categories and computated. The first category is termed Priority "A" Limiting Factors and includes pool frequency, pool quality, stream bottom materials, bank cover, and bank stability. The second category is termed Priority "B" Limiting Factors and includes average stream depth, average width, percent clinging vegetation, percent rooted vegetation, percent rooted vegetation, average stream gradient, average velocity, average water temperature, turbidity description, access, and pH.

The division of habitat factors is an arbitrary separation based on the premise that "A" factors are often more limiting than "B" factors. The "A" factors are computed into a numerical figure called "percent of habitat optimum". Changes in "percent of habitat optimum" reflect the condition of the physical habitat. Priority "B" factors are used to support conclusions in the narrative description.

Data collected utilizing the ocular component are analyzed and interpreted for inclusion into the narrative. If necessary, items i and k under Ocular Component #12 may be assigned ratings and computed into "percent of habitat optimum".

DISCUSSION

The procedure appears to work best on small, clear streams and rivers where it is easier to observe fishes and then deduce conclusions in regard to habitat parameters affecting fish species, size and numbers.

The procedure serves as a standard method. A limitation with a standard survey is that it does not provide the surveyor with techniques to be applied to special situations. A standard survey procedure should be a starting point from which to put continuity into the procedure and to establish a base for comparison among units surveyed. Special situations will require changes and/or additions to the standard procedure at the discretion of the surveyor or other knowledgeable persons. For example, the "Critical Area Method" (Isaacson, 1974) is utilized on those streams which are subjected to manipulated changes in discharge. It is desirable that the procedures employed have a history of use and acceptability.

A considerable portion of the procedure requires subjective input. Thus, a limitation which may appear is variability in ratings among field personnel. In all probability, such variation is small among trained personnel. Ratings on the same stream by different trained Northern Region personnel have varied little. There is very little disagreement in rating of pools, bottom materials, bank cover, and bank stability, all of which are important for determining overall habitat quality "percent of habitat optimum".

Cost is a concern. A level I survey is considerably more expensive than a level II survey. When utilizing a level I survey, it takes two man-days to complete the field work on 1.5 miles of stream. A level II survey takes two man-days to complete 6 to 12 miles of stream. There is little difference between the two levels concerning office preparation, analysis, or filing efforts. The narrative for a level I survey may take more time to write than a narrative for a level II survey because of political or social sensitivity which justified a level I survey.

Time is a concern, and time is cost as implied above. It is important that sufficient lead time be planned for gathering data to take advantage of the most desired conditions for which the survey is being conducted. Relevant parameters should be measured. It may not be sufficient to document spawning flow needs and then not consider rearing flows.

A significant aspect of the Northern Region procedure is the utilization of the ocular component. Those items dealing with pool quality and the hydrologic rating can be converted to "percent of habitat optimum." It is possible to employ the lengthy transect technique on those streams requiring statistical reliability and the less lengthy ocular component on less "important" streams and still relate to "percent of habitat optimum".

Although stream habitat data may be collected by a trained non-professional, interpretation of the data requires considerable knowledge about fishes and fisheries habitat. Interpretation should be accomplished by an experienced fisheries biologist. Also, it should not be overlooked for whom or what the data are being collected. To collect and interpret data for a casual evaluation may not require a level I effort; however, data collection and interpretation to be used in litigation, for example, would require a level I effort for sufficient documentation and accuracy to be acceptable to the court.

Interpretation of habitat parameters relies on observations, measurements, deduction, and analysis. Part of the analysis includes computation of priority factors (pool-riffle ratio, pool quality, streambottom materials, bank cover, and bank stability), which are represented by the phrase "percent of habitat optimum."

"Percent of habitat optimum" may be a valid concept concerning the relationship between discharge and physical habitat at base flow periods. Dunham and Collotzi (1975) noted a relationship between discharge and "percent of habitat optimum" for streams in the Central Utah Water Development Project.

For one stream it was determined that at 50 percent of base flow discharge, a distinct break occurs after which habitat rapidly degrades as discharge is further reduced. "Percent of habitat optimum" was reduced 25 percent as discharge was reduced to 50 percent of base flow.

Relationship between discharge and "percent of habitat optimum" has not been worked out for Northern Region streams. "Percent of habitat optimum" may have local or regional value, but a standard figure or acceptability of habitat degradation from one regional entity should not be extended into regions where the relationship between discharge and "percent of habitat optimum" has not been established.

Although it appears to be valid to relate discharge to "percent of habitat optimum" for base flow periods, biological outputs such as fish production, carrying capacity, and species size, numbers, and composition have not been satisfactorily related to "percent of habitat optimum". Numerous papers exist that describe the significance of habitat factors such as water depth, gravel size, water velocities, pool cover, water temperature, etc., to biological production. However, "percent of habitat optimum" does not take into account sufficient information to consistently handle variables affecting biological outputs. It is probable that "percent of habitat optimum" has value when comparing habitat extremes, but the author feels that "percent of habitat optimum" is not a valid tool as now computed for determining relationships among discharge, physical habitat, and biological output for small to moderate manipulations in stream flows. Expansion of the "percent of habitat optimum" concept to include more variables, including social variables such as fishing pressure, and to be responsive to specific values such as spawning value, nursery value, and cover value may make it a valid concept.

If a significant correlation among discharge, biological output, and "percent of habitat optimum" can eventually be determined, benefits would more easily be quantified and intended water use maximized.

Rating

Above Average

G-1. One or more class one pools per half mile with at least 35% of stream area in class one, two and/or three pools, and to include at least two classes of above pools, but not to exceed 70% of total area.

G-2. One or more class one pools per half mile with at least 35% of stream in class one pools, and total area class one pool not to exceed 65-70%.

Average

F-1. Class one, two and/or three pools exceed 70% of total stream area per half mile.

F-2. Stream area consists of 20-35% of class one pools; no class two or three pools per half mile.

F-3. Class two and three pools comprising 35% or more of stream area; no class one pools per half mile.

F-4. Stream area consists of 20-35% of class one, two and/or three pools with at least two of the above pool classes represented per half mile, including at least one class one.

Below Average

P-1. Stream area consists of a combination of class one, two and/or three pools with at least two pool classes represented and total area of above pools not to exceed 10-20% per half mile.

P-2. Two or more class two pools present per half mile, not to exceed 10-20% of stream area; no class one or three pools.

P-3. Two or more class three pools per half mile, to include 20% or more of stream area; no class one or two pools.

P-4. One or more class one pools per half mile, not to exceed 10-20% of stream area; no class two or three pools.

Well Below Average

V-1. Class three pools comprise less than 20% of stream area per half mile; no class one or two pools.

V-2. Less than 10% of stream per half mile in class two and/or three pools; no class one pools.

None

N-1. No class one, two, or three pools per quarter mile started.

Fig. 1. Pool Quality Rating

Rating

Well Above Average

1. 50% or more of channel bottom material in 3/8" - 2" gravel size in areas of one square foot or more.

2. Sufficient velocity (.5 to 20 cfs) to provide oxygenation of gravel area.

3. Cover in area of gravels total to partial.

Above Average

1. 20 - 50% of channel bottom material in 3/8" - 2" gravel size in areas of one square foot or more.

2. Sufficient velocity (.5 to 2.0 cfs).

3. Cover in area of gravels at least partial.

Average

1. 10 - 20% of channel bottom material in 3/8" - 2" gravel size in areas of one square foot or more.

2. Sufficient velocity (.5 to 2.0 cfs).

3. Cover in area of gravels partial to scattered.

Below Average

1. 1 - 10% of channel bottom material in 3/8" - 2" gravel size in areas of one square foot or more.

2. Sufficient velocity (.5 to 2.0 cfs).

3. Cover in area of gravels scattered to poor.

None

NOTE: Look closely at cover quality and siltation potential. These factors must be considered and noted with ratings.

Fig. 2. Spawning Quality Rating

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DETERMINING INSTREAM FLOWS USING THE SAG TAPE METHOD AND R2CROSS X COMPUTER PROGRAM

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ABSTRACT

The procedure currently used by Regions One and Two of the U.S. Forest Service for determining instream needs for different ecological considerations is described. A description of the two computer programs: Sag-tape and R2cross X, that are used by this procedure, is included. Also explained are alternative methods of selecting field stations, along with a procedure for collecting field data in the appropriate manner for computer use in analyzing and interpreting back at the office. This presentation is an informal discussion of techniques now available with the emphasis on interchange between speaker and audience.

Today we are briefly describing the method used in Region One and Region 2 of the U.S. Forest Service for determining instream flow hydrologic data. This method consists of 2 main procedures; one - the field work utilizing either level and rod or the sag-tape method. The second is the analysis and interpretation available using the R2cross X program. I will discuss the field procedure utilizing the sag-tape, and Lee Silvey, Regional Hydrologist of Region 2, will discuss the R2cross X computer model.

Let us suppose that you have been given the task of determining the flow values needed for a complex reach of a stream or river, or maybe it is as much as 250 different streams and not much time, let's say 6 months, to work on the problem. Where do we start?

I believe the starting point is with the other disciplines; fisheries, aesthetics, natural beauty, ecology, etc. Can they tell you the needs and changes in values as flow is drawn off or removed. Can they give you a cutoff point where the value drops to zero. We will work out the hydrology to give them answers in cfs of flow needed to meet their specifications.

We now have the project ahead of us and have already conferred with the other specialists. For example: let's say this is an important fish spawning and rearing stream for large trout. Our Fishery Biologist states that the very minimum depth of water in the thalweg at any time during migration and spawning must be .5 foot. In this case Jim Cooper is the Biologist, he will explain the procedure used for determining the depths needed later this afternoon.

Now we are beginning to pull together a few items. We can now make some basic assumptions for determining flow requirements.

1. We have a project to complete with time for one field visit.
2. The minimum depth required for fish survival is .5 foot at some point in the cross section profile.

How do we relate a depth figure to flow values and where is the key depth figure needed? This is where the Hydrologist comes into the picture.

Our procedure begins with an office examination of the area on the most recent aerial photos available, preferably during a period of low water. In our area we are lucky with this - most of the aerial photo flights are during the August-November period or during our season of low flow. From the photos the different reaches of stream can be determined. This is usually a function of slope gradient and should show up with different meander patterns, width-depth ratio, meander lengths, radius, etc.

A good reference to study for this type of determination is "Fluvial Processes" by Leopold, et al.

First, divide the stream into homogeneous reaches - you may be lucky, the area under study may be all the same category. Now examine each reach individually. Pick out the key riffle areas to look at in the field. Look for length of the riffle, width-depth ratio in relation to the rest of the stream.

We are now ready to venture into the field and pick out the key riffles. If the fishery survey is completed, the riffles to study may already be defined and outlined by the Biologist completing the ocular fish habitat survey. Again, this will be explained later by Jim Cooper.

Now, a determination as to which riffle areas are the key to field measure. Having completed this decision, we are ready to make our field measurements. We must ask ourselves, "If the water is deep enough on this riffle, may we assume it will be on all others?" If not, we must pick another one that meets this test.

We establish transects to get a good accurate cross section at the riffle area. We should establish at least two and preferably three cross-section transects through the shallowest portion of the riffle. We use the sag-tape method. An alternative would be the level and rod method of surveying the cross section.

Sag-tape Method

The sag-tape method of channel cross-section measurement, developed by C.A. Shumway, is a simplified method for measuring and recording changes in stream channel cross-sections. Previously these types of measurements involved the use of surveying equipment, 2 - 3 men, and considerable time and effort. The sag-tape technique requires only a steel engineer's tape or chain, a measuring rod, two stake fasteners, a small spring scale and tape clamp, a data form; and can be conducted by one man in about 1/5 of the time required for the old level and rod method.

Presently there are at least three computer programs available which utilize sag-tape data. They include "Debris" and "Plot-D" along with the R-2 "cross" program developed in Region 2. The first two are utilized for calculations of sediment volumes, as in a series of transects or cross-sections in a debris basin. The programs provide a printout of the channel as well as before-after sediment volumes and/or cross-section areas. The R2-cross X is a refinement that Lee will discuss.

Field Measurements

There are two rules we must follow in setting up our transects to get correct readings.

1. We must establish the transects parallel to each other and perpendicular to the flow.

2. We must establish the tape with the tops of the end stakes level. An abney or hand level is adequate.

The procedure goes in the following steps:

1. Establish stakes with tops level above the high water line. R-2 has established self leveling stakes.

2. Slip on pipe clamps.

3. Stretch and clamp the steel tape with enough tension to give 5 pounds plus one pound for each 10 feet of transect lengths.

(Note: The computer will correct for depth errors due to tape sag if it is given the weight of the tape; the length of tape across the transect or cross section, and the tension in pounds on the spring scale.)

4. Depth measurements are now taken from the tape to the ground surface or channel bottom and recorded in feet and tenths. (Note: look at Figure 2.) The first and last measurements are always taken at the cross section stakes. Measurements may be taken along the tape at fixed or variable intervals. There should be adequate measurements to show the shape of the stream bottom as the computer will reconstruct the profile as a series of straight lines. (Look at Figure 2 - the dotted lines).

5. While recording this data, mark the high water mark on the field forms and the water intersect on each side of the cross-section.

6. While the tape is stretched take an accurate measurement of the streamflow. This is used later in the cross x program to estaglish Mannings N. Use your current meter and take several measurements along the tape using the prescribed USGS method for determining flow measurements.

7. A measurement of the slope of the water must be taken now to be used in the calculations later.

8. We have also collected rock samples from the stream bottom to be measured later for determining Mannings "N". We statistically pick up samples across the section by selecting a set distance like each even foot on the tape and picking the rock below this point to be measured.

Complete the above steps for each transect determined earlier and at each key riffle area.

Lee will now show you how to take the field date we have collected and turn it into a useful tool through analysis using the R2cross X program.

Components and Arrangement of Sag Tape Kit
(photos - following page)

1. Pipe - Tape Support: Slides over transect stake; constructed locally from 3/4 inch water pipe, pipe cap, 1/4 x 2 inch stove bolt with nut, and series of washers which act as a "bearing" and clamping surface for the tape end, and wing-nut.

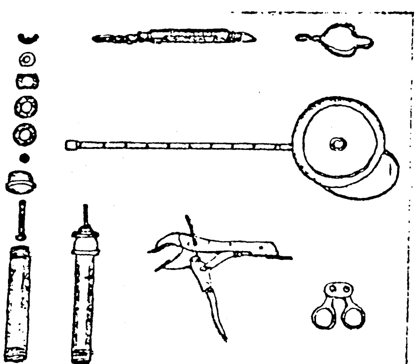
2. Scale: Item shown is a "K&E" Tension Handle, #89-1071, 30 lb. or 15 kg. capacity.

3. Wire Handle for Scale: Designed locally from #9 phone wire, to fit readily over pipe-tape support.

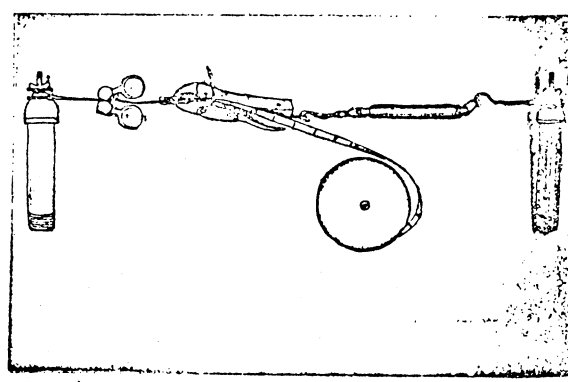
4. Gripping Pliers: Item shown is a 6 inch "Leversrench", automatic adjusting for tension or jaw pressure, manufactured by "Leverwrench" Tools, Inc., Glenvil, Nebraska 68941. A "vicegrip" type pliers works equally well.

5. Clamping Handle: From K&E, #89-1098, for pulling up steel tapes, especially when working in cool weather without gloves and tape lengths greater than 15 feet.

6. Tape: Item shown happens to be a K&E product, "Stevens Wyteface A"; 100', #86-0124, with end fastener, and measurements starting at tip of ring on 0 - end of tape.



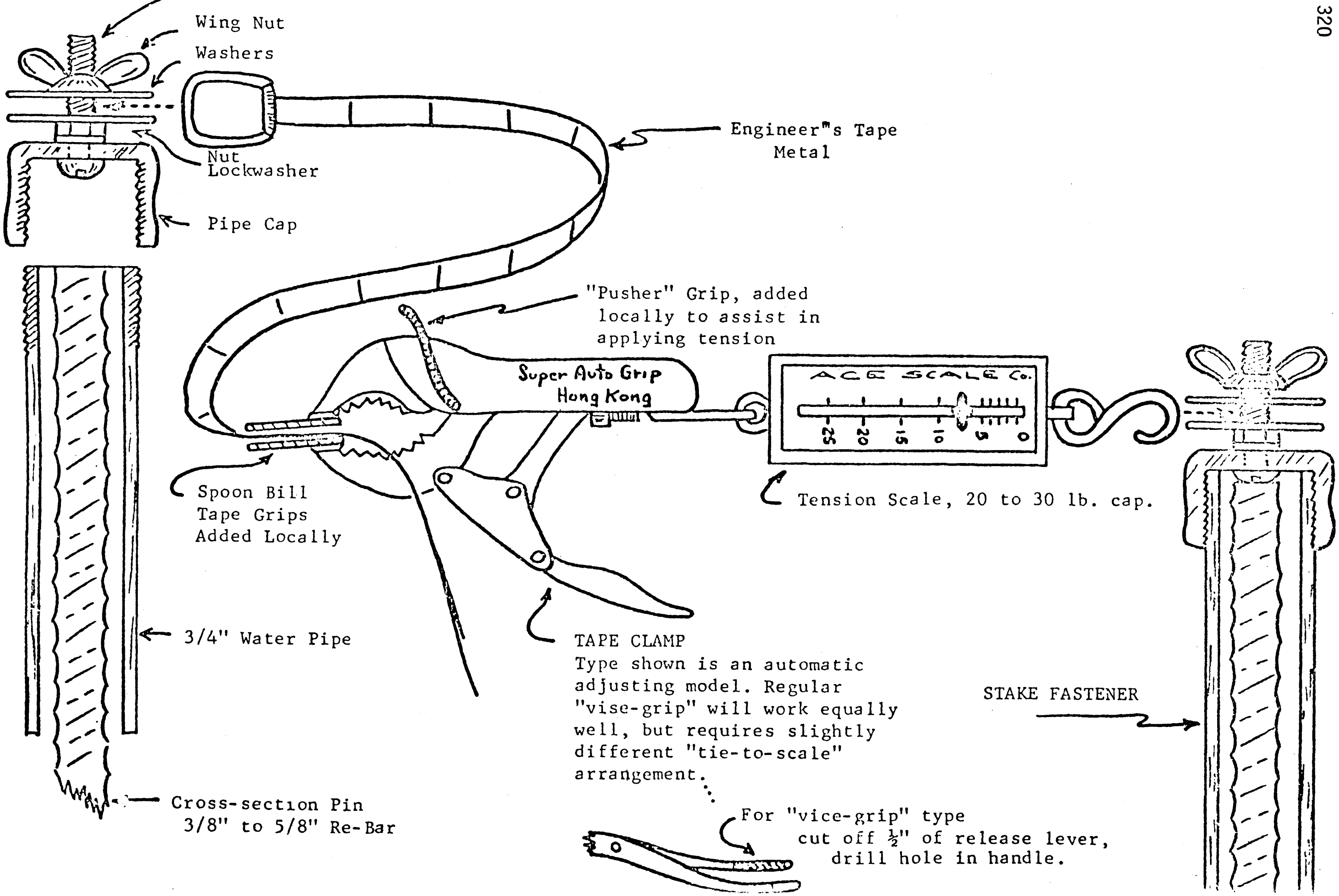
Components of Sag Tape Kit



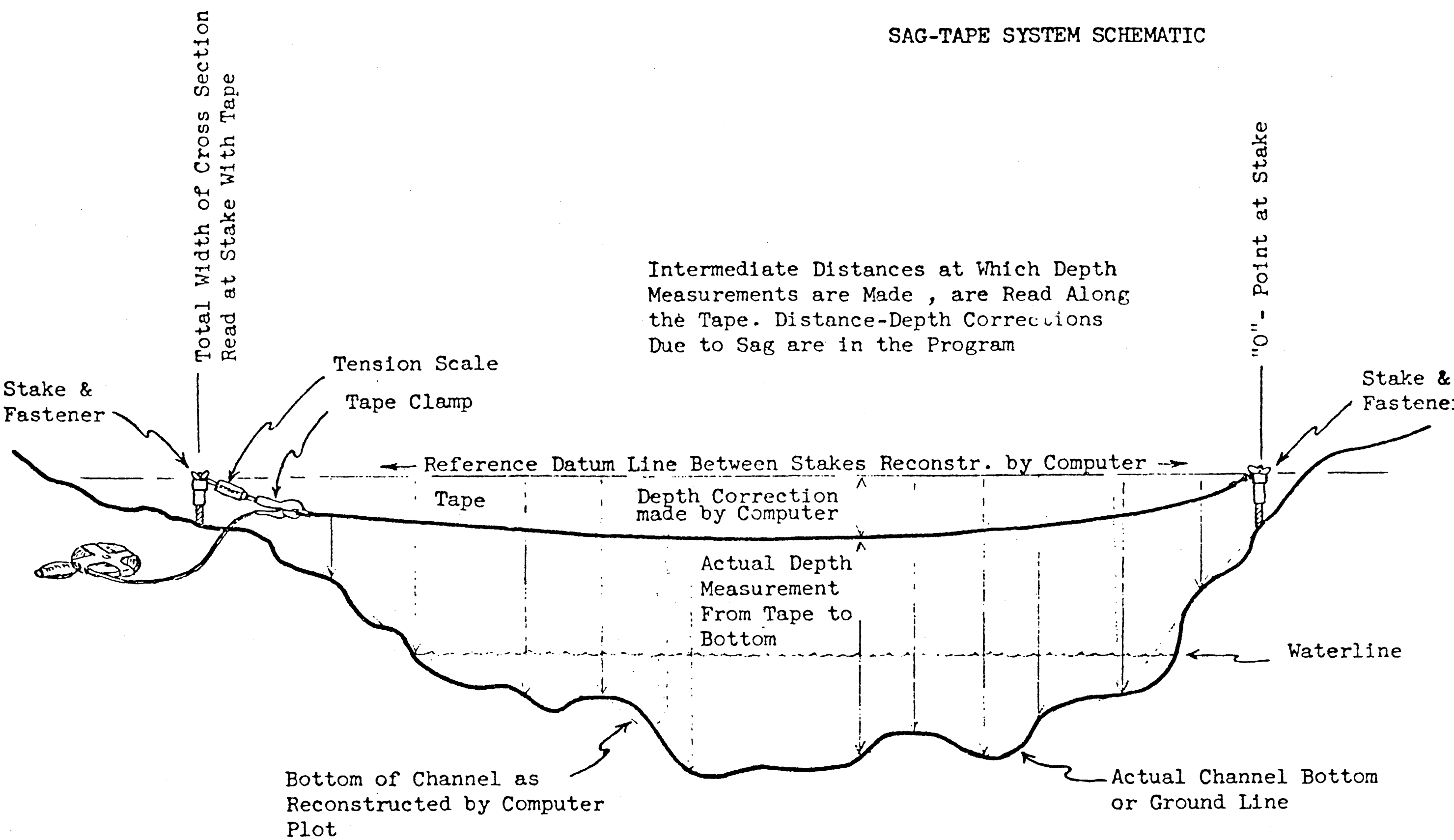
Arrangement of Sag Tape Components

Note: The above apparatus was designed to be used in collecting field data for DEBRIS and PLOT D which are computer programs for determining cross sectional areas of stream channels and volumes of Debris collection basins.

SUGGESTED SAG-TAPE EQUIPMENT SET UP



SAG-TAPE SYSTEM SCHEMATIC



ESTHETIC CONSIDERATIONS FOR INSTREAM FLOW DETERMINATION

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ABSTRACT

Consideration of esthetics in land management activities has become an important factor. When considering instream flow, especially for adjudication purposes, ethetics must be included just like hydrologic, fisheries or any other aspect which will be affected by an altered stream flow. To do this, a methodology which is simple with quantifiable results is a necessity. This methodology must be based on the established natural flow pattern of any stream and the effect which either lowering - adding water will have on the stream from the esthetic standpoint. A basic inventory of stream as well as characteristic landscape features will be a key in visualizing how the stream and the riparian vegetation will be affected by the different water flow levels. Based on this information, the flow level which is acceptable from the esthetic standpoint can then be selected and considered with the acceptable level for fisheries and hydrologic aspects as well as any other consideration to determine an overall acceptable water flow level.

INTRODUCTION

Esthetics has become a major consideration for all of our land management activities. This consideration is especially important for all projects which deal with the alteration of any part of our landscape. Planned stream flow changes therefore must be given special consideration from the esthetic standpoint. "Esthetics" as defined in Webster's Seventh New Collegiate Dictionary is: "A branch of Philosophy dealing with the nature of the beautiful and with judgements concerning beauty." I propose that we can make judgements concerning esthetics based on a thorough inventory and a methodology which is simple and quantifiable.

ESTHETIC CONSIDERATIONS

Basic Assumptions

A. The effects of stream flow changes are evident to people who are:

1. Observing the stream.

2. Using the stream.

Since approximately 87% of our perception is through seeing, this methodology will concentrate on the visual aspects. The other four senses of hearing, smelling, touching and tasting will be discussed where they become a major part in how people experience the water flow in streams and any changes that take place when this flow is altered.

B. The evaluation of flow changes from the esthetic (visual) standpoint will be based on the concepts, elements and principles set fourth in Volume One of National Forest Landscape Management and the Visual Management System which is Chapter One of Volume Two of the same publication series.

C. There are two major visual impacts which are caused by stream flow changes that need to be considered:

1. The visual impact on the stream channel itself.
2. The ecological changes in areas which are directly dependent on the stream and the associated water table.

D. The stream is part of a characteristic landscape. Its importance will have to be determined based on Volume One and Two of National Forest Landscape Management Publications.

Inventory

Based on these assumptions, there are six specific categories of inventories to be made.

1. Flow Season.
2. Streambed configuration and Composition.
3. Streambed Gradient.
4. Special Features within the Streambed.
5. Riparian Vegetation - Ecosystem.
6. Landscape Character.

Flow Season

Since flow seasons vary considerably with the different localities, they should be determined for the different regions of the country.

There are three basic flow seasons which need to be considered in Colorado, Wyoming and South Dakota.

1. High Flow Season - May to Mid-July.
2. Normal Flow Season - Mid-July to Mid-September.
3. Low Flow Season - Mid-September through April.

All streams have established a certain flow regime on which the cycle of vegetative growth as well as the terrestrial and aquatic life regime is dependent. If the flow is altered during any of these three flow seasons for an extended period of time, then the riparian as well as the aquatic regime will change. The type of change that takes place form the ecological standpoint is not easily predicted and more research is necessary in this area to predict ecological changes more accurately.

The visual impact will depend on the severity of the change.

The seasonal flow has to be used as a reference to base judgements on how a stream would appear from the visual standpoint at different times of the year. For example, if a stream is dry or at very low flow during the high or normal flow season, it must from the esthetic standpoint be considered as a minus deviation and therefore is a discordant feature in the natural landscape. If this is recognized, then adjustments must be made seasonally to increase the flow to a point where it is considered adequate from the esthetic standpoint or visually acceptable.

Streambed Configuration

There are two aspects to be considered from the streambed configuration standpoint. One is the cross-sectional shape of the streambed and the other is the composition of the materials making up the surface of the streambed.

There are three basic streambed cross-sectional shapes.

1. The "V" Shaped Channel. (See Figure 1)

   The results of lowering water flow in the "V" shaped channel are exposure of stream banks and decrease in water surface. The visual impact will have to be analyzed with each specific situation.

2. Streambed with vertical sides and flat bottom. (See Figure 2)

   From the visual impact standpoint this channel is the one that will show the least visual impact until the flat bottom is exposed. The premise is that the vertical sides are no more than half as high as the channel is wide and that the streambed bottom is fairly even with only occasional large rocks.

3. The shallow bowl-shape streambed. (See Figure 3)

   From the visual standpoint this type of stream channel will create the highest visual impact when the water is lowered. The reason for this high visual impact is two-fold. First the shallow shape of the streambed contributes to the exposure of a large amount of streambed as the water is lowered. Secondly this type of streambed is usually found on fairly flat ground, thus it is visible from the distance.

Naturally there will be many variations to these shapes; however, from the visual standpoint, they will all relate to either of these three basic shapes. In general, the visual impact is mainly caused by the exposure of dry streambed as the flow level of water is lowered. Thus, the more shallow the streambed is the more visible the exposed streambed will be.

The "V" shaped channel and the channel with vertical sides and the flat bottom will expose less dry streambed when the water level is lowered.

Streambed Composition

Another aspect that is very important in the stream channel analysis is the composition of the materials which make up the streambed above the solid stream bottom line. There are three basic combinations of stream bottom material compositions which will show different results from the visual appearance standpoint as the water level in a stream is lowered or raised.

1. Smooth with sand, solid rock or small gravel up to three inches in diameter. (See Figure 4)

   The water level can be lowered considerably before the stream bottom material is exposed. From the visual standpoint it will take less water to be acceptable. The water surface will have minimal variety.

2. Smooth with sand and gravel up to one foot in diameter. (See Figure 5)

   If the water is lowered to a point where it will just expose some of the tops of the rocks, it is acceptable during low flow or normal flow. Actually the exposure of some of the rocks would create variety and thus enhance the stream from the visual standpoint.

   If the rocks in the water are numerous and all approximately the same size, close to one foot, then a water level six inches or lower would make the water visually subordinate. Unless this occurs at the low season, this flow would not be considered normal.

3. A mixture of the above with boulders up to three feet or more in diameter. (See Figure 6)

   With this type of streambed a much higher level of water is needed than in the other two examples to make the water visible. The exact level will have to be determined on a case-by-case basis.

In general it must be assumed that the rougher the stream channel material composition, the more water is needed from the visual standpoint. The overall composition of the streambed will have to be analyzed and the most critical areas found so that the correct water level can be determined.

Stream Gradient

The steeper the stream gradient the faster the water runs and the faster the water runs, the more visual and noise effect is created. Thus in comparison to a stream with a low gradient a high gradient stream can be more visually pleasing with less water because of the water's movement and the noise effect created.

It can then be concluded that from the visual standpoint the lower the gradient the more critical the stream is. Low gradient areas within the different stream reaches will have to be identified to aid in the evaluation of the entire stream.

Special Features within the Streambed

When inventorying a stream, special features such as waterfalls, cascades, rock formations, or any other type of feature which is out of the ordinary should be noted and described in detail. The visual analysis must be made on the effects of raising or lowering the waterflow in the stream. The special features in streams are most sensitive because they are the features that attract people. When inventorying streams, these features must be identified as critical and any change in waterflow must be thoroughly analyzed.

In addition to those features in the streambed, we have those that are dependent on the waterflow in the stream but are not part of the actual streambed. Examples in this category would be lower ponds, wet meadows and swamps or bogs. Considerable research will be necessary to determine what the effects on these areas are if the water is decreased or increased.

Stream Reaches

To aid in the overall analysis of a stream, those portions of the stream that have similar visual characteristics should be identified. Generally the stream reaches for fisheries or hydrologic aspects will coincide with the stream reaches that are identified from the visual standpoint.

The most critical reaches can then be identified so that stream flow studies can be initiated to determine how much water is adequate from the visual standpoint.

Riparian Vegetation - Ecosystem

The effects of waterflow changes will eventually be reflected in the reaction of the riparian vegetation. Most of the time the effects on the vegetation will be minimal. Usually vegetation will adapt to the change. However, there are those instances where the effect on the vegetation is major and usually reflected in a negative visual impact caused by dying trees and shrubs as well as other low vegetation. If major vegetative changes take place, habitat for wildlife will change as well as the overall ecological makeup of the area. As previously mentioned, research will be necessary to determine what the actual effects of raising or lowering water will have on the ecological makeup of the affected area.

Landscape Character

From the visual standpoint it is a key to determine how important a feature the stream is in the landscape. The more prominent the stream is, the more of a focal point it is and therefore any change that occurs in flow will be more visible. This is directly related to the attraction that water represents to people from the recreation as well as esthetic standpoint. The analysis of the landscape should be done based on the system in Volume One and Chapter One of Volume Two of National Forest Landscape Management.

Inventory

Natural Physical Features; streambed configuration, streambed composition, stream gradient, average flow volume for each flow season, riparian vegetation, waterfalls, cascades, tunnels, and other special features that might occur in different situations.

Man-made features, present and planned; roads, trails, campgrounds, picnic grounds, beaches, boat docks, stream improvement structures such as small dams and gabions, bridges, overlooks, fishing docks, and other man-made features not mentioned here.

This inventory should be made for every stream. Special features should be located on either a map or aerial photograph. Stream reaches should be established at the time of the inventory. Tributary streams should be located and volumes of water indicated for the different flow seasons.

Analysis

Based on the inventory, the data can be analyzed and the critical sections of the stream identified. Usually critical stream reaches will be identified, however at times the critical water flow point might be directly related to a special feature such as a waterfall.

If there is already a diversion existing then the water flow above the diversion should be used for analysis. Conditions below the diversion should be described with the amount of released water indicated.

Stream Flow Determination

Use the average seasonal flow as a basis to compare any reduction or increase in flow. Establish cross sections at critical stream reaches or at special feature areas.

Use Manning's Equation to compute cross-sectional areas for different flow volumes and describe the effects each will have from the visual standpoint. Select a range of flows from adequate to fully satisfactory from the visual standpoint and also determine the flow volume which will not be adequate.

Inadequate stream flow could be related to a declining water table with detrimental effects on riparian vegetation or the ecological makeup of the stream environment or visually to a flow which is much different from the flows of all other streams in the area. The final determination will have to be based on each situation taking all factors into consideration.

Conclusion

Enough factual information can be gathered for each stream to determine where the critical areas are from the esthetic standpoint. By being able to compute cross-sectional areas for different flow volumes through Manning's Equation an array of visual effects can be portrayed and described to determine the adequacy of specific flow levels from the esthetic standpoint. Combined with the fisheries and hydrologic aspects these findings can be used to determine a flow level which will be satisfactory for all circumstances.

Fig. 1. The "V" Shaped Channel

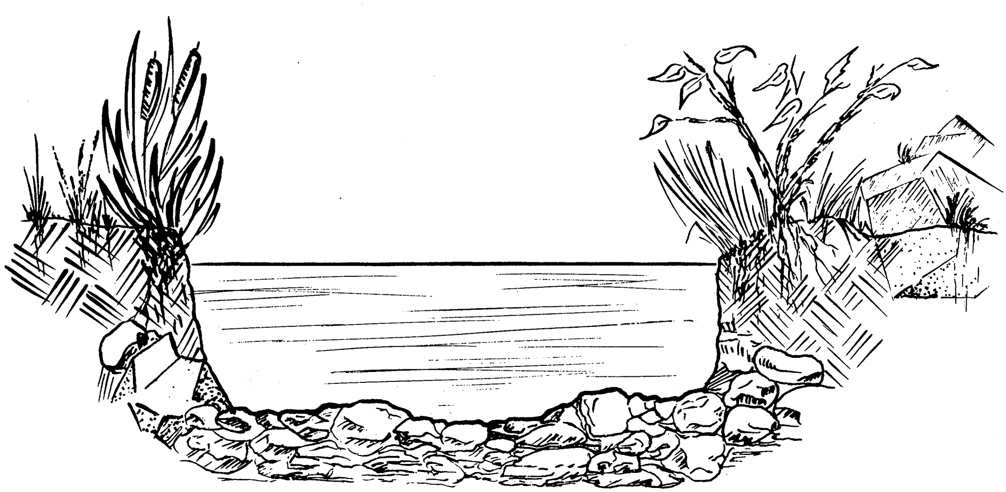

Fig. 2. Streambed with Vertical Sides and Flat Bottom

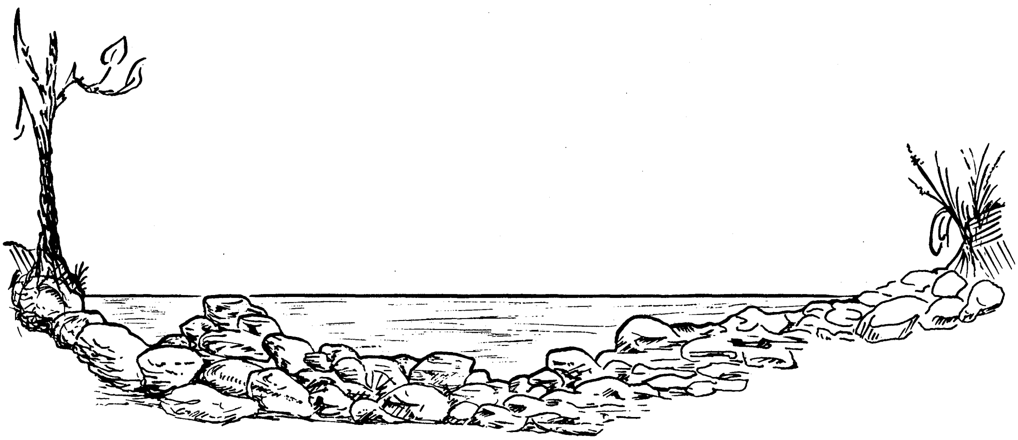

Fig. 3. The Shallow Bowl-Shape Streambed

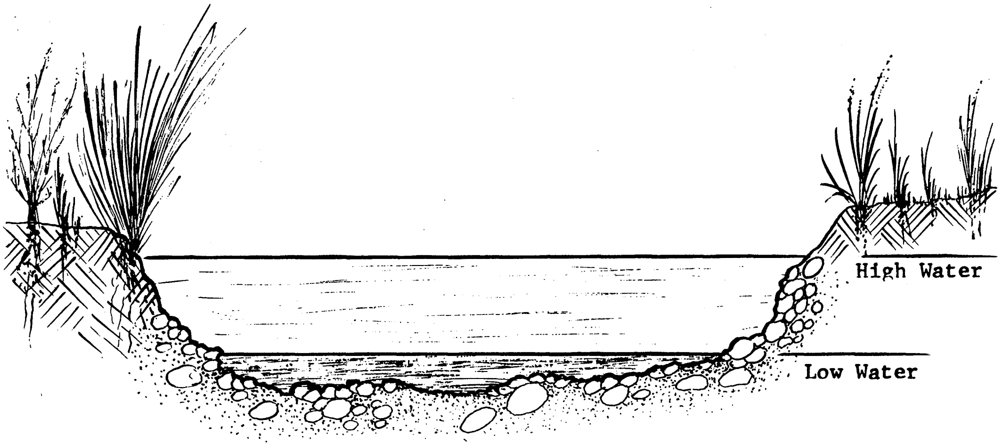

Fig. 4. Streambed Composition--Smooth with Sand, Solid Rock, or Small Gravel up to 3" in Diameter

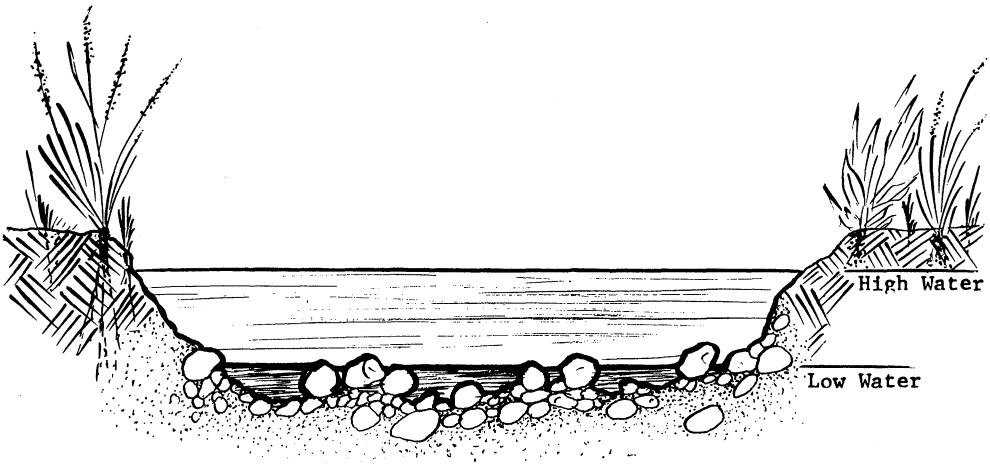

Fig. 5. Streambed Composition--Smooth with Sand and Gravel up to One Foot in Diameter

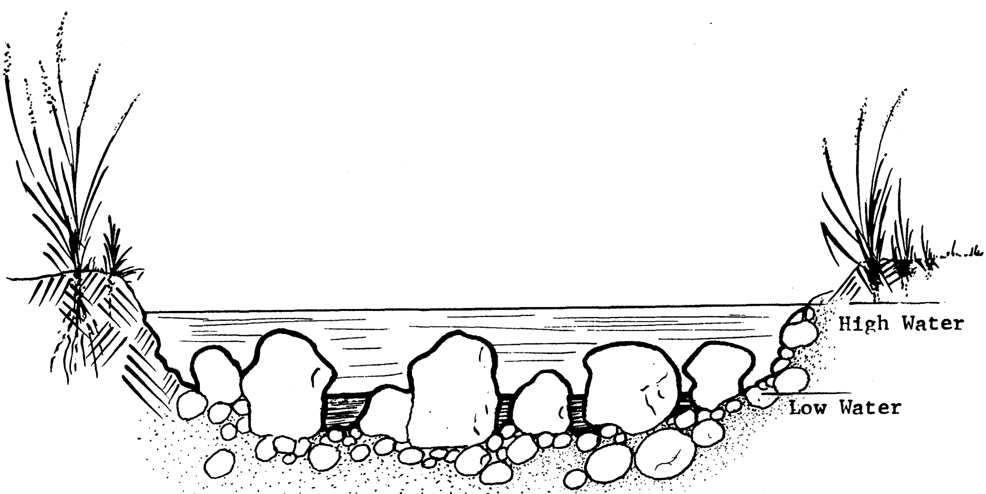

Fig. 6. Streambed Composition--A Mixture of Sand, Gravel and Boulders up to Three Feet or More in Diameter

sites (that meet site requirements) already exist without a lengthy calibration period of various flow conditions.

3. The same basic procedure can be used either for sophisticated needs (e.g., legal action) or for broad purposes (e.g., land use planning).

4. The procedure is easily usable by others than just those trained in hydrology and fisheries.

Disadvantages

1. Unless the stream is or has been gaged, carefully scheduled visits to the site over a range of flow conditions (usually a year) is needed to adequately define the curve.

2. Where existing gaging station flow measurements are used, it is important to select those measurements that were taken at the exact same channel cross-section, otherwise the measurements are often not comparable and may produce inconsistent results.

3. Depending on channel hydraulics several bell-shaped curves can result if excessively high flows are used. For example, the amount of usable width for rearing usually increases as flow increases up to a point where velocities become excessive, which causes the usable width to decrease. As the flow continues to increase, water spills into the flood plain and additional width of suitable depth and velocity becomes available. This causes a second bell-shaped curve. From a practical standpoint, flows that exceed the capacity of the channel are not included in the optimal flow recommendations. When this occurs, there are usually other overriding factors such as quality, accessibility, etc., that rule the subsequent peaks out as an optimum flow.

4. While a flow duration curve is not an essential tool of this procedure, it is helpful to characterize streamflow in this way. However, it is often difficult to develop such curves for ungaged or short-term stations.

CASE STUDIES

North Fork Crooked River

The North Fork of Crooked River is a typical "eastside stream" which gets quite low in the summer and high during the spring (flows have varied from 1500 cfs - <1 cfs). The North Fork supports a resident rainbow trout fishery.

Three types of stream sections were selected which represented the various fish habitats found in the river. A measuring site representative of each section was selected and measured at three different flow conditions -- high, low, and near average on 5/29/74, 10/13/73, and 6/18/74 respectively. (See Figures 1-8.)

A flow duration curve was made based on past stream gaging records.

From the graph (Figure 9), 35-40 cfs is the maximum desirable flow for fisheries at all three stations. This flow (as shown on the flow duration curve - Figure 10) is exceeded about 45-50% of the time under normal unregulated conditions. If, for some reason, one had to settle for less than the maximum, then the loss in habitat can be estimated. For example, a reduction in rearing flow from 35-40 cfs to 5 cfs results in a habitat reduction of 14 usable width to 9 feet (or about a loss of 35 percent). Whether habitat loss can be equated to numbers of fish is questionable. However, the assumption is made that habitat loss is proportional to fish production loss. Gross observation indicates this is true, but it has not been experimentally demonstrated using the criteria.

Williamson River

The Williamson River is a flat gradient, spring-fed stream of fairly constant flow. It supports a resident trout fishery.

Sixteen flow measurements from an existing gaging station on the Upper Williamson River, plus two field measurements by the Forest Service, were used to construct the curve (Figure 11). Flows varied from 62 cfs - 214 cfs. Not all the measurements were made at exactly the same channel cross-section nor was the stream reach typical of all the fish habitat criteria. However, a field survey indicated the optimum flows determined at the gaging station were reasonable for other sections of the stream. Other stream reaches have since been selected to verify this evaluation.

Figure 11 illustrates that there is a second peak for rearing flow criteria which is discounted because of hydrologic phenomenon discussed previously.

Optimum flow can vary, depending on criteria, from 60-90 cfs. If rearing habitat were the most important and because habitat is reduced greatly at 90 cfs, the optimum flow in this instance might be closer to 60 cfs.

A flow duration curve (Figure 12) constructed from two years of record and adjusted for long-term records indicates that 60 cfs is exceeded 75 - 97% of the time.

INTERPOLATION

The procedure described can be used to predict optimum flows for ungaged areas pending more detailed field investigation. Such a procedure might be particularly useful for broad land use planning purposes, for example.

Approximately sixty existing U.S. Geological Survey stream gaging stations in Oregon have been tentatively analyzed in an attempt to develop a relationship between optimum flow and mean annual flow. Then, if a relationship does exist, optimum flows can then be predicted for ungaged areas by estimating mean annual flows by various hydrologic techniques.

Five streamflow measurements for each station covering the range of measured flows were used, trying to use the same channel cross-section measuring site where possible.

The sixty stations were stratified by broad physiographic areas within the State and analyzed using the criteria and procedure described in this paper.

Preliminary analysis indicates that:

1. For the Blue Mountain area of eastern Oregon the optimum flow is about 60% of mean annual flow.

2. For the Wallowa Mountain area of eastern Oregon the optimum flow is about 90% of mean annual flow.

3. For the west slope of the Cascades in northern Oregon, the optimum flow is about 100% of mean annual flow.

As of this date, the data has not been completely analyzed and there is obvious need to have additional stations and other flow measurements but there does appear to be a relationship between optimum flow and mean annual flow for certain areas -- at least enough to merit further evaluation.

Fig. 1.
North Fork of Crooked River (Oct., 1974).
Flow = 2.5 cfs.
Steeper gradient section.

Fig. 2.
Same point on North Fork of Crooked River (June, 1975). Flow = 520 cfs.

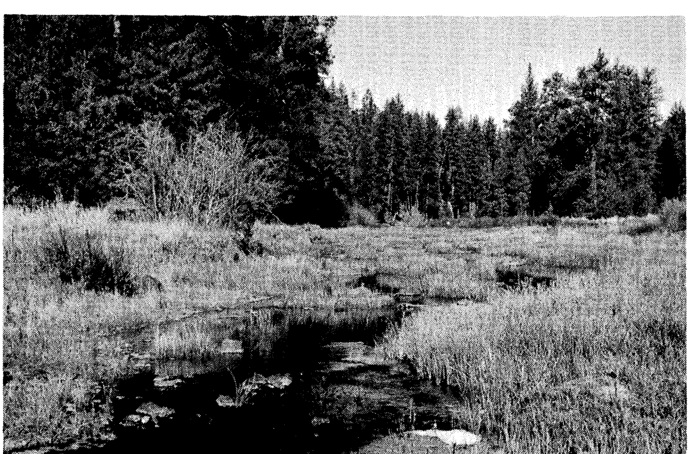

Fig. 3.
North Fork of the Crooked River (Oct., 1974).
Flow = 2.5 cfs.
Moderate gradient section.

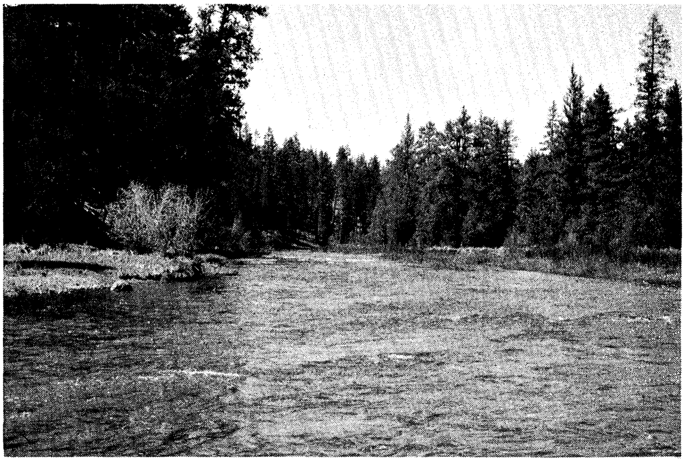

Fig. 4.
Same point on North Fork of the Crooked River (June, 1975).
Flow = 520 cfs.

Fig. 5.
North Fork of Crooked River (Oct., 1974).
Flow = 2.5 cfs.
Low gradient section.

Fig. 6.
North Fork of Crooked River (June, 1975).
Flow = 520 cfs.
Low gradient section.

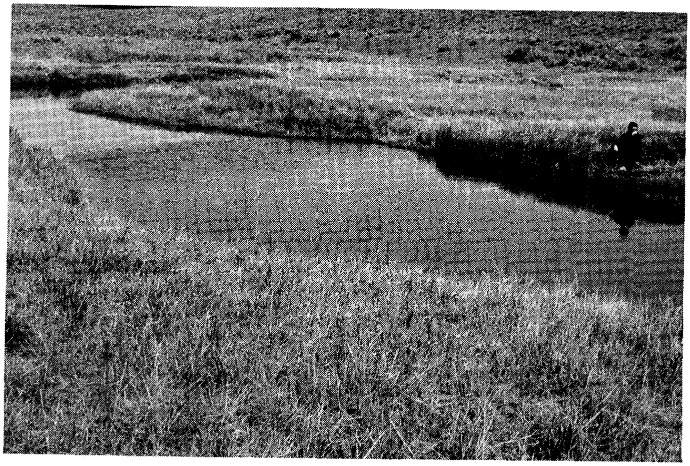

Fig. 7.
North Fork of Crooked River (Oct., 1974).
Flow = 2.5 cfs.
Low gradient, meadow type section.

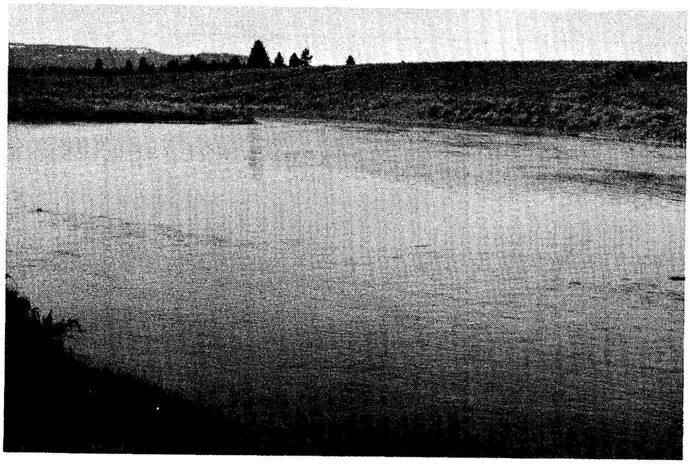

Fig. 8.
Same point on North Fork of Crooked River (June, 1975).
Flow = 520 cfs.

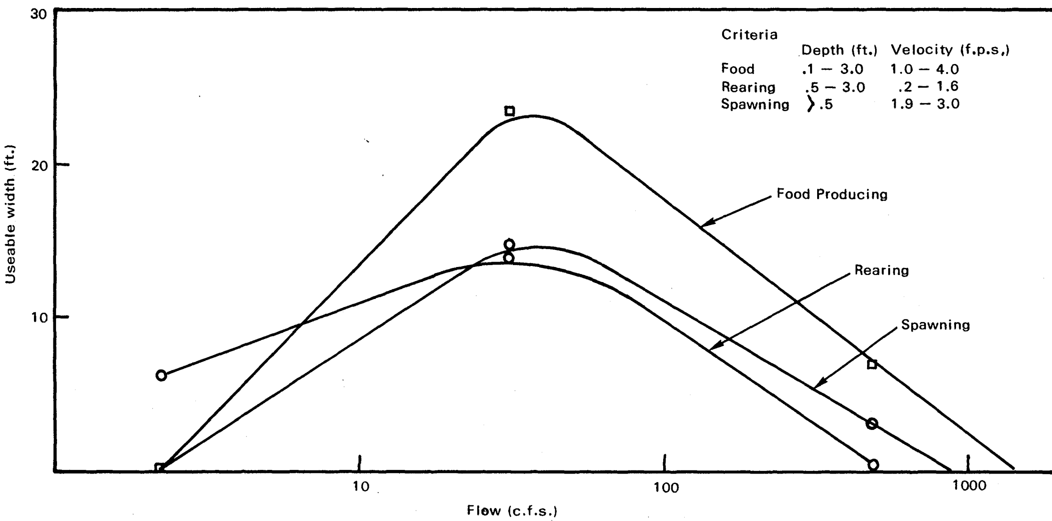

Fig. 9. North Fork of Crooked River--Instream Flow Analysis

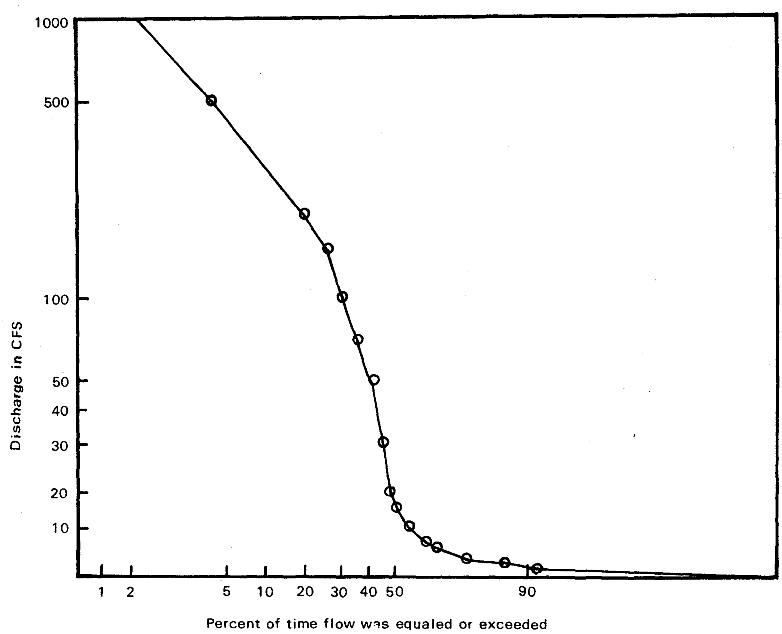

Fig. 10. Flow Duration Curve--North Fork Crooked River

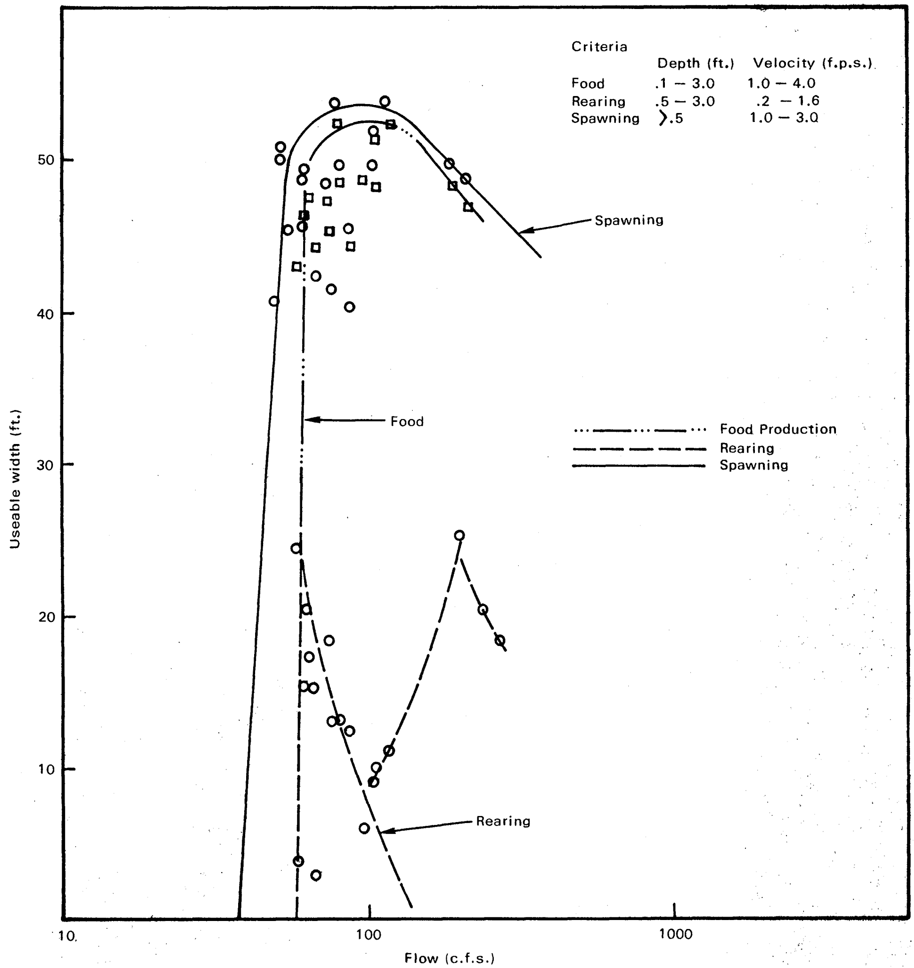

Fig. 11. Williamson River--Instream Flow Analysis

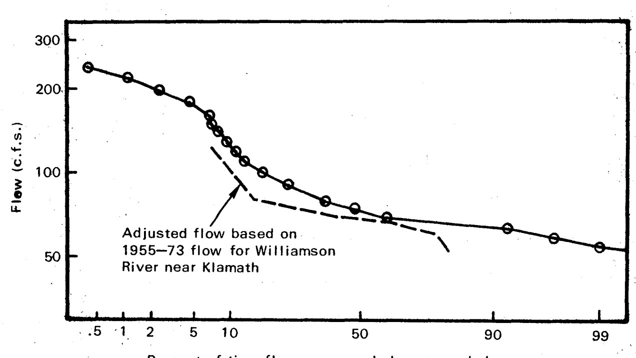

Fig. 12. Flow Duration Curve--Williamson River

TOPIC V-C. RECREATIONAL IFN METHODOLOGY

INTRODUCTION

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We are all familiar with the problems of consumptive uses of water and their effects on stream-based recreation. Tools and techniques for making stream flow determinations at various levels for recreation and aesthetic purposes are almost nonexistent. If scenic and recreational uses of streams are to have a fair change of competing for scarce water resources, planners must be able to identify various stream flows that will satisfy these needs.

Current methodologies for determining stream resource maintenance flows are based on fishery needs, which may or may not be the same as those for other instream uses such as recreation or aesthetics. The fishery flow requirement generally has been assumed to be adequate for other instream uses, but this relationship has not been verified.

A milestone study, the "Anatomy of a River" published in July, 1974 by the Pacific Northwest River Basin Commission, monitored the effects of controlled flows on the biological community and man's nonconsumptive uses of the Snake River from Hell's Canyon Dam to Lewiston, Idaho. The objective of the recreation element of the study was to judge the relative effect of various controlled flows on recreational opportunities.

Another study worthy of mention is the "Methodologies for Determination of Stream Resource Flow Needs: An Assessment." This study was conducted by Utah State University for the Fish and Wildlife Service. A draft report of the study's findings was discussed at an Instream Flow Workshop held at Logan, Utah, on September 17-19, 1975. The workshop consisted of an interdisciplinary, interagency group brought together to comprehensively evaluate the state-of-the-art of existing methodologies for the determination of necessary stream flows, wildlife, water quality, estuarine inflow, recreation and aesthetics; and to identify specific research needs. The report was just published and includes chapters on recreation and aesthetics.

The Bureau in cooperation with the Fish and Wildlife Service through the assistance of the Office of Water Resources and Technology, hopes to establish similar workshops when its instream flow study is completed. We view these studies as the steps in the right direction to provide us with the adequate tools and techniques to further the cause for the recreational use of instream flows for the recreating public.

Today we will hear papers discussing:

(1) BOR's involvement in the study leading to the report "Anatomy of a River" and our current contract on in-stream flows for recreation;

(2) The "Montana Method" of determining in-stream flow needs for Fish and Wildlife, recreation and aesthetics; and

(3) Two recent court decisions regarding nonconsumptive appropriations of water and problems leading to current legislation in Idaho.

The importance of in-stream water use for recreation and fish and wildlife is now being recognized. The necessity to plan for these purposes is being highlighted by the environmental mistakes of the past. The BOR contract and those of FWS along with others will hopefully come up with a means of dealing with these water needs.

INSTREAM FLOWS - LEGAL OBSTACLES

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ABSTRACT

Constitutional prohibitions against denial of the public's right to appropriate the unappropriated waters of the state of Idaho and lack of any kind of legislative authorization are the biggest obstacles to instream flows in Idaho. The Idaho Supreme Court has apparently indicated its willingness to accept instream flows as a beneficial use of water upon declaration of that fact by the legislature, and provides some guidelines to establishment of instream flows. Instream flows are not likely in Idaho until such time as the legislature responds to the apparent public desire for such use of our waters and, in the final analysis, the obstacle may be more legislative than legal.

TEXT

Idaho's Constitution, Article 15, Section 3 states:

> "The right to divert and appropriate the unappropriated waters of any natural stream to beneficial uses, shall never be denied, except that the state may regulate and limit the use thereof for power purposes. Priority of appropriation shall give the better right as between those using the water; but when the waters of any natural stream are not sufficient for the service of all those desiring to use of the same, those using the water for domestic purposes shall (subject to such limitations as may be prescribed by law) have the preference over those claiming for any other purpose; and those using the water for agricultural purposes shall have preference over those using the same for manufacturing purposes. And in any organized mining district those using the water for mining purposes or milling purposes connected with mining, shall have preference over those using the same for manufacturing or agricultural purposes. But the usage by such subsequent appropriators shall be subject to such provisions of law regulating the taking of private property for public and private use, as referred to in section 14 of article I of this Constitution."

This provision has stood for many years as the apparent obstacle to instream flows. In an attempt to shed some light on instream flows as a beneficial use, the case of <u>State Department of Parks -vs- Department of Water</u>

Administration, 96 Idaho 440, 530 P_2 924 (1974) was brought before the Idaho Supreme Court. The issues presented were:

(1) Whether a state agency could appropriate water;

(2) Whether instream flows were beneficial in Idaho; and

(3) Whether an actual physical diversion of water was necessary to make a valid appropriation.

The Malad Canyon case, as it is known, was created by the legislature directing the Department of Parks to appropriate the entire natural flow of certain springs for park purposes and declared that use to be beneficial.

In upholding the District Court decision, the Supreme Court (2-1-2) held that:

(1) A state agency could appropriate water;

(2) The listing of uses in Article 15, Section 3 was not exclusive and the Court was not willing to overrule the legislature; and

(3) An actual physical diversion was not required by the Constitution, though the legislature does require it for Idaho's mandatory permit-license system.

In the Malad Canyon case, the Court found the legislature had specifically removed the physical diversion requirement. Of equal importance, the Court held that it was unwilling and could find no basis, at this time and under the facts, to disturb the declaration of beneficial use made by the legislature.

In so holding, the Court said:

> ". . . legislation in other states carries no binding effect on this court but, in the absence of persuasive case law to the contrary, it would appear to indicate that the use of water for providing recreational and aesthetic pleasure represents an emergency recognition in this and other states of social values and benefits from the use of water. . ." (Emphasis Added) Depart- of Parks, supra, 444.

The concurring opinion of Justice Bakes adds some element of doubt as to the viability of instream flows. He believes, within the concept of "beneficial use" is the concept of change to meet changing conditions. Except for those uses listed in the Constitution, all other uses are subject to change that may make them an unreasonable use of water and therefore not beneficial. Justice Bakes stated:

> "I would restrict today's holding to the narrow proposition that the use before us is beneficial so long as, and only so long as, the circumstances of water use in the state have not changed to the extent that it is no longer reasonable to continue this use at the expense of more desirable uses for more urgent needs. It should receive the same treatment as all other non-constitutional beneficial uses." Department of Parks, supra, at 448.

With this severe limitation, the practical ability of the state to accomplish minimum stream flows is in grave doubt without constitutional amendment. For as we all know, minimum flows are worth nothing if they can later be avoided in the name of higher beneficial use.

Thus, the Court did not flatly and unequivocally hold that minimum stream flows were a beneficial use. They did recognize that the legislature has the authority to declare what is or is not a beneficial use, as long as it is not clearly in conflict with the Constitution. The dissent found instream flows to be in violation of Article 15, Section 3 of the Idaho Constitution and that a physical diversion was required by Idaho's Constitution.

Perhaps as a result of this Court case, four different legislative proposals were made in 1976. Three bills were introduced: House Bill 365 (executive bill); House Bill 461 (legislative committee bill); and House Bill 511 (Idaho Water Users bill). Each of these bills has the following common features:

(1) Declaration that public health, safety and welfare require that stream environments be protected against loss of water; and instream flows are beneficial uses of water;

(2) Establish a permit procedure;

(3) Covers lakes, springs, creeks, streams, rivers or other natural body of standing or moving water;

(4) The Idaho Water Resource Board is authorized to make appropriation in its name, by application to the director of the Department of Water Resources, with the following information:

(a) Name of stream or lake, and legal description of point at which flow to be determined,

(b) The flow or lake level proposed,

(c) Purpose of such flow,

(d) Period or season for such flow,

(e) Any other information required by the director.

(5) Director required to get comments from interested agencies (Fish and Game, Health and Welfare, Parks and Recreation) and publish notice of application twice;

(6) Hearing must be held on proposed appropriation;

(7) Approval must be based on findings that:

(a) Not interfere with prior water right,

(b) Is in public, as opposed to private, interest,

(c) Is necessary for preservation of fish and wildlife habitat, aquatic life, recreation, aesthetic beauty, navigation, transportation, or water quality of the stream or lake,

(d) Is the minimum flow or lake level and not the ideal or most desirable flow or lake level, and

(e) Is capable of being maintained.

(8) Other entities may request Idaho Water Resource Board to file application with director;

(9) Appropriation so allowed to be considered and dealt with just like any other water right.

The differece between the bills is only as to the area of applicability. House Bill 365 would apply to the entire state; House Bill 511 to all rivers except the Snake and all tributaries above Weiser gage, the Big and Little Lost Rivers, Lemhi River, Bear River, and Malad River. This, in effect, exempts for all practical purposes all rivers and streams in Southern Idaho below the Salmon River drainage. House Bill 461 applied only to the Salmon River and its tributaries and all rivers and lakes north thereof.

If House Bill 461 or House Bill 511 had been passed, their impact on Idaho would have been minimal. The areas covered by those bills are generally water abundant and there is no real threat or possibility of drying up those streams. The area that is subject to heavy development pressure and a real threat of drying up our streams (Southern Idaho) and where instream flows would have meaning, were totally exempted. The only real positive aspect of those bills would have been introduction of the idea to Idaho law. In spite of the fact that none of the interested groups spoke against minimum flows, and all recognized their values, the legislature failed to pass this legislation.

In addition to the above approach, a bill was drafted (but never introduced) that would have provided matching funds from the state for the construction of dams to store water for minimum flow releases. An addition to fishing licenses and boat licenses would help finance the projects. The managing agency would be authorized to pay up to 80% of the cost of constructing an eligible project (50% if federal agency involved).

The project proposer would come up with 20%, and is subject to strict operational guidelines including a guarantee that the facilities would be operated continuously for the purpose and in the manner authorized. The project proposer would be required to designate the downstream point, in Idaho, to which the water released from impoundment must reach, and until it has reached that point, it would not be subject to appropriation for use out of the stream.

This approach presents means of capturing flood waters for use in mid or late summer when flows are always low. Although this approach does not directly solve the constitutional question, it may present the practical means of avoiding conflict over the availability of water because the appropriation is made at a time when water is abundant and released when water availability is critical.

In conclusion, the legislative approaches already suggested could present the solution to instream flow needs. If the legislature acts to declare instream flows a beneficial use of water, it seems clear that the Courts will be reluctant to disturb that declaration. However, lacking this clear legislative action, the future of instream flows in Idaho could be blocked by Idaho's Constitution.

INSTREAM FLOW EVALUATION FOR OUTDOOR RECREATION

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ABSTRACT

Recreation is gradually receiving acceptance as a legal competing use for water. Recent planning guidelines have accented the need for a process to evaluate the trade-offs among all water uses, including recreation, in water resource planning. A methodology is needed to evaluate the effects of different instream flows on river related recreation. The methodology proposed here is based upon subjective evaluations of the affect of different flows on various recreation activities. Emphasis is placed upon developing a process with relatively simple application and adaptable to existing water resource planning guidelines.

INTRODUCTION

As the demands for water grow, the competition for available supplies intensifies. Water running through stream beds, undiverted or without some reserved purpose such as generation of hydroelectric power, is rapidly becoming less common in some areas of the western States. At the same time more and more people are discovering and seeking the recreational opportunities offered in and along rivers. Thus, it is becoming more essential to develop an acceptable procedure for evaluating instream flows for recreation.

The keenest competition for water is frequently between instream uses and out-of-stream or diverted uses. It thus becomes necessary to justify the costs of allowing water to flow seemingly unused in river channels. It becomes a question of how much water is necessary in the stream to support instream uses such as fish and wildlife, power production, and recreation, and what are the benefits obtained compared to the probable facility costs and opportunity costs of maintaining the flow of water?

The problem is currently most critical on rivers whose waters have already been fully appropriated for out-of-stream uses. The only apparent means of attempting to assure any water for instream uses in such rivers is to build new or increase the size of existing impoundments thereby storing more water for later release, or by purchase of existing water rights. Many states have taken steps to stem the tide of appropriations of water for out-of-stream uses. The traditional water law doctrine of "first in time, first in right" in appropriating water to beneficial uses has been superseded in some States by a policy of allocating unallocated water to the highest or best use. The States are holding back on further water allocations until studies have been conducted on the need for water by instream uses and the benefits to be derived from such uses.

Responding to this opportunity to protect fish and other aquatic life of streams, the fishery agencies are far ahead of recreation in development and actual application of methodologies. State agencies with assistance from Federal agencies and universities have developed recommendations for minimum and optimum flow levels to preserve or enhance aquatic life on many streams. Some follow-up action has occurred in attempting to actually maintain instream flows at or near these recommended levels in some streams.

With the work already completed and ongoing on recommended flows for fisheries, the question has often been raised of why duplicate this effort in order to determine flows for recreation? The primary argument is that the most critical objective is to assure at least a minimum flow of water for instream uses. If the flow is determined to be sufficient to support fish life, then it is probably adequate for recreation. This observation is reasonable except for two points. One, there are rivers that because of their location in respect to population centers and/or because of some unique characteristic, recreation use of them might be regarded as the, or one of the highest and best uses. The Boise River, particularly the segment from Lucky Peak Dam through the City of Boise, for example, is a very valuable recreation resource. The recreational value of this river is too great to simply assume that the institutional, financial, and technical problems associated with creating optimum flow levels for recreation are too much to overcome. The second point is that recreation should neither be considered as competing against fishery and other instream uses of water nor as a duplication in terms of its water needs. Rather, recreation and other instream uses need to compliment one another in displaying the total benefits from maintaining a minimum flow of water in streams versus diverting more water.

The adoption of Principles and Standards for Planning of Water and Related Land Resources has accentuated the importance for water planners to develop the tools to enable them to assess the effects of proposed water plans. Principles and Standards require the formulation of at least two alternative plans, one emphasizing national economic development, the other environmental quality. Principles and Standards also require an evaluation and display of the expected adverse and beneficial effects of each alternative plan within each of the four accounts: national economic development, environmental quality, social well being, and regional economic development. Water projects or programs involving study of rivers should include an evaluation of the effects on river related recreation opportunities, including how these opportunities may or may not be enhanced by provisions in the plan for instream flows. The evaluations will need to address the environmental quality as well as the economic values.

ONE METHODOLOGY

In developing the procedure discussed here, I have attempted to incorporate two objectives. The first is to keep the method simple. The second is to make it applicable to the guidelines for implementing Principles and Standards.

The first task is to identify the primary water dependent recreational activity or activities of the segment of river in question. The primary recreation activities may be those receiving the most participation and/or the activities which are most dependent upon a minimum flow of water. For example, in Hells Canyon along the Snake River, much of the recreation participation is dependent upon boats being able to navigate up or down stream past some of the more hazardous rapids. The primary water dependent recreation activity for evaluating flow levels may then be power and float boating. Other important water dependent or related recreation activities in Hells Canyon which should be considered include fishing, swimming, and sightseeing.

The second task is to evaluate the effects of different levels of flow on recreation activities. It is expected that water requirements will differ considerably for each activity. After all it is natural to assume that more water is required to provide a satisfying experience for the experienced white water boater than for the fly fisherman within the same river segment. Also people's preferences naturally differ from one another. These differences need to be considered in the evaluations.

The ideal study situation might be to control the levels of flows for specified periods of time. This allows observation of flow conditions which normally occur over a one-year or longer period within a relatively short period of time. This is the situation we had in March 1973 during the controlled flow studies of the Snake River in Hells Canyon.

The method is basically to observe the effects of various flow levels on individual recreation activities. Sites along the river are chosen for making the observations. Ideally, existing or potential recreation sites are chosen. If boating is a popular activity on the river, points along the river which could prove hazardous or impassable during low or high flows, as well as particularly popular stretches of boating water should be selected for observations.

Other popular recreation sites such as swimming holes and beaches should be included among the observation sites.

The evaluation is largely subjective. Evaluators are encouraged to test conditions of the water during different flows by actual recreation participation. The best way to evaluate the conditions of the river for swimming and wading is to wade out and test the current, water temperature, and slope of the beach. If recreationists are in or along the river, their opinions should be sought. Some objectivity can be obtained by taking measurements of water temperature, beach slope, current velocity, and water quality. Photographs are a valuable aid to later evaluations, review of evaluations made in the field and as a permanent record of the conditions. The value of photos is enhanced if visible markers can be placed along the high-water line of each flow level as the water lowers.

It is not often possible, nor always desirable to collect information on instream flow during controlled flow conditions. Evaluations will usually need to be made over a one-year or longer period in order to observe a full range of flow levels. The same procedures are used. Observations are consistently made at the same sites throughout the study period. There are definite advantages to observing flow levels as they naturally occur, rather than within a short time period under controlled conditions. Several of the parameters relied upon for making the evaluations have time to stabilize and the evaluators have the opportunity to measure and observe them under natural conditions. For example, beaches and sand bars have an opportunity to stabilize a little. Water temperature and water quality can be measured under normal conditions with outside influences such as air temperature and pollution discharges involved. The long term effects of flow levels on shoreline vegetation may be observed.

The procedure can also be used with little or no field work. There are normally lots of people with first hand knowledge about rivers and the conditions for recreation use which have existed in the past. Suspected knowledgeable persons such as members of kayak/canoe clubs, sportsmen clubs and boating organizations, river guides and outfitters, and resource managers could be contacted to obtain information on conditions which have existed in past years. If this information can be related to approximate dates, then corresponding flow records might be obtainable from the U.S. Geological Survey. This procedure has the advantage of low cost, and information can be gathered in a relative short time. However, if possible, the conclusions should be reinforced with field observations.

Once conclusions have been formulated on the effects of different flow levels on recreation activities, then this information can be displayed on a matrix (see Figure 1) along with information on other water uses. The matrix allows quick comparison of the effects of different flows on any one use or recreation activity. It also allows review of the effects of any one flow level on all identified instream and out-of-stream uses of the water.

It will be useful in the planning process to be able to generalize this information for the purposes of supporting recommendations on flow levels and for indicating the overall effects to river dependent recreation opportunities from existing or recommended flow levels. The following guidelines are offered as one means for categorizing the recreation evaluations:

Minimum Acceptable. The minimum acceptable flow is that flow which provides only for the most limited recreational use of the stream. Compatible streamside recreation opportunities include picnicking, camping, and sightseeing activities, and compatible instream activities include nature study, wading, and possible swimming in the pool areas.

Low Satisfactory. Low satisfactory flow is compatible with a range of both instream and streambank recreation pursuits, including camping, picnicking, and sightseeing. The most probably problem area at this flow rate would be the lack of sufficient water depth to adequately float a boat over stream riffle areas at some locations.

Optimum. Optimum flow is that flow which will maintain the unique characteristics of the stream area and will provide for an optimum combination of uses. Generally, this flow will accommodate swimming, boating, sailing, canoeing, study nature, and streambank activities such as picnicking, camping, hiking, and sightseeing. This flow produces a visual and audible enhancement of the stream resource which is generally pleasing to the recreationist and notably adds to the quality of the recreation experience.

High Satisfactory. At the high satisfactory flow, many instream activities would be curtailed substantially, particularly swimming. All streambank recreation activities such as camping, picnicking, and sightseeing can still occur.

Maximum Acceptable. Maximum acceptable flow is assumed to be the highest rate of flow usable by the recreationist. This flow represents an upper limit beyond which further beneficial uses of the stream for recreation are severely restricted. Recreation uses of streamside lands include picnicking, camping, and sightseeing. At this flow, instream activities such as swimming, studying nature, sailing, and leisure boating are no longer acceptable. The only instream activity that may possibly occur if this flow rate is approached is whitewater boating.

The application of this process to an economic benefit/cost analysis has never been attempted. However, in order to properly consider the effects to recreation within the multi-objective planning process, it is essential that benefits and costs be assessed in economic terms, as well as in qualitative terms. I think we have the basic tools to do this. Principles and Standards provide the guidelines for assessing the value for a single recreation day. The unit day values for a "General Recreation Day" range from 75¢ to $2.25. A "Specialized Recreation Day" is evaluated at $3.00 to $9.00. Benefits from maintaining a desirable instream flow for recreation will accrue primarily in response to an increase in the number of days annually that recreation activities are possible. Conversely, a decrease in benefits would result from decreasing the number of days annually that a desirable flow exists. In addition, the recreation value theoretically derived by each recreationist from use of the river may increase or decrease depending upon the adequacy of the flows for recreation. In other words, using the guidelines on unit day values indicated above, the planner could select a value relative to the quality of recreation experience provided by a particular flow of water. Of course, the flow of water is only one of several parameters to consider in assessing the value placed on a recreation day.

CONCLUSIONS

My objective in this paper has been to demonstrate the need for including the analysis of instream flows for recreation in water studies and to offer one method for conducting these analyses. The need for a methodology is perhaps more critical now than ever before. Principles and Standards, approved in 1973, require the consideration of total environmental and economic trade-offs in water resource planning. In projects affecting stream flow, this includes evaluating how stream related recreation opportunities are affected. Also, the States in considering future allocations for water are giving increased attention to instream uses, not only uses requiring diversion of water. Subsequently, it will be necessary to evaluate the benefits to all instream and out-of-stream uses, including recreation, from alternative levels of instream flow.

The Bureau of Outdoor Recreation has recognized the importance of evaluating instream flows for outdoor recreation purposes. As a result, the Bureau has granted a contract to Jason M. Cortell and Associates, Inc. to develop, refine, and test an acceptable methodology. Field study has already been completed on the Chattahoochee River in Georgia. Additional rivers to be studied include the Saco River in New Hampshire, Rio Grande River in New Mexico, the North Platte River in Nebraska, the Huron River in Michigan, the Russian River in California, and the Boise River in Idaho.

Figure 1 Instream Flow Evaluations

Stream Name and Reach: Typical River--From Big Dam to Confluence with Little Creek

Demonstration Only

FLOW (cfs)	RECREATION				FISH		WATER QUALITY	IRRIGATION
	Canoeing/ Kayaking	Power Boating	Swimming	Aesthetics	Anadramous	Resident Trout		
100	Too little water to float over many areas.	Insufficient water	Best holes drained of water and/or water is slightly stagnant	Slow moving current, exposed shoreline, dried up pool areas	90% reduction in spawning areas. Very poor conditions for adult migration	Large areas of exposed spawning gravel	Stagnation in pools	Sufficient water diverted upstream, no pumping downstream
500	Suitable for navigating most of segment. Not too challenging	Navigation hazardous in many areas	Swimming holes in good condition; no stagnation	Pool areas filled with water; faster moving water	30% reduction in spawning areas. Poor conditions for adult migration	Good conditions for spawning; little exposed gravel	Insufficient flow to completely dilute pollution from return irrigation flows	Sufficient water diverted upstream, some pumping downstream
800	Entire segment is navigable. Conditions are slightly challenging	Generally navigable. Care necessary to navigate around some rocks and shallow areas	Swimming holes in good condition. No stagnation, water temperature a little below comf. lev	Little difference from 500 to 800 cfs flows	Best conditions for spawning	Best conditions for spawning	Good quality	10% reduction in water diverted upstream, pumping downstream
1000	Good conditions	Best conditions for most boats normally used on this river	Increased current through swimming holes. Water temperature below comfortable level	Most of river channel filled with water; some white water	Good conditions for spawning, optimum flow for adult migration	Siltation and displacement of gravel in spawning areas	Good quality	50% reduction in water diverted upstream
1500	Advanced level of skill advisable. Very challenging rapids	Not advisable for lower powered boats or inexperienced operators	Hazardous conditions	Good white water conditions	Scouring of river bed, good flow for adult migration		Good quality	No diversion upstream

INSTREAM FLOW REGIMENS FOR FISH, WILDLIFE, RECREATION and RELATED ENVIRONMENTAL RESOURCES

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ABSTRACT

Describes a quick, easy methodology for determining flows to protect the aquatic resources in both warmwater and coldwater streams based on their average flow. Biologists do their analysis with aid of hydrological data provided by the U.S. Geological Survey. Detailed field studies were conducted on 11 streams in 3 states between 1964 and 1974, testing the "Montana Method." This work involved physical, chemical, and biological analyses of 38 different flows at 58 cross-sections on 196 stream-miles, affecting both coldwater and warmwater fisheries. The studies, all planned, conducted, and analyzed with the help of state fisheries biologists, reveal that the condition of the aquatic habitat is remarkably similar on most of the streams carrying the same portion of the average flow. Similar analyses of hundreds of additional flow regimens near U.S.G.S. gages in 21 different states during the past 17 years substantiated this correlation on a wide variety of streams. Ten percent of the average flow is a minimum instantaneous flow recommended to sustain short-term survival habitat for most aquatic life forms. Thirty percent is recommended as a base flow to sustain good survival conditions for most aquatic life forms and general recreation. Sixty percent provides excellent to outstanding habitat for most aquatic life forms during their primary periods of growth and for the majority of recreational uses.

INTRODUCTION

Natural, free-flowing streams are one of the world's most beautiful and valuable resources. Before the coming of Christ, the Roman Emperor Justinian said: "By the law of nature certain things are common property; for example, the air, running water, and the sea." America's late Senator Norris from Nebraska said: "The streams that are flowing downhill were given us by a creator. They do not belong to any special interest or to any individual. They belong to the people and ought to be utilized for the benefit of all of them."

Few streams in the United States have escaped degradation from land use practices or altered flows by some kind of man-made, "water development" project. Some recognition is finally being given to instream flow regimens to protect the natural environment. Scientists from many disciplines are seeking reliable, practical methods for determining streamflow requirements to protect fishes, waterfowl, furbearers, reptiles, amphibians, mollusks, aquatic invertebrates, and related life forms from all the various people competing for our Nation's water.

With the help of several hydrologists and many state and federal biologists, this quick, easy method was developed for determining flows to protect the aquatic resources, in both warmwater and coldwater streams. This methodology evolved over the past 17 years from work on hundreds of streams in the states north of the Mason-Dixon Line between the Atlantic Ocean and the Rocky Mountains. This work has been cited in a score of publications and is best known as the "Montana Method."

Method

The Montana Method is so brief it can be typed on a 3 x 5 inch card. It can be applied rapidly to many segments of thousands of streams by referring to Table 1 of this paper and surface water records of the U.S. Geological Survey (U.S.G.S.).

Table 1

Instream Flow Regimens for Fish, Wildlife, Recreation and Related Environmental Resources

Narrative Description of Flows 1/	Recommended Base Flow Regimens Oct.-Mar.	Apr.-Sept.
Flushing or Maximum	200% of the average flow	
Optimum Range	60%-100% of the average flow	
Outstanding	40%	60%
Excellent	30%	50%
Good	20%	40%
Fair or Degrading	10%	30%
Poor or Minimum	10%	10%
Severe Degradation	10% of average flow to zero flow	

1/ Most appropriate description of the general condition of the streamflow for all the parameters listed in the title of this paper.

The following intensive use of this method will produce a factual, conclusive streamflow study on any stream. First, determine the average annual flow of the stream at the location(s) of interest (listed as AVERAGE DISCHARGE by U.S.G.S. and herinafter called average flow). If the average flow isn't published by the U.S.G.S., they can quickly calculate it for you. Visit the stream and observe, photograph, sample, and study flow regimens approximating 10%, 30%, and 60% of the average flow. Other flows can be studied, but these three regimens will cover a flow range from about the minimum to near the maximum that can normally be justified and recommended to protect the natural environment on most streams.

The average flow of a stream (or any given portion or percent of the average flow) is a composite manifestation of the size of the drainage area, geomorphology, climate, vegetation, and land use. These relationships have also been evaluated and reported by other biologists and hydrologists.[2, 5, 6, 7, 8, 16, 18]

On uncontrolled streams, study U.S.G.S. records for daily, monthly, and annual flow patterns, then go to the field and check their gage(s) until you can view and study natural flows approximating 10%, 30%, and 60% of the average flow.

If flows are controlled, begin by having the highest flow you wish to study released first, then regulate so that each succeeding lower flow will begin the following midnight. Photos taken early the next morning will reveal the difference in exposed substrate or wetted perimeter. This is photographic "regression analysis." An 8-10 hour interval will normally be sufficient to negate any appreciable differences in flow levels due to bank storage.

Pictures may be the best data you will collect for selling your recommendations to the general public, administrators of construction agencies managing water development projects, and judges or juries adjudicating water laws. Black and white photographs and 35 mm. slides of key habitat types (e.g., riffles, runs, pools, islands, and bars) from elevated vantage points like bridges and high stream banks will give results superior to ground level shots or photos from aircraft high above the stream. Record appropriate, vital information on all photographs and slides as soon as they are received.

U.S.G.S. monthly measurements of width, depth, and velocity cover a variety of flows at most of their stream gage or cable crossings. Obtain cross-sectional data on width, depth, and velocity measurements from the local U.S.G.S. field office for flow regimens under study. Use this information to plot and compare water widths, depths, and velocities to known requirements for aquatic resources. As manpower and money permit, U.S.G.S. will make specific cross-sectional measurements of width, depth, and velocity for government agencies at any point on any stream. It requires proper experience, equipment, and plenty of time for others to make the necessary cross-sectional measurements. Study average daily, monthly, and annual stream-flow regimen tables and previous historic low-flow data published by U.S.G.S. to learn the base flow patterns of the climatic year and help determine flows that mimic nature and justify your final recommendations. Recommend the most appropriate and reasonable flow(s) that can be justified to provide protection and habitat for all aquatic resources.

Results

Detailed field studies were conducted on 11 streams in 3 states between 1964 and 1974 testing the Montana Method (Table 2). This work involved physical, chemical, and biological analyses of 38 different flows at 58 cross-sections on 196 stream miles, affecting both coldwater and warmwater fisheries. Reports or publications on 6 study streams are available as indicated in Table 2. Numerous black and white photos and 35 mm. slides were taken of all the flow stages studied at each cross-section. The studies, all planned, conducted, and analyzed with the help of state fisheries biologists, reveal that the condition of the aquatic habitat is remarkably similar on most streams carrying the same portion of the average flow.

Width, depth, and velocity are physical instream flow parameters vital to the well-being of aquatic organisms and their habitat. Sixteen-hundred measurements of these parameters for 48 different flows on 10 of the streams cited in Table 2 show that they all increase with flow and that changes are much greater at the lower levels of flow (fig. 1). Width, depth, and velocity all changed more rapidly from no flow to a flow of 10% of the average, than in any range thereafter. Ten percent of the average flow covered 60% of the substrates, depths averaged 1 foot, and velocities averaged 0.75 foot per second. Studies show that these are critical points or the lower limits for the well-being of many aquatic organisms, particularly fishes. This substantiates the conclusion that this is the area of most severe degradation or that 10% is a minimum short-term survival flow at best. Flows from 30% to 100% of average result in a gain of 40% for wetted substrate, average depth increases from 1.5 to 2 feet, and average velocities rise from 1.5 to 2 feet per second. These are within good to optimum ranges for aquatic organisms, however, it requires 3 to 10 times the amount of water needed for a short-term minimum or good base flow, and gains or benefit:cost ratios may become questionable. Increasing flow from 100% of average to 200% of average (doubled) only increases average wetted substrate by 10%, average depth increases from 2 to 3 feet, and average velocity rises from 2 to 3.5 feet per second. Velocities averaging 3.5 feet per second are probably too high for the general well-being of most aquatic organisms but good for moving sediment, bedload, and white water boating. In all 11 field tests of the Montana Method, water depth appeared adequate for aquatic organisms whenever velocities were satisfactory.

Analyses of hundreds of additional flow regimens near U.S.G.S. gages in 21

Table 2

Detailed Studies of Instream Flow Regimens Using the Montana Method

Name of Stream	State	Date	Miles Studied	Number of Stations	Number of Flows	Parameters Studied (1)	Type of Fishery (2)	Ref.
Republican R.	NB	1964	40	3	4	W,D,V,S,B,C,T,F,M,E	WW	14
Wind-Bighorn R.	WY	1968	50	10	3	W,D,S,B,C,T,F,M,E	CW & WW	13
Marias R.	MT	1968	67	9	3	W,D,V,S,B,C,T,F,M,E	CW & WW	
Missouri R.	MT	1970	15	8	4	W,D,V,S,B,C,I,F,M,E	CW & WW	
Blacks Fork R.	WY	1971	16	4	3	W,D,V,S,C,I	CW	18
Shoshone Creek	WY	1971	1	2	9	W,D,V,S,B,C,F,M,E	CW	
Ruby R.	MT	1971	1	4	3	W,D,V,S,B,C,F,M,E	CW	4
W. Fk. Bitterroot	MT	1971	1	5	3	W,D,V,S,B,C,F,M,E	CW	4
W. Rosebud R.	MT	1971	3	3	4	W,D,V,S,B,C,F,M,E	CW	4
N. Platte R.	WY	1974	2	10	2	W,D,V,S,B,C,F,M,E	CW & WW	
Totals			196	58	38			

(1) Parameters Studied -- W=Width, D=Depth, V=Velocity, S=Substrate & Sidechannels, B=Bars & Islands, C=Cover, M=Migration, T=Temperature, I=Invertebrates, F=Fishing & Floating, E=Esthetics & Natural Beauty

(2) Type Fishery -- WW=Warmwater, CW=Coldwater

different states during the past 17 years substantiate these correlations between similar flows on a wide variety of streams. Running waters studied ranged from small precipitous brooks high in the Rocky Mountains, to large, low-gradient rivers out on the prairies of mid-America and streams along the coastal plains. This phenomenon of nature is documented with hundreds of black and white photographs and 35 mm. slides that are registered and filed with the U.S. Fish and Wildlife Service (FWS) in Billings, Montana; Grand Island, Nebraska; and Denver, Colorado.

Use of the Montana Method has produced over 100 separate streamflow recommendations to protect fish, wildlife, and environmental resources in more than 70 reports issued by the FWS.[9] The recommendations were made with the aid of district fishery biologists from 11 different states, endorsed by both the Directors of their state Fish and Game Departments and the Director of the FWS and generally accepted by various construction agencies. This work occurred on at least 30 warmwater streams and 70 coldwater streams. It has also been very useful for prescribing streamflows on large rivers where data are difficult to obtain using other procedures.

Many of our recommendations were not adopted, since providing streamflow for fish, wildlife, and environmental preservation or enhancement is not a legal beneficial use of water in most of the country, especially the 17 western states.[3] Administrators managing water development projects have generally been willing to regulate flow regimens for instream flow studies and provide minimum flows necessary to protect these resources when there is plenty of water. However, these resources are the first to suffer when water is short.[1, 3, 13, 14, 15]

In 1970, the project managers of the U.S. Bureau of Reclamation, U.S. Corps of Engineers, and the Montana Power Company were requested to identify the minimum flows that they recognized solely for the protection of fish, wildlife, and the aquatic environment, downstream from dams under their jurisdiction.[10] These agencies control the operation of 23 major dams in Montana and Wyoming. (Table 3)

The agencies reported minimum flows for fish, wildlife, and environmental protection which ranged from zero (four instances) to 38% of the average flow. The 38% flow was the result of fish and wildlife interests getting 500 cubic feet per second (cfs) released below Kortes Dam on the North Platte River in Wyoming. Congress reauthorized the operation of that project, which took about 10 years and is the only known accomplishment of its kind in the U.S.A.

Table 3

Minimum Instantaneous Flows for Fish, Wildlife, and Aquatic Environment Below Dams in the Missouri River Basin in Montana and Wyoming - 1970

Dam & Agency	Minimum Flow for Fish Recognized by Construction Agency	% of Mean Flow	Mean Flow of Record	FWS Recommended Minimum Flow	% of Mean Flow	Minimum Reservoir Inflow or Natural Flow of Record
Seminoe[1/] (BR)	---		1279 cfs			70 cfs
Kortes (BR)	500 cfs	38%	1300 cfs	500 cfs	38%	70 cfs
Pathfinder (BR)	0 cfs	0%	1423 cfs			70 cfs
Alcova[2/] (BR)	---		1500 cfs	330 cfs	22%	70 cfs
Gray Reef (BR)	330 cfs	22%	1500 cfs			70 cfs
Glendo (BR)	0 cfs	0%	1680 cfs			170 cfs
Guernsey (BR)	0 cfs	0%	1710 cfs			170 cfs
Boysen (BR)	100 cfs	7%	1350 cfs	250-400 cfs	19-30%	42 cfs
Buffalo Bill (BR)	15 cfs	1%	1256 cfs	350 cfs	28%	41 cfs
Heart Mountain (BR)	200 cfs	16%	1256 cfs	350 cfs	28%	41 cfs
Yellowtail (BR)	1000 cfs	29%	3500 cfs	1000 cfs	29%	179 cfs
Clark Canyon (BR)	25 cfs	8%	324 cfs	250 cfs	77%	69 cfs
Barretts Div. (BR)	25 cfs	6%	405 cfs	200 cfs	29%	69 cfs
Hebgen (MP)	50 cfs	5%	969 cfs	400 cfs	41%	200 cfs
Ennis (MP)	200 cfs	12%	1675 cfs			275 cfs
Holter (MP)	1000 cfs	19%	5289 cfs	2000 cfs	38%	747 cfs
Moroney (MP)	1500 cfs	20%	7362 cfs			1760 cfs
Ft. Peck (CE)	3000 cfs	32%	9292 cfs			1120 cfs
Gibson (BR)	50 cfs	6%	850 cfs	270 cfs	32%	60 cfs
Sun River Div. (BR)	100 cfs	12%	852 cfs	270 cfs	32%	47 cfs
Sherburne (BR)	0 cfs	0%	200 cfs			0 cfs
St. Mary's Div.[3/] (BR)	25 cfs	3%	790 cfs			16 cfs
Fresno (BR)	25 cfs	6%	430 cfs			0 cfs
Tiber (BR)	100 cfs	11%	880 cfs	250 cfs	28%	10 cfs

1/ Outflow directly into Kortes
2/ Outflow directly into Gray Reef
3/ A Canal to Milk River - Canada

Twelve of the 21 flows accepted by the agencies were less than 10% of the average flow of record, which is inadequate to sustain the normal life cycles of either warmwater or salmonid fishes.

Federal and state biologists analyzed flows and made flow recommendations on 12 of the streams involved. However, flows accepted by the agencies agreed with these recommendations in only 3 instances.

In 10 of 20 cases, the minimum natural inflow of record to the regulating reservoirs exceeded their recognized release for the conservation of fish, wildlife, and the aquatic environment downstream below the dams. All flow recommendations should stipulate that outflow from dams should at least equal inflow when managing agencies cannot release the flow regimens requested to protect the environment. Project managers often reminded us that there were no legal requirements for providing <u>any</u> water specifically for the conservation or enhancement of fish, wildlife, and environmental resources. Water agencies "sell" their projects by declaring that their operation will moderate the extreme high and low flows that occur naturally. Just the opposite was true on half of these projects. Our analysis did not include scores of existing, smaller projects under the programs of the U.S. Forest Service and the U.S. Soil Conservation Service, most of which did not recognize or provide any minimum flows for fish, wildlife, or the environment.

<u>Application of the Montana Method</u>

The Montana Method has virtues other than being quick and easy to use. It assures consistency from stream to stream or state to state. You always know the portion of the total streamflow requested and will never get a zero flow recommendation like some other methods produce (e.g., use of 7-day or 3-day minimum or historic minimum flow criteria). In 1970, I compared 7-day record minimum flow criteria input for the Upper Missouri, Yellowstone, Kansas, and Platte-Niobrara Sub-Basins of the Missouri River Basin Comprehensive Study. I found that these criteria resulted in <u>zero flow</u> in 86 of 305 instances, or about 28% of the time.[11]

In 236 of 305 cases (77%), the 7-day minimum flow was less than 10% of the average flow, which is considered in the range of severe degradation for most elements of the aquatic environment. Criteria for 3-day minimum flows would be worse yet, and recommending the meager, alltime, historic minimum flow would be unthinkable. That would be like prescribing a person's alltime worst health condition as a recommended level for a portion of his future well-being.

Using the Montana Method, it is easy to adjust to above or below normal water years and maintain stream flows that are appropriate portions of monthly, quarterly, or annual instream supplies of water. This helps fish, wildlife, and aquatic resources share surpluses and shortages of water equitably with other users.

With the Montana Method, U.S.G.S. measures the hydraulic characteristics of the stream and biologists interpret the biological responses. This saves considerable precious time that biologists can use on a more complete ecological analysis of streamflow needs.

There is significant hydrological and biological evidence that the Montana Method can be used successfully on streams throughout the United States and in other parts of the world.[1, 2, 4, 5, 6, 7, 8, 12, 13, 14, 15, 16, 17, 18]

U.S.G.S. is considering the revision of streamflow data programs for most of the states.[12] The majority of existing gages may be discontinued under its future program. Techniques like measuring channel geometry, interpolation from a known flow to an unknown flow, and correlations with adjacent streams will be used to provide streamflow information at any point on any stream. Simple channel geometry measurements have produced average flow data as accurate as 10 years of continuous gage records.[5] The standard errors were lowest for mountain regions and in competition with 5 to 10 years of gaged records for the plains region. There is very little variation when results are compared between channel width and average flow (fig.2). Mean annual discharge is one of the few criteria that will be routinely provided by this future program. Therefore, the Montana Method can still be used with this new program, since it is based primarily on knowledge of the mean annual discharge or average flow. The ability to provide the average flow at any point on any stream at any time would actually facilitate the use of the Montana Method in the future.

Adopting the metric system would not require conversion tables or other problems since this method is based on percentages of the average flow however it is expressed.

Conclusions

Ten percent of the average flow: This is a minimum instantaneous flow recommended to sustain short-term survival habitat for most aquatic life forms. Channel widths, depths, and velocities will all be significantly reduced and the aquatic habitat degraded (fig. 1). The stream substrate or wetted perimeter will be about half exposed, except in wide, shallow riffle or shoal areas where exposure could be higher. Side channels will be severely or totally dewatered.

Gravel bars will be substantially dewatered, and islands will usually no longer function as wildlife nesting, denning, nursery, and refuge habitat. Streambank cover for fish and fur animal denning habitat will be severely diminished. Many wetted areas will be so shallow they no longer will serve as cover, and fish will be crowded into the deepest pools. Riparian vegetation may suffer from lack of water. Large fish will have difficulty migrating upstream over riffle areas. Water temperature often becomes a limiting factor, especially in the lower reaches of streams in July and August. Invertebrate life will be severly reduced. Fishing will often be very good in the deeper pools and runs since fish will be concentrated. Many fishermen prefer this level of flow![17] However, fish may be vulnerable to overharvest. Floating is difficult even in a canoe or rubber raft. Natural beauty and stream esthetics are badly degraded. Most streams carry less than 10% of the average flow at times, so even this low level of flow will occasionally provide some enhancement over a natural flow regimen.

Thirty percent of the average flow: This is a base flow recommended to sustain good survival habitat for most aquatic life forms. Widths, depths, and velocities will generally be satisfactory (fig. 1). The majority of the substrate will be covered with water, except for very wide, shallow riffle or shoal areas. Most side channels will carry some water. Gravel bars will be partially covered with water and many islands will provide wildlife nesting, denning, nursery, and refuge habitat. Streambanks will provide cover for fish and wildlife denning habitat in many reaches. Many runs and most pools will be deep enough to serve as cover for fishes. Riparian vegetation will not suffer from lack of water. Large fish can move over riffle areas. Water temperatures are not expected to become limiting in most stream segments. Invertebrate life is reduced but not expected to become a limiting factor in fish production. Water quality and quantity should be good for fishing, floating, and general recreation, especially with canoes, rubber rafts, and smaller shallow draft boats. Stream esthetics and natural beauty will generally be satisfactory.

Sixty percent of the average flow: This is a base flow recommended to provide excellent to outstanding habitat for most aquatic life forms during their primary periods of growth and for the majority of recreational uses. Channel widths, depths, and velocities will provide excellent aquatic habitat (fig. 1). Most of the normal channel substrate will be covered with water, including many shallow riffle and shoal areas. Side channels that normally carry water will have adequate flows. Few gravel bars will be exposed, and the majority of islands will serve as wildlife nesting, denning, nursery, and refuge habitat. The majority of streambanks will provide cover for fish and safe denning areas for wildlife. Pools, runs, and riffles will be adequately covered with water and provide excellent feeding and nursery habitat for fishes. Riparian vegetation will have plenty of water. Fish migration is no problem in any riffle areas. Water temperatures are not expected to become limiting in any reach of the stream. Invertebrate life forms should be varied and abundant. Water quality and quantity is excellent for fishing and floating canoes, rafts, and larger boats, and for general recreation. Stream esthetics and natural beauty will be excellent to outstanding.

A flow of two to three times the average flow is often best for kayaks and whitewater canoeing. A flow of this magnitude is also preferable for larger boats with inboard or outboard motors, like those many people use on the annual Missouri and Yellowstone River floats held in June and July in Montana.

Recommendations

1. Request "instantaneous flows" to prevent flow releases from dams and diversion structures that are averaged over a day, month, or year, which permits erratic releases or even no flow at times.
2. Recommend that dual or multiple outlets to all dams be designed and constructed so that minimum flows of an appropriate temperature and quality to protect the aquatic environment can be by-passed at all times, including during drawdowns for safety inspections and emergency repairs.
3. Insist that costs for providing of instream flows to protect the aquatic environment downstream below dams be project costs, including costs for unforeseen emergency repairs and routine maintenance over the life of the project.
4. Justify only that portion of a stream flow required to fulfill specific instream needs. If fish need a flow of 100 cfs in a segment of stream where there are already legal requirements of 25 cfs for municipal water, 15 cfs for irrigation water transport, and 10 cfs for a U.S. Environmental Protection Agency water quality requirement, you logically and legally should only have to justify a flow of 50 cfs. Planners of water development projects may ask you to justify and apply benefit:cost ratios for fish to the 100 cfs flow because this makes their "project purpose" look more favorable on a comparable benefit:cost basis.
5. Stipulate that the downstream flow will not be less than the inflow to impoundments, whenever operators of water development projects cannot

provide specific flow requirements. Make this an integral part of every flow regimen recommendation, preferably part of the same sentence.

6. Reduced releases to a stream should not exceed a vertical drop of 6 inches in 6 hours. Fluctuations greater than this may significantly degrade aquatic resources.
7. Request that maximum flows released from dams not exceed twice the average flow. Prolonged releases of clear water greater than this will cause severe bank erosion and degrade the downstream aquatic environment.
8. Use "undepleted" U.S.G.S. hydrology data for flow recommendations that relate to the stream in its pristine conditions (e.g., before dams, diversion, pumps, etc.). Otherwise, recommendations from the Montana Method may relate to depleted stream conditions and result in less than ideal flows.
9. Avoid recommending minimum instantaneous stream flow regimens less than 10% of the average flow since they will result in catastrophic degradation to fish and wildlife resources and harm both the aquatic and riparian environments. Encourage lawmakers to pass legislation that would prevent diversions or regulation at dams, whenever it would reduce streamflow below this level. If water development projects cannot make it on 90% of the water carried by a stream, use of the remaining 10% probably won't justify their projects. Philosophically, it is a crime against nature to rob a stream of that last portion of water so vital to the life forms of the aquatic environment that developed there over eons of time.

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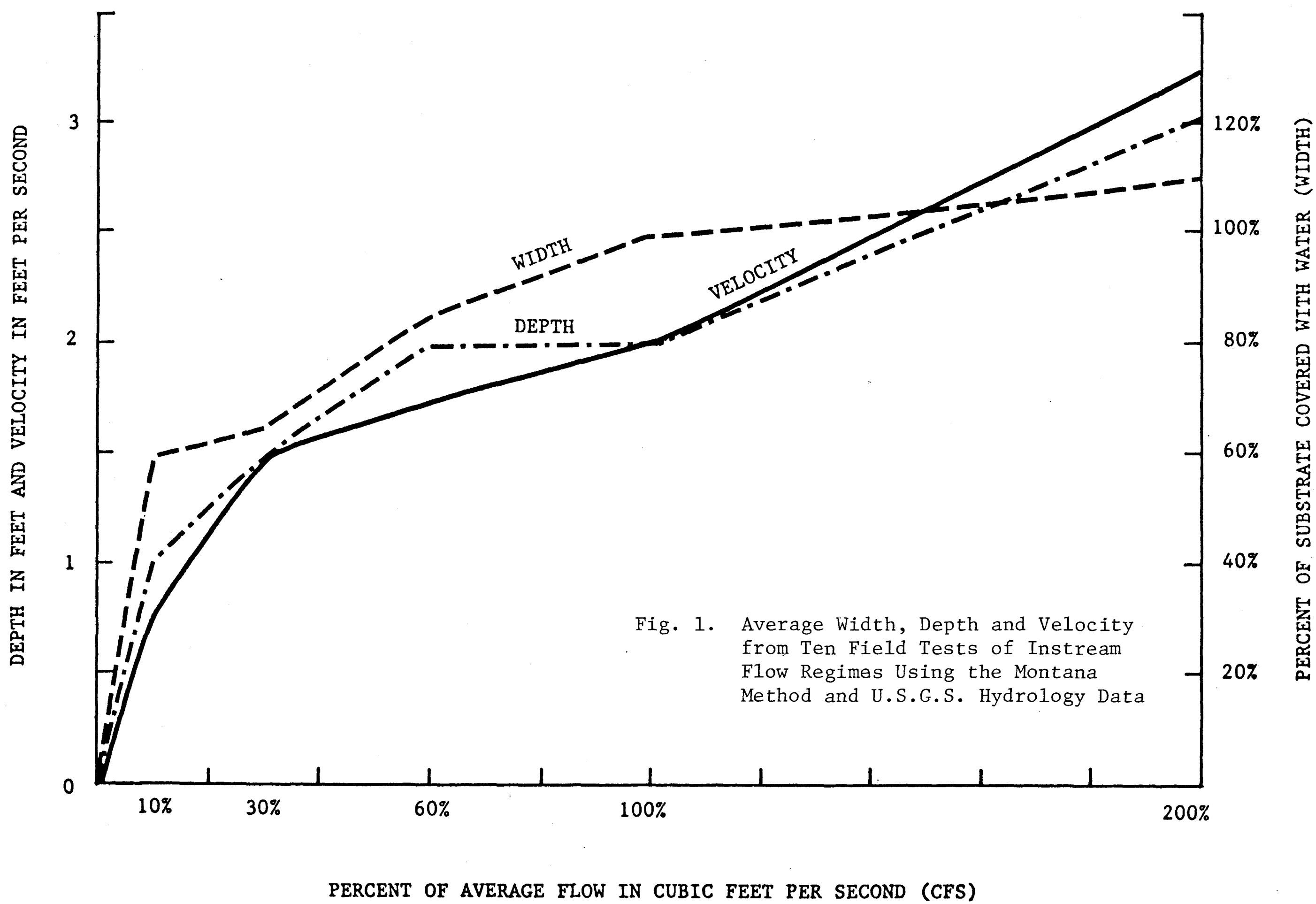

Fig. 1. Average Width, Depth and Velocity from Ten Field Tests of Instream Flow Regimes Using the Montana Method and U.S.G.S. Hydrology Data

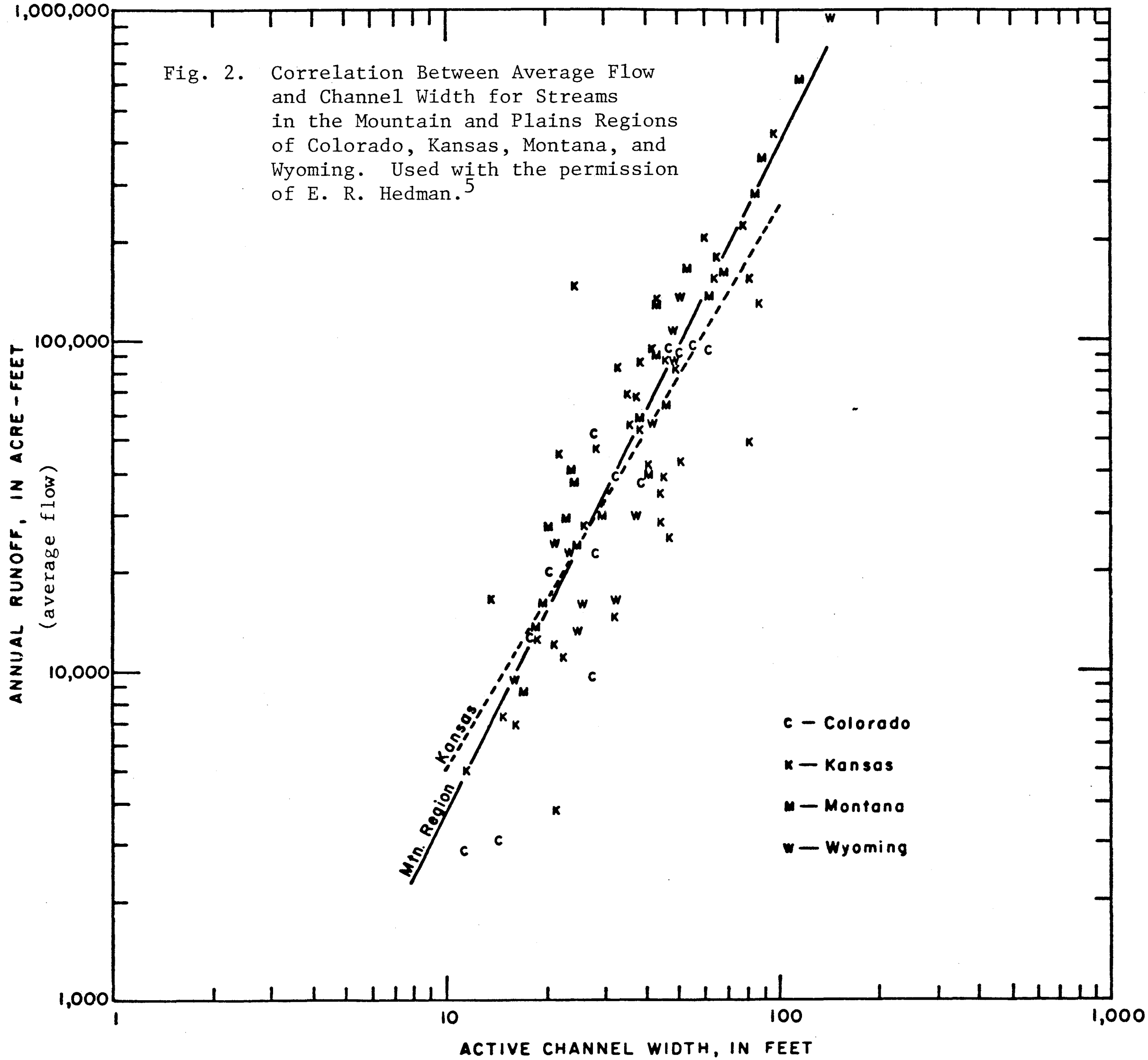

Fig. 2. Correlation Between Average Flow and Channel Width for Streams in the Mountain and Plains Regions of Colorado, Kansas, Montana, and Wyoming. Used with the permission of E. R. Hedman.[5]

TOPIC V-C.

RECREATIONAL IFN METHODOLOGY

Summary Discussion

Mr. Morris was asked:

Question: How are economic benefits determined for recreational activities?

Response: Benefits are presently determined through application of one of the methods in the Water Resources Council's "Principles and Standards" which provide a range for general and specialized recreation activities.

Comment by Moderator: The Economic's Committee of the Water Resources Council is presently studying the entire spectrum of economic benefits for recreation activities. A contract has recently been let by the Water Resources Council for this purpose.

Mr. Tennant was asked:

Question: Is the Montana method applicable to large (1 mile wide) eastern rivers?

Response: All evidence indicates that it is applicable, because the Montana method has been tested on several eastern rivers such as the Delaware.

Question: Does asking for 25 to 35 percent flow level entail enhancement over some natural flow levels?

Response: Yes, it does when you consider that seasonal natural flows may be much less than this. This is a benefit for the environment, particularly when a water development project may be authorized or justified for recreation, fish and wildlife, and aesthetics.

Mr. Higer was asked:

Question: Why hasn't the state of Idaho granted a permit for instream uses?

Response: The state has not received any such applications.

Question: Does the proposed Idaho Water Plan call for minimum instream flows?

Response: Yes.

Question: Who owns lands under the streams (for recreational use)?

Response: With respect to stream bed ownership, where federal navigability has been determined, then the state owns the land. Where there is no federal navigability, the landowner owns the land under the streams.

Question: Does State Fish and Game appropriate water for instream flows?

Response: The State does request flows where protection is needed for fish and wildlife from diversion works. They are not requested only for enhancement or maintenance of fish and wildlife resources.

<u>Question</u>: What is the best strategy for getting instream flows as a legal beneficial use in Idaho.

<u>Response</u>: They must become a legal use under the Idaho Constitution.

<u>Question</u>: How do you do that?

<u>Response</u>: It is a basic philosophical obstacle that must first be overcome. After this is accomplished then various strategies (e.g., economic, political, social) can be used for individual streams and projects. One approach might be to increase legal precedence such as the Malad Canyon case.

The session discussion indicated that there are many complexities to developing a recreation methodology for one activity or several groupings of activities. In some areas there are formidable legal obstacles to ensuring the provision of instream flows for recreation.

Notes by panel moderator: Gerard A. Verstraete, U.S.D.I.-BOR
Division of Water Resources,
Washington, DC

A METHODOLOGY FOR RECOMMENDING STREAM RESOURCE MAINTENANCE FLOWS FOR LARGE RIVERS[a]

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ABSTRACT

Methodologies currently available for recommending instream flows for fish species are not directly applicable to large, unwadable rivers. Due to the need for approaches suitable for large rivers, a methodology was developed. The methodology is a field-oriented approach based upon transect analysis of representative habitat of key fish species for passage, spawning, and rearing. The basic distinction between this approach and those presently in use is its predictive component. Most field oriented methodologies are based upon data collected at several reduced discharges while the proposed method requires only one set of field observations. A computer implemented model developed by the Bureau of Reclamation is used to predict channel morphometry and hydraulic characteristics at specified lower or higher discharges. From these predictions, changes in river habitat can be determined and related to ecological requirements of key fish species. Application of the proposed methodology to the Snake River, Idaho, for meeting ecological requirements of white sturgeon, smallmouth bass, and channel catfish is described.

INTRODUCTION

Persons working in the area of determining instream flow requirements for fish species are aware of the lack of suitable methodologies for large rivers. Two possible reasons for this are: 1) when the need to determine instream flow requirements of fish species was first recognized, it was in the smaller streams that the impact of low flow was most obvious and the need most urgent, and 2) large rivers are physically and biologically difficult to study.

With the accelerating demand for water, large river waters are being over-allocated at a rapid rate. The need is immediate for the development of methodologies suitable for defining the instream flow requirements for fish, wildlife, recreation, and other water uses of large, unwadable rivers. Participants in the U.S.F.W.S. Instream Flow workshop held at Utah State University, September, 1975, considered the development of large river methodologies as a high priority research need.

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[a]Presented at the AFS-ASCE Instream Flow Needs Symposium and Specialty Conference, May 3-6, 1976, Boise, Idaho; based upon a completion report submitted to Idaho Department of Fish and Game, 1975.(1)

Methodologies currently available for recommending instream flows for fish species range from those which are basically subjective, relying upon little or no field data, to ones based upon in-depth quantification of a number of variables which are related to ecological requirements of fish species. Subjectively-based recommendations of an experienced fishery biologist have, in some instances, provided similar stream flow recommendations to those developed by quantitative methods. However, because these recommendations lack field quantification, they are more difficult to defend from a legal standpoint. Methodologies utilizing field measurements are more costly but provide biologically reliable and defendable information with a minimum amount of subjective judgment involved.

All available methodologies have been developed to determine flows which meet the environmental requirements of fish species at one or more life history stages (passage, spawning, incubation, rearing). Most methods are directed toward meeting flow requirements of salmonids, with special emphasis on anadromous forms; those methodologies involving field techniques have been tailored to relatively small, wadable cold water streams.

The most difficult problem in recommending stream resource maintenance flows for fish species is relating the physical characteristics of the stream to the ecological requirements of the fish. Despite the availability of a great amount of literature dealing with life histories of fishes, comparatively little information is available on specific ecological requirements. Many studies have described food habits and the general habitat needs of a particular species but few have determined the specific microhabitat requirements, such as depth and velocity, of the species or of its food organisms. In comparison to other fishes, knowledge of stream flow requirements of salmonid species is the most advanced, but even in this extensively studied group information on rearing requirements is limited. Much less is known about all phases of the life histories of many non-salmonid species. Lack of knowledge of ecological requirements of certain fish species has been a major constraint in the development and implementation of methodologies for evaluating instream flow needs.

No single methodology will likely be adequate for evaluating instream flow needs for all species of fish. This is not to suggest, however, that the basic approach should be different. In all instances the premise behind recommending stream resource maintenance flows is to provide flows which accommodate the habitat requirements of the species at each stage of its life history. Ideally, standard methodologies will be developed which will apply to a group of species with generally similar biological and physical needs (i.e. resident salmonids). Specific requirements of a particular species within this group (i.e. cutthroat trout) would be accommodated by altering the physical and biological criteria, not the procedure for measuring these criteria. Recommendations based upon standardized methodologies would provide additional credibility in establishing and implementing stream resource maintenance flows.

Despite gaps in our knowledge, it is necessary for agencies to develop interim stream resource maintenance flow recommendations based upon our present understanding of the fluvial ecosystem and to proceed as rapidly as possible with research directed toward meeting informational needs.

METHODOLOGY

Determining resource maintenance flows for large rivers is a difficult problem with which fisheries scientists must deal. Like other methodologies, the approach I have proposed addresses the environmental requirements of fish species at each life history stage. In comparison with other methodologies, it can be categorized as a transect approach which considers discharge requirements of fish species for successful passage, spawning, and rearing. The basis of the methodology is to predict loss of habitat at reduced discharges and relate this loss to physical and biological requirements of key fish species.

The basic distinction between the proposed methodology and those presently available is its predictive component. Most field methodologies are based upon field data collected at several reduced discharges while the proposed method requires only one set of field observations. By way of a predictive computer implemented model, field observations are used to predict channel morphology and hydraulic characteristics at any specified discharge.

A number of models are available for predicting changes in hydraulic characteristics with reduced discharge. These range from a basic model developed by the Forest Service to the complex model developed by the Bureau of Reclamation. Both the Forest Service and Bureau of Reclamation models are based upon linear cross sectional transect analysis. Although data needs are similar for the two approaches, the Bureau of Reclamation model has the capability of partitioning a transect into as many as nine parts and predicting hydraulic characteristics for the transect as a whole and for each subsection. This partitioning capability is a distinct advantage since it allows the investigator to examine specific portions of a cross section for suitability in meeting the needs of a species for a particular biological activity. If, for example, we were specifically interested in that portion of a transect which provided adequate habitat for spawning, changes in mean depth and velocity and in total surface width for that linear length could be predicted for any specified discharge. The Bureau of Reclamation model gives us a much more refined capability of estimating the effects of various discharges on each phase of a fish's life history. The Forest Service model predicts mean depth and velocity (and other parameters) for the entire transect but does not have the partitioning capability. Both models are based upon Manning's equation for calculating discharge.

Application of Bureau of Reclamation Model: Water Surface Profile

The Water Surface Profile (WSP) computer program was designed to perform the computations necessary to estimate water surface elevations at various cross sections in a particular reach of channel. From one set of field observations made at known discharge, the program allows the user to predict various changes in stream characteristics at any desired discharge. Like other transect methodologies, depth, velocity, and wetted perimeter, measured at known discharge, are the channel characteristics in which we are most interested. In order to predict changes in these characteristics additional data are necessary including a description of stream bottom materials along each transect, distance between transects, and elevation at each transect; transects must be located at right angles to the flow. A minimum of four transects is necessary at each study site. To improve accuracy of predictions, field observations should be made at the lowest practical discharge. The reader is referred to Dooley for a detailed description of data requirements for the WSP model (2).

Study transects for determining stream resource maintenance flows for fish species are not selected at random. Rather, a thorough reconnaissance of the river segment for which flows are to be recommended is made and study sites are selected which are representative of habitat available to meet the needs for passage, spawning, and rearing of key fish species.

Physical difficulty in measuring hydrologic characteristics of large, deep rivers has been a major constraint in development of methodologies suitable for recommending resource maintenance flows for fish species in large rivers. However, with the advent of precision direct read-out current meters and the ingenuity of biologists, good physical measurements are possible. The quality of the field data determines the accuracy of computed predictions. Care must be exercised in all phases of data collection and good survey techniques must be used. The proposed methodology has been used on the Snake River in Idaho and details of field techniques are presented by Cochnauer. (3)

Data Processing

In the data processing phase, the biologist needs the technical expertise of a hydrologist. In both Idaho and Montana this expertise is provided by the Bureau of Reclamation through its Federal Technical Assistance Program. This is a good example of Federal-State cooperation toward solving important natural resource problems.

With the aid of a hydrologist familiar with the water surface profile program, data are organized for analysis and analyzed. Output from the program includes specific data on each cross section and summary tables of predicted hydraulic characteristics at increments of reduced discharge.

Relating Predicted Physical Characteristics to Biological Needs of Fish Species

As previously noted, relating physical characteristics to the ecological needs of fish species is the most difficult part of any methodology. Using the proposed approach, flows are evaluated relative to meeting known biological criteria of important fish species (as defined by management agencies) for successful passage, spawning and rearing. For example, in the Snake River, Idaho Department of Fish and Game had identified white sturgeon (*Acipenser transmontanus*), smallmouth bass (*Micropterus dolomieui*), and channel catfish (*Ictalurus punctatus*) as key species which must be accommodated by recommended flows. As an example, I will describe the application of the proposed methodology to the Snake River based upon ecological requirements of the key fish species.

Passage: Historically, white sturgeon were anadromous in the Snake River and therefore have well developed migratory behavior. Flows suitable for passage of sturgeon should also accommodate any passage requirements of smallmouth bass and channel catfish.

Unfortunately, little is known about the extent of movement in the present land-locked white sturgeon population or about specific requirements for passage or for other biological activities. Until these criteria are determined, certain assumptions and inferences drawn from the literature must suffice in developing flow recommendations.

A spawning migration of land-locked white sturgeon in the Snake River is assumed to occur, but its extent is unknown. During most of the year, Coon (4), documented little movement for small sturgeon <1.1 m (3.5 ft) total length in the middle Snake River while sturgeon greater than 1.8 m (6 ft) total length were observed to be quite mobile. Extensive movement may be necessary for large sturgeon to obtain an adequate food supply. Based upon this information, passage becomes an important consideration throughout much of the year.

To evaluate passage, shallow riffles or sandbars which would possibly impede up- or downstream movement are located. Since the entire length of these areas will probably not be at right angles to the flow, a varying number of transects are needed to describe a potential passage block (Figure 1). One depth profile along the shallowest course of the riffle or bar should be made. This information will be useful in final analysis and in determining the location and number of transects needed. For analysis, the shallow area of each transect is partitioned from the remainder of the transect and depth and velocities predicted for the range of flows desired.

Predicted depths and velocities of the critical segment of each transect are then examined and channel characteristics are projected for the total nonlinear length of the potential passage block. From these projections, a minimum passage flow is recommended for those months in which sturgeon are active (mid-February to mid-November).

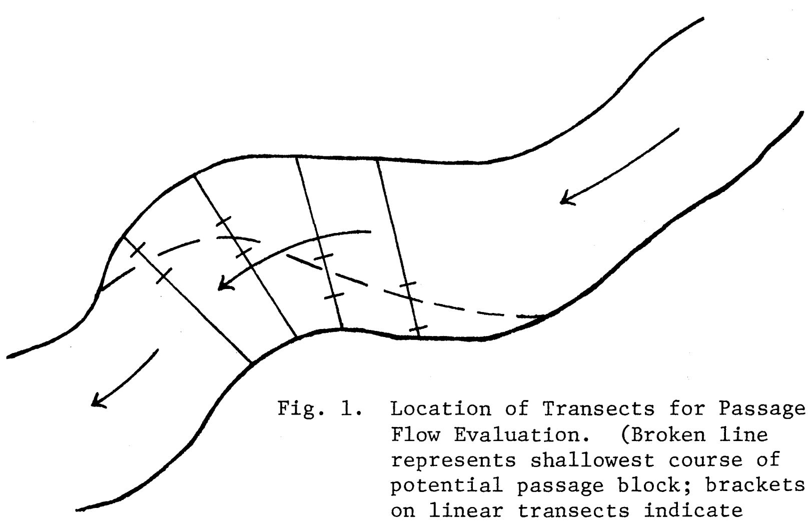

Fig. 1. Location of Transects for Passage Flow Evaluation. (Broken line represents shallowest course of potential passage block; brackets on linear transects indicate partitioned segments.)

For paddlefish, Bovee (5) recommended that 50 percent of the total transect length, as measured by the Oregon Method, meet passage criteria with a continuous portion equalling at least 30 percent of the total transect length. Until flow criteria for passage of white sturgeon are determined, it is recommended that a minimum continuous depth of 1.5 m (5 ft) be maintained over 25 percent of the length of the potential block. Adjustments in these criteria will probably be necessary based upon field observations.

Spawning: Stable flow during the spawning and incubation period of smallmouth bass and channel catfish is probably more important for spawning success than recommending a specific stream resource maintenance flow for this activity.

The spawning period of white sturgeon is reportedly May and June with spawning probably taking place over rocky substrate in swift current near rapids when water temperatures are between 8.9 and 16.7 C (48-62 F). These general requirements are similar to requirements reported for other sturgeon species of North America and Russia.

Since no specific information on the preferred location, depth, or velocity for successful spawning of white sturgeon has been reported, research should be initiated to determine physical requirements. However, until specific information becomes available, inferences of the spawning requirements must be made from known requirements of other species of sturgeon. The reliability of such comparisons is not known but is considered superior to no information at all. At least among Russian species of sturgeon, spawning requirements are similar.

Most sturgeon literature examined reported that spawning occurs at the foot of a riffle or below a waterfall, in swift water over rocky substrate. Unconfirmed accounts of sturgeon spawning in the Snake River suggest that white sturgeon spawn in similar habitat.

Anadromous species of sturgeon native to Russia are reported to spawn at depths ranging from 1.5 to 5.0 m (5.0-16.4 ft) and at velocities of 0.7 to 1.1 mps (2.3-3.6 fps) (6,7). Lake sturgeon (a small adfluvial species) are reported to spawn at depths ranging from 0.6-4.6 m (2.0-15.0 ft) (8,9); no velocity requirements have been reported.

Until spawning requirements of white sturgeon are documented, it is recommended that minimum depth criteria for spawning be set at 1.5 m (5 ft). This estimate appears reasonable when one considers the large size of mature fish and the fact that one female is accompanied by two or more males during the spawning act. A range of velocities from 0.6-1.1 mps (2.0-3.5 fps) is recommended.

Transects for evaluating flow suitability for meeting spawning criteria are established in representative reaches of the river, as near the tail of riffles as physically practical for measurement. At least three potential spawning riffles of comparable size should be examined in each study reach. Field measurements are made and the data analyzed by the WSP program. At each of several predetermined discharges, those portions of the transects having suitable depths for spawning are partitioned and analyzed a second time for the purpose of determining velocity in these areas.

Mean spawnable width of transects analyzed is determined for each discharge and the flow which provides maximum spawnable width is considered optimum. The minimum sustained discharge for spawning will be some specified percentage of this value and will be determined after original data analysis. Oregon has set minimum sustained discharge at 80 percent of optimum for salmonids (10) and Bovee recommends minimum discharge of 75 percent optimum for paddlefish (5). Optimum is defined as the maximum efficient flow for creating or maintaining suitable spawning areas.

Rearing: Rearing requirements of fishes in general are less understood than requirements for other phases of the life cycle. Successful rearing of stream fishes depends upon adequate food supply, and suitable physical habitat and water quality.

Virtually nothing is known about the early life history of white sturgeon. Information available suggests that sturgeon larvae are demersal. The area of residence of white sturgeon smaller than 381 mm (15 in) in length is not known; large sturgeon inhabit deep pools.

Sturgeon up to 482 mm (19 in) in length are reported to feed on plankton and small macroinvertebrates (8) while larger white sturgeon feed primarily on fish, crayfish, molluscs, and chironomid larvae (9). In general sturgeon are omnivores and scavengers.

White sturgeon, smallmouth bass and channel catfish require pool-associated habitat for rearing. Also each species has two food sources in common: aquatic insects and crayfish. Since invertebrate production takes place primarily in riffle areas and riffles are most affected by reduced discharge, it is reasoned that maintenance of suitable riffle conditions will also maintain suitable pool conditions.

The U.S. Geological Survey--Washington Department of Fisheries method for recommending rearing flows for Pacific Salmon species is based upon the assumption that rearing is proportional to food production, which is in turn assumed proportional to wetted perimeter (11). No studies have been reported which were specifically designed to determine the validity of this assumption and if valid, it is applicable only to pool-riffle type channels. Until better information is obtained, I recommend that determination of rearing flows in the Snake River be patterned after the above method.

In determining rearing discharge, several representative, physically accessible riffles are located and one transect is established in each. Standard physical measurements are made and riffle characteristics predicted with the WSP program. Wetted perimeter is calculated and plotted against discharge.

Starting at zero discharge, wetted perimeter increases rapidly for small increases in discharge up to the point where the river channel nears its maximum width. Beyond this inflection point, wetted perimeter increases slowly while discharge increases rapidly. The optimum quantity of water for rearing (food production) is selected near this inflection point (Figure 2).

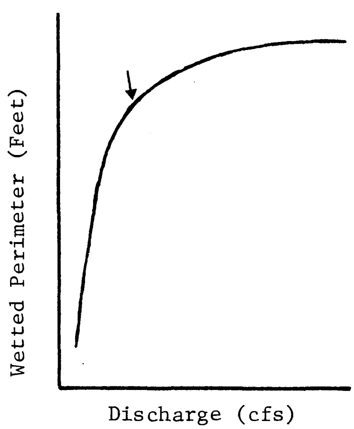

Fig. 2. General Representation of the Wetted Perimeter - Discharge Relationship. (Arrow approximates the recommended rearing discharge.)

Preparation of Recommended Flows

After analysis of field data, recommended flows are assigned by month or 2-week period for each biological activity. The stream resource maintenance flow which is the highest for the critical biological activity of any given time period is the flow selected.

Although the above approach does not take into consideration resident and/or anadromous salmonids, where these species are important, their flow requirements should be evaluated as part of the overall recommendations.

ADVANTAGES AND DISADVANTAGES OF METHODOLOGY

The major advantage of the proposed methodology over those currently available is the reduced time involved in making field observations and consequently the reduced cost of determining stream resource maintenance flows. The initial expense for field equipment, however, is greater than for methodologies currently applied to wadable streams.

A disadvantage of the methodology is that accuracy is probably not as good as would be obtained from actual field measurements. Using Manning's equations for calculating discharge, an error of ± 15-20 percent may occur, depending upon cross section configuration and substrate (12). Also, Manning's roughness coefficient, calculated at observed discharge, is held constant in the WSP model, while it actually increases as discharge is decreased (Figure 3). Error resulting from changes in roughness, however, is minimized by collecting field data at the lowest practical discharge.

The WSP model predicts mean values for hydraulic characteristics for desired subsections (maximum of 9) within each transect. These are potentially less accurate than actual field measurements taken at a series of reduced discharges, as required by other methodologies employing field measurement. Montana Department of Fish and Game personnel are using the WSP program to make flow recommendations for small, wadable salmonid streams and have found good reliability between observed and predicted physical values (14). Validation of the technique for large rivers will be necessary. The weakest point in the application of the proposed methodology to the Snake River is the limited available information on ecological requirements of the fish species involved.

This methodology is proposed only as a starting point for developing flow recommendations for large rivers. It is based upon the best available information and with research and field experience will hopefully evolve into a sound approach to recommending resource maintenance flows for large rivers.

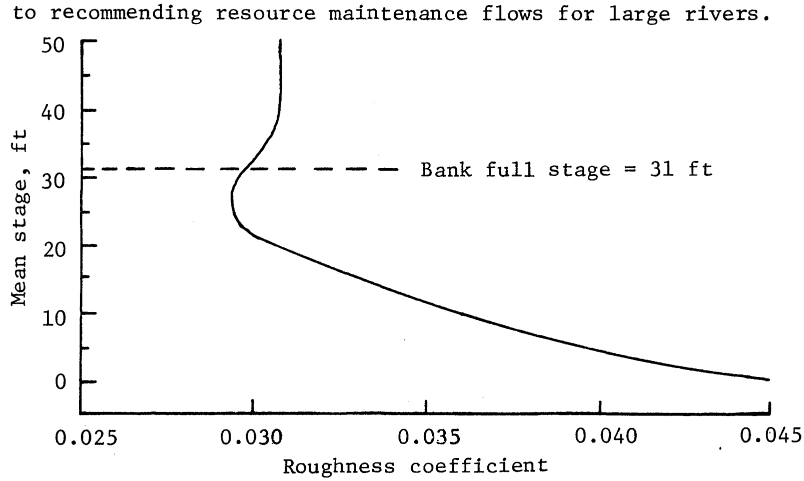

Fig. 3. Changes in Roughness Coefficient with River Stage. Modified from Chow (13).

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INSTREAM FLOW TECHNIQUES FOR LARGE RIVERS

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ABSTRACT

White (1975) proposed a methodology for use in determinations of stream resource maintenance flows for large unwadeable rivers. The basis of the proposed methodology is the Bureau of Reclamation's water surface profile computer program. The techniques involved in collecting the data for use in the program is described.

The predictive capability of the program requires only one set of field data. The data output for any given number of discharges are correlated with known biological criteria of the species in the Snake River to determine stream flow requirements. Fish passage flows, fish rearing flows, and waterfowl nesting flows are determined from the data output.

INTRODUCTION

White (1975) proposed a methodology for use in determinations of stream resource maintenance flows on large unwadeable rivers. The basis of the methodology is the Bureau of Reclamation's water surface profile computer program. The predictive capability of this program allows for one set (at one discharge) of field data per study site to determine stream resource maintenance flows for that site.

The techniques discussed are those used in collecting data for the computer program and in determining resource flows from the computer output.

FIELD DATA

The field data required for the water surface profile program include:

1. A minimum of four stations per study site.
2. Relative elevation of each station at a study site.
3. Thalweg distances between stations.
4. A known discharge.
5. Depth profile of channel at each station.

6. Description of streambed material and identification of points where material changes.

7. Description of bank and overbank material and vegetation.

In addition, velocities are measured on each transect aid in the determination roughness coefficients.

TECHNIQUES

Equipment

The following pieces of equipment are used in collecting data for use in the water surface profile computer program.

Transit/level with tripod	Sounding reel
Philadelphia rod	Boat with motor
Measuring tape	Direct readout current meter
Survey stakes	CB transceiver
Camera	

Station location

The habitat types to be measured are dependent on the requirements of the resources within the stream. The location of each habitat station is permanently marked with survey stakes, and a permanent bench mark is located and marked for future reference.

At each study site, a minimum of four stations are measured (Figure 1). The most downstream station is designated as a discharge control station and is located to most accurately measure the discharge. The middle two stations are located over the habitat to be measured.

The habitat requirements for the important game fish species in the Snake River (American Falls to C.J. Strike) are listed in Table 1.

Measurements

At each station a line-of-sight transect is established by use of a transit/level. The transect is located at right angles to the stream flow (Figure 2) and each side is permanently marked at the high water mark.

Table 1. Stream flow life history requirements for fish in the Snake River study section.

Species	Spawning	Passage	Rearing
White sturgeon *Acipenser transmontanus*	X	X	X
Smallmouth bass *Micropterus dolomieui*	X		X
Channel catfish *Ictalurus punctatus*	X		X
Rainbow trout *Salmo gairdneri*			X

A boat with a suitable motor to stabilize on the transect is used for taking depth and velocity measurements. A transit operator signals the boat operator as the boat approaches the transect (position A, Figure 2) and again when the boat is on the transect (position B). At this time the sounding reel operator lowers the sounding weight and current meter to record the depth and then adjusts the meter depth to record the velocity. If the boat drifts from the transect, the parameters are measured again.

Depths and velocities are measured in accordance with standard U.S.G.S. procedures (U.S. Geological Survey, 1969). A minimum of 20 points are measured on each transect with no more than 10% of the flow in each distance. Velocities are taken at 0.6 of the depth in water less than 75 cm, and at 0.8 depth and 0.2 depth in water over 75 cm. Any significant drop in depth requires additional measurements to insure an accurate identification of the stream channel configuration that transect.

Relative elevations of water levels at each transect are made along the thalweg if possible. If not, then elevations are taken from the same side of the stream.

Distances between transects are measured by tape or by use of the transit and stadia rod at the same time elevations are measured. If possible, transect and established bench mark elevations are measured from one transit location.

Depths of the water are recorded from designated high water levels. Overbanks of the stream width which are dry at the time of measuring are also measured for relative depths to high water.

Streambed materials

Streambed substrates are categorized on each transect with notations made as to where the materials change (Figure 5). The following guidelines are used for identification of materials.

Bedrock . . . . . . .large mass of solid rock

Boulder . . . . . . .rocks over 30 cm in diameter

Cobble(rubble). . . .rocks 7.6 to 30 cm in diameter

Gravel . . . . . . .rocks 0.3 to 7.5 cm in diameter

Sand, silt, clay. . .particles less than 0.3 cm in diameter

Vegetation. . . . . .describe type

Photographs

Photographs showing the overall perspective of the stream at each transect are taken.

Data preparation

Channel configurations are graphed and bottom materials are noted for each transect (Figure 5).

Distances (X coordinates) on a transect and depths as relative elevations (Y coordinates) are coded into the computer program (Figure 6) in accordance with U. S. Bureau of Reclamation procedures (U. S. Bureau of Reclamation, 1968).

A maximum of nine segments are designated for each transect and roughness coefficients are estimated for each segment (Figures 5 and 6). Each segment is designated by its right most coordinate.

Velocities measured for each segment are matched with predicted velocities for determination of more accurate roughness coefficients.

RESULTS

Hydraulic data (velocity, discharge, wetted perimeter) are predicted by the computer for a range of water surface elevations (Figure 7). This data is then used to construct curves for correlation with known biological criteria for the fish species within the stream.

Passage information for a typical study site is given in Figure 8. A discharge allowing 25% of the continuous potential block a minimum depth of 1.5 m is regarded as the minimum passage flow (White, 1975).

Rearing flows are determined from wetted perimeter versus discharge curves (White, 1975). Starting at zero discharge, wetted perimeter increases rapidly for small increases in discharge up to the point where the river channel nears its maximum width (Figure 9). Beyond the inflection point (noted by arrow), the wetted perimeter increases slowly while discharges increases rapidly. The discharge at the inflection point provides the optimum quantity of water for rearing (food production) and is considered the minimum rearing flow.

No spawning information for the Snake River was collected due to lack of knowledge of specific requirements for those species found in the study section.

Considerations for stream resource maintenance flows for waterfowl nesting are also given. One or two transects are located at or near known waterfowl nesting sites. Elevations of these sites are determined and designated as the maximum allowable water levels during the waterfowl nesting period. The channel configuration graphs provide minimum water surface elevations to maintain island integrity for nesting geese. These elevations are related to discharges on the computer output. For example, a flow of 450 cu m/s (Figure 10) results in flooding of the island, while a flow of 140 cu m/s allows the island to be continuous with the mainland. Flows of 250 or 340 cu m/s provide the situation desired for waterfowl nesting on islands. A flow of 250 cu m/s does not flood the mainland bank, which may be utilized by some waterfowl.

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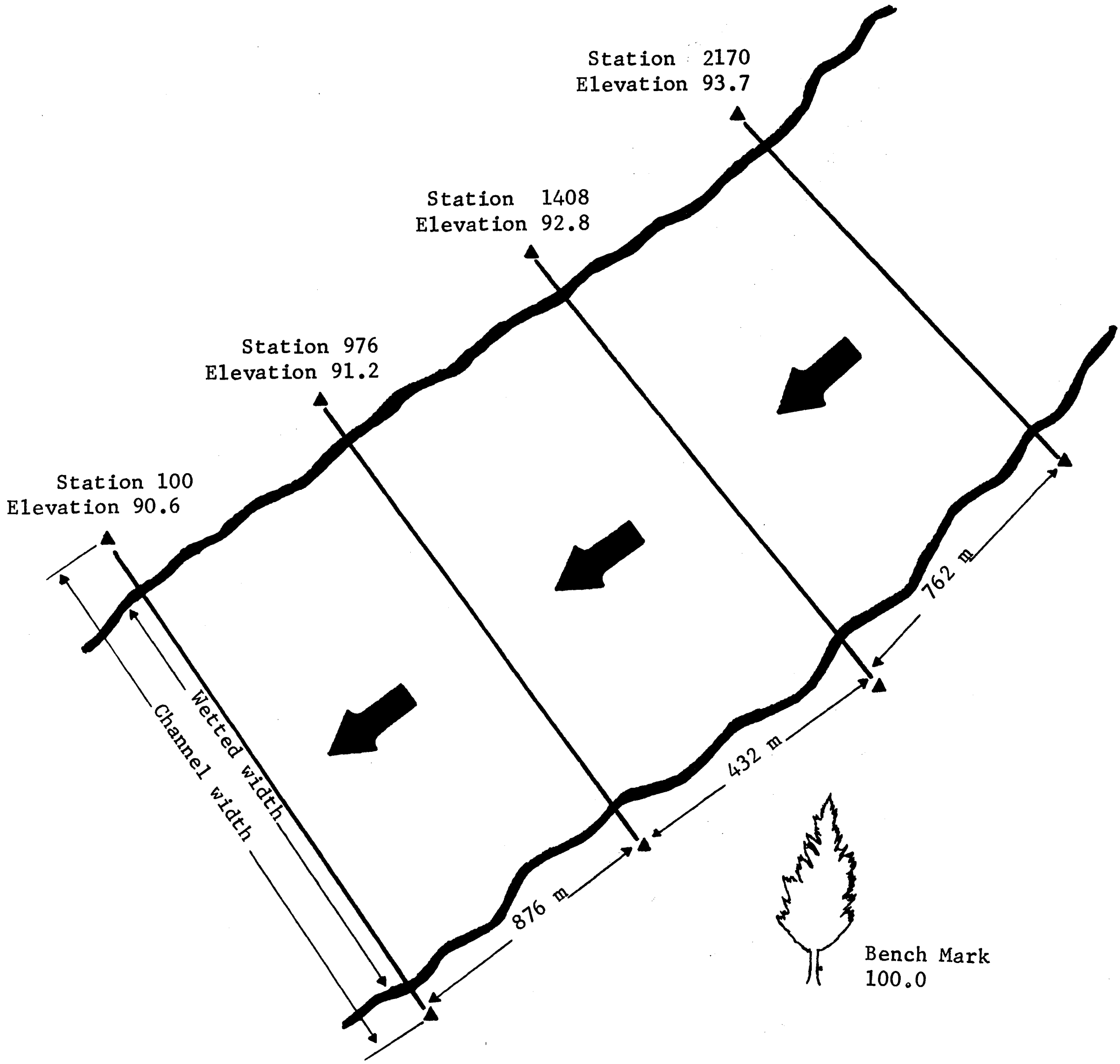

Fig. 1. Typical Stream Study Site

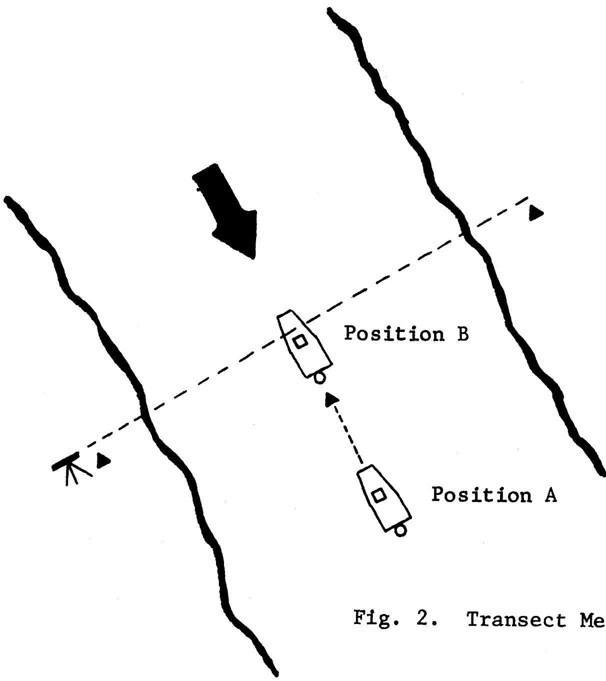

Fig. 2. Transect Measuring Technique

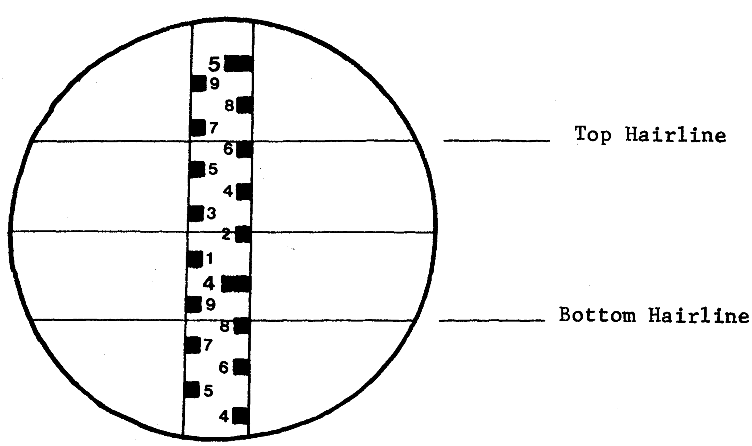

Fig. 3. Distance Measuring Technique Using Transit Stadia

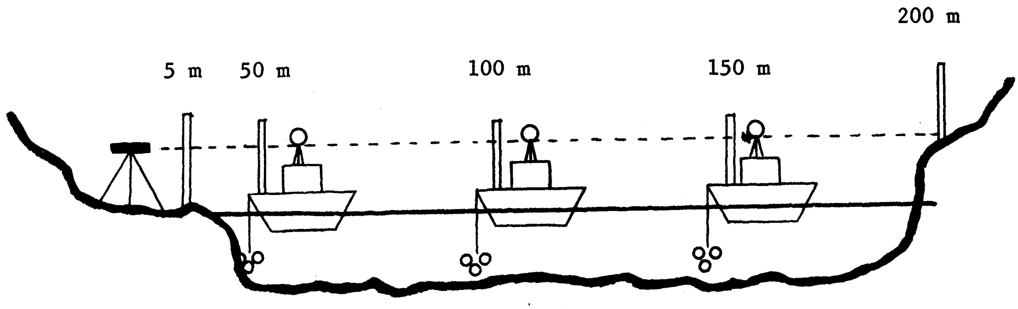

Fig. 4. Boat Displacement on Transect

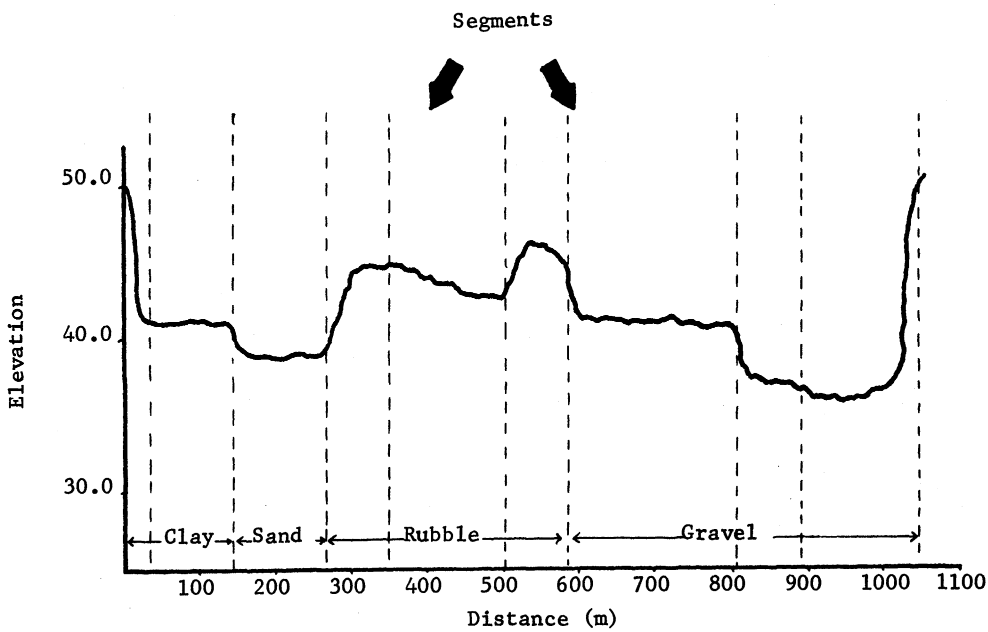

Fig. 5. Stream Channel Configuration

SUMMARY OF OPTION AND COORDINATE DATA

Idaho Department of Fish and Game   December 9, 1975   Run - 1
Stream Flow Study   Snake River at Loverbridge   LB 16817

Station 2464	Number of roughness segments in section	Elevation of sediment delta	Elevation of observed profile	Incremental discharge
	9	0.0	0.0	0

Number of coordinate pairs - 50
Option parameters of zero indicate a redundance

Right most coordinate	Roughness coefficient	Reach length of centroid
22.	.137	2364
93.	.141	2364
179	.066	2364
490	.074	2364
537	.075	2364
796	.064	2364
1092	.061	2364
1442	-.078	2364
1731	.087	2364

X Coordinates	0.0	5.0	11.0	22.0	43.0	63.0	93.0	121.0	135.0	141.0
Y Coordinates	50.2	49.2	46.9	43.8	40.8	38.4	38.2	42.4	45.0	44.7
X Coordinates	179.0	227.0	265.0	299.0	353.0	431.0	465.0	490.0	505.0	520.0
Y Coordinates	45.2	46.4	47.9	48.0	47.5	47.9	48.4	49.2	50.2	50.5
X Coordinates	535.0	537.0	574.0	598.0	646.0	712.0	768.0	778.0	796.0	806.0
Y Coordinates	49.7	49.4	47.7	47.3	46.0	45.5	45.2	45.0	43.0	39.6
X Coordinates	838.0	880.0	946.0	1002.0	1044.0	1092.0	1148.0	1202.0	1260.0	1334.0
Y Coordinates	38.1	38.5	36.2	35.6	35.0	35.2	35.3	35.8	35.5	34.4
X Coordinates	1390.0	1442.0	1514.0	1562.0	1606.0	1626.0	1676.0	1722.0	1726.0	1731.0
Y Coordinates	34.2	35.5	37.2	41.6	47.2	47.7	47.5	47.2	49.2	50.2

Fig. 6. Example of Data Input

Idaho Department of Fish and Game Stream Flow Study Run - 1 Page No. 1
Snake River at Loverbridge LB 16817 December 9, 1975

Station 24 + 64 English system Assumed elev. 0.00 Thalweg elev. 34.2 Thalweg slope .0002

Computation line HFI = .08 HV1 = .02 Avg overbank reaches Left = 410. Right = 2364

Length of centroid	Conveyance areas	Top widths	Hydraulic Radii	Roughness coefficients	Conveyance factors	Velocities	Discharges
2364	50	17	2.8	.13700	1080	.28	14
2364	668	71	9.4	.14100	31367	.62	416
2364	519	86	6.0	.06600	38701	.99	513
2364	546	311	1.8	.07400	15991	.39	212
2364	0	1	0	.07500	0	0	0
2364	787	259	3.0	.06400	38353	.65	509
2364	3676	296	12.4	.06100	480053	1.73	6366
2364	4964	350	14.2	-.07800	554604	1.48	7354
2364	1831	284	6.4	.08700	108051	.78	1433
Sum or avg	13041	1675			1268200	1.48	16817

This section has 9 roughness segment or segments. 9 segment or segments used for this discharge computation line HF2 = .42 HV2 = .03 SF voided Total head = .24 crit. flow not required W. S. elev. = 49.27

Fig. 7. Example of Data Output

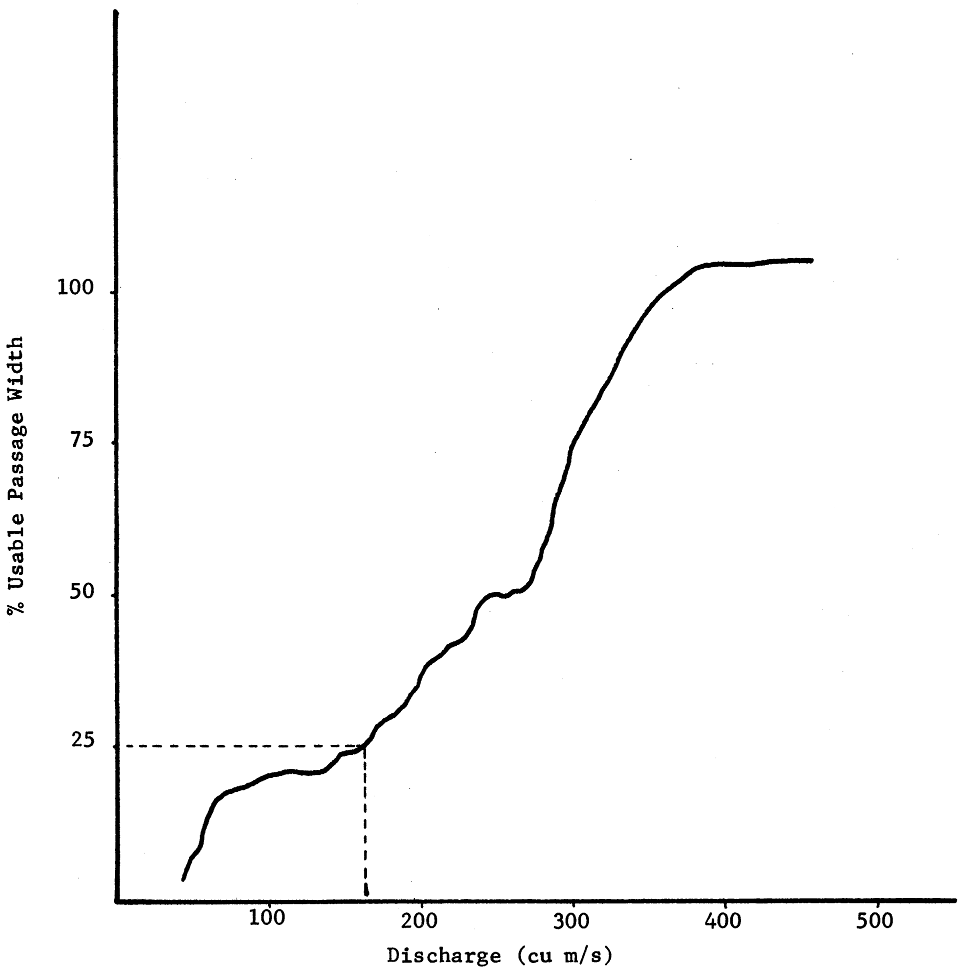

Fig. 8. Minimum Passage Flow Curve

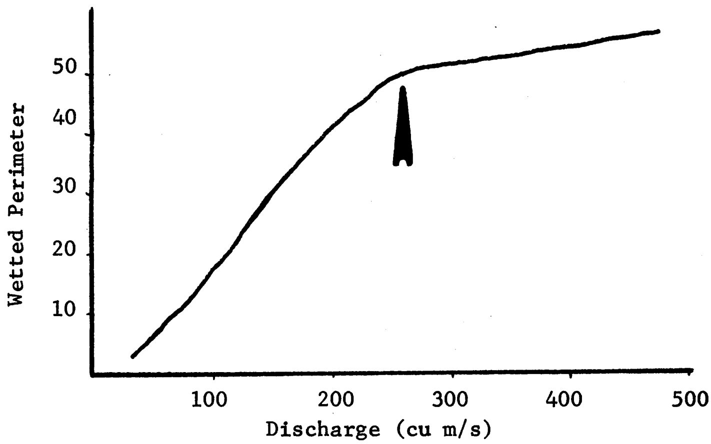

Fig. 9. Minimum Rearing Flow Curve

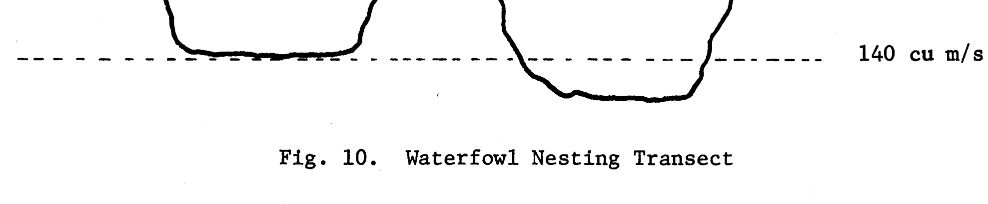

Fig. 10. Waterfowl Nesting Transect

NEGOTIATIONS FOR FISHERY FLOWS IN COLUMBIA RIVER

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The water development of the Columbia Basin has been extensive and it has been designed to provide irrigation, hydroelectric power, and flood control benefits. The yield of benefits has been tremendous, but one of the costs has been the severe losses of anadromous fish resources. In 1974, upriver stocks of salmon and steelhead had declined to extremely low numbers in Columbia and Snake Rivers, and the impact of low runoff year 1973 on juvenile survival was apparent. The decline would have been more dramatic if hatchery production had not produced good returns in recent years.

The Columbia Basin Fishery Technical Committee, recognizing the critical condition of upriver stocks, recommended that the flows of the Columbia and Snake Rivers be regulated in 1975 to increase the survival rate of migrating salmon and steelhead, both adult and juvenile, particularly in view of a forecast of poor runs of spring and summer chinook and summer steelhead destined for the Snake River.

On February 20, 1975, top administrative people from the USCE, BPA, USBR, public and private utilities, and Federal and State fishery and water management agencies met to review the problem particularly as related to 1975. The fishery agencies presented a series of recommended flows for 1975 in terms of minimum and maximum average daily flows for the mid-Columbia River, Lower Snake River, and Lower Columbia River. The rationale for selecting the range of flows was as follows: (1) Maximum flows were intended to limit nitrogen supersaturation to a level that adult and juvenile salmonids could tolerate; (2) Minimum flows were estimated on the basis of requirements for passage of adult and juvenile salmonids. For downstream passage of juveniles, the minimum requirement was based on a combination of factors including provision of transportation water to prevent delay in passage through the reservoirs and some discharge through the spillways and to lessen the mortality that occurs in passage of juveniles through turbines. The recommended flows and spills for the critical fish migration periods are illustrated in Figure 1.

As a result of the February 20 meeting, the Ad Hoc Committee on Fishery Operations was formed under the aegis of the Columbia River Water Management Group on March 11, 1975. The Ad Hoc Committee, in turn, appointed a 13-member Work Group to carry out meetings through the March-August period.

In addition to minimum and maximum daily average flows, the fishery agencies recommended, with certain exceptions, that not less than 20 percent nor more than 60 percent of the project flows be spilled during the smolt migration period, April 15 to June 15, on the Snake and Columbia and in late July and August on the Columbia. Fortunately, 1975 turned out to be a somewhat higher than average water year, and it was possible to maintain a substantial part of the recommended spill on the Snake and Lower Columbia during the most critical smolt migration period this spring. On the other hand, it was not possible to maintain the recommended spill on the mid-Columbia, particularly in late July and August. Because of this, considerable effort was made by the Work Group to set spill priorities to accomplish the most benefit within the ability to manipulate spill among projects. When unused spill at that plant exceeded the fishery requirements, energy was generated at the Federal project and delivered to the mid-Columbia PUD projects in order for those projects to spill. A total of 621,233,000 kilowatt-hours were delivered for this purpose.

During a considerable portion of the summer, the discharge and spill at Lower Granite Dam was fluctuated daily in order to attract more fish into the fishladder facilities. This was accomplished by cutting the spill down to 60,000 cfs during the early morning hours. Indications are that this operation did enhance the fish movement.

Dissolved gas levels (nitrogen) were generally above the 110 percent standard on the Snake River from mid-April to late July and on the Lower Columbia River from mid-May to late July. Saturation levels reached around 130 percent at times on the Snake River, while on the lower Columbia River, below the Bonneville spillway, the saturation level reached nearly 140 percent at one time. Saturation levels of this magnitude do have adverse effects on fish and some evidence of gas bubble disease was detected on both adult and juveniles. Saturation levels might have been reduced somewhat by eliminating or reducing spills; however, when weighed against the increased chance of juvenile survival by providing spill, the higher nitrogen levels seemed acceptable.

In 1975, because of the orderly and near normal volume runoff, there was no significant impact on either power, flood control or irrigation from the cooperative actions taken to assist fish passage. However, this will not always be the case, particularly when lower than normal runoff volumes are experienced. Under lower than normal runoff conditions some adverse impact can be expected if recommended flow and spill requirements are to be met. The heaviest impact would be on power production.

Following the water year 1975, the Columbia River water management group recognized a continuing need for a mechanism to provide close coordination of river regulation with fishery needs and formed a permanent committee for that purpose entitled, "Committee on Fishery Operations." This committee has met several times in 1976 and has functioned similar to the 1975 Ad Hoc Committee on Fishery Operations. Because of the similarity of hydrological conditions in 1975 and 1976, the results of flow regulation for fisheries in 1976 will probably be similar to those results in 1975.

The real need for flow regulation for fisheries becomes apparent only in a water year that has a runoff much below average. The effectiveness of this committee cannot be tested until a water year similar to 1973 occurs.

The cooperative attitude of the water management entities has been extremely good. Cooperative attitudes may not be enough to provide flows necessary to the survival of salmon and steelhead in a low runoff year.

The fishery agencies are working through a number of planning groups in an attempt to incorporate flow requirements for fishery resources in future water management plans for the Columbia River Basin. Interagency cooperation has yielded good results in the operations committee, but it will take more than cooperation to provide the water needed for fishery resources in the future. If Columbia River salmon and steelhead are to survive in the future, their flow requirements must be established as an instream flow need along with hydroelectric power, navigation, wildlife and recreation and those instream flow needs must be protected and provided through legal means in the future.

Determination of the flow requirements for anadromous fish must be based on factual data. Criteria and methodologies will change as conditions change on the Columbia River. There will be a continuous need for research in the area. Water management entities and fishery agencies should cooperatively seek the best possible definition of flow requirements for anadromous fish.

Although an effective means of providing flows required for anadromous fish in the Columbia River system is not available at this time and divergent and conflicting water planning efforts are occurring in the Basin, the fishery agencies will continue to provide input regarding fishery flow requirements at every opportunity.

FIGURE 1.

PROVISIONAL RECOMMENDATIONS FOR
INSTANTANEOUS AND DAILY AVERAGE MINIMUM FLOWS
AT THE COLUMBIA RIVER FORKS, 1000's cfs

9/15/75

Month	Priest Rapids		Lower Snake		McNary	
	Inst	Daily Average	Inst	Daily Average	Inst	Daily Average
January	36	40	10	20	20	60
February	36	40	10	20	20	60
March	36	40	10	20	20	60
April						
1-15	36	60	15	40	40	100
16-25	36	60	30	85	70	150
26-30	60	110	30	85	70	200
May						
1-15	60	130	30	85	70	220
16-31	60	95	30	85	70	190
June						
1-15	60	110	30	85	70	200
16-30	36	80	15	30	50	120
July						
1-15	36	80	15	30	50	120
16-31	60	110	10	20	50	140
August	60	95	10	20	50	120
September	36	40	10	20	40	60
October	36	40	10	20	40	60
November	36	40	10	20	20	60
December	36	40	10	20	20	60

(12/24/75 - Footnote amended to reflect 1985 condition for CR&T Study)

[ ] During these periods of juvenile migration a minimum of 20% of the discharge at each project should be spilled except at those projects where fingerling bypass systems are installed and operated efficiently.

TOPIC V-D.

LARGE RIVER METHODOLOGIES

Summary Discussion

The observation was made that the serious problems with the anadromous fishery of the Columbia and Snake Rivers described by Terry Holubetz was a commentary on the ineffectiveness of the fish and wildlife agencies' ability to influence water development decisions. He pointed out that the losses due to turbine mortality were predicted prior to construction of Bonneville Dam. The panel responded that while this was true we must continue to persevere and that recent successes indicate an improvement in development agency attitudes. There is cause for optimism.

Mr. Holubetz was questioned about how downstream fish passage could be accomplished in less than average runoff years when it will be very difficult to meet the Columbia River Fisheries Technical Committee's passage flow recommendations. He answered that use of screens in the turbine intakes is effective in guiding downstream migrants into the gatewells for collection and bypassing of the turbines. Also, an experiment in collecting fish at upstream dams and trucking them to a release point below Bonneville Dam indicates feasibility as an emergency measure.

Another question was raised regarding the economic benefits of continued investment in measures to mitigate fish losses on the Columbia and Snake Rivers. Terry pointed out that public and Congressional support has always been very strong and that simple economics may not be the dominant influence in the future decisions regarding such investments. Furthermore, the Corps of Engineers indicates that the economic benefits are there.

It was suggested to Tim Cochnauer that use of a hydrofoil on their boat may help them hold a more stable position in the current, thereby improving accuracy of data collection.

The panel concluded that:

1. We are still feeling our way in our study methods on big rivers.
2. A lot of work remains in developing IFN study techniques.
3. This is important not only to the fish, wildlife and recreational agencies, but to development agencies as well.
4. The panel believes it is appropriate for all interested parties to get involved in the work that lies ahead.

Notes by panel moderator: Keith Bayha, Office of Land Use and Water Planning, Dept. of Interior, Washington, DC

FACTORS AFFECTING UPPER COLORADO RIVER RESERVOIR TAILWATER TROUT FISHERIES

James W. Mullan, U. S. Fish & Wildlife Service, Vernal, Utah
Victor J. Starostka, Utah Division of Wildlife Resources, Dutch John, Utah
Joseph L. Stone, Game & Fish Department, Pinetop, Arizona
Robert W. Wiley, Game & Fish Department, Green River, Wyoming
William J. Wiltzius, Division of Wildlife, Montrose, Colorado

ABSTRACT

Each tailwater presents its own set of factors influencing trout abundance, but within the following premise. Productivity of the water is substantial and limiting factors do not include nutrients, lethal chemical conditions or failure of natural reproduction, with the latter circumscribed by stocking. Tailwater rearing habitat primarily involves considerations of flow, shelter, temperature, and food, but with sequential deferment to the pervasive influence of increasing downstream turbidity. Purge of sediments, by arrest in the reservoirs, resulted in four of the tailwaters; temporal discontinuities of clear river which revert to turbid river.

Less than optimum minimum flow appeared to be a major limiting factor only in the Gunnison River tailwater. In Glen Canyon and Fontenelle tailwaters, discharge resulted in excessive water velocities in relation to available shelter as reflected in modest standing crop (25-38 pounds/acre), low yield (6.9 and 7.4 pounds/acre) and use (21 and 23 hours/acre), but with the catch favoring trout 12 inches or over capable of coping with strong currents. Discharge and shelter components of the Navajo and Flaming Gorge tailwaters, by contrast, apparently approached the ideal as denoted by exceptional trout yield (inherent production of 169 and 93 pounds/acre), prior to dysfunction by low water temperatures.

Water temperatures were reduced in all the tailwaters to varying extents by reservoir operations. Fontenelle tailwater was least affected with water temperatures remaining near freezing in winter and approaching the maxima for trout in summer. As the much larger Flaming Gorge and Navajo Reservoirs filled over a number of years, a more regular hydroelectric operation produced stable flows of water from deeper and colder strata, reducing water temperatures most. At 39.0^{o}-49.0^{o} harvest no longer even equaled the weight of trout stocked. Availability of insect food to rainbow trout, not the total that occurred, declined drastically at the lower water temperatures.

INTRODUCTION

The tailwaters of the upper Colorado River reservoirs represent a unique opportunity for assessment of regulated discharges on fish life. Despite numerous investigations, no attempt has been made to view findings as a whole.

With impoundment of Lake Powell, Flaming Gorge, Navajo, Blue Mesa, and Fontenelle Reservoirs, over 90% of the runoff is now controlled (8). The aim of this report is to describe and correlate differences in trout production of these tailwaters in terms of water quality and quantity, food supply, reproduction, and interaction between fish species. Source materials were drawn from Colorado River Storage Project, Section 8, job progress reports and Bureau of Reclamation and Geological Survey water records, with the former only recognized in the literature cited.

ARIZONA GLEN CANYON TAILWATER AND FISHERIES

Discharge from Glen Canyon Dam began in 1963 and averaged 12,000 cfs daily, with seasonal fluctuations of 1,000 to 58,100 cfs. In the years 1963-72, Lake Powell filled to 60% of pool level (125,290 surface acres, 20 million acre-feet, 166 foot average depth, 506 foot maximum depth, 175 foot outlet depth, 2.0 year storage ratio, 3,646 foot elevation, 1.0 pound trout and warm water fish/acre harvest).[1/]

Access is limited to Lee Ferry, 16 miles below the dam, and it was this canyon-walled stretch that was studied by the Game and Fish Department.

Rainbow trout[2/] (93%) and channel catfish made up most of the catch (1963-72) (Table 1). Catch rate varied from 0.26 to 0.99 fish/hour, while annual fishing effort, yield and stocking averaged 21.2 hours/acre, 6.9 pounds/acre, and 9.2 pounds of rainbow trout/acre. Average return of marked trout was: adult, 33.0%; sub-adult, 0.9%; and fingerlings, 1.2%. Comparing weight of trout stocked for the nine-year period with the weight harvested indicates a return of 75%. The average trout stocked was 7.5 inches (0.17 pounds) and the average trout caught was 11.7 inches (0.64 pounds). Recruitment of marked fingerling and sub-adult trout into the catch suggest an annual growth of 3-4 inches. Scale aging of 190 rainbow trout showed individual growth from one to six inches/year.

NEW MEXICO NAVAJO TAILWATER AND FISHERIES

Discharge from Navajo Dam began in 1962 and averaged 692 to 2,655 cfs daily, with fluctuations of 105 to 11,800 cfs. Generally, flows of 700 to about 1,200 cfs prevailed through 1968, when Navajo Reservoir filled to 61% of pool level (15,630 surface acres, 1.7 million acre-feet, 109 foot average depth, 360 foot maximum depth, 310 foot outlet depth, 2.0 year storage ratio, 6,085 foot elevation, $\leq$ 5.0 pounds/acre cold and warm water fish harvest).

1/ As defined by Jenkins, 1967 (23).

2/ Common names of fishes are those in Special Publication No. 6, A.F.S.

Table 1. Summary of fishery statistics, Glen Canyon tailwater.

Year	1964-65	1965-66	1966-67	1967-68	1968-69	1969-70	1970-71	1971-72	Average1/
Trout caught	13,512	7,757	7,899	6,597	4,082	8,016	8,421	4,372	7,923
Other species caught2/	985	138	695	2,638	945	57	24	44	625
Angler hours	15,723	11,424	18,952	22,829	11,717	17,563	15,620	16,595	15,577
Catch/hour	0.99	0.68	0.40	0.39	0.43	0.44	0.53	0.26	0.51
Average weight trout caught	0.72	0.54	0.70	0.68	0.58	0.65	0.61	1.3	0.64
Rainbow trout stocked:	33,500	26,000	22,100	33,800	47,495	38,536	24,725	4,760	39,635
Adult (8.0+")	23,500	7,000	7,100	3,800	7,495	4,550	4,725	4,760	19,836
Sub adult (5.0-7.9")	---	---	---	10,000	40,000	33,986	---	---	10,465
Fingerling (2.0-5.0")	10,000	19,000	15,000	20,000	---	---	20,000	---	9,333
Pounds trout stocked	13,932	1,665	3,043	3,302	4,650	4,829	1,858	1,550	6,770
Number trout stocked/acre	45.5	35.3	30.0	45.9	64.4	52.3	33.5	6.4	53.8
Pounds trout stocked/acre	18.9	2.3	4.1	4.5	6.3	6.5	2.5	2.1	9.2
Trout harvest pounds/acre	13.2	5.7	7.5	6.1	3.2	7.1	6.1	7.7	6.9
Angler hours/acre	21.3	15.5	25.7	31.0	15.8	23.8	21.2	22.5	21.2

1/ Partial year, November 1, 1963-July, 1964 included.

2/ Mostly channel catfish with a scattering of crappie, carp, largemouth bass.

The eight miles (145 acres) below the dam were most studied and stocked by the Department of Game and Fish. All brown trout fry and a few rainbow trout fingerlings were stocked in the 10 miles (180 acres) below, but calculated as having been stocked in the upper reach. Annual stocking consisted of 4% adult rainbow, 5% sub-adult rainbow, 54% rainbow fingerlings, and 41% brown trout fry (Table 2). There were an estimated 647 hours of angling/acre annually during the four years 1965-68.

Rainbow (97%) and brown trout, averaging about 12.0 inches, were caught at 0.50 fish/hour. Between two-three percent of the rainbow and 40% of the brown trout ranged from 15 inches to more than six pounds. Yield amounted to 220 pounds/acre and stocking to 50.6 pounds/acre annually. Return of fin-clipped or tagged rainbow trout was: adults, 52-70%; sub-adults, 27-30%; and fingerlings, 15-24% (1% calculated for brown trout fry). Observations of marked fish showed a growth of at least 6-8 inches/year.

WYOMING FONTENELLE TAILWATER AND FISHERIES

Discharge from Fontenelle Dam began in 1964 and averaged 1,648 cfs daily, with seasonal fluctuations of 250 to 18,600 cfs. The impoundment filled almost immediately (8,058 surface acres, 345,000 acre-feet, 30 foot average depth, 100 foot maximum depth, 75 foot outlet depth, 0.2 storage ratio, 6,392 foot elevation, 4.0 pounds trout/acre sport harvest). The Game and Fish Department has made various studies of the 73 mile (2,913 acres) tailwater to Flaming Gorge Reservoir.

Fishing effort averaged 23.0 hours/acre (1970-74). Rainbow (80%) and brown trout averaging 0.9 to 1.5 pounds, but with fish up to 15 pounds, were caught at the rate of 0.22 to 0.33 fish/hour. Annual stocking averaged 141 fingerling rainbow (80%) and brown trout, or 3.7 pounds/acre. Yield averaged 7.4 pounds/acre. While return was low (5%), three- to five-inch fingerlings grew to 10-15 inches in a year, showing a net gain (3.7 pounds/acre) over weight stocked.

UTAH FLAMING GORGE TAILWATER AND FISHERIES

Discharge from Flaming Gorge Dam began in 1962 and has averaged 1,200 to 4,000 cfs, with fluctuations of 400 to 5,000 cfs. The reservoir attained pool level in 1973 (42,000 surface acres, 3.8 million acre-feet, 90 foot

Table 2. Summary of fishery statistics, Navajo tailwater.

Year	1965 1/	1966 1/	1967 2/	1968	Average	1971 3/	1972 3/	1973 3/
Trout caught	42,836	29,179	36,790	78,656	46,865	10,642	31,047	4,844
Angler hours	77,875	81,054	75,052	141,279	93,815	48,375	91,316	32,294
Catch/hour	0.55	0.36	0.49	0.56	0.50	0.22	0.34	0.15
Average weight trout caught	0.70	1.24	0.43	0.43	0.68	----	----	----
Number of trout stocked:	268,259	348,000	519,145	374,654	377,515	----	----	----
Rainbow								
Adult (8.0+")	19,941	10,067	8,100	21,150	14,814	----	----	----
Sub adult (5.0-7.9")	0	0	7,028	0	1,758	----	----	----
Fingerling (2.0-5.0")	149,310	163,933	323,545	179,792	204,145	----	----	----
Brown								
Fry (1.0")	99,008	174,000	180,472	173,712	156,798	----	----	----
Pounds trout stocked	8,631	5,913	6,803	8,017	7,341	----	----	----
Trout stocked/acre	1,850	2,400	3,580	2,584	2,604	----	----	----
Pounds trout stocked/acre	59.5	40.8	46.9	55.2	50.6	----	----	----
Trout harvest pounds/acre	162.5	249.5	109.1	233.3	219.8	----	----	----
Angler hour/acre	537	559	518	974	647	----	----	----

1/ Except for 1967 and 1968, intensive creel census limited to months of June, July and August. These figures were expanded by 2.25 to estimate annual harvest based on the ratio between summer and year-round angling determined in 1968.

2/ June, July, August, October and November creel data expanded on basis of 62% coverage for year.

3/ Patterson, 1974, data extrapolated as in 1/.

average depth, 420 foot maximum depth, 190 foot outlet depth, 1.7 year storage ratio, 6,040 foot elevation, 20 pounds trout/acre sport harvest).

In Utah the tailwater extends to the Colorado state line 30 miles downstream. The entire 735 acres has been subject to a continuing creel census by the Division of Wildlife Resources.

Most of the catch consisted of rainbow trout (1964-74) with annual variations of: 0.32 to 0.96 trout/hour; 11 to 97 hours of fishing effort/acre; 5.5 to 97.8 pounds of trout harvested/acre; and 1.4 to 52.1 pounds of trout stocked/acre. Variations were largely the result of a decline in water temperatures beginning in 1967-68. Until this juncture the fisheries had been largely sustained by stocking fingerling rainbow trout. With the decline in water temperatures, larger trout and other salmonid species (i.e., grayling and Snake River strain cutthroat) were increasingly stocked in coping with changed conditions. Return of rainbow trout fingerlings declined from 25% to one percent, but, while declining, growth remained good. Three-inch fingerling rainbow trout attained 10.0 inches at age I and 13.8 inches at Age II in 1965-67 (N=430), whereas similar values for 1974 (N=310) were 9.0 and 13.1 inches from five-inch fish.

COLORADO GUNNISON RIVER TAILWATER AND FISHERIES

There are three reservoirs in the deep canyon of the Gunnison River. Blue Mesa Reservoir began filling in 1965 and reached pool level in 1970 (9,040 surface acres, 915,000 acre-feet, 101 foot average depth, 340 foot maximum depth, 168 foot outlet depth, 1.0 year storage ratio, 7,520 foot elevation, 23 pounds/acre cold water sport harvest). Coincidentally, the downstream Morrow Point Dam resulted in an even deeper (143 foot average, 117,000 acre-feet) and colder ($\leq 65^{\circ}$) reservoir inundating 12 miles of river. The re-regulating Crystal Reservoir (25,000 acre-feet) is under construction below, but above the Gunnison diversion tunnel adjacent to the boundary of Black Canyon National Monument.

The precipitous upstream descent (986 foot drop in about 38 miles) is accelerated (1,170 feet) in the 12 miles through the monument. The monument comprises the narrowest, deepest and most spectacular portion of the 50 mile canyon. The torrential nature of the river moderates for 15 miles below the Monument to where it is joined by the turbid North Fork. Fifteen miles downstream at Delta, transition to a silted lowland stream is complete. Below

Delta the river flows 50 miles through desert and canyon to the Colorado River at Grand Junction.

Historical flows at Grand Junction and just below the Gunnison diversion tunnel averaged about 2,600 cfs and 1,460 cfs, with average snow-melt maxima about three-fold these values. Flows have been relatively stabilized as a result of the dams, but with less than optimum flow ($\leq$ 50 cfs) persisting below the Gunnison diversion at times. When Crystal Reservoir is completed, 200 cfs is scheduled as a minimum release below this point.

Historically, the Gunnison River was widely recognized for its trout fishing, but with interest primarily on the section inundated by Blue Mesa Reservoir, which received 80% of the 49,100 fisherman days estimated in 1956. The lower river then as now was largely ignored because of difficult access (i.e., 682-1,365 fisherman days annually estimated within the National Monument, 1970-75). There is little direct stocking below Blue Mesa Reservoir.

LIMITING FACTORS

Tailwaters differ from natural rivers in two respects. First, reservoirs act as sediment traps. Also, if water is released from the surface, the reservoir is a nutrient trap and heat exporter, whereas if water is released from near the bottom, as is the usual case for Colorado River hydroelectric dams, the reservoir may be a heat trap and nutrient exporter (33).

Second, arrest of sediment transport in reservoirs built on alluvial rivers results in vastly increased sediment transport potential of the discharge. Close to 152 million cubic yards of material was removed, with resultant lowering of the channel, for 92 miles below Hoover Dam on the lower Colorado River during the period 1935 to 1951 (18). The changes include not only river morphology and metamorphosis (51, 27, 13, 39, 40, 25), but also the aquatic ecosystem, which has only been noted relative to initial erosion (38).

Water Quantity and Shelter

Above an "extinction" flow level, velocity is the major factor controlling animal communities in streams (16, 21). Current is largely a mechanical restraint to trout survival except for reproduction. Shelter allows trout to maintain themselves in currents bearing the greatest drift of food.

Shelter may consist of water depth, submerged logs and rocks, etc. Trout generally occupy a limited area, providing shelter or microhabitat, which provides focal point residency in feeding and resting. Newly hatched trout can only tolerate nearly still water. As the fish grow, they are associated with velocities and depths in proportion to body size, i.e., maximum three to four fish lengths per fps (6), shifting to faster deeper waters and larger territories as they become larger. In winter trout seek deep pools, become non-aggressive, and feed less actively than at warmer temperatures when the fish are widely distributed according to the availability of microhabitat (10, 17).

Return of stocked trout and yield were inversely correlated with volume of discharge. Increasing discharge, however, resulted in decreasing fishing success, and, as a consequence, utilization. Thus, actual production, and requisite shelter, may have been higher with larger discharge than indicated by yield. Survival of hatchery trout, required for production, could also have been masked by non fishable discharge that dispersed stocked trout. In Glen Canyon tailwater, with highest average and maximum discharge and lowest return and yield, only 16 miles below the dam was stocked, whereas there was another 52 miles downstream largely denied to the angler, but not to trout.

Observation of such downstream movement, while limited, was impressive. Marked trout were consistently recovered miles downstream from the point of stocking in all the tailwaters. Other species and trout from the reservoirs were also consistently sampled. Omitting an annual trout stocking of Lake Powell (500,000 sub-adult rainbow) was followed the next year (Table 1, 1971-72) by halving of the catch rate and harvest in the tailwater. Moreover, occasional loss of several hundred kokanee salmon through Blue Mesa dam parallels quantified, heavy loss of warm water fishes and benthos from Missouri River impoundments (45, 46).

Besides the more obvious flow level needed for good fishability, there is reason to suspect that if production could be plotted against stream-flow, the curve would also rise to a plateau and then decline. Increasing discharge, however, increases sediment transport thereby extending trout habitat further downstream than with a smaller flow. The highly productive (1963-68), but limited Navajo tailwater (18 miles; 325 surface acres) compared to the less productive, but much larger Glen Canyon tailwater (68 miles; estimated 3,132 acres) is an example.

Glen Canyon tailwater is more of a tailrace than a typical natural river. Water depth as shelter in this narrow, but deep tailwater (10-20 feet) may thus be largely negated by excessive velocities[3/]. Furthermore, a large deep river with the same gradient as a small headwater stream will have much higher velocity than the headwater stream (27). A 1964 estimate of 75% sand, 5% boulder-rubble and 20% sand-boulder-rubble substrate is suggestive of a channel lacking in microhabitat for coping with high water velocities.

Shelter components of the Navajo and Flaming Gorge tailwaters were only noted in general, but efficiency of occupancy of the channel by trout and food organisms had to be good as denoted by exceptional initial trout yield (98 and 220 pounds/acre). Banks, et al. (2) utilized a 64 cell depth-velocity matrix with established habitat criteria, expressed as percentage of surface area, at four discharges in arriving at an optimum flow for Fontenelle tailwater. This tailwater contains extensive areas of deep, swift current over fairly uniform rubble, lacking microhabitat, referred to as "runs". The analysis showed that base flow of 1,600 cfs favored trout 12 inches or over capable of coping with strong currents. Wiley and Dufek (49) subsequently confirmed a lightly exploited (25%) standing crop of large rainbow and brown trout ranging from 25 to 38 pounds/acre for the years 1970-75.

Glen Canyon tailwater, with its extensive "run" habitat and monotonous five foot gradient, is also similar to Fontenelle tailwater in yield and fishing pressure (6.9 and 7.4 pounds, and 21 and 23 hours/acre), suggesting a similar trout crop between the two waters.

Water Quality

The conclusions of Moyle (30), Leitritz (26), Jenkins (23) and others, who have concerned themselves with nutrients as one of the keys to fish production, suggest chemical values of the tailwaters are acceptable to highly favorable for trout production. Chemical content increases downstream, with the prevalent chemical type grading from calcium-magnesium, carbonate-bicarbonate to calcium-magnesium, sulfate-chloride. Total dissolved solids range from 100 to 900 ppm.

Trout require well oxygenated water ($\geq$ 5.0 ppm), generally less than 70° in temperature. Optimum water temperatures approximate 55° to 65°. Temperatures in the range of 45° to 55° are believed only slightly less desirable.

3/ Although flow duration curves were unavailable for confirmation, available mean discharge records suggest that frequent increases in base discharge of $\geq$ 200%, particularly in early years of the tailwater, could have resulted in increasing average velocities from 2 to $\geq$ 3.5 feet per second (42) some 25 to 50% of the time.

Near saturation of oxygen usually prevailed in Colorado River tailwaters in contrast to the Southeast where oxygenless water may be discharged from the reservoirs (37). On the other hand, supersaturation of nitrogen was a potential limiting factor to trout in the Navajo tailwater (29). Periodic fish losses were not severe, however. Supersaturation of nitrogen has only occurred in water releases from the auxiliary and not the primary outlet. There have also been instances of supersaturation of nitrogen below Morrow Point Reservoir on the Gunnison River, but with no problems noted.

Nation-wide, high water temperatures generally limit trout in tailwaters (15, 37). Maximum water temperatures in Colorado River tailwaters are spatially variable and generally less than lethal ($\geq 77^{\circ}$ for $\geq$ 24 hours). Minimum temperatures, however, have been a problem.

The storage ratio of Fontenelle Reservoir is low (0.2 years), so water exchange may be as rapid as five days. Water temperatures follow climatic influences, with a lack of strong thermal stratification in the reservoir and bottom water temperatures in summer as high as 69°. Temperatures in the tailwater, however, remain suitable for trout in summer. This results because of strong cooling at night due to high evaporation and radiation. Conversely, during winter, water temperatures plunge (Figure 1) and cause heavy ice cover, except for 10 miles below the dam.

Downstream Flaming Gorge Reservoir has a higher storage ratio (1.7 years). In the initial years of filling (1962-66) discharge was sporadic, allowing the water in the channel to warm more in summer before being replaced. As the reservoir filled, a more regular hydroelectric operation produced stable flows of water from deeper and colder strata, reducing water temperatures (Figure 1). Comparing weight of trout stocked with estimated weight harvested indicates a maximum net gain of 93 pounds/acre in 1967 associated with water temperatures of $37.5\text{-}53.5^{\circ}$. Owing to the subsequent decrease in water temperatures to $39.5\text{-}48.5^{\circ}$, annual net gain steadily declined from 66.7 in 1968 to 1.5 pounds/acre in 1970, with a net loss in subsequent years.

Water temperatures in Navajo tailwater were optimum for year-round growth and survival of trout through 1968, but then began to decline for the reasons described for Flaming Gorge tailwater (29). Water temperatures averaging 50° prevailed over an eight month season (1963-68). McNall (29) described mean water temperatures for the same period in 1969, 1970 and 1971 as 46°, 44°, and 41°, and predicted a mean temperature of 39° in 1973. Presumably these decreases in water temperature caused the drastic reduction in trout harvest indicated by Patterson (34) (Table 2).

Mean annual water temperatures in Glen Canyon tailwater trended from 58.8^{o} in 1964-65 to 50.7^{o} in 1971-72. Lake Powell has the lowest altitude, highest heat budget, and lowest latitude of the upper basin reservoirs. Mean monthly temperatures of the tailwater through 1972 were reduced only to the sub optimum level for trout (45^{o}-55^{o}), but with virtual disappearance of channel catfish. Peak harvest (2,638) occurred in 1967-68 whereas only five were caught in 1971-72.

One of the earlier alterations of the natural hydrology of the Gunnison River was storage of 106,200 acre-feet of water in the headwater (elevation 9,330 ft.) Taylor Park Reservoir for major delivery to the Gunnison trans-basin, irrigation diversion tunnel 80 miles downstream beginning in 1937. Effects noted were decreased silt load and lower summer temperature (24), and earlier emergency of willow fly (Pteronarcys) as a result of earlier warming during spring (50). Coincidentally, native bluehead and flannelmouth suckers disappeared and were replaced by white and longnose suckers.

With completion of Blue Mesa and Morrow Point Reservoirs, mean monthly temperatures have been reduced 5.8^{o} to 9.0^{o} in summer and increased 3.3^{o} to 7.2^{o} in fall and winter in the Black Canyon Monument, with an annual range of 36.8^{o} to 51.3^{o}. Correspondingly, peak summer temperatures have been reduced in the lower river, with trout appearing in areas where they were once rare or absent.

Food Supply

Natural running waters form a continuum from erosional mountain streams, dominated by rapid flow and removal of finer sediments, to lowland rivers, characterized by slow currents and the deposition of finer sediments. Cold water invertebrates have adapted over time to erosional channels that are rich in configuration and substrate (48) and, as a result, possess rather specific velocity requirements.

Abundance and diversity of invertebrates in the Navajo tailwater paralleled the benthos of erosional streams (12). Invertebrate densities increased from 1963 ($77/ft.^2$) to 1968 ($625/ft.^2$) for the 8 miles below the dam where turbidity (0-30 JTU) was least. Lowest densities ($3\text{-}18/ft.^2$) were found in the depositional area of perennial turbidity (40-1,211 JTU) furthest downstream, which did not support trout. The 10 mile reach in between supported trout and had only occasional high turbidity (50 JTU) and intermediate invertebrate densities.

Mayflies (Baetidae, Heptageniidae, Ephemeridae) and midges (Tendipedidae and Simulidae) were the most abundant of the 26 taxonomic groups collected. Caddisflies (Tricoptera, dominantly Hydropsychidae) were common, but not considered abundant. Snails (Lymnaeidae, Physidae and Ancylidae) were very abundant. Fresh water scuds (Amphipoda) were abundant only below the dam.

Examination of 50 trout in 1964 showed midges, black flies and caddisflies abundant in 41 stomachs, with mayflies, grasshoppers, beetles, stoneflies (Plecoptera) and dragonflies (Odonata) occurring in low numbers. Snails had been heavily eaten by one-half the trout examined. Fish were found in two stomachs, and three stomachs were packed with algae. In 1965, 80 stomachs were examined: 70 contained algae, 56 contained midges, stoneflies and mayflies, 26 contained snails (two 18 inch rainbow had an excess of 200 each), and six contained fish remains. Casual observations in 1967 and 1968 tended to confirm a largely insectivorous diet.

The benthos in the Glen Canyon tailwater originally was largely limited to a small bloodworm (Tendipedidae) and a snail (Helisoma) (Table 3). Attempts at increasing invertebrates by introductions[4/] were only partially successful. The introduced snails (Physa and Stagnicola) were increasingly noted in bottom samples and a few trout stomachs at the end of the study in 1972. By 1975 it was reported (J. L. Stone) that introduced snails were abundant from Glen Canyon Dam to Lee Ferry and heavily used by trout, with five-pound trout not uncommon.

A niche exception--the slack water around a dam diversion tunnel where a more diverse benthic community was consistently collected (Table 3, Surber sampler, 1967 to 1972)--points to the limiting factor of excessive water velocities. Particularly incriminating was the scouring action of rapidly fluctuating changes in stage (up to 5,000 cfs daily), not simply a high volume of discharge, but the added force required in starting sediment particles moving (27). By 1969, luxuriant growths of filamentous green algae (predominantly Cladophora) extended five miles below Glen Canyon dam and it was repeatedly observed that benthos abundance declined drastically downstream of the algae mat, and that fluctuations in discharge dislodged the algae so as to thoroughly clog gill nets.

4/ 8,000 crayfish, 50,000 snails, 10,000 mayfly larvae, 3,000 dragonfly and damselfly naiads, 1,000 caddis larvae, 500 leeches, and numerous water boatman, backswimmers, water striders, beetle larvae, cranefly larvae, and midge larvae, 1967-69.

Table 3. Relative abundance of benthos measured by Ekman dredge and Surber sampler, Glen Canyon tailwater. (N = number of stations, times samples, and number of samples.)

	Ekman Dredge			Surber Sampler		
	N	Organisms/ $Foot^2$	Range	N	Organisms/ $Foot^2$	Range
1963-64	2 (6) 180	3.8 1/	0-15	2 (10) 100	2.9 1/	0-6
1964-65	3 (17) 258	2.1	0.1-10	1 (2) 10	2.8	0.4-5
1965-66	3 (19) 955	2.5	0-20	4 (23) 460	0.9	0-23
1966-67	3 (12) 540	4.2	0-261	3 (12) 180	1.9	0-6
1967-68	2 (9) 270	12.8	0-153	1 (9) 45	12.3	8.1-34
1968-69	2 (24) 720	4.9 2/	0-22	1 (14) 70	83.5 3/	10-398
1969-70	2 (8) 240	0.9	0-2	1 (8) 40	25.3 3/	6.6-65
1970-71	3 (10) 225	0.7	0-19	1 (6) 30	51.5 3/	61-143
1971-72	---	---	----	1 (4) 20	48.8 3/	14-77

1/ 1963-64 through 1967-68, organisms primarily midge larvae and a snail (Helisoma).

2/ 1968-69 on: snails (including Physa and Stagnicola), snail eggs, midge larvae, clams (Sphaeriidae).

3/ Below west diversion tunnel: snails (including Physa and Stagnicola), snail eggs, midge larvae, unidentified dipteria larvae, caddis fly larvae, leeches, aquatic earthworms, freshwater scuds.

Algae growths are typical in tailwaters (31) and illustrate transport and ultimate distribution of detrital materials believed to play the major role in primary and secondary (insect) production in streams. Typically they harbor a unique microfauna (12), owe their origin to nutrient loading of the discharge (7), and diminish downstream due to self-purification processes (7). In the Glen Canyon tailwater secondary consumers, except for midges and snails, were all but absent, and trout (N=2,839, 1964-70) mainly consumed algae and cladocerans, the latter of reservoir origin, through 1970.

The fauna of the Green River was reduced by pre-impoundment rotenone treatment to reduce non game fish in 1962 (3, 4). One year later invertebrate numbers were equal to or greater than those prior to treatment, but there were changes in composition. New fauna included alderflies (Sialidae) and five mayfly genera. Monitoring by Binns (5) in the period 1965-67 confirmed the trend towards small (midges) or compressed body form insects (mayflies) adapted to inhabit crevices or sediments at the water-substrate interface below high velocity currents. Diversity and abundance generally decreased with: (1) distance from the dam (av. 524, 353, 121/ft.^{2} at 4.6, 30 and 70 miles), (2) following ice-out, and (3) record flows (18,600 cfs) of September 1965. Thirteen of the 25 taxonomic groups described were also found in 84 rainbow trout stomachs examined. Cladophora made up most of the volume (64%). Larger trout also ate some fish, and Daphnia and copepoda were common in trout sampled in the first 10 to 15 miles below the dam. Food content of trout in recent years has been similar.

In the downstream Flaming Gorge tailwater Pearson (35) described a similar fauna for the period 1964-65, including 28 species of mayflies. Highest invertebrate densities (115-6,347/ or av. 222/ft.^{2}) were found in the canyon below the dam and lowest (15-588/ or av. 143/ft.^{2}) downstream where the river courses an alluvial valley.

Although 26 groups of organisms were identified from the erosional zone (gradient 9.9 feet/mile) below the dam, the invertebrate community was almost entirely composed of mayflies, midges, blackflies, and aquatic earthworms. The substrate was largely rubble and rocks with luxurious growths of Cladophora with some stream margins of silt. The downstream depositional zone (gradient 2.5 feet/mile) consisted of shifting sand substrate with few silt-free patches of gravel or rubble and very little Cladophora, but with strands of algae noted as drifting from upstream and becoming attached to an abundance of woody debris.

Thirty-six invertebrate forms were collected in the depositional zone. Aquatic earthworms and midges were restricted to quieter waters near shore and behind bars and snags. A few midge larvae were found in channels where sands were continuously sorted and graded by the current. The most abundant organisms on debris substrates were midges, aquatic earthworms, and mayflies. Of the 11 species of mayflies, six were either burrowers, trash and debris inhabitors, or were adapted to live on the silt bottom in quiet water. Three flattened forms, usually found on gravel-rubble in swift water, were rare.

Turbidity below the dam rarely exceeded 25 JTU. Values as high as 750 JTU were recorded in the lower river. Daily fluctuations (2,500 to 400 cfs) in flow were most pronounced near the dam and were dampened downstream, accounting for sediment particles not moving once they were dropped by low flows in the lower river. Conversely, drift rates of mayfly nymphs (Baetis) and blackfly larvae were highest nearest the dam where Cladophora was most abundant. Despite an apparent abundance of insects, between 58% and 89% of the volume of 236 trout stomachs consisted of algae in the period 1963-67.

The depression of water temperatures after 1968 is purported to have diminished the benthos. Cummins (12) has cautioned, however, that a simple temperature food-density relationship, as applied to fish populations, will not serve for benthic invertebrates. Many lotic invertebrates show cold temperature compensation wherein metabolism is optimized at low temperatures. Blum's observations (7) strongly suggest such temperature compensation in Cladophora.

Wiltzius (50) chronicled the exceptional quality of the fisheries of the Gunnison River (i.e., egg taking from 3,232 rainbow trout averaging four, but ranging to 13 pounds, 1903), typical of the 22.5 miles of river inundated by Blue Mesa Reservoir. Wiltzius also reported on the food supply that underpinned the trout population: 27 mayfly, 18 stonefly, 19 caddisfly, and 23 diptera species, with midges and black fly most common, as well as 93 algae species of which Cladophora was most abundant. Pratt (50) examined 10,000 trout stomachs between 1934 and 1937 and depicted a typical opportunistic use of the complex and stable benthic community according to season, size of fish and species. Significantly, rainbow trout consistently consumed appreciable quantities of Cladophora between periods of major insect emergence.

Considering the good to excellent condition (average C or K calculated from 1.0-1.3) and growth of rainbow trout in the tailwaters, the herbivory described for these waters appears of more than casual significance as in the Gunnison River. Trout less than 12 inches in length are largely insectivorous and any appreciable departure from such a diet can only be interpreted as versatility in using less preferred foods. The versatility of rainbow trout to flourish on zooplankton in reservoirs is well known. However, energy expenditure in food gathering must not be less than the energy derived or there is no growth (22). This is demonstrated in reservoirs where growth of trout on zooplankton diets all but ceases at a size of around 12 inches. Although food abundance is important in such trophic relationships, Ivlev (22) has demonstrated in most cases that it is the degree of difficulty (energy expenditure) experienced in obtaining food that limits feeding versatility of fishes.

The conclusion is inescapable that although insect food was relatively abundant in Flaming Gorge tailwater, availability was less than algae. The only way this can be explained is that rainbow trout were forced by low water temperatures and resulting low metabolism, even prior to the decline in water temperatures, to forego typical aggressive drift feeding in high velocity water, bearing the greatest volume of insect food, and, instead, concentrated in areas of least water velocity, where algae was most abundant.

Interactions Between Fish Species

The Colorado River begins as a cold, clear stream in the Rocky Mountains, then plunges into a semi arid uplift where it has cut spectacular canyons. In its pristine state it was a warm, turbid, often violent river, given to sudden and drastic changes in volume and turbidity. Large warm water fish that evolved to cope with high velocity-turbid habitat included Colorado squawfish, humpback chub, bonytail chub, and humpback sucker, which are now considered endangered. The decline of these unique species has been associated with changes in habitat and introduction of exotic species. The now omnipresent carp and channel catfish became established in the early 1900's (19).

At least 24 fish species were recorded in the Glen Canyon tailwater during post-impoundment, with carp, channel catfish, and flannelmouth sucker appearing co-dominant with rainbow trout. Abundance of carp was no doubt more conspicuous than real. Channel catfish disappeared with decreasing water temperatures. The flannelmouth sucker was by far the most abundant large native species. Other endemic species were uncommon pre- and post-impoundment. Lack of fish in rainbow trout diets agrues against abundance of minnow species.

Despite pre-impoundment treatment of the San Juan River drainage, apparently none of the native or introduced fishes were eliminated. Former dominance in the Navajo tailwater by flannelmouth sucker, roundtail chub, and channel catfish was almost entirely replaced by trout, fathead minnows and a scattering of fishes from the reservoir.

Squawfish, bonytail chub, humpback sucker, channel catfish and bullhead, never abundant, disappeared from the Fontenelle tailwater of the Green River with impoundment. Flannelmouth sucker and carp declined in relative abundance, whereas mountain sucker, whitefish, speckled dace, fathead minnow, redside shiner, sculpin, Utah chub, and roundtail chub have either maintained or in- increased their abundance (4, 5). Whitefish appear to be co-dominant with trout, but with only 700 to 2,700 caught annually. Large trout are mainly piscivorous and consume small non game fishes.

Some 20 native and introduced fishes in the Flaming Gorge tailwater were largely replaced by trout, although no species was eliminated initially (44).

Seven species of fishes were collected in the Gunnison River below the Crystal Dam site in 1965-66 (24): rainbow and brown trout, white, bluehead and flannelmouth sucker, speckled dace, and roundtail chub, with suckers most abundant. In the intervening years white and longnose suckers have largely replaced the native suckers, and lake trout and kokanee salmon have been recorded along with various other transitory species.

Aside from the Gunnison River tailwater, these changes in fish composition are about what might be expected with change from turbid and warm to clear and cold water habitat, with only relative minor interaction indicated between species.

Reproduction

Apparently, cold tailwaters are essentially dependent upon stocking in providing angling (37).

In the erosional-to-dispositional continuum of natural streams there are usually intermediate zones characterized by loose gravel (0.25 to 1.5 inches in diameter) used by trout in depositing and covering their eggs. It is essential that the eggs not be smothered by sediments or dislodged. Water must percolate through the redd and aerate the eggs for two to three months to assure development and hatching.

Substrate of Colorado River tailwaters generally is out-of-phase with conditions favoring significant trout reproduction, a situation compounded by the lack of small to intermediate size tributaries for spawning. Existing tributaries are largely intermittent and/or turbid in keeping with the more erosive character of the downstream watershed.

Extensive spawning activities by large trout and low egg survival in the Fontenelle tailwater was correlated with severe winter cold and high destruction of trout redds by ice. Even in natural streams where water temperatures remain near freezing for several months, developing eggs undergo excessive mortality (47). Drifting ice particles (frazil) that develop under such severe cold are also suspected as a cause of death among adult trout, a mortality not unlike that noted for stocked fingerling trout in Flaming Gorge tailwater associated with turbidity from landslides.

Lack of hatching and survival of trout in all tailwaters can be primarily ascribed to fluctuations in flow (20), yet, alteration of gravel permeability associated with river bed degradation below dams could be a common limiting factor as well. In this channel degradation, finer fractions of bed material are removed from the bed surface by sorting and are transported downstream. Consequently, the channel in the upstream is armored with coarser bed material in arresting degradation processes and achieving a static equilibrium (25, 51, 39).

INSTREAM FLOW NEEDS

Besides the more obvious need for outlet modification (9) to control water temperatures in tailwaters, there clearly exists the need to know what the trade-offs are. Pfitzer (37, 38) has long pleaded that water managment in reservoirs not be fixed rigidly, and Stroud (41) has cautioned that construction modification should not be recommended unless their biological effects--in the upstream reservoir as well as in the downstream tailwater--are known; a truism reflected in the strong linkages indicated between reservoir and tailwater.

Reduction of sediment loads by better land use and retention constitutes a major inflow need in extending the utility of tailwaters as trout habitat. More than generally recognized this involves control of return irrigation water linked to the immense salinity problem of the Colorado River system.

Introduction of food organisms and unique salmonids also is an area warranting clarification. Pennak (36) described aspects of the aquatic fauna of the Rocky Mountains as relatively impoverished because the richer eastern and western faunas had been confronted with difficult geographic barriers, including shifting, silted rivers. It was his conviction that low fish production could be partly remedied by introducing suitable food organisms. The comparison of Fisher and LaVoy (14) between tidal fluctuations in seashore areas and the fluctuations below dams has the same implications. They reasoned that since a freshwater "intertidal" condition is a recent artifact of man's activities, insufficient time had elapsed to allow evolution of complex and productive communities such as exist in saltwater.

Shelter requirements of trout and food organisms can be critical in depositional reaches of streams changed to erosional, but uniform channels with monotonous, "armored" substrate. Water management in which rapidly fluctuating changes in stage are avoided appear to offer some amelioration from high water velocities, i.e., pumpback storage. However, where only a small portion of the total channel can be effectively used by trout, instream shelter will have to be provided in correcting the major deficiency. But, before initiating other than a prototype program, it would seem essential to determine whether a state of equilibrium has been reached in the channel and, coincidentally, whether there actually exists unused food production potential required for added trout production.

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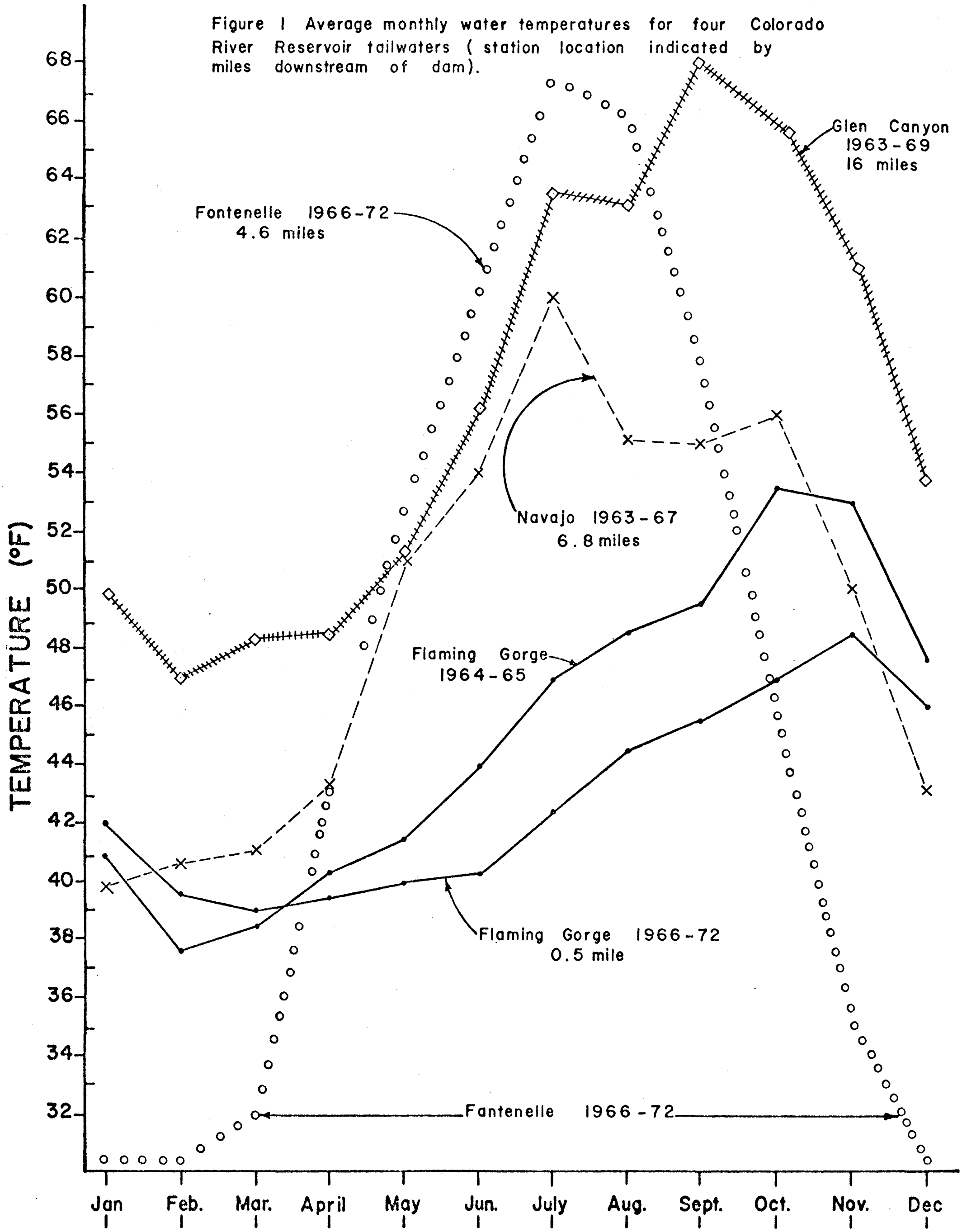
Figure 1 Average monthly water temperatures for four Colorado River Reservoir tailwaters (station location indicated by miles downstream of dam).
TEMPERATURE (°F)
68
66
64
62
60
58
56
54
52
50
48
46
44
42
40
38
36
34
32
Glen Canyon 1963-69 16 miles
Fontenelle 1966-72 4.6 miles
Navajo 1963-67 6.8 miles
Flaming Gorge 1964-65
Flaming Gorge 1966-72 0.5 mile
Fantenelle 1966-72
Jan
Feb.
Mar.
April
May
Jun.
July
Aug.
Sept.
Oct.
Nov.
Dec

REGULATION OF INSTREAM FLOW NEEDS AT LICENSED PROJECTS

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ABSTRACT

The Federal Power Commission is a quasijudicial, independent agency of the Federal government which regulates the non-federal hydroelectric power industry. It licenses the construction, operation, and maintenance of projects which utilize waters and lands of the United States under the constraints of the Federal Power Act and other Federal laws, and with conditions relating to the storage, use, and discharge of water from the projects to meet various instream flow needs and other water uses. It depends to a large degree on the recommendations of other Federal, and of State and Local agencies and others in meeting stream flow and other water needs. Those interested agencies and organizations are challenged to make recommendations in a timely manner as the needs are known or may arise.

INTRODUCTION

Since the 1920 enactment of the Federal Water Power Act (now the Federal Power Act) the Federal Power Commission has authorized the construction or operation and maintenance of about 1160 hydroelectric power structures which divert or impede the flows of streams. License applications are now pending for about 320 similar structures.

Each of these has been built or proposed as an integral part of a facility to convert a natural resource, falling water, into electric energy. Each

*The opinions expressed herein are those of the author and do not represent an official statement of the Federal Power Commission.

Section 9(b) requires each applicant to submit to the Commission satisfactory evidence of its compliance with State laws "with respect to bed and banks and to the appropriation, diversion, and use of water for power purposes."

Section 10(a) provides that the project adopted (licensed) "shall be such as in the judgment of the Commission will be best adapted to a comprehensive plan for improving or developing a waterway or waterways for the use or benefit of interstate or foreign commerce, for the improvement and utilization of water power development, <u>and for other beneficial public uses</u>, including recreational purposes..." (emphasis supplied).

Section 10(c) provides that licensee shall maintain and operate the project works as not to impair navigation, and shall conform to such rules and regulations as the Commission prescribes for the protection of life, health, and property.

Section 15 provides, upon the expiration of a license, for the issuance of an annual license from year to year to the licensee under the terms and conditions of the original license.

Section 309 gives the Commission authority to make such rules and regulations necessary to administer the Act.

Section 304(a) gives the Commission authority to require the filing from licensee or public utility such annual, other periodic, or special reports as necessary or appropriate to administer the Act.

<u>Other Federal Statutes</u>

There are a number of other Federal laws which the Commission must take into consideration in its issuance of licenses under the Federal Power Act. Insofar as these are applicable to matters relating to instream flow needs they would include:

The Administrative Procedure Act,
Water Resources Act and the organic acts creating the several river basin commissions,
BOR Organic Act,
Wild and Scenic River Act,
National Environmental Policy Act,
Federal Water Pollution Control Act,
Fish and Wildlife Coordination Act,
Endangered Species Act, and
Various flood control, reclamation, and water development acts.

Let me demonstrate how one of these acts is used procedurally. The Commission issued in 1966 and 1967 Orders 323, 350 and 358 containing its regulations to implement the requirements of the Fish and Wildlife Coordination Act. These are the Exhibit S regulations and require:

1. Consultation by an applicant for license or amendment to license, with State and Federal fish and wildlife agencies on the natural resources affected by the proposed project or alteration of project, together with measures needed to prevent damage to or to enhance those fish and wildlife resources.

   This is the appropriate time for those agencies to make at least preliminary recommendations for water release measures needed at the dam and powerhouse. It is the appropriate time because the economic feasibility of a project may hinge upon the amount of water that cannot be used to generate energy, the primary purpose of these projects.

2. The applicant conducts any studies on fish and wildlife needed to prepare the Exhibit S.

3. Preparation of the Exhibit S and its filing with the Commission as part of the application.

4. The application is noticed and a copy together with its Exhibit S and appropriate drawings is mailed to the fish and wildlife agencies for their formal comments and recommendations to the Commission in compliance with the Fish and Wildlife Coordination Act.

   This is the appropriate time for those agencies to provide the Commission with their recommendations for stream flow releases. To delay this action could jeopardize their positions on these matters.

5. The staff of the FPC makes independent studies and writes its report to the Commission which may be in the form of an environmental impact statement. If it is an EIS the comments of all agencies and the public are invited.

6. After notice and opportunity for hearing the Commission considers the application together with the agency, staff and other recommendations. If a formal hearing is held a record is made upon which the Commission bases its decision.

7. The Commission Order becomes effective following a 30-day period of notice, subject to petitions for rehearing or reconsideration.

Instream Flow Uses

From the earliest licenses issued to the most recent there have been conditions imposed on project operations relating to the release of water flows downstream of the project works. The "beneficial public uses" to which these flows are required include:

1. Industrial uses such as agriculture, navigation, power production downstream, cooling water for thermal power plants, log transport,

2. Public safety uses -- flood control (evacuating storage space prior to floods), stream fishing (changes in rate of release), flushing action to remove pollutants, boating safety, fire suppression,

3. Streambed protection -- to prevent streambed erosion and sedimentation,

4. Ecological uses -- to provide water for aquatic habitat, fish migration, attraction, and spawning; to prevent fish stranding; to provide flushing action to improve spawning gravels; to improve water quality including temperature; to operate fish artificial production facilities,

5. Public water supply and domestic use by riparian land holders,

6. Public recreation -- boating, swimming, and fishing, and

7. Aesthetic and scenic uses -- reducing obnoxious odors and improving the scenic values.

In addition to regulating the quantity of water released, license conditions or approved drawings may also designate varying seasonal, weekly, or daily releases; the location from which releases are made at the dam, spillway, or powerhouse of waters taken from various levels of the reservoir; and limitations on the rates of change of flows being released.

At times one downstream flow release use may conflict or be inconsistent with another and downstream uses may conflict with reservoir uses for the same water. In these cases a judgement decision is needed, a decision in which the reasonableness of all beneficial uses is considered.

Instream Flow Needs in Hydro Licenses

Finally, let me demonstrate how instream flow requirements are provided for in the licenses of projects.

At run-of-river and base-load plants the plant inflows and any available pondage are utilized as they occur and the river is passed through the project without much alteration. Specific flow release requirements are not generally needed.

At run-of-river hydro plants with pondage, the releases through the powerhouse may fluctuate hourly, daily, and weekly during all but flood seasons. Minimum flow, and rate of change in flow, release requirements are desirable to protect both instream needs and appropriated rights for diversions downstream of the dam.

Reservoir storage plants store seasonal flood flows for power generation during seasons or cycles of low stream flow. In effect they reduce the size of flood flows and increase the magnitude of flows during otherwise low-flow and drought periods. When they operate to meet power peak loads, however, the plant discharges fluctuate considerably during the hours of each weekday and during the days of each week. The total discharge for each week of the year generally will not show such wide fluctuation. In plants of this type it is also desirable to regulate the minimum flow and rate of change in flow releases downstream of the project. Additionally, it may be advantageous to obtain storage in the reservoir for particular instream flow needs downstream.

The two following examples demonstrate widely divergent methods of providing instream flow needs.

Figure 1 shows a diagram of the Blue Ridge project reservoir storage uses, as approved in the license issued by the Commission on June 14, 1974, for the construction and operation of this combination pumped storage-conventional hydroelectric project consisting of 2 reservoirs on the New River, Virginia and North Carolina. Article 51 (Appendix A) of the license contains the specific language on minimum flows (e), reservoir storage for reserved uses (b,c), rate of change in flow releases (e), with designated periods of storage and release of stored waters (b,f). Of particular interest is the assignment of 130,000 acre-feet of storage in the lower reservoir for flow augmentation in the New River below Bluestone dam some 100 miles downstream in the State of West Virginia. The releases are to be made between July 1 and September 30 of each year to benefit the fishery habitat and sport fishing [51(b)]; the storage to meet these releases to commence March 1 of each year.

Appendix B presents Article 13 of the new license for the Bucks Creek Project, No. 619, located in the Feather River drainage, California. This license was issued December 19, 1974, for the period ending October 31, 2004, following a 50-year period for the original license with 6 annual licenses issued thereafter. The instream flow releases below the two dams of the project are designated seasonally for normal and dry water years with the dry year definition based on the April 1 run-off forecast as 50 per cent or less of the 50-year average flows from April 1 to July 31.

Although these minimum stream flow releases of one, two, three, and four cfs as recommended by the fish and wildlife agencies appear to be small, it is my understanding that they meet the instream flow needs for the downstream aquatic habitats. They also represent a power loss of some 7,324,000 kWh each normal water year, valued at $177,680. This high value is a result of the 2557-foot static head at the project. There were no minimum flow release requirements in the original license for the Bucks Creek project under which the project operated for 56 years.

In cases where there is inadequate information on instream flow needs at a proposed or existing project the Commission has required hydrologic or other studies by the licensee in cooperation with interested agencies for a determination of those needs. An example of this is shown in Appendix C as Article 36 of the license for Blenheim-Gilboa, Project No. 2685, in New York.

Conclusion

I have described the constraints and procedures on providing instream flow needs at licensed projects and demonstrated how consideration is given to these needs through the recommendations of the agencies which have statutory responsibilities for protecting the environment and the natural resources of the project area. Those recommendations are vitally important in regulating the non-federal hydroelectric development in the United States under the Federal Power Act.

It is desirable for any potential user or advocates of uses of downstream water flows at proposed hydro plants to have knowledge and understanding of the functional basis for the design of proposed plants. This knowledge, together with information on the physical layout of the plant and of its operation, would be of value during discussions in the planning stages of the project on multiple use water releases. It would also be invaluable in discussions on any proposed modification of water releases at existing projects, where such multiple uses were not considered during the planning stages.

Instream Flow Needs:

Minimum flow release - 350 cfs (fish habitat)
Industrial release - 1200 cfs, weekly average at Radford, Va.
*Flow augmentation - to provide 2500 cfs below Bluestone dam, W. Va., for fish habitat and fishing during July, August.

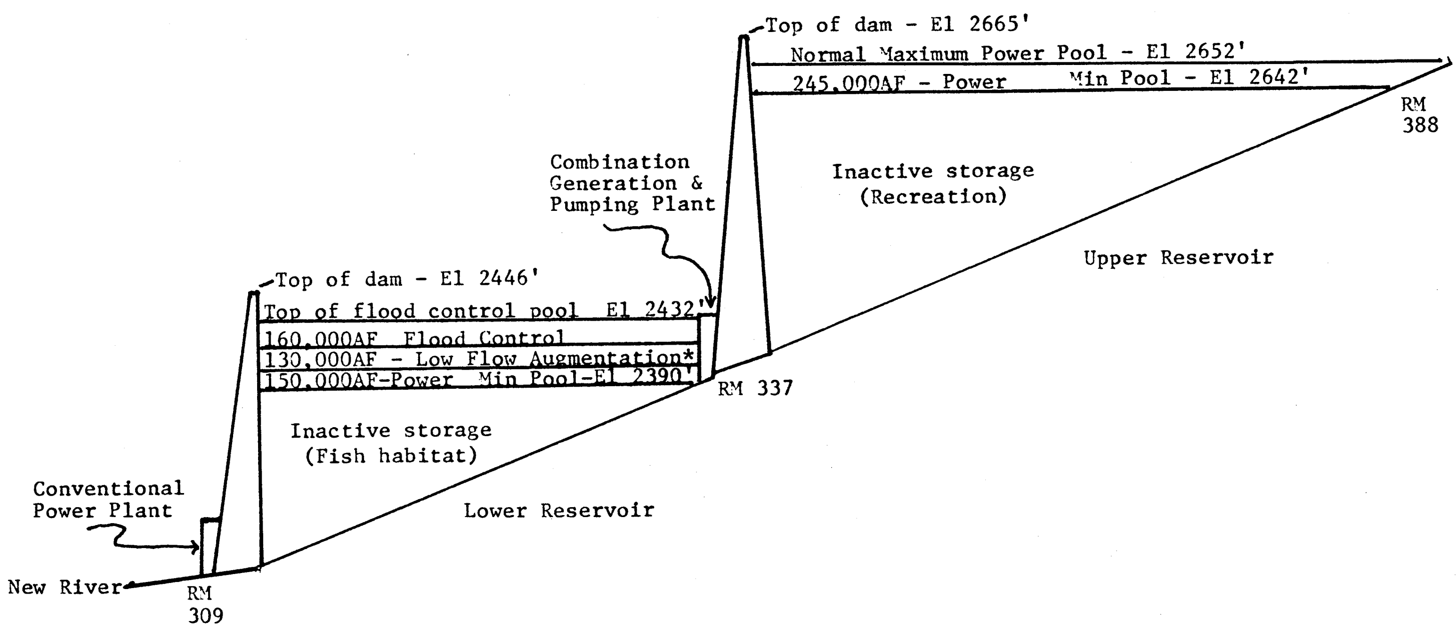

Figure 1. Modified Blue Ridge Project, No. 2317, New River, Virginia, North Carolina. Project Profile Diagram.

Project No. 2317

Article 51. The Licensee, following consultation with the States of Virginia, North Carolina and West Virginia, the Environmental Protection Agency and the Department of the Interior, shall cooperate with the Corps of Engineers in an effort to reach a mutually satisfactory agreement to operate the reservoirs of the project to achieve the public benefits herein provided for, and such agreement shall be generally in accordance with the following:

(a) The usable storage capacity of the lower reservoir, which consists of approximately 440,000 acre-feet between elevations 2,390 and 2,432, shall not be utilized for water quality control in lieu of adequate treatment or other methods of controlling waste at the source.

(b) The project shall be operated to provide each year 130,000 acre-feet of storage in the lower reservoir to be used to augment low flows below Bluestone Dam from July 1 through about September 30, for the benefit of fishing and recreation, to the extent augmentation is necessary to bring such flows up to a weekly average of 2,500 cfs. The releases made from the lower reservoir to assure such flows shall be made so as to provide up to 1,200 cfs at Radford through the year 1999 and up to 1,400 cfs thereafter, as the need arises. The determination of Radford's needs up to such amounts shall be made by the State of Virginia, consistent with the provisions of this Article, but the Commission reserves the right after notice and opportunity for hearing to prescribe any such releases as the public interest may warrant. If the releases provided herein do not deplete all storage for low-flow augmentation (130,000 acre-feet) by October 1, the remaining storage shall be evacuated during the month of October at an average weekly rate, in cfs, approximately equivalent to the remaining storage in acre-feet divided by 61.5.

(c) The reservoir of the lower development shall be operated to provide approximately 160,000 acre-feet of flood control storage space, except that during emergency power operations when the Licensee requires additional storage to meet its electric system load requirements, flood control storage space in the lower reservoir may be temporarily utilized for power purposes, provided that an equivalent amount of such storage space is made available for flood control purposes in the upper reservoir. In addition, the Licensee shall operate the upper development reservoir at all times so as not to exceed reservoir elevation 2,652 m.s.l., except when the inflow to the upper development reservoir is greater than the maximum spillway discharge capacity at reservoir elevation 2,652 m.s.l. (approximately 270,000 cfs). In the event of disagreement between the Licensee and the Corps of Engineers, the Commission expressly reserves the right to prescribe, after notice and opportunity for hearing, the operation of the project in the interest of flood control.

(d) For the purpose of normal power operations, and to provide for the operation of spinning reserve capacity,maximum drawdown of the upper reservoir shall be 10 feet, to elevation 2,642. Maximum drawdown of the lower reservoir shall be to elevation 2,390.

(e) Minimum releases from the lower reservoir shall be at least 350 cfs measured at a gauge below the confluence of the New River and Meadow Creek, and the rates of flow increase and decrease below the lower dam shall not exceed two feet vertically per hour as measured at such gauge; and

(f) To provide the 130,000 acre-feet of storage prescribed in subsection (b) hereof, the lower reservoir shall be refilled beginning March 1 of each year on a rule curve, with water in excess of the filling requirement under the rule curve released from the lower reservoir in addition to the minimum releases prescribed in subsection (e) hereof.

The Commission expressly reserves the right to prescribe the operation of the project reservoirs if the Licensee and the Corps of Engineers have not entered into an operating agreement within four years from issuance of the license for the project, and to modify the operation of the project, on its own motion or at the request of the Licensee, the Corps of Engineers, the Environmental Protection Agency, the Department of the Interior or the directly affected States, after notice and opportunity for hearing.

Article 13. The operations of the Licensee, so far as they affect the use, storage and discharge from storage of waters affected by the license, shall at all times be controlled by such reasonable rules and regulations as the Commission may prescribe for the protection of life, health, and property, and in the interest of the fullest practicable conservation and utilization of such waters for power purposes and for other beneficial public uses, including recreational purposes, and the Licensee shall release water from the project reservoir at such rate in cubic feet per second, or such volume in acre-feet per specified period of time, as the Secretary of the Army may prescribe in the interest of navigation, or as the Commission may prescribe for the other purposes hereinbefore mentioned. Pending further order by the Commission on its own motion or at the request of others, after notice and opportunity for hearing, the Licensee shall:

(a) Discharge minimum stream-flows in accordance with the following schedules; Provided that, such flows may be modified temporarily if required by operating emergencies beyond the control of the Licensee, for short periods for fishery management purposes upon mutual agreement between the Licensee and the California Department of Fish and Game or the United States Forest Service; and Provided further that during flood periods releases shall be no greater than the natural inflow:

(1) Minimum stream flow from Lower Bucks Lake into Bucks Creek:

Period	Normal Year (c.f.s.)	Dry Year (defined below) (c.f.s.)
May 1, through Oct. 31	3	1
Nov. 1, through April 30	1	1

(2) Minimum stream flow from Grizzly Forebay into Grizzly Creek:

Period	Normal Year (c.f.s.)	Dry Year (defined below) (c.f.s.)
May 1, through Oct. 31	4	2
Nov. 1, through April 30	2	2

(b) Operate the project in accordance with the following criteria:

Project No. 619

Article 13 (cont.)

Lake	Minimum Elevation* Except for Maintenance
Bucks Lake: Normal Year Drawdown between June 1, and Sept. 1, shall not exceed 15 feet below the surface elevation of June 1	5,100 ft.
Bucks Lake: Dry Year (defined below) Drawdown to elevation 5,080 shall not be reached prior to Sept. 1	5,080 ft.
Lower Bucks Lake	4,966 ft.
Grizzly Forebay	4,303 ft.
Lower Three Lakes	6,050 ft.
Middle Three Lakes	6,057 ft.

Note: A dry year is defined as any year beginning May 1, in which the natural run-off of the Feather River at Oroville for the April 1 to July 31 period, as forecast on April 1** by the State of California Department of Water Resources, will be 50 percent or less of the 50 year average for such period.

*All elevations are on Feather River Power Company datum. USGS datum = Feather River Power Company datum + 3.5 feet.

**As may be adjusted by the State on May 1.

APPENDIX C

Project No. 2685

Article 36. Licensee shall consult with appropriate State and Federal agencies and make, or pay the cost of making, studies to determine: the magnitude of existing fish and wildlife populations and how they will be affected by the construction and operation of the project and any measures needed to protect and develop the fish and wildlife resources of the project area. Based upon findings of the studies, Licensee, shall, following consultation with appropriate State and Federal agencies, prepare a revised Exhibit S which shall include, but not be limited to, consideration of (1) provisions for minimum releases from the lower dam to the 5-mile reach of Schoharie Creek immediately downstream, (2) provisions for developing and managing suitable areas, including the Mine Kill area, as replacement habitat for deer winter range without conflicting with general recreational use at the project, (3) provisions for preventing or alleviating any deer migration blocks created by the project, and (4) a schedule for constructing any facilities and making any changes needed in the operation of the project or for management or development for fish and wildlife enhancement or conservation. The revision of the Exhibit S, as well as any amendments to the Exhibit R required by the fish and wildlife management proposals shall be completed and submitted for Commission approval within 1 year from the date of issuance of this license, with the provision that replacement of lost deer winter browse areas shall be completed and ready for use prior to the initial filling of the reservoirs.

EFFECT OF DAMS AND RIVER REGULATION ON RUNS OF ANADROMOUS FISH TO THE MID-COLUMBIA AND SNAKE RIVERS

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ABSTRACT

Trends in abundance of adult salmon, Oncorhynchus spp., and steelhead trout, Salmo gairdneri, to the mid-Columbia and Snake Rivers are related to conditions faced when they migrated downstream as juveniles. Major causes for losses and delays are outlined. Potential solutions for maintaining these runs in the face of increasing demand for power and irrigation are summarized.

INTRODUCTION

Dams constructed on the Columbia and Snake Rivers in the past decade to provide hydroelectric energy have impounded most of the free flowing sections of these rivers and created water conditions that in both high and low flow years are deadly to migrating salmon, Oncorhynchus spp., and steelhead trout, Salmo gairdneri. With high spills, the water becomes supersaturated with atmospheric gases to levels that are lethal to fish. In low flow years, with no spill, an even more destructive situation develops in which all downstream migrants must pass through turbines where many are killed outright and others are injured or stunned and left vulnerable to intensive predation. Young migrants from the Salmon River (a tributary of the Snake River) must pass through eight large impoundments and over eight major dams to reach the sea (Figure 1). Even small losses or delays at each dam become serious because of the large number of dams.

Additional river development in the form of large storage reservoirs and power peaking has already affected juvenile outmigrations from the mid-Columbia area. Timing of juvenile outmigrations has coincided with periods of maximum river runoff. In recent years storage reservoirs in Canada have provided a means to significantly reduce the crest of the spring runoff in order to maintain higher river flows in other months for maximum power production. Migrations triggered by runoff in tributary streams have been slowed significantly by regulation of runoff. Cumulative delay in passage through reservoirs has increased holdover or residualism (failure to migrate to the ocean).

Significant declines in adult runs to the mid-Columbia and Snake River in recent years reflect rapidly deteriorating fish passage conditions for successful smolt migrations. We are therefore greatly concerned about the future as spill at dams is reduced by increased demand for power and irrigation, and smolt migrations through impoundments are further delayed by projected additional reductions in river flows during peak runoff.

In response to this problem, a major research effort is in progress to develop methods of minimizing losses and delays to smolts. This report summarizes current status of our research and discusses the probability of maintaining these fish runs in future years.

TRENDS IN THE SNAKE RIVER SALMON AND STEELHEAD TROUT POPULATIONS

A superficial examination of available data (Top panels-Figures 2 and 3) indicates there was no serious decline in chinook salmon, O. tschawytscha, and steelhead trout runs to the Snake River until 1974. However, an analysis of adult returns by year of outmigration shows Snake River runs have been declining since 1969. Greatly increased releases of chinook salmon and steelhead fingerlings from hatcheries have generally offset losses to downstream migrants when runoff was average or above. Production from hatcheries, though, could not offset disastrous losses of juveniles from poor downstream passage conditions in 1972 and 1973. Returns in 1974 and 1975 from these outmigrations were dangerously low.

The percentage of adults returning from known populations of juvenile chinook salmon and steelhead migrating downriver each year reflects the status of fish passage conditions in the Snake and Columbia Rivers. While total numbers of both chinook salmon and steelhead smolts increased significantly starting in 1970 (Middle panels-Figures 2 and 3), adult return percentages of both species have declined at an alarming rate since 1969 (Bottom panels-Figures 2 and 3). Prior to installation of recent dams and resulting reservoirs in the Snake River (1964 and 1968), returns of chinook averaged about 4%. In 1969, with the completion of Lower Monumental Dam, adult returns from that year's juvenile population dropped to 3.5%, and to 3.2% in 1970, after the completion of Little Goose Dam. Since that time, adult returns from juvenile populations migrating downstream have declined sharply to 2.2% in 1971, 0.8% in 1972 and only 0.3 to 0.4% from those migrating downstream in 1973. Steelhead runs show a similar decline from 5 to 6% through 1966 to: 2.5% in 1969, 2.1% in 1970, 1.4% in 1971, 1.0% in 1972, and 0.2 to 0.3% in 1973.

The drop in adult return percentages reflects losses of juveniles due to fish passage problems in the Snake and Columbia Rivers. From 1969 to 1971, river flows were high. Spilling at dams entrained air and supersaturated the water below the dam with atmospheric gases. With little equilibration in reservoirs, levels of dissolved gases measured at and between dams (130 to 140%) remained well above critical levels for fish survival and significant juvenile losses occurred (Ebel et al., 1975). Slotted bulkheads installed in skeletal bays of Snake River dams in 1972 to alleviate nitrogen saturation proved to be disastrous. Survival of juveniles from Little Goose to The Dalles Dam was 15% for chinook and 25% for steelhead (Figure 4).

Spillway deflectors (concrete sills placed near the base of the spillway (Figure 5) to direct flow horizontally into the stilling basin) proved more promising. The lateral deflection of the water prevents deep plunging action where air entrainment, the primary source of supersaturation, takes place. Studies by Ebel, Krcma, and Raymond (1973), Long and Ossiander (1974), Johnsen and Dawley (1974), and Monan and Liscom (1974, 1975) show that supersaturation of the water with air (primarily nitrogen) is substantially reduced and no injury or adverse effect on either adults or juveniles could be measured.

The problem of supersaturation in high flow years has nearly been alleviated. Spillway deflectors have already been installed on all Snake River dams except Ice Harbor Dam (to be installed in 1976) and at McNary and Bonneville Dams on the Columbia River.

Information obtained from migration rates, timing and survival studies indicated that smolt survival during high river flows should substantially improve once the nitrogen problem is solved. Delays in migration will be minimal. Travel time through an impounded river during high flow approximates travel time in a free-flowing stream during low flow (Table 1). Losses through turbines should also be minimal since most of the water and fish will pass safely over spillways.

The concern is maintaining viable runs during low to moderate flows. Data from migration rate and timing studies (Raymond 1968a, 1968b, 1969) indicate that juvenile chinook salmon move about one-third as fast through impounded areas of the river as through free-flowing areas. During low-flow years, we estimate (Table 1) that juvenile chinook and steelhead migrating from the Salmon River will take 78 days to reach the estuary; arriving there about 40 days later than they did before the dams were constructed. The total effect of this drastic change in the timing of anadromous fish with a life cycle precisely tuned to specific environmental patterns is not yet completely known.

Table 1.--Travel time[1/] estimates in days for Snake River juvenile chinook and steelhead trout to travel from the Salmon River to the estuary.

Stretch of River	Flow[2/] Low	Moderate	High
Salmon River to Lewiston (115 miles)-free-flowing	8	5	3
Lewiston to Lower Granite Dam (35 miles)-impounded	7	4	2
Lower Granite to Little Goose Dams (40 miles)-impounded	8	5	3
Little Goose to Ice Harbor Dams (63 miles)-impounded	13	8	4
Total Snake River 253 miles	36	22	12
Ice Harbor to The Dalles Dams (143 miles)-impounded	29	18	10
The Dalles Dam to the Estuary (192 miles)-like free flowing	13	8	6
Total Columbia 335 miles	42	26	16
Grand Total 588 miles	78	48	28

1/ Travel time based on following migration rates:

	Low	Moderate	High
free-flowing	15m/day	25m/day	34m/day
impounded	5m/day	8m/day	15m/day

2/

low flow	Snake River	30-50,000 cfs	Columbia River	150-180,000 cfs
med flow	" "	80-100,000 cfs	" "	200-300,000 cfs
high flow	" "	120-180,000 cfs	" "	350-500,000 cfs

(Estimated from the data of Raymond, 1968b, 1969; Bentley and Raymond, 1975)

One immediate effect in low flow years is a tendency for some fish to residualize and spend their entire life cycle in fresh water. Of even greater consequence are the effects of prolonged exposure to intensive predation, exposure to disease organisms, and exposure to stresses imposed by pollution. The impoundment of river flows by dams has more than doubled the time required for the hazardous migration of juvenile salmon and steelhead to the sea.

During the record low flow of 1973, when most of the river and fingerlings passed through the powerhouses of 7 dams, we measured a 95% loss of both chinook and steelhead smolts from Little Goose to The Dalles Dam (Figure 4). Migrations that usually peak around May 1 at The Dalles arrived on June 5, a delay of 35 days (close to the 40 days predicted). Major cause of chinook mortality was turbine-predator related. Tests pertinent to the Kaplan turbines of the Columbia River indicated a mean loss of 7%. However, these data frequently included only direct mortality. Indirect mortality, such as increased predation on temporarily debilitated fish slightly injured or stunned by passing through the turbines, can be substantial. More recent studies by Long et al. (1968, 1975) showed that mortality of juvenile coho salmon, O. kisutch, passing through turbines at Ice Harbor and Lower Monumental Dams was as high as 30% when indirect mortality from predation was included. Losses from predation will vary from dam to dam and year to year depending on the fluctuating populations of predators. However, when the predation loss at dams is combined with the direct loss in turbines, it becomes apparent that the turbine-related mortality occurring to a population of downstream migrants passing over a long series of dams can be enormous. An average 30% loss at each dam adds up to a cumulative loss of 92% over 7 dams; close to the 95% loss actually measured.

Steelhead survival down the Snake River was twice that of chinook (25% vs. 12%). We suspect that steelhead being larger were less subject to predation and suffered less turbine-related mortality. By contrast, their survival from that point to The Dalles was apparently much less than for chinook. Steelhead migrations are triggered more by freshets than chinook. Their timing usually coincides with the major river runoff. Lack of a freshet in 1973 may have resulted in significant holdover or residualism in reservoirs below Ice Harbor Dam. Numbers of steelhead collected by purse seines in John Day Reservoir in the summer and fall of 1973 were much higher than in the higher runoff years of 1974 or 1975. Very few steelhead holding over in reservoirs resumed their journey the following spring, indicating they either succumbed or residualized.

While there is little storage and regulation presently on the Snake River, the rapid acceleration of powerhouse construction on the Snake River in response to the national energy crisis means that by 1979 the disastrous "no spill" condition of 1973 will occur with greater frequency and an even greater percentage of young migrants will pass through turbines. Present powerhouse capacity of 65,000 cfs will be doubled to 136,000 cfs. Average river discharge during major smolt outmigrations now averages 100,000-120,000 cfs. Thus, critical losses that in the past occurred during low flow years also can be expected during average flow years after 1979. This compounded by additional water withdrawals from anticipated increases in irrigation could spell the end of anadromous fish runs in the Snake River.

TRENDS IN THE MID-COLUMBIA SALMON POPULATIONS

Priest Rapids, Wanapum and Rocky Reach Dams were completed in the early 1960's. Wells Dam was completed in 1967. Regulation of the river through use of Canadian storage reservoirs has significantly reduced river flows and spilling at dams during major juvenile outmigration periods since 1972. Daily peaking, which is practically non-existent to date on the Snake River during periods of juvenile migrations, has occurred since 1964 on the Columbia River. This has affected the latter part of the juvenile migration which occurs in July and August. Since 1972 peaking has affected much of the spring juvenile migrations.

Salmon populations, as a result of this river development, have been declining for a longer period of time than those in the Snake River. While no studies have been made to obtain comparable measures of juvenile mortalities prior to and after new dams, there is available data from adult returns indicating that new dams and river regulation have had a detrimental effect on anadromous fish runs to the mid-Columbia River. Adult runs (including contribution to the sport and commercial fishery) were compared for three stages of river development: returns during 1951-61, from juvenile outmigration of 1949-59 prior to completion of Priest Rapids, Wanapum, Rocky Reach and Wells Dams; returns during 1962-73, from juvenile outmigrations of 1960-71 after new dams but prior to major river regulation; and returns in 1974-75, from juvenile outmigrations of 1972-73 after major river regulation had reduced flows during the major spring runoff.

Comparisons were made on spring and summer chinook and sockeye salmon, _O. nerka_. Trends for coho, fall chinook and steelhead were difficult to interpret. Coho and steelhead runs are small and mostly from hatchery releases which were not consistent from year to year. Trends in abundance of fall chinook have been biased by increased spawning in recent years from displacement of fish into this area caused by flooding of spawning areas above the John Day Dam.

The trend is ominous. Sockeye have declined from an average run of 216,000 fish to just over 40,000 fish; summer chinook from 82,000 to 22,000 fish; and spring chinook from 26,000 to 11,000 fish (Figure 6).

Cause for the decline of spring chinook and sockeye was probably similar to that encountered by juveniles from the Snake River since their timing is comparable. This is not so with summer chinook. Historically, these fish migrated downstream as 0-age fish during major river runoff in late May and June (Mains and Smith, 1964). Studies by Park (1969) showed that since power peaking has been occurring at Priest Rapids and Wanapum Dams timing of these fish has been significantly altered. Peak migrations of summer chinook juveniles at Priest Rapids Dam in 1965 and 1966 occurred in August (Figure 7). Subsequent sampling in 1969-70 and 1973-75 verified Park's findings. The significance of this change in timing in relation to their ultimate survival was discussed by Park (1969):

"Historically, most juvenile chinook salmon have migrated down the Columbia River in the spring when environmental factors were most favorable for their survival. Flows were generally high, water temperatures were within optimal ranges for salmon, the river was sufficiently turbid to protect them from predators, and no impoundments delayed their migration to the sea.

"In recent years, both the time of migration and the environment in the upper Columbia River have changed. These juveniles now migrate down an almost totally impounded river during July and August, when environmental conditions for salmon are far from optimum. By mid-July, the spring runoff is usually completed, flows are reduced, water temperatures begin to rise, and the water clears up and thus affords little protection from predators. Water temperatures by August are often above the optimal range for salmon. Predation in fall months is generally higher, and disease is usually more prevalent than in the spring. In addition, reduced flows in the reservoirs probably cause a loss of orientation and hence a delay of the migrants.

"Additional impoundments behind Wells and John Day Dams and future increases in water temperature from thermal electric plants will compound problems of migration. An almost continuously impounded river, with resultant trends toward warming water and increased numbers of predators, and other complex changes in the environment, could eventually jeopardize the existence of chinook salmon in the upper Columbia River."

Since Park completed his studies, power peaking at dams has significantly increased. Flows are reduced at night and are accelerated during daylight hours when power demand is highest. Significant delays to migrants could occur if they hold their normal behavior of migrating mainly at night.

We have seen how seriously runs of salmon and trout have already been affected by river development to date. Additional development by 1979 could spell the end of the upriver runs. Thus, the time to develop and refine solutions to fish passage problems has been severely shortened. Fortunately, our research has already pointed the way to several important practical steps to minimize salmon and steelhead losses.

RECOMMENDED MEASURES FOR REDUCING LOSSES

Collect and Transport

One practical way to reduce losses of juveniles during their downstream migration is by a collection and transportation system whereby fish are collected at an upstream dam and transported to the estuary around many dams. This would eliminate losses of juveniles from turbines, nitrogen supersaturation, pollution, and delay at a large number of dams.

A summary, therefore, of the recent results of collection and transportation experiments follows:

Since 1970, the National Marine Fisheries Service (NMFS) has been concentrating on an experiment where migrating juvenile salmon and steelhead trout are collected at Little Goose Dam and transported to two locations downstream from Bonneville Dam (Figure 8). The experiment is designed to determine the effect of transportation on homing and survival. The data, summarized in Figures 9 (chinook salmon) and 10 (steelhead) indicate that survival of both chinook and steelhead can be increased by collection and transportation. The percentage increase in survival varies from year to year depending on river conditions. During years when survival of natural migrants was very low, survival of control releases was also low and the percentage benefit from transport was greatest. For example, in 1973 we measured an all time low survival rate of 5% for both juvenile chinook salmon and steelhead migrants; transport/control ratios obtained from adults returning were the highest (16:1 for chinook and 13:1 for steelhead). Survival rate calculated from the transport/control ratio on returning adults was 7-8%, nearly the same as we measured on juveniles.

Low survival of naturally migrating smolts in 1972-73 prompted a decision by Northwest fisheries agencies during the winter of 1974 to mass transport steelhead trout from Little Goose Dam in the spring of 1975 and both chinook salmon and steelhead trout in 1976.

Recent adult return data for steelhead transported in 1972-73 clearly justifies the decision to mass transport. About 3.5% (177,000) of the steelhead smolts were transported in 1973. There were approximately 11,000 adult steelhead returning in 1974-75 runs from the smolt outmigration in 1973. The transport contribution for steelhead hauled in 1973 was 4,375 or about 40% of total returns. If no transportation had taken place, only 6,600 adults would have returned from that outmigration. Unfortunately, we returned 695,000 steelhead smolts to the river at Little Goose Dam; our return data indicate that had these been transported along with experimental fish, the total adult return from 1973 would have been about 29,000 rather than the actual 11,000.

Screen and Bypass

Collection and transportation can provide one practical solution to turbine mortality. Another solution would be to install traveling screens in every turbine intake and bypass the fish around the turbines. However, the cost would be very high and at some dams, such as John Day, where the juvenile fish bypass system functions poorly, the losses might be greater from screening and bypass than from turbines. In addition, the problems of migration delay and predation in reservoirs would still exist.

Additional studies are needed to determine how screening and bypass systems can be made more effective at dams like John Day. The intake traveling screen system currently in use at Little Goose Dam, for example, is adequate for collection and bypass of steelhead, but could be improved for collection and bypass of chinook salmon. We anticipate the collection and bypass system at Lower Granite Dam will be an improvement over that operating at Little Goose Dam; preliminary information indicates this is correct but evaluation is not complete at this time. Of great concern at all existing dams is the potential for predation where young fish are concentrated at a bypass exit.

Bypass systems must be carefully evaluated on a dam by dam basis before the use of screens is recommended. Bonneville Dam, which will soon have a second powerhouse, should receive a high priority for consideration of a screening and bypass system. Several million juvenile salmonid migrants will have to pass through the turbines of this dam in the near future. However, even at the new Bonneville installation, the bypass system should be evaluated before the screens are installed.

Flow Control

A committee was established recently to recommend minimum flows in the Snake and Columbia Rivers for enhancing downstream migrations of juveniles. The recommendation provided sufficient flows to minimize delay through reservoirs and a minimum 20% spill at dams to offer some protection from turbine loss during major juvenile outmigration periods. At present, during average to above average runoff the recommended flows will probably be met in most years during spring outmigration periods. The requirement of 20% spill at dams will become increasingly difficult to meet with the increasing demands for hydroelectric power. Research is currently underway to investigate the benefits of controlled spill at dams for only a few hours at night when power demand is less rather than the present 24 hour requirement.

PREDICTED BENEFITS OF REMEDIAL ACTION

Preliminary steps have been taken on two major actions to minimize the losses caused by dams: (1) reduction of supersaturation by installation of spillway deflectors at Bonneville, McNary, and Little Goose Dams; and (2) the initiation of a full-scale test of the collection of juvenile steelhead and chinook migrants from the two uppermost dams (Lower Granite and Little Goose) and transportation to below Bonneville Dam. In Figure 11, we have attempted to predict the benefits that can be realized from these actions.

Steelhead are used to illustrate the scale of benefit anticipated because we now have enough survival information on steelhead for a reasonable projection. We expect to have sufficient information on survival of juvenile chinook salmon to make similar estimates on the benefits to chinook salmon next year. It is anticipated that the benefit to chinook salmon will be of the same order of magnitude as the benefit to steelhead.

Adult returns are predicted to increase from the low of 11,000 fish back from the disastrous 1973 outmigration to an average of 127,000 fish as a result of the installation of spillway deflectors and initiation of a collection and transportation system. This, we believe, is a conservative estimate. The maximum benefit occurs after the two collector dams, Lower Granite and Little Goose, each has installed six screened turbines, permitting maximum collection of downstream migrants. Even so, all of the losses caused by dams will not be eliminated by these actions.

Increased hatchery production has been recommended to compensate for the remaining losses. The importance of the proposed actions in obtaining the maximum benefit from additional hatchery production is illustrated in the lower panel of Figure 11. With the remedial actions, an additional production of 2 million smolts would produce 55,200 adults; without the proposed measures, we estimate 12,000 adults would be produced.

Benefits from flow control and screening and bypassing may further increase the size of the adult returns. Thus, we feel that viable runs of salmon and trout to the mid-Columbia can be maintained by incorporating the suggested corrective actions. Without corrective action, salmon and steelhead runs will be unable to survive long after 1979.

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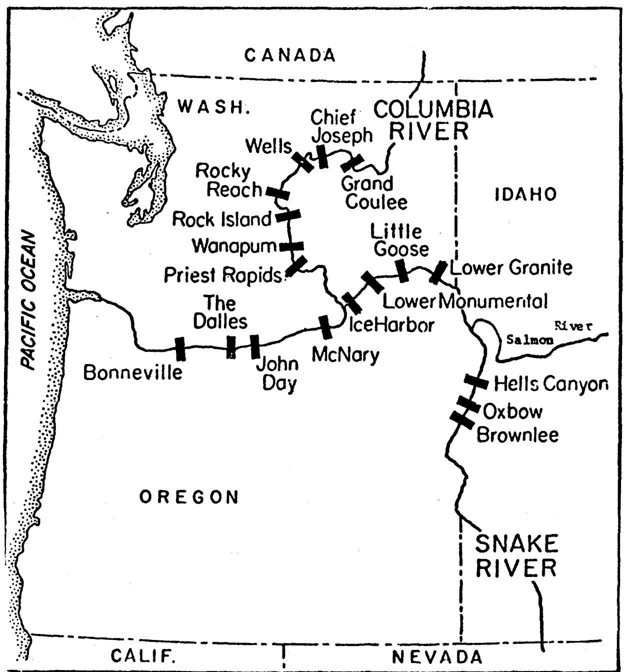


Fig. 1. Main Stem Dams in the Columbia River Basin

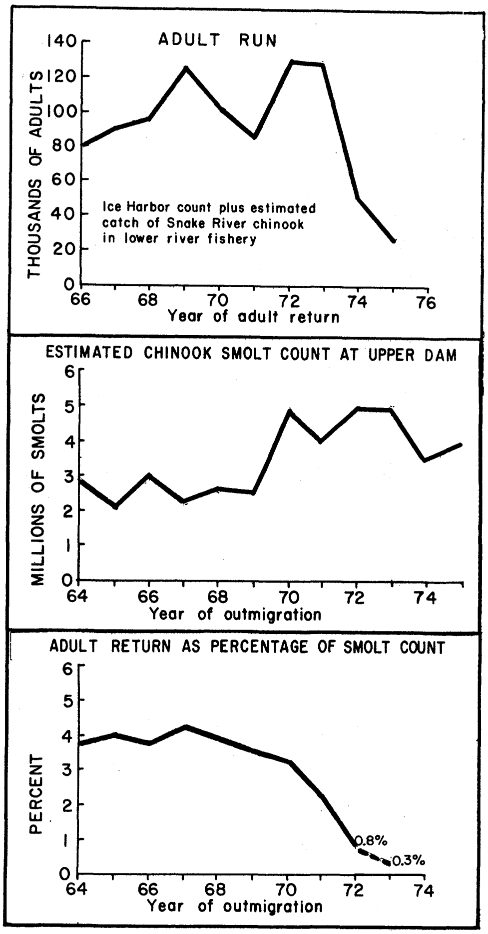


Fig. 2. Snake River Chinook Runs

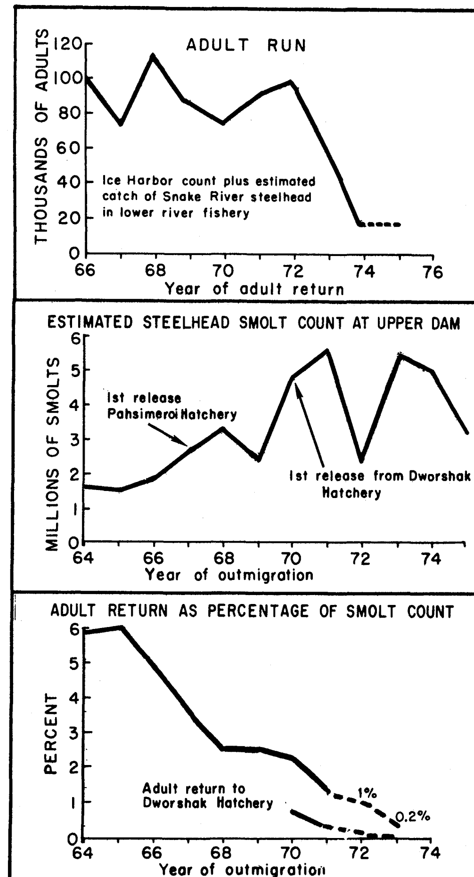


Fig. 3. Snake River Steelhead Runs

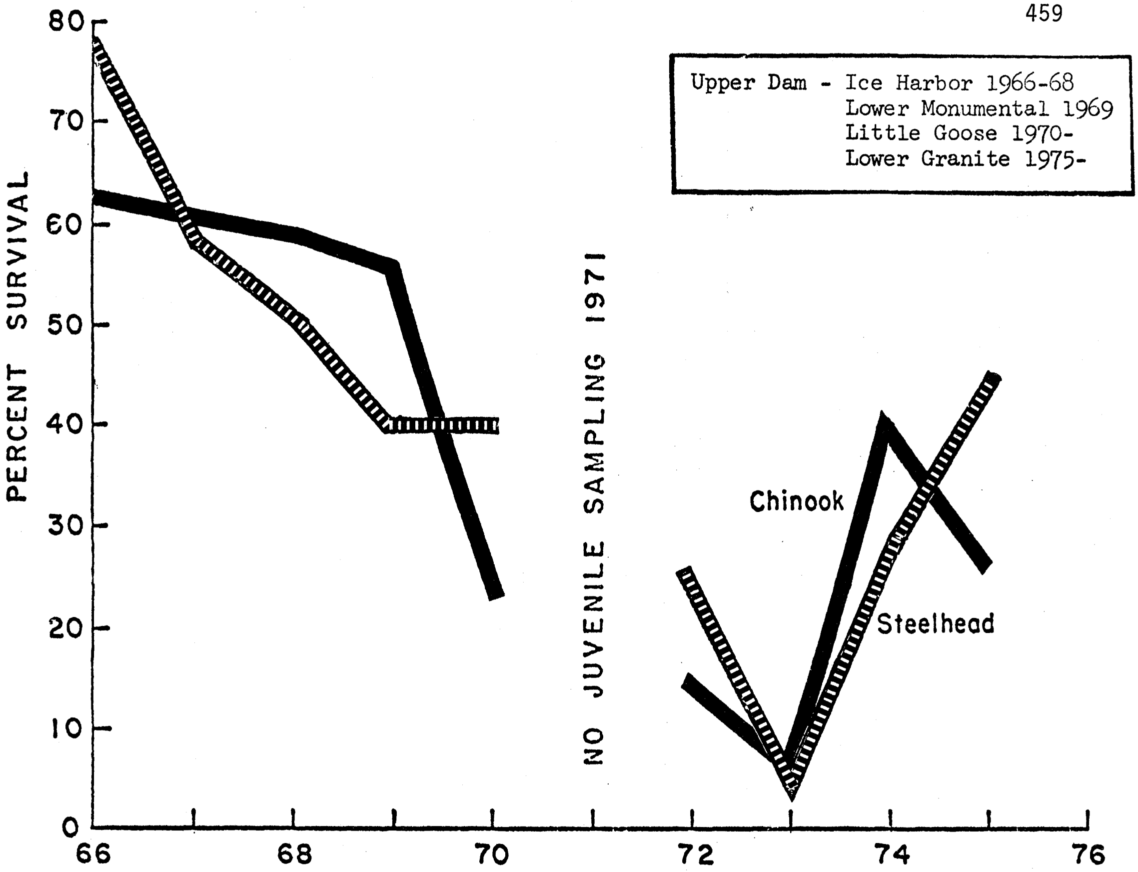


Fig. 4. Survival of Snake River Juvenile Chinook Salmon and Steelhead from the Upper Dam Down to The Dalles Dam, 1966-1975

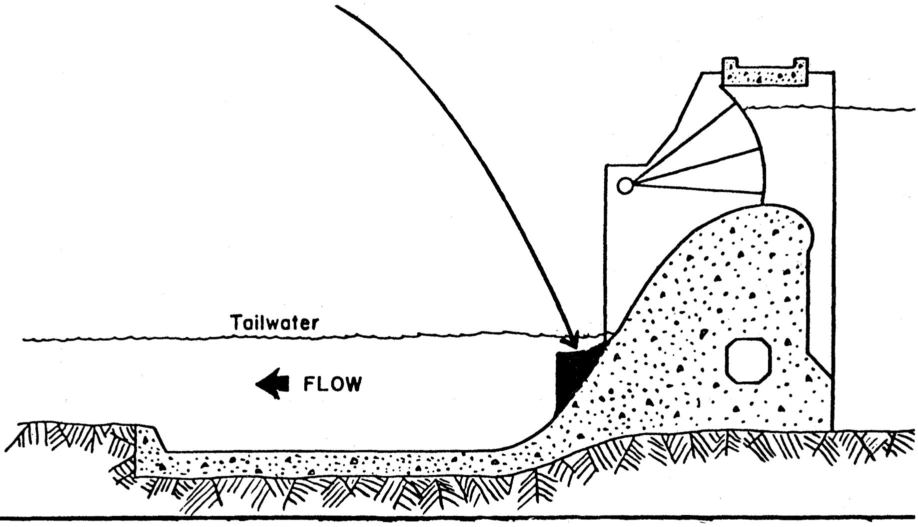


Fig. 5. Sketch of Spillway Deflector - A Structural Design Used to Reduce Gas Supersaturation

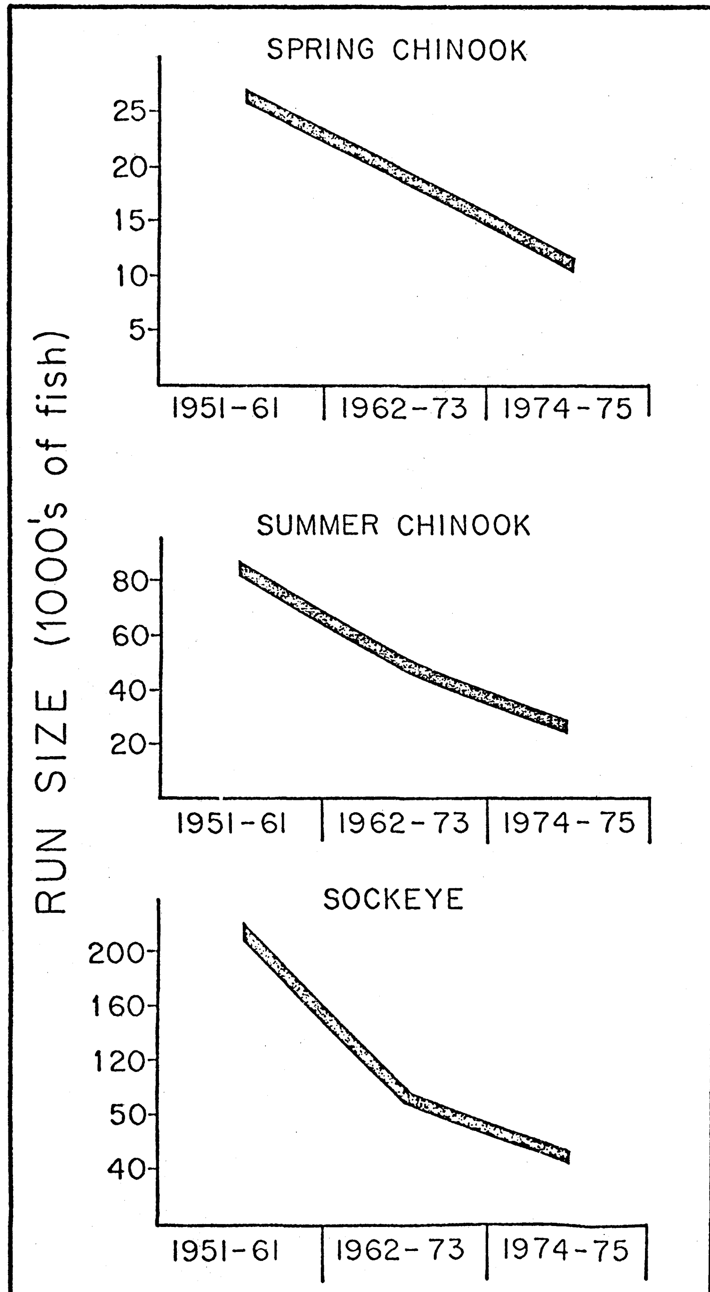


Fig. 6. Effects of Dams and River Regulation on Runs of Adult Salmon and Steelhead to the Mid-Columbia River

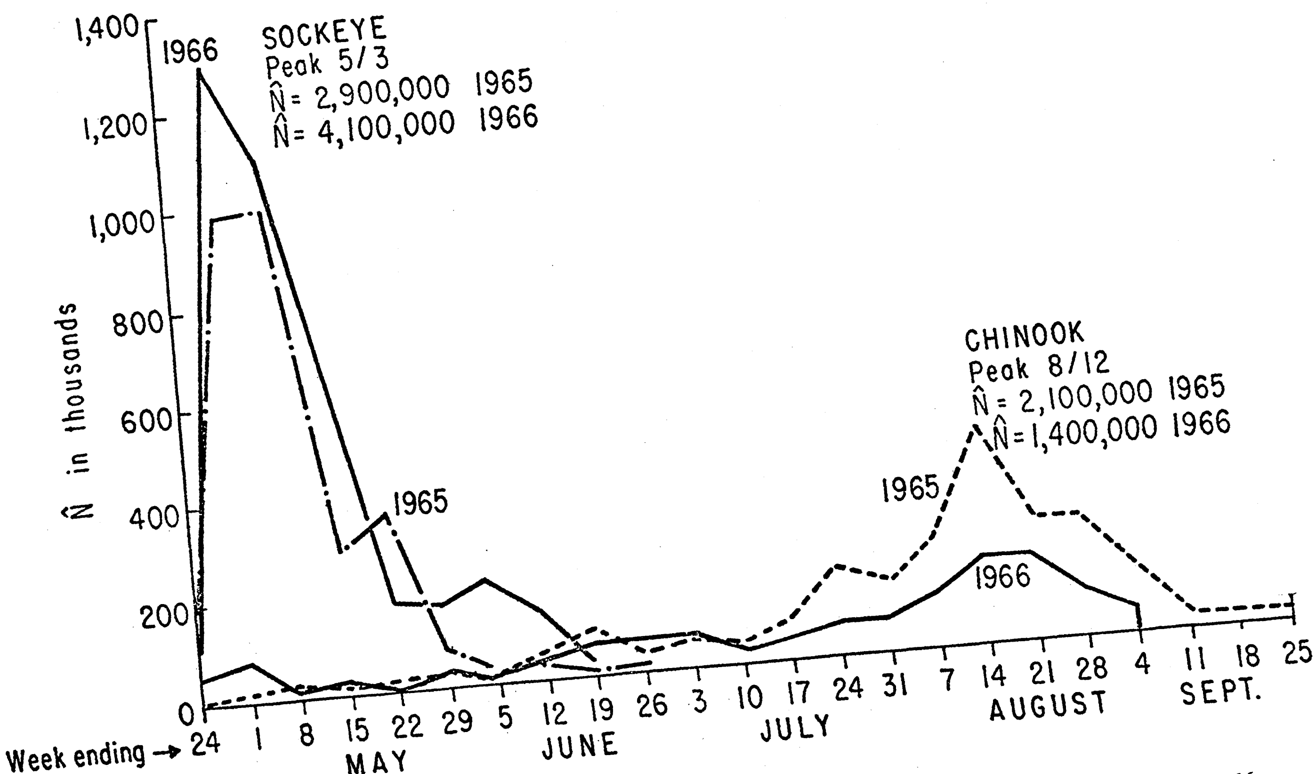
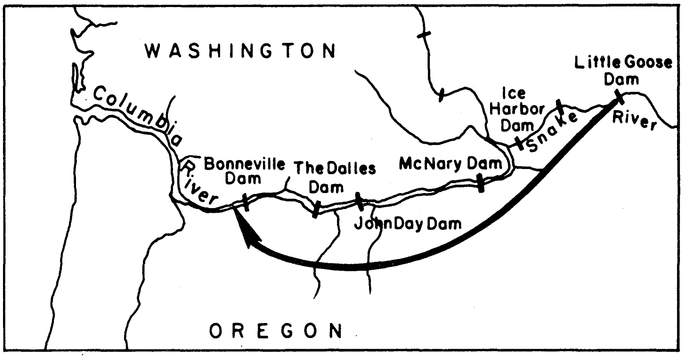
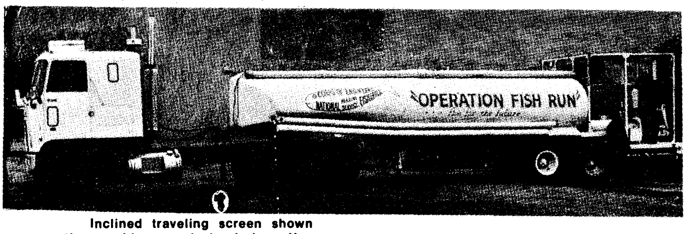


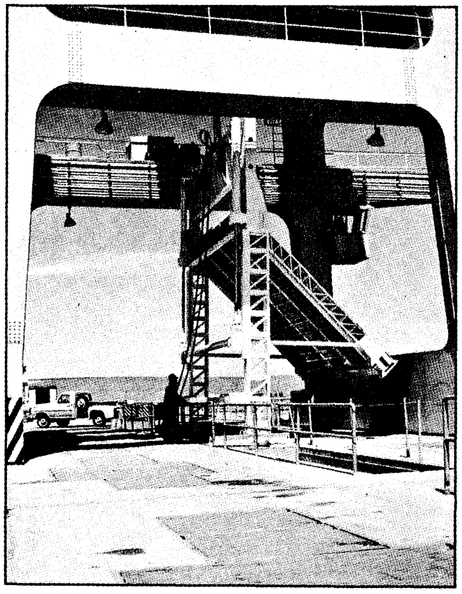
Fig. 7. Timing and Relative Magnitude--Chinook and Sockeye, Priest Rapids Dam, 1965 and 1966



Transportation route (heavy black arrow) from Little Goose Dam to Bonneville tailrace.



Inclined traveling screen shown in operating position on deck of dam. Hydraulically operated arm is withdrawn to permit lowering of screen through gatewell slot.



Sectional view of powerhouse showing traveling screen in operating position within turbine intake.

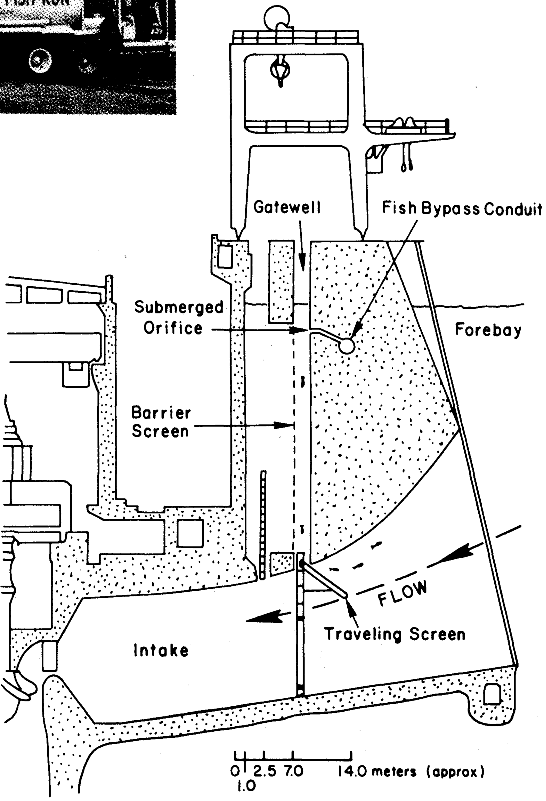


Fig. 8. Collection and Transportation of Juvenile Chinook Salmon and Steelhead

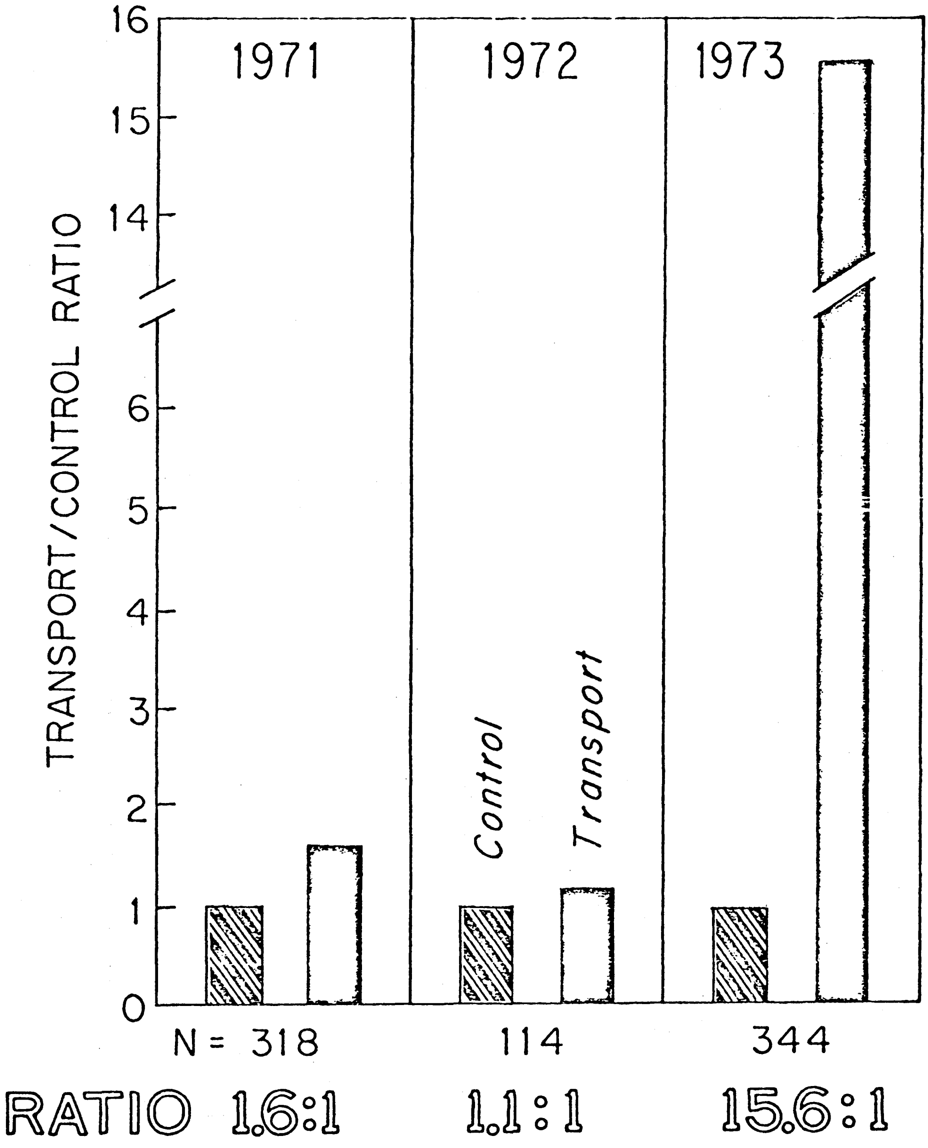


Fig. 9. Comparisons of Adult Returns from Control and Transported Releases of Juvenile Chinook Salmon from Little Goose Dam

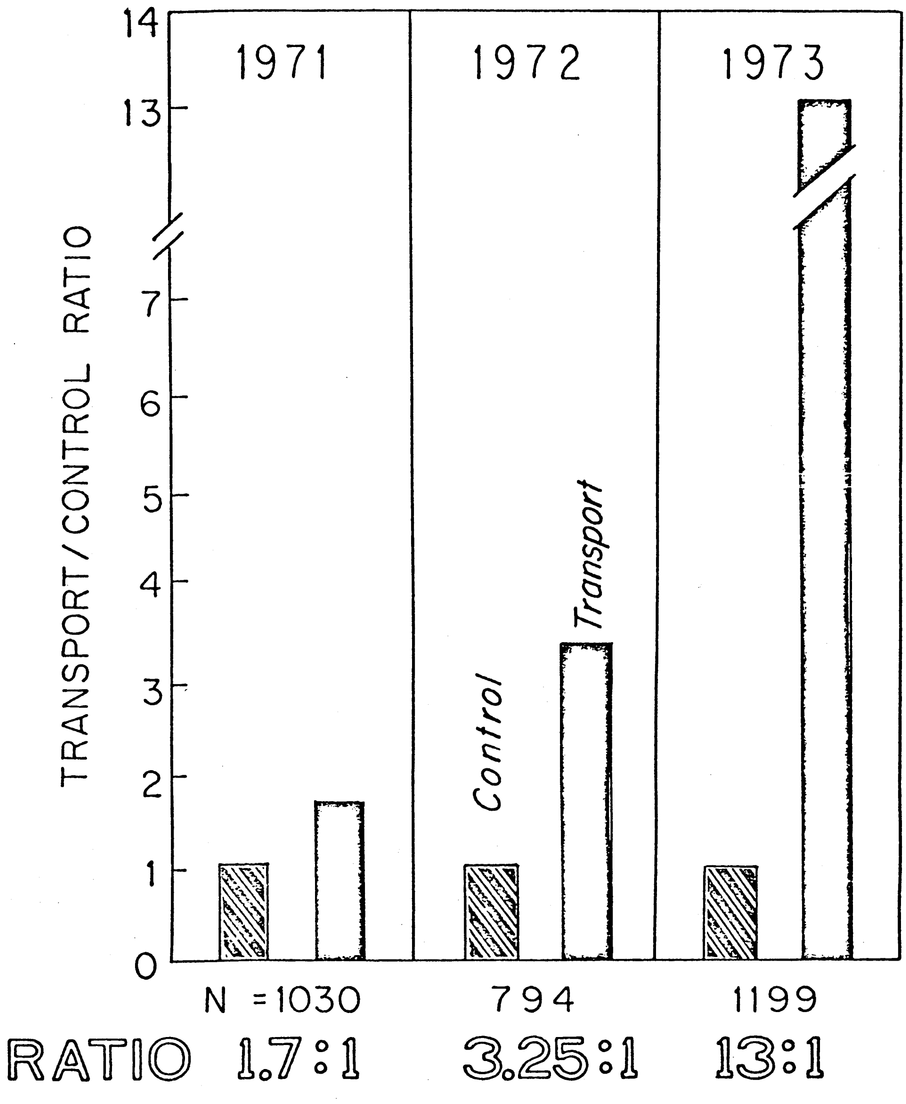


Fig. 10. Comparisons of Adult Returns from Control and Transported Releases of Juvenile Steelhead from Little Goose Dam

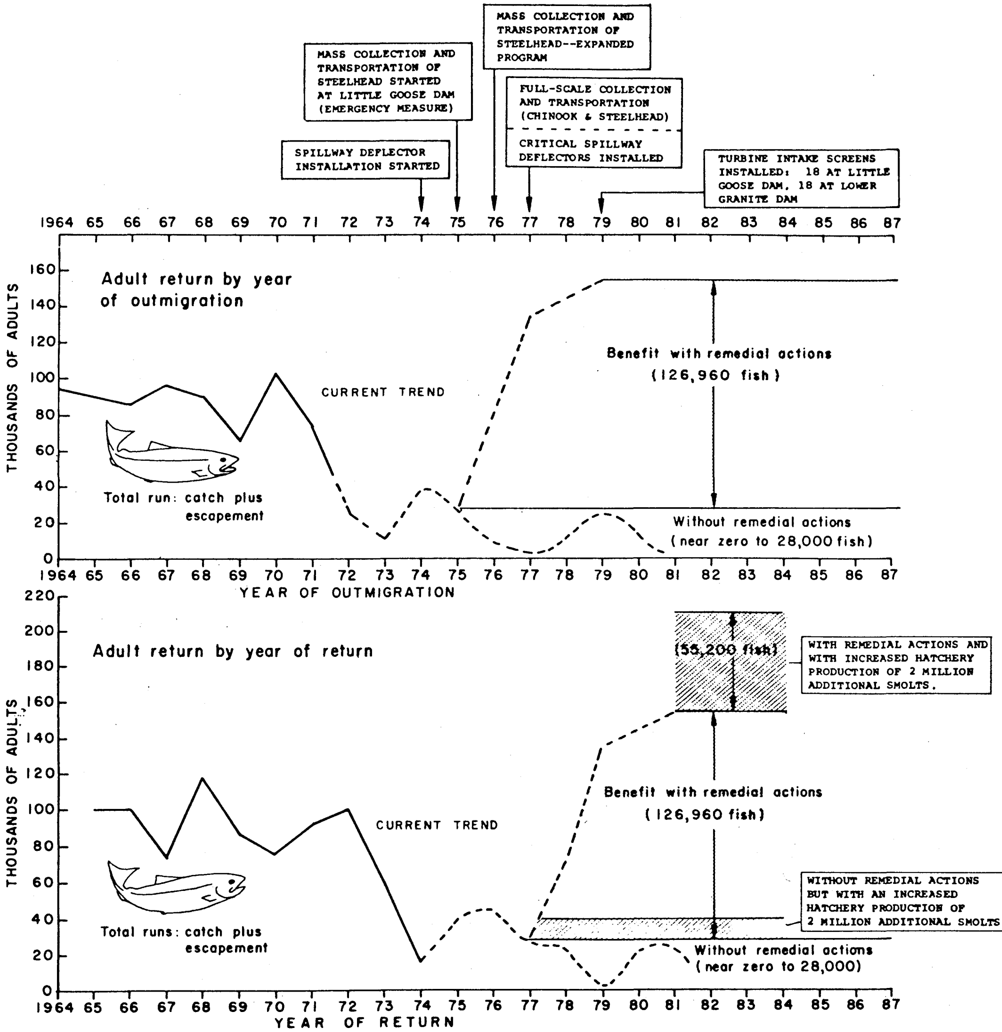


Fig. 11. Predicted Benefits--Numbers of Adults Returning (Steelhead)

OPERATION OF RESERVOIR SYSTEMS FOR INSTREAM FLOW NEEDS RESEARCH

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ABSTRACT

Observations on effectuating fishery objectives in relation to water development planning and reservoir operations based on 25 years experience are made. Examples of opportunities for stream flow research under controlled conditions in reservoir systems are reviewed, using material supplied by the Bureau of Reclamation. Suggestions for future action include increased emphasis on communications between professionals as exemplified at this conference, optimum involvement by fishery agencies in reservoir operations planning, stream flow research as a purpose of such planning whenever possible, the formation of a permanent regional group to coordinate stream research, and the gathering a bank of information on as many streams as possible.

INTRODUCTION

This paper is addressed primarily to those of you who contribute to the making of decisions, to those who are charged with responsibilities for water and its living residents, and especially to persons who will direct the course of future studies of stream flow needs. These thoughts are based on more than 25 years of work in water-use planning. Reflecting that career, I am still interested in seeing that the job gets done,having never had the chance to construct and carry out a research project as such.

In developing the theme of this title, it will be necessary to touch on the related topics of water-use planning and reservoir operations planning, as well as planning for stream research per se. Many of you are no doubt familiar with agencies and their personnel who are responsible for operation of reservoirs and reservoir systems. The essence of this message is to urge that stream-flow research be introduced, wherever possible, into operations planning as one of the purposes of such reservoir management.

The basic reasons for the enlarged interest of fisheries people in stream flow studies during the last several years are well known. In general, such studies have been conducted in response to the threat of proposed new water developments, or from a desire to improve existing controlled situations. To my knowledge only a relatively small amount of research was conducted to find ways to improve on natural conditions, or conditions established by long-standing diversions under early water rights.

I am mindful also of the varying objectives of fishery people in different areas of the Western States. To the northwest, including Idaho especially, much study has been directed to what is needed to preserve existing relatively underdeveloped fisheries and to justify preservation. In many areas, such as those east of the Continental Divide and the Upper Colorado River Basin, fishery biologists are concerned about the operation of constructed river control systems, as well as plans for authorized additional developments. In water-short areas, such as parts of Arizona, the emphasis has been on capturing meager or intermittent water sources to provide fishing in ponds or lakes. Multiple-purpose water developments have been welcome there if fisheries have been created where none existed before.

In developing recommendations for stream flows in connection with water development planning, they were too often, and usually, based only on an examination of gage records and water supply studies. These methods for comparing varying hydrologic situations will continue to be the cornerstones for predicting fishery productivity and for good planning. In addition short-term studies have been made of the effects of specific, controlled reservoir releases on the stream habitat. In Utah, Don Dunham developed a detailed method for measuring flows and habitat of forest streams late in the fall when flows approach winter lows. But all of these examples were concerned with collection of morphometric data. I submit that more biological studies are needed that can be correlated with the physical measurements. What better way can such correlation be attained than in studies of prescribed, controlled reservoir releases? Such arrangements are about as close as possible to outdoor laboratory conditions.

In making the above point, we are of course generally aware of the great amount of progress in research and study methods during the last few years. Also I mention that earlier in this topic Jim Mullan made some comparisons of the significance of varying factors on the fisheries in the tailwaters of Upper Colorado River reservoirs. Such comparisons will be most useful in developing comprehensive data on streams, even though the studies funded by Colorado River Storage Project construction appropriations were directed primarily to better fishery management rather than improvements in reservoir operations.

I thoroughly support this conference and its objectives. It is an endorsement of your chairman's approach to fishery development and management, a philosophy I have shared since we first met about 25 years ago. We were then concerned about existing and impending developments of the North Platte River in Wyoming. Then, as now, I was a proponent of good definitive research on the impact of reservoirs and diversions on streams. I still believe that such research can be most effective if carried out under controlled situations - control that is possible through reservoir regulation. Obviously, any such research effort requires the cooperation of the hydrologists and others responsible for the operation of reservoirs.

In approaching water development planners in earlier years, we often felt that they didn't want to be bothered. To dismiss us, we were frequently told that water supplies were allocated to power, or irrigation, or municipal purposes, and no water was available for fisheries. With perseverance, however, we could usually find much more operational flexibility than the absence of storage for fishery purposes would indicate. After all, the fish doesn't care what kind of water passes through its gills. Pisces will swim in power water or irrigation water as readily as any other H_2O of good quality in their environment. Over the years I came to enjoy some very interesting associations with hydrologists and other planners.

The degree of communication with water development agencies by fishery agencies is in great part a reflection of the fishery biologists of those agencies, and vice versa - the restrictions placed on biologists by their superiors. In my experience, many fishery management biologists have been antipathetic to the developers and have not been as aggressive in contacts with water-use planners and administrators as they might have been. Such attitudes can result in "taking a position", when searching, cooperative examination of all the possibilities would better serve the fisheries affected by project development or reservoir operation. The biologist may have problems within his agency as well as externally. I have known biologists who wanted to know about and be involved in everything affecting their area of responsibility, and who were frustrated by supervisors who thought they should be planting fish, pulling gill nets, and other jobs most any strong back could do. On the other hand, administrators are understandably concerned that unfettered action in the field will embarrass their agencies. Good supervisory guidelines are, of course, essential.

In urging more effective exchanges with water development agencies I mention, by the way, that hydrologic studies and forecasts are fascinating. All fishery people will profit by intimate acquaintance with the field of water management planning as it applies to the waters of their respective areas of responsibility. And the subject is not so difficult. If a competent biologist masters an understanding of the immensely complex field of aquatic ecology, he will find hydrology much simpler in that it deals with specific quantities, such as acre-feet, cubic feet per second, etc. He will gain much satisfaction in learning about and contributing to comprehensive water operations plans, plans which may vary greatly from year to year in keeping with probabilities for different ranges of water supplies.

The title of this paper might seem to indicate that I have a ready-made list of possibilities for research. I obviously could not investigate that deeply, knowing that anyone interested will have to seek out individual prospective research potentials in detail. The several Regional Directors of the Bureau of Reclamation were, however, consulted for examples of reservoirs which might be available for studies of specific releases. Their replies are summarized.

These paragraphs were included in my request:

> In the paper, I want to cite examples of reservoirs with enough operational flexibility to allow for controlled situations for fisheries research. Your help in identifying such reservoirs will be appreciated. Operations that could be modified for short periods or seasonally, as well as annually, would be of interest.
>
> An example of seasonal flexibility would be a reservoir operation with a specific allocation for minimum flows during the winter. Such an amount of water might be programmed for release in varying amounts during particular months. Or perhaps there are power reservoirs designed primarily for winter production that could be operated with planned variations in the summer.
>
> I would be especially interested in reservoirs with more than seasonal operational latitude. They would include those with storage that is not yet fully committed to primary purposes.

> With the above in mind, would you kindly identify pertinent reservoirs in your region, with notes on possible operational variations at each? (They need not be Reclamation reservoirs).

In the Upper Missouri Basin Region, the Regional Director noted especially the possibilities at Tiber Reservoir on the Marias River in Montana. Full use of the conservation storage has not been developed. He also noted that they often have several special operations for fishery studies of only a few days duration being conducted by State game and fish agencies and the Fish and Wildlife Service.

From the Lower Missouri Region at Denver, the Director emphasized their annual operating plans which are prepared with input from all interested agencies and persons. (I recall when these plans were first initiated for multiple purposes. They resulted, in part, from the agressive representations of the Wyoming Game and Fish Commission and the Fish and Wildlife Service, Missouri River Basin Studies.) All of the reservoirs in the region have some degree of flexibility, and operations have been adjusted, at times in the past, to meet request of fish and wildlife agencies for research purposes.

Copies of the operating plans for 1974-1957 were sent to me. Special note is made of the plan for the Fryingpan - Arkansas Project, including Ruedi Reservoir, Colorado. Winter releases of 100 second-feet have been provided to enhance the brown trout fishery, but this is a luxury that will not be possible when storage is eventually committed to authorized purposes. This transitory situation would appear to be ideal for testing productivity associated with several levels of winter-releases, including the 39 second-feet provided in the legislation. Perhaps a change in that minimum might be justified and eventually brought about.

Regional Director Bradley at Amarillo (Southwest Region) explains, in some detail, the Palmetto Bend Project on the Navidad River in Jackson County, Texas. He states, "The projects proximity to the Lavaca - Matagorda estuary system offers a unique opportunity to study the effects impoundment and subsequent controlled releases of water will have on stream and estuarine ecosystems. The firm annual yield for municipal and industrial purposes will not be required for some time."

The Navajo Reservoir on the San Juan River in New Mexico was also described. The best trout fishery in New Mexico has developed downstream, and its preservation has been fostered by favorable operations pending diversion for the uncompleted Navajo Indian Irrigation Project. Is this a site for research, as well as fish management objectives?

Being personally familiar with the Upper Colorado River Regions, I met with Don Barnett in the river control section. We discussed, especially, the operation of Taylor Park Reservoir in Colorado. The Colorado Game, Fish and Parks Department is taking advantage of a situation to conduct some special studies on the Taylor River. Since the construction of Blue Mesa Reservoir, downstream, full control of water supplies to the Uncompahgre Project is assured, and Taylor Park Dam can be operated with a high degree of pre-selection and flexibility. It is understood, also, that the Utah Division of Wildlife Resources is making special studies of the Strawberry River downstream from Soldier Creek Dam under interim operations, during the early part of the filling period. Another reservoir with storage not fully used for primary purposes is Electric Lake on Huntington Creek, a facility of the Utah Power and Light Company.

One intriguing question has been the value of set winter releases below dams, on smaller mountain trout streams. For example, is a flat 10 second-feet the best pattern in the November - March period? Would not the same quantity of water be more effective if varied, say from 13 to 7 second-feet with lowest flows in dead of winter, January - February, as they normally would under natural conditions? In Utah, Joe's Valley Reservoir of the Emery County Project, and several reservoirs of the Weber Basin Project are accessible enough to allow changes in releases during the winter. Studies might be carried out on the affected streams to answer the questions posed here.

Regional Director Lopez, of the Lower Colorado Region, explained that the magnitude of flows in the Colorado River, which are controlled for specific purposes, preclude any special operations for stream flow studies. He did mention, however, the special operational modifications intended for enhancement and study of the Lake Mead bass fishery.

From the Pacific Northwest Regional Office, here in Boise, I learned that short term operations for instream needs research have been made in recent years at Island Park, Palisades, American Falls, Lake Walcott, Anderson Ranch, Lucky Peak, Cascade, and Deadwood Reservoirs. Possibilities for similar studies exist at Bumping Lake, Cle Elum, Kachess, Keechelus, and Rimrock Reservoirs in Washington; Henry Hagg Lake, Prineville, Ochoco, Wickiup, Crescent Lake, Warm Springs, Beulah, Phillips Lake, Unity, and McKay Reservoirs in Oregon; and Jackson Lake in Wyoming. The opportunity for longer term studies may exist in a few cases where part of the storage capacity is not yet permanently committed, but it was emphasized that important interim uses have been established.

Mr. David G. Coleman, Chief of Central Valley Operations Coordinating Office wrote from Sacramento for the Mid-Pacific Region. In describing the comprehensive and complex Central Valley Project, he explained that much flexibility of operation is possible because of the virtually complete control of water supplies. His office is in constant communication with the California Department of Fish and Game and the Fish and Wildlife Service for recommendations on day-to-day project operations. Those agencies and the National Marine Fisheries Service also contribute to the preparation of annual operating plans.

The above sampling of Reclamation operations is only illustrative. Similar information could be obtained from offices of the Corps of Engineers, public power companies, and other entities responsible for reservoir operations.

To conclude this presentation, I offer a number of suggestions for further action by the conferees or the agencies represented:

1. Emphasize communication between professionals, so evident at this conference.
2. Fishery people, and their agencies, should become as involved as possible in reservoir operations planning, wherever full cooperation with the operating agencies has not yet been effected.
3. As part of such operations, opportunities for stream flow research should be sought, and whenever feasible, carried out.
4. The formation of a permanent interstate group, whose purpose would be coordination of stream research, should be considered. It would identify research deficiencies and provide a clearing house for exchange of information, and would help to avoid duplication of effort. The wildlife profession has organized a bighorn sheep council and a prairie grouse council. A similar organization may be needed for stream flow research.

5. A comprehensive approach to this research problem might also develop a bank of information on the habitat of a great number of streams from which the relative importance of various habitat factors may be deduced. Such might lead to the measurement of significant habitat factors, as a basis for confidently predicting productivity and seasonal flow needs for any particular stream. Multiple regression analysis of habitat factors may be feasible, although it is realized that such elements are tremendously more varied than in reservoirs, as described by Jenkins (1968).

REFERENCES

Bureau of Reclamation Regional Directors:

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Billings, Montana (450) Letter February 19, 1976
Boise, Idaho (430) Letter March 4, 1976
Boulder City, Nevada (LC-460) Letter February 27, 1976
Denver, Colorado (LM-430) Letter February 19, 1976
Sacramento, California (MP-117, Mr. David G. Coleman) Letter March 3, 1976
Salt Lake City, Utah (460) Letter February 25, 1976. Subsequent meeting with Don H. Barnett

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TOPIC V-E.

EFFECTS OF PROJECT OPERATIONS ON IFN

Summary Discussion

Mr. Hauck was asked:

Question: How are required flow releases monitored at projects licensed by Federal Power Commission?

Response: Water releases are not continuously monitored at the projects, but records from established downstream gaging stations are consulted periodically and the FPC relies on correspondence from Fish and Game and other concerned agencies.

Question: Has the time frame for licensing projects changed since initial development?

Response: Most recent renewal was for 30 years, and thus projects can be authorized now for longer periods. In the relicensing process, projects can be considered as new projects in light of environmental concerns. Recommendation for project removal could be advanced.

Question: Can requirements specified in old permits be reconsidered so that flows can be provided for fishery benefits?

Response: Any changes in operation must be considered unilaterally between the agencies involved before any interim changes can be made.

Mr. Raymond was asked:

Question: What are the effects of project operations on anadromous fish runs from mid-Columbia and Snake Rivers? Have the recorded declines in fish runs at dams been mirrored in commercial harvests?

Response: Stocks of spring chinook have been only lightly exploited. Steelhead have never been harvested commercially and the decline in steelhead runs argues that dams have had a dramatic effect on returns.

Question: Are there sufficient monies to fund the research on the movement of salmonids through projects?

Response: There currently are sufficient funds, primarily because of the results of analyses and program progress which has been made.

Notes by panel moderator: Robert W. Wiley
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Green River, WY

WSP - WILL IT DO THE JOB IN MONTANA?

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The determination of instream flows for fish, wildlife and recreation is a problem in Montana, as it is in other western states. We are many years late in developing suitable methodologies which would enable us to compete with current and increasing diversionary water demands.

Fish, wildlife and recreation are beneficial water users in Montana under the state's new water law which became effective in 1973. The Montana Water Use Act, as this law is called, placed these uses on the same basis as those which were traditional - namely, agricultural (including stock water), domestic, industrial, irrigation, mining, municipal and power uses. Currently in Montana one water use has no legal preference over any of the other water uses, although there are indications such a preference listing may be proposed to the next legislative session.

Montana now has a permit system for acquiring diversionary water use rights. This is a new system and is much different than the past methods used to acquire a right to appropriate water. "First in time" is still "first in right," but new rights are now obtained only through application to the state.

Also, under the new water law, instream rights can be acquired by state agencies and certain other entities of state government. These rights are termed "reservations of water." Reservations of water can be acquired for "existing or future beneficial uses, or to maintain a minimum flow, level, or quality of water throughout the year or at such periods or for such length of time as the board (State Board of Natural Resources) designates."

Unlike diversionary water use permits which can be approved by the State Department of Natural Resources and Conservation, instream water reservations must be approved by the Board of Natural Resources, composed of politically appointed citizens of the state. The board cannot adopt an order reserving water unless the applicant establishes to the satisfaction of the board:

(1) The purpose of the reservation,

(2) The need for the reservation,

(3) The amount of water necessary for the purpose of the reservation, and

(4) That the reservation is in the public interest.

Since passage of this new authority to reserve water, we have sought to find a method, or methods, we could use to arrive at and justify suitable instream flow regimens to satisfy the above requirements, particularly number (3). The problem lies not so much in finding a methodology (since there are some successful ones available) to determine these flows, as it is finding a methodology suitable to our own situation.

Thus, we sought to find a methodology which could be used by our existing field personnel within our budget and manpower limitations. The WSP (Water Surface Profile) program seemed to fit those needs. Limited field time is needed to acquire the basic data for the program. However, as with any method, the output is only as good as the input. Poorly collected data result in poor answers, particularly in a predictive program like WSP.

A good job of surveying is a must if field data input into the program is to be accurate. We have gained much experience in basic surveying techniques, but not without problems. We still need to improve these techniques.

Another problem we have experienced in the field is not recognizing all the necessary flow control points in a stream section. Failure to recognize all controls makes the program difficult to calibrate, and in turn causes errors in predictions. In some cases the program will not work at all.

We believe certain of the predictive data are quite reliable; for example, water depth, width and cross sectional area. However, there are some questions about the velocity predictions which must be resolved, since this parameter is used in current criteria for arriving at flow recommendations. We have only limited data which test the reliability of actual point velocities to velocities predicted by WSP at the same streamflow.

We hope we can resolve some of the problems so far experienced and further test the program's results. Since the program was originally developed for other purposes, some of the output data are in a form not readily usable by us. For example, wetted perimeter is not directly calculated and can only be accurately obtained by measuring the plotted cross sections. We are attempting to correct this by modifying portions of the program.

In summary, WSP has good possibilities for certain instream flow determinations, but is not without some problems with both input to the program and the usefulness of some of the data generated. We hope these problems can be solved. WSP is a method. If adequate use can be made of the data it produces and these data can be generally applied to the needs of the aquatic resources, another instream flow methodology will be available to workers concerned with maintenance of a suitable environment for aquatic resources.

We will not limit ourselves to use of WSP, but will investigate other possible methodologies which will meet our needs. As with any methodology, the lack of suitable criteria reflecting the biological/streamflow requirements of aquatic resources is still a limiting factor. We hope to narrow this data gap through research investigations of the flow needs of both salmonid and nonsalmonid species in Montana.

APPLICATION OF U.S. BUREAU OF RECLAMATION WATER SURFACE PROFILE PROGRAM (WSP)

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ABSTRACT

The U.S. Bureau of Reclamation's Water Surface Profile Program (WSP) is explained by discussing the program and the various data components necessary to properly use and apply it. Included is a brief discussion of the Montana Fish and Game Department's use of the program. The program is described, field data requirements are listed, processing of field data is explained, calibration of the program to the study area is outlined, and available output is discussed. Examples of a field layout, stream cross sections, and various types of output are included with the discussion.

Suggested rules to follow when collecting necessary field data are listed. Items of particular interest in the output are highlighted in the tables included with the paper.

INTRODUCTION

The Bureau of Reclamation has used various methods to compute water surface profiles for many years. These methods, for the most part, have concentrated on determining reservoir backwater elevations above and tailwater elevations below various instream structures.

The Montana Fish and Game Department has the task of determining stream maintenance flows for rivers and streams and sections of rivers and streams throughout Montana. After the stream maintenance flow has been determined, a water right to insure this flow's availability must be established. Physical parameters needed to determine the proper stream maintenance flow include; flow velocities, flow quantities, water depths, stream widths, water surface elevations, and cross sectional areas. These data can be collected through actual field measurements at many flows or can be determined using one good set of field measurements and the Water Surface Profile Program (WSP) to predict the physical parameters for various flows. Predicted values do match measured values when good field data are collected.

In late 1973 and early 1974, after many contacts between the Montana Fish and Game Department and the Bureau of Reclamation's Upper Missouri Regional Office, a cooperative venture of technical assistance was initiated. This Technical Assistance Program allows the Bureau of Reclamation to share its technical expertise and computer capability with this State agency.

DESCRIPTION OF WSP

WSP is a computer adaptation of the Bureau of Reclamation's Water Surface Profile Computation Method B. The program was written to computerize computations necessary to determine tailwater and backwater elevations. These are the water surface elevations below dams and river control structures and above reservoirs. The hand calculations needed to compute these elevations are very tedious and time-consuming.

WSP is adaptable to instream applications. The program allows the user, after sufficient fieldwork, to predict and/or study various changes in stream characteristics at many different flows. The predicted values are within the accuracy of the field data. The program (model) is calibrated to a specific stream study section using one or two observed flows, the corresponding water surface elevations, cross sectional data at stream controls and at other locations within the study section, and the distance between cross sections. Stream characteristics determine the minimum number of cross sections needed to sufficiently describe a stream study section. These characteristics include steepness of the stream or stream gradient, size of the stream, stream meanders (bends), bottom roughness, debris in the stream channel, water surface controls, and bridge crossings or diversion structures. In essence, the number of cross sections needed will vary from stream to stream, but a minimum of four sections is necessary for proper use of WSP.

FIELD DATA REQUIREMENTS

Field data needed for input to the WSP Program include the information previously mentioned plus a physical description of the stream section. Quality of this field data determines the accuracy of the computed results. These field data include:

1. A map showing stream section being studied and cross section locations,
2. Cross section survey data,
3. Distance between cross sections, including inside and outside distances at stream meanders,
4. Measured flow in cubic feet per second,
5. Corresponding water surface elevations at all cross sections at the measured flow,
6. Photographs of the stream reach being studied and photographs at each cross section,
7. Description of the streambed material at each cross section (sand, gravel,

cobbles, boulders, muck, debris),

8. Description of bank and overbank material and vegetation (trees, brush, grass, logs),

9. Identification of points where streambed material, vegetation, and streambank changes within the cross sections,

10. A list of flows to be used for predicting various physical parameters within the study section.

If elevations of the water surface elevations and cross section elevations are accurate to within ± .1 of a foot, the predicted water surface elevations will be accurate within ± .1 of a foot. Accuracy of results depends directly upon accuracy of field data.

Figures 1 and 2 show a typical stream section to be studied, without the cross section locations and with the cross section locations established. Cross sections should be taken at right angles (normal) to the streamflow. Distance between cross sections should be measured along the line of flow or along thalweg (deep part of channel). Measurements should also be made at inside and outside of stream meanders. Control sections must be included as a cross section. Where specific information in a transect is desired, cross sections of that area are necessary. Examples of these are a spawning area, feeding area, a resting area, or a passage or run area.

When a bridge is located in the study reach, cross sections must be taken within 50 to 100 feet above and below the bridge and at the bridge opening.

The most downstream cross section should be at a stream control. A stream control is a point in the river or stream where flow control is affected on the stream by a construction, riffle, bottom change, or by some other means.

Consistency is most important when collecting field data. Cross sections should originate from the same side of the stream if possible. The left streambank is identified as left when looking downstream. Cross sections should be taken in order, whether progressing upstream or downstream, if at all possible. All cross sections should not be surveyed from the same point. The surveying instrument should be moved to each cross section location.

DATA PROCESSING

After the field data are taken, cross sections plots are made (see examples, Figures 3 and 4). The field data are submitted to the Bureau and are readied for keypunching and processing with the computer. An edit program is used to check the keypunched field data for errors. Roughness coefficients ("n" values) are determined from the field data, observations, and photographs. The data are then processed using the Water Surface Profile Program. WSP processes the data in a step-by-step manner from the most downstream section through the most upstream section. An energy slope is determined from the streambed thalweg and observed water surface elevations. These observed water surface elevations have been associated with the measured streamflow as mentioned previously.

CALIBRATION

The computer output for the observed flow is examined to determined if predicted water surface elevations match observed values. Adjustments in roughness coefficients ("n" values), and minor adjustments in cross sections and station distances are made to bring predicted values within $\pm$ .1 feet of the observed values. After these adjustments have been made, a series of flows that include a probable low flow or observed low flow and the probable maximum flood flow, if desired, are compiled. These flows are ranged to give a good rating curve for the most downstream cross section. This set of flows including the observed flow is combined with the cross sectional and distance data and then processed using WSP to compute the estimated water surface elevations for the series of selected flows.

OUTPUT

Available output from WSP includes specific data for each cross section and summary tables of data for all flows that were investigated. Specific cross section output includes water surface elevations, flow velocities in the cross sections, conveyance areas and top widths, hydraulic radius, and discharges (see output section). Summary table information includes water surface elevations, main channel velocities and discharges, roughness coefficients, tractive forces (amount of force exerted upon stream bottom), and main channel distances for the set of flows that have been used.

From the output data a water surface profile showing water surface elevations, streambed thalweg, and cross section location (by station) is plotted (Figure No. 5). A rating curve for the most downstream section is also plotted (Figure No. 6).

The cross sectional data, computer output, water surface profiles, and rating curve are returned to the investigator.

SUMMARY

Use of these data will aid in determining stream maintenance flows and will help determine the effects higher or lower flows have on fish habitat. The output will enable the user to predict changes in stream characteristics without having to make many field observations and measurements at different flows.

Tables 1 through 6 are examples of the typical output data set from a WSP computer run. These data of course vary from application to application and are only an example of the total available output.

GLOSSARY OF TERMS

Station - an expression of distance, measured in feet, between cross sections. This distance is normally measured along the line of flow or along the thalweg. Example, see Figure 2; cross section No. 1, Sta. 0+00 and cross section No. 2, Sta. No. 2, Sta. 0+85; the distance between these cross sections is 85 feet.

Thalweg - the thalweg is the low part or deepest part in a channel.

"n" factor - "n" factor is the roughness coefficient of the channel or parts of the channel. The roughness coefficient is an expression of resistance to flow caused by the streambed.

Energy Balance - computation performed by the computer to balance flow and velocity between cross sections to observed water surface elevations.

Stream Segment or Section - a portion of the stream being studied (see Figure 1).

Cross Section - transect or section taken at right angles to the flow in stream (Figure 3).

Control Section - a section in the stream that controls the flow and water surface elevation. This control can be exerted by a riffle, channel construction, diversion dam, etc.

Cross Section Segment - a portion of the cross section isolated by bottom type, roughness, or for particular study.

RULES FOR TAKING FIELD DATA

Number 1 - follow good surveying techniques.

Cross Sections - cross section locations should be marked first, the minimum number of cross sections necessary for reliable computation is four.

Flow Measurements - the flow measurement should be made when the river or stream is stable. Water surface elevations at the other cross sections should be marked just before or after the flow measurement is made.

Distance between Cross Sections - the distance between cross sections or the number of cross sections depends on the river reach being studied. A good rule is to take as many cross sections as needed to describe the stream. Measurements on stream bends or curves should include the outside and inside streambank distances.

Cross Section Extension - cross sections should extend up the overbank far enough to properly describe this area for high flows, if the investigator is interested in effects of high flows.

Bottom Type Description - the bottom type should be described as follows:

Vegetation - weeds, moss, etc.

Sand, Silt, Clay - particles less than 0.1 inch

Gravel - rocks 0.1 to 3 inches in diameter

Cobbles (rubble) - rocks 3 to 12 inches in diameter

Boulders - rocks over 12 inches in diameter

Bedrock - large mass of solid rock

Bench Marks - Establish a permanent bench mark or some other identification so cross section locations can be found when study site is revisited.

Table 1

SUMMARY OF PROFILE DATA

TOM MINER CREEK -- T7S R7E SEC30 -- TRIBUTARY TO YELLOWSTONE RIVER
SOUTH OF LIVINGSTON, MONTANA

Discharge Data

DISCHARGE	BEGINNING ELEVATION	ROUGHNESS MODIFIERS FOR OVERBANK	ROUGHNESS MODIFIERS FOR MAIN CHANNEL	ESTIMATED BEGINNING HYDRAULIC GRADIENT
25.	REDUNDANT	1.00	1.00	.01034
40.	REDUNDANT	1.00	1.00	.01034
50.	REDUNDANT	1.00	1.00	.01034
60.	REDUNDANT	1.00	1.00	.01034
77.	992.10	1.00	1.00	REDUNDANT
90.	REDUNDANT	1.00	1.00	.01034
100.	REDUNDANT	1.00	1.00	.01034
125.	REDUNDANT	1.00	1.00	.01034
150.	REDUNDANT	1.00	1.00	.01034
200.	REDUNDANT	1.00	1.00	.01034
250.	REDUNDANT	1.00	1.00	.01034
300.	REDUNDANT	1.00	1.00	.01034
400.	REDUNDANT	1.00	1.00	.01034
500.	REDUNDANT	1.00	1.00	.01034

Cross Section Data

SUMMARY OF OPTION AND COORDINATE DATA

TOM MINER CREEK -- T7S R7E SEC30 -- TRIBUTARY TO YELLOWSTONE RIVER
SOUTH OF LIVINGSTON, MONTANA

STATION		NUMBER OF ROUGHNESS SEGMENTS IN SECTION	ELEVATION OF SEDIMENT DELTA	ELEVATION OF OBSERVED PROFILE	INCREMENTAL DISCHARGE
	82.	4	0.0	0.0	0.

NUMBER OF COORDINATE PAIRS = 17
OPTION PARAMETERS OF ZERO INDICATE A REDUNDANCY

RIGHT MOST COORDINATE	ROUGHNESS COEFFCIENT	REACH LENGTH OF CENTROID
8.	.055	29.
31.	-.035	29.
53.	.035	29.
61.	.055	29.

X COORDINATES	0.0	8.0	9.0	10.0	11.0	12.0	16.0	21.0	25.0	28.0
Y COORDINATES	1001.6	999.0	998.7	997.9	997.8	997.1	995.9	995.3	995.7	996.4
X COORDINATES	31.0	33.0	41.0	45.0	50.0	53.0	61.0			
Y COORDINATES	996.8	997.3	997.2	996.9	997.3	998.3	1001.0			

Table 2

TOM MINER CREEK -- T7S R7E SEC30 -- TRIBUTARY TO YELLOWSTONE RIVER
SOUTH OF LIVINGSTON, MONTANA

TABLE OF MAIN CHANNEL DISTANCES

STATION	DISTANCE BETWEEN CROSS SECTIONS	CUMULATIVE DISTANCE
0.		0.
	48.	
48.		48.
	5.	
53.		53.
	29.	
82.		82.
	115.	
197.		197.
	104.	
301.		301.

TOM MINER CREEK -- T7S R7E SEC30 -- TRIBUTARY TO YELLOWSTONE RIVER
SOUTH OF LIVINGSTON, MONTANA

TABLE OF ROUGHNESS COEFFICIENTS

STATION				
0.	.050	-.040	.050	
48.	.055	-.045	.045	.055
53.	.050	-.040	.040	.055
82.	.055	-.035	.035	.055
197.	.050	-.045	.060	
301.	.055	-.050	.060	

Table 3 Flow Data

PAGE NO. 5

TOM MINER CREEK -- T7S R7E SEC30 -- TRIBUTARY TO YELLOWSTONE RIVER
SOUTH OF LIVINGSTON, MONTANA

STATION 0 + 82 ENGLISH UNITS ASSUMED ELEV. 0.00 THALWEG ELEV. 995.3 THALWEG SLOPE .0103

COMPUTATION LINE HF1 = .52 HV1 = .54 AVG OVERBANK REACHES - LEFT = 29. RIGHT = 29.

29	42	21	1.9	-.03500	2808	2.70	116
29	20	21	1.0	.03500	853	1.68	34
SUM OR AVG	62	42			3661	2.50	150

THIS SECTION HAS 4 ROUGHNESS SEGMENT OR SEGMENTS. 2 SEGMENT OR SEGMENTS USED FOR THIS DISCHARGE
COMPUTATION LINE HF2= .05 HV2= .10 SF VOIDED TOTAL HEAD= .78 CRIT. FLOW= 398 W.S. ELEV.= 998.18

* * *

STATION 0 + 82 ENGLISH UNITS ASSUMED ELEV. 0.00 THALWEG ELEV. 995.3 THALWEG SLOPE .0103

COMPUTATION LINE HF1 = .43 HV1 = .53 AVG OVERBANK REACHES - LEFT = 29. RIGHT = 29.

LENGTH OF CENTROID	CONVEYANCE AREAS	TOP WIDTHS	HYDRAULIC RADII	ROUGHNESS COEFFICIENTS	CONVEYANCE FACTORS	VELOCITIES	DISCHARGES
29	46	21	2.1	-.03500	3272	3.14	148
29	25	22	1.1	.03500	1164	2.08	52
29	0	0	.0	.05500	0	.13	0
SUM OR AVG	71	43			4436	2.90	200

THIS SECTION HAS 4 ROUGHNESS SEGMENT OR SEGMENTS. 3 SEGMENT OR SEGMENTS USED FOR THIS DISCHARGE
COMPUTATION LINE HF2= .06 HV2= .13 SF VOIDED TOTAL HEAD= .69 CRIT. FLOW= 486 W.S. ELEV.= 998.38

* * *

TOM MINER CREEK -- T7S R7E SEC30 -- TRIBUTARY TO YELLOWSTONE RIVER
SOUTH OF LIVINGSTON, MONTANA

Table 4

TABLE OF WATER SURFACE ELEVATIONS

STATION	THALWEG	25.	40.	50.	60.	77.	90.	100.	125.	150.	200.	250.	300.	400.	500.
		WATER SURFACE ELEVATIONS----FEET													
0.	990.6	991.6	991.8	991.9	992.0	992.1	992.2	992.3	992.4	992.6	992.8	993.0	993.3	993.6	994.0
48.	991.0	992.2	992.4	992.5	992.6	992.8	992.9	992.9	993.1	993.2	993.5	993.7	993.9	994.3	994.7
53.	995.0	996.1	996.3	996.5	996.6	996.8	996.9	997.0	997.3	997.4	997.7	997.9	998.1	998.4	998.6
82.	995.3	996.9	997.1	997.3	997.4	997.6	997.8	997.9	998.0	998.2	998.4	998.6	998.8	999.2	999.6
197.	998.8	999.7	999.9	1000.0	1000.0	1000.2	1000.3	1000.3	1000.4	1000.6	1000.8	1001.0	1001.2	1001.6	1001.9
301.	1004.4	1005.5	1005.3	1005.4	1005.5	1005.6	1005.7	1005.7	1005.9	1006.0	1006.2	1006.4	1006.6	1007.0	1007.3

TOM MINER CREEK -- T7S R7E SEC30 -- TRIBUTARY TO YELLOWSTONE RIVER
SOUTH OF LIVINGSTON, MONTANA

Table 5

TABLE OF MAIN CHANNEL DISCHARGES AND VELOCITIES

FLOWS IN CFS

	25.	40.	50.	60.	77.	90.	100.	125.	150.	200.	250.
	300.	400.	500.								
STATION	DISCHARGES IN CFS -/- VELOCITIES IN FT./SEC.										
0.	25.	40.	50.	60.	77.	90.	100.	125.	150.	199.	249.
	2.40	2.77	2.96	3.15	3.43	3.59	3.74	4.06	4.35	4.84	5.25
	299.	399.	499.								
	5.60	6.20	6.70								
48.	22.	31.	37.	43.	52.	58.	64.	76.	88.	110.	132.
	3.11	3.50	3.71	3.90	4.17	4.33	4.46	4.75	4.99	5.36	5.64
	152.	189.	220.								
	5.86	6.14	6.21								
53.	25.	40.	50.	60.	77.	90.	100.	120.	141.	172.	205.
	4.31	4.84	5.14	5.38	5.70	6.09	6.17	5.55	6.09	6.20	6.66
	237.	297.	356.								
	7.06	7.73	8.27								
82.	25.	40.	49.	57.	68.	76.	82.	101.	116.	148.	177.
	1.50	1.87	2.03	2.10	2.18	2.15	2.21	2.63	2.70	3.14	3.38
	205.	262.	317.								
	3.58	3.93	4.25								
197.	25.	40.	50.	60.	77.	90.	100.	125.	150.	200.	250.
	3.64	4.08	4.36	4.60	4.91	5.06	5.23	5.62	5.94	6.32	6.73
	300.	400.	500.								
	7.07	7.63	8.11								
301.	25.	40.	50.	60.	77.	90.	100.	125.	150.	200.	250.
	1.93	3.94	4.25	4.52	4.91	5.17	5.35	5.57	5.90	6.47	6.94
	300.	400.	500.								
	7.34	8.02	8.59								

TOM MINER CREEK -- T7S R7E SEC30 -- TRIBUTARY TO YELLOWSTONE RIVER
SOUTH OF LIVINGSTON, MONTANA

Table 6

TABLE OF IN CHANNEL TRACTIVE FORCES

FLOWS IN CFS

TRACTIVE FORCE---LBS/SQ. FT.

STATION	25.	40.	50.	60.	77.	90.	100.	125.	150.	200.	250.	300.	400.	500.
0.	.3274	.4047	.4463	.4904	.5594	.5984	.6348	.7199	.7971	.9251	1.0469	1.1567	1.3502	1.5189
48.	.6907	.7973	.8765	.9620	1.0554	1.0880	1.1737	1.2757	1.3776	1.5146	1.6477	1.7277	1.8128	1.8119
53.	1.0395	1.2055	1.3044	1.3894	1.4928	1.6774	1.7080	1.3043	1.5368	1.4915	1.6638	1.8223	2.0752	2.3024
82.	.0813	.1200	.1337	.1406	.1425	.1370	.1429	.2012	.2060	.2683	.3011	.3305	.3860	.4320
197.	1.0538	1.2245	1.3418	1.4382	1.5797	1.6255	1.7001	1.8755	2.0233	2.1600	2.3483	2.5116	2.7866	3.0147
301.	.3194	1.4443	1.6042	1.7484	1.9527	2.0972	2.1960	2.2560	2.4415	2.7644	3.0426	3.2894	3.7175	4.0654

TYPICAL STREAM Study Section

Deer Creek - Study Section 1, Montana

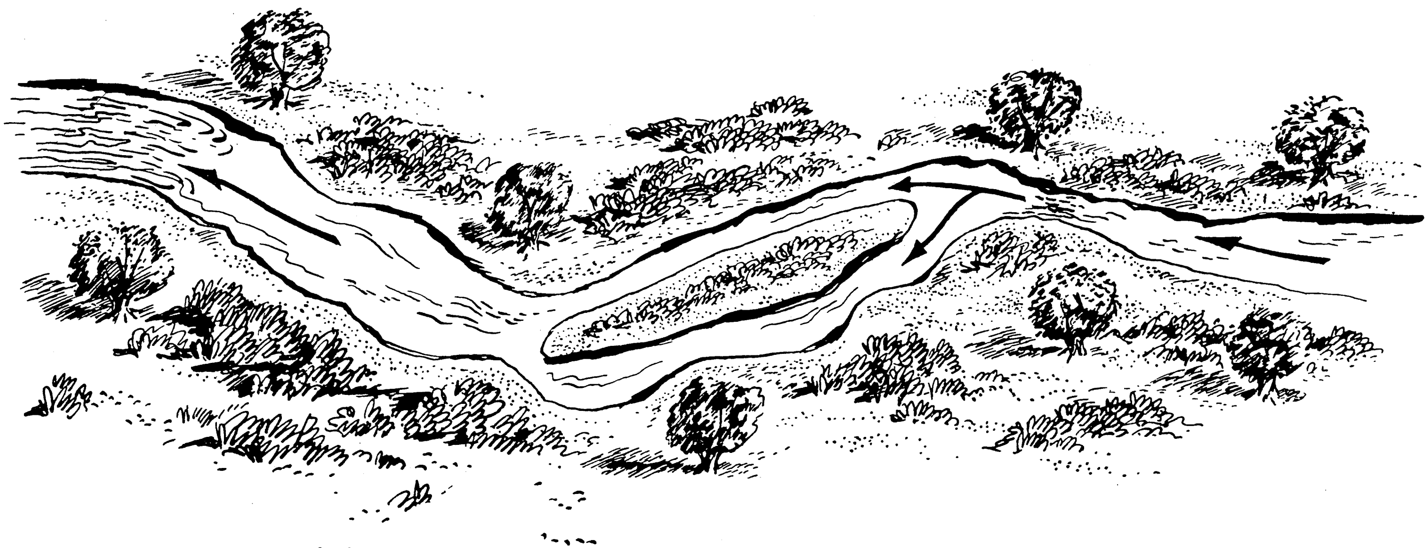


FIG. 1

TYPICAL STREAM Study Section WITH CROSS SECTION LOCATIONS

Deer Creek - Study Section 1, Montana

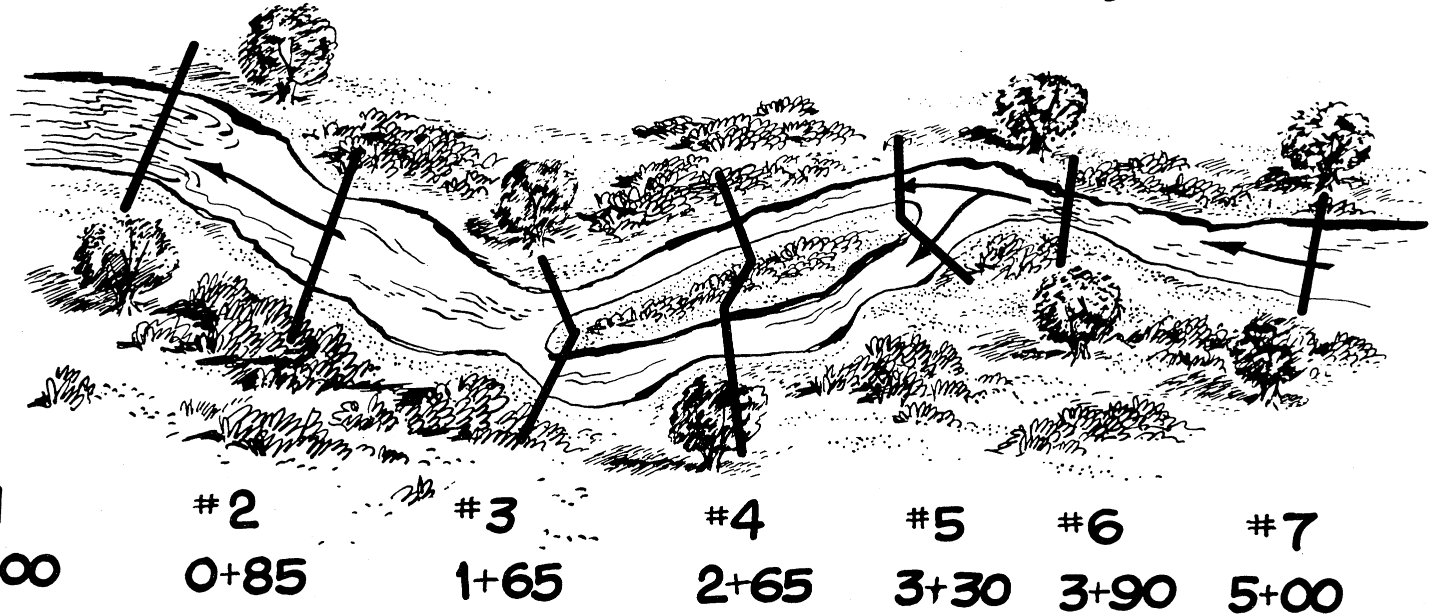
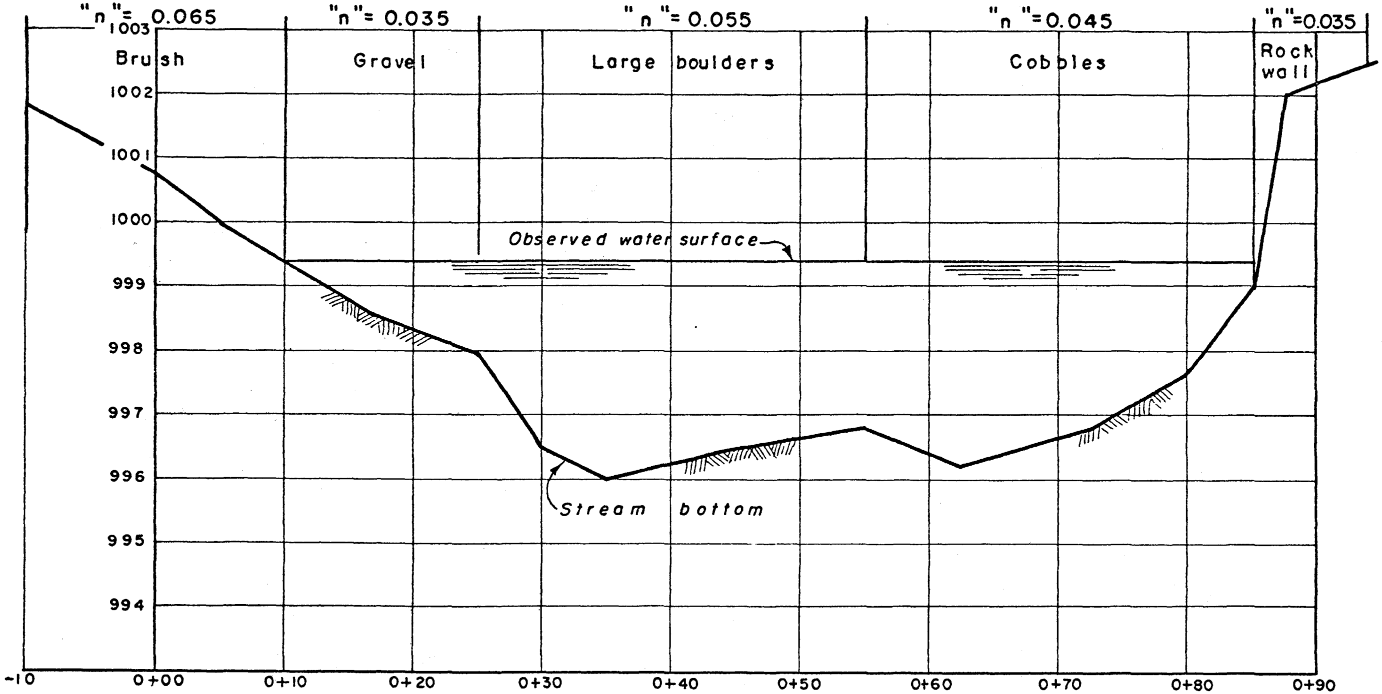
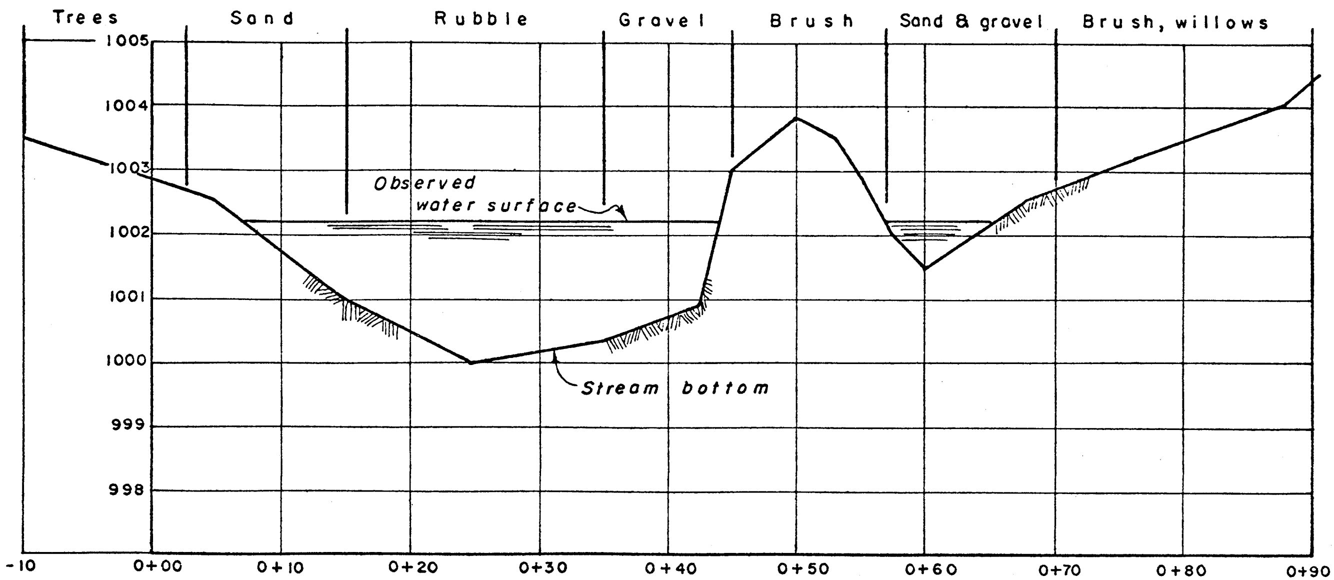


FIG. 2



SECTION I
STA. 0+00
DEER CREEK, STUDY SECTION I
MONTANA

Figure 3



SECTION 5
STA. 3+30
DEER CREEK, STUDY SECTION I
MONTANA

Figure 4

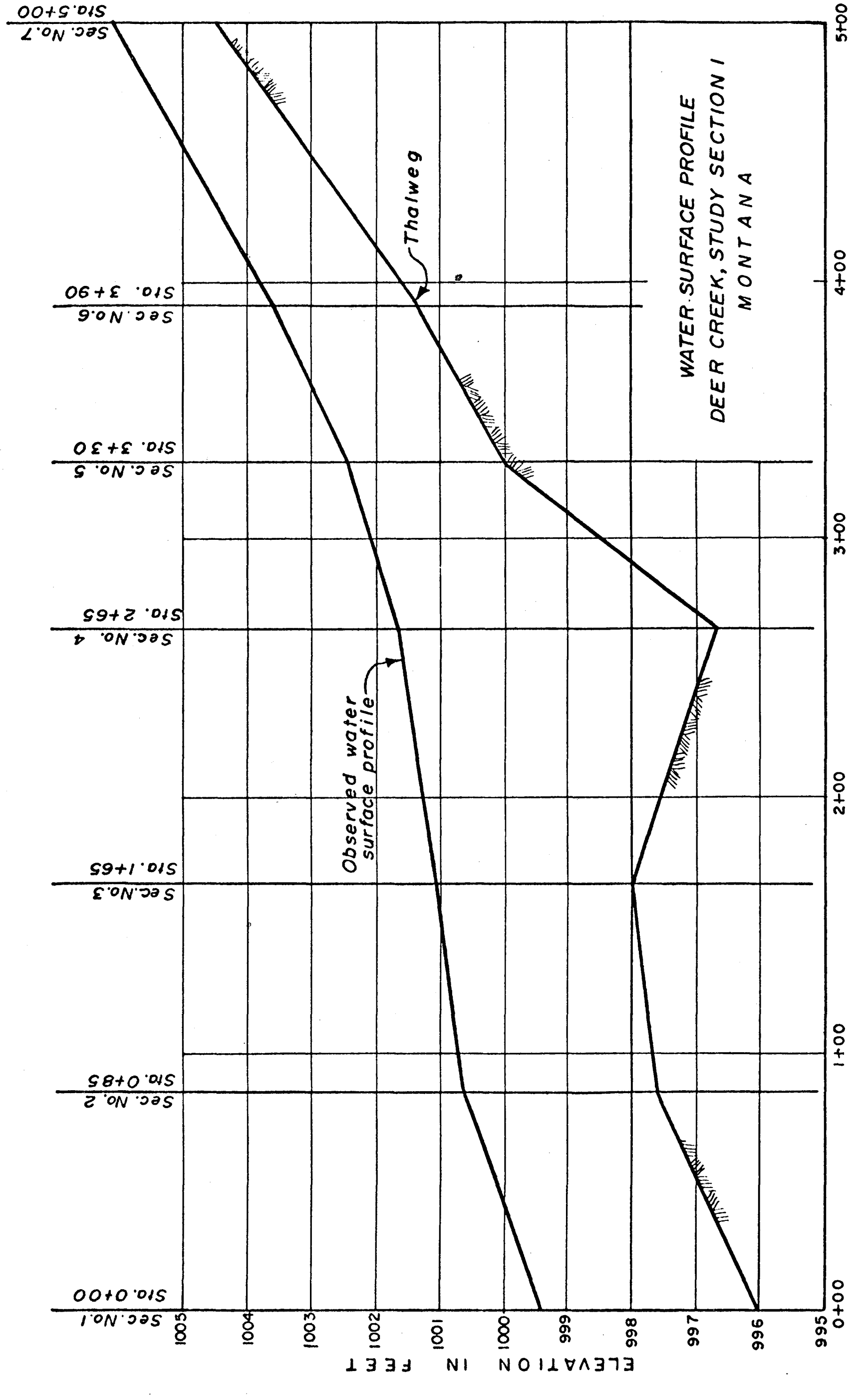
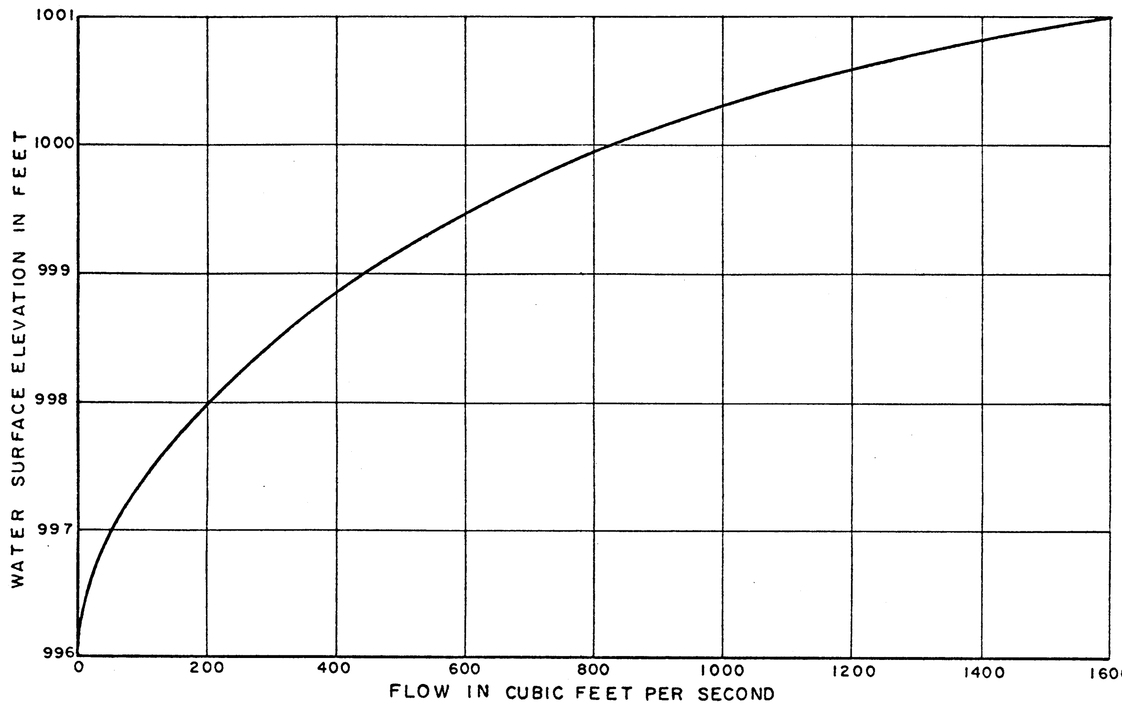

WATER SURFACE PROFILE
DEER CREEK, STUDY SECTION I
MONTANA
Thalweg
Observed water surface profile
Sec. No. 1 Sta. 0+00
Sec. No. 2 Sta. 0+85
Sec. No. 3 Sta. 1+65
Sec. No. 4 Sta. 2+65
Sec. No. 5 Sta. 3+30
Sec. No. 6 Sta. 3+90
Sec. No. 7 Sta. 5+00
STATION IN FEET
ELEVATION IN FEET
0+00
1+00
2+00
3+00
4+00
5+00
995
996
997
998
999
1000
1001
1002
1003
1004
1005

Figure 5



RATING CURVE
STA. 0+00
DEER CREEK, STUDY SECTION I
MONTANA

Figure 6

USE AND RELIABILITY OF WATER SURFACE PROFILE PROGRAM DATA ON A MONTANA PRAIRIE STREAM

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ABSTRACT

The applicability of the Water Surface Profile Program (WSP) as a method of determining instream flow values for a prairie stream was investigated on the Tongue River, Montana. Flows for migration, spawning and rearing were evaluated using the WSP as a base. Predicted values for water surface elevation and mean velocity were found to be non-significantly different from actual values. The WSP is applicable to a prairie stream for fishery, aquatic invertebrate, waterfowl and recreational flow needs.

INTRODUCTION

Water development projects are resulting in a rapidly declining flowing aquatic resource. Industrial, agricultural and domestic users are putting tremendous pressures on our rivers and expanding energy development programs will accelerate these demands. Existing and proposed projects will eventually result in the removal of substantial amounts of stream flow.

The Fort Union Coal area is perhaps the largest coal basin in the world and underlies a substantial portion of the Northern Great Plains. Total reserves have been estimated to be 1.3 trillion tons (Montana Coal Task Force, 1973), which represents 40 percent of the United States reserves. Potential utilization of this coal, an immediate but possibly short-term energy source, is probably the most critical social, environmental, legal and institutional problem facing the Great Plains.

Water controls all activity in this semiarid region and the industrial future of the Fort Union coal fields is no exception. Since most coal fields are far removed from the existing sources of surface water, the nature and extent of development would depend on the quantity of water available at the mine site. Withdrawal of large volumes of water from Great Plains rivers and streams will include storage facilities and diversion structures which will certainly affect the current flow regimen and associated aquatic communities. The magnitude of proposed industrial use of prairie streams makes it imperative that adequate flow levels are identified and insured to protect the fishery.

The objective of this segment of the study was to investigate the use of the Water Surface Profile Program (WSP) for use in determining instream flows for a warm water stream and to evaluate the reliability of the WSP. The study was funded by the Old West Regional Commission.

TONGUE RIVER

The Tongue River Basin is a rectangular, rolling to mountainous valley of southeastern Montana and northeastern Wyoming. The Tongue River, an important tributary of the Yellowstone River flows 463 kilometers (288 river miles) from its source on the eastern slopes of the Big Horn Mountains of Wyoming, to its confluence with the Yellowstone River at Miles City, Montana. One-hundred and twenty-seven river kilometers (79 miles) flows in Wyoming. The Tongue heads at over 3,355 meters (11,000 feet) above sea level, dropping to 701 meters (2,300 feet) at its mouth. Upstream, near the Montana-Wyoming state line the average annual flow is 445 hm^3 (360,800 acre/feet), and at its mouth it averages 381 hm^3 (309,400 acre feet) per year. Flow in Montana is controlled by the Tongue River Dam, an earthen structure impounding 68,000 acre feet of water.

The Tongue River is important to the people of southeastern Montana, providing water for domestic use by man and livestock, irrigating crops and offering recreation. As coal development threatens the Northern Plains, the Tongue River takes on a new importance.

A total of 29 species of fish were collected in the Tongue River. Fish populations in the Tongue exhibit a succession from torrent zone fishes to quiet zone fishes (Elser, 1975). Smallmouth bass, walleye, and northern pike constitute the important game fish throughout the majority of the river. Migrant fish from the Yellowstone River include paddlefish, shovelnose sturgeon, sauger and channel catfish. These species move into the Tongue during the spring to spawn. Thus, two distinct fish populations are involved, resident (entire river) and migrant (lower 15 miles).

METHODS

Fish populations were sampled by electrofishing with an output of 0-500 volts variable direct current; seining with a 100-foot, 1/4-inch mesh beach seine; a 3-inch bar mesh gill net, drifted; and baited hoop nets and wire frame traps. Discharges and water temperatures were recorded during the runoff period and compared to daily catch rates.

Physical parameters were measured on four sections using the Bureau of Reclamation Water Surface Profile program (WSP). The procedures followed are outlined by Dooley (1975) and Spence (1975). Instream flow needs were then evaluated in terms of stream conditions predicted by the WSP.

RESULTS

Many techniques and methodologies are available for the recommendation of instream flow needs. While physical and chemical parameters form the basis for some methodologies, biological parameters, particularly the fishery, are utilized in most techniques. Relating the environmental needs of the organism to the physical characteristics is the most critical and difficult problem in recommending instream values. Ecological needs of salmonids has been researched extensively but still has many gaps. Needs of warm water fish have attracted much less attention until recently when Bovee (1974) proposed a methodology based on an extensive literature review and White and Cochnauer (1975) began looking at warm water fish needs in Idaho.

Bovee (1974) identifies three life history phases of warm water fish to be covered by a flow determination: migration, spawning and rearing. Walleye and sauger spawn immediately prior to the runoff period, while paddlefish and shovelnose sturgeon spawn during this period. Channel catfish utilize the Tongue River for spawning following runoff.

Montana's use of the WSP closely parallels Idaho's ideas of a modification of the "usable width" approach, considering discharge requirements for passage, spawning and rearing (White and Cochnauer, 1975). However, we believe that if flow is adequate for passage, spawning requirements will also be met. The methodology is founded upon the concept of predicting loss of habitat at reduced discharges and relating the predicted loss to physical and biological requirements of key species.

Application of WSP

To evaluate passage, we select the shallow riffles which would possibly hinder upstream movement. A depth profile is taken over the shallowest reach. Predicted depths are evaluated in terms of channel characteristics and projected for the reach. From these projections, a minimum passage flow will be recommended for three time periods (sauger, paddlefish and channel catfish).

Information necessary to implement spawning flows for these species is sparse. However, if adequate flows are maintained for passage, spawning should be successful.

Rearing requirements are also generally less understood. Adequate food base, physical habitat and suitable water quality are necessary for successful rearing (Bovee, 1974). Collings (1974) uses the assumption that rearing is proportional to food production, which is in turn proportional to wetted perimeter when recommending rearing flows. As in passage flows, several riffles are located and a transect established on each. Wetted perimeter is calculated and plotted against discharge. This concept hinges on the fact that, in typical channels, the perimeter of the average stream reach that is wetted increases rapidly with discharge as the streambed is covered with water. Past a point when the majority of the stream bottom is covered, increases in flow bring about only small increases in wetted perimeter as streamflow approaches bankfull. The breaking points are assumed to provide optimal discharges for rearing and are recommended as such.

Aquatic insect production can also be evaluated with the WSP. Newell (1976) has evaluated insect preferences for depth and velocity in the Yellowstone River. By utilizing predicted depths and velocities, insect losses with decreasing flows can be evaluated.

A recreational survey in relation to water withdrawals is also utilizing the WSP (Erickson, 1976). Water-based recreational activities such as boating and rock picking can be assessed in terms of water levels. A transect established over shallow areas of the stream can predict flows at which the area will no longer be passable to recreational boaters.

Waterfowl production can be evaluated in terms of island integrity. Hinz (1976) has documented high predator losses for nesting geese associated with reduced flow levels in the Yellowstone River. With a cross-section established across an island, the WSP could predict flow levels which would retard access to the island by predators.

Reliability of WSP

A major question concerning the use of the WSP method for determining instream flow values is one of accuracy (White and Cochnauer, 1975). The reliability of any methodology is only as good as the confidence field biologists, engineers, water programers and lay people have in it. Repairs to the Tongue River Dam in 1975 provided an opportunity to compare predicted values for depth and velocity with actually measured values.

Cross sections were taken at 198 cfs and the data tabulated. Controlled flows during the repair period stabilized at 100 cfs at the S-H section (70 river miles above the mouth). Water surface elevations were remeasured at each cross section and compared with the values predicted by the WSP at 100 cfs. These water surface elevations are compared in Table 1. A non-parametric, two-tailed significance test (Wilcoxon) was run between program predicted and measured water surface elevations. No significant difference was detected at the 80 percent level ($p > .20$). The greatest difference at any transect was 0.11

feet with an average deviation of 0.004 feet and an average absolute deviation of 0.04 feet. Therefore predicted deviations are considered to be very reliable.

Table 1. Predicted and measured water surface elevations (feet) at S-H Section, Tongue River, at 100 cfs

	TRANSECT						
	1	2	3	4	5	6	7
Program	992.98	993.37	993.42	993.50	993.58	993.66	993.73
Actual	993.09	993.39	993.41	993.57	993.57	993.61	993.64
Absolute deviation	.11	.02	.01	.07	.01	.05	.09

No significant difference $p > .20$

Mean velocities measured at five flows (100, 150, 200, 260, and 390 cfs) at the Viall Section (91 river miles upstream from the mouth) were compared with predicted values (Table 2). A non-parametric, two-tailed significance test (Wilcoxon) showed no significant difference at the 80 percent level ($p > .20$) at flows of 100, 200, 260 and 390 cfs. A significant difference at the 80 percent level ($p > .07$) was found for the 150 cfs flow. Again reliable predictions for mean velocities.

DISCUSSION

The use of the WSP as a methodology for determining instream flow needs for a prairie stream appears to be valid. Comparisons of measured water surface elevations with predicted values adds credibility to the method. While hydraulic characteristics predicted by the WSP are mean values, they are adequate for use with current knowledge of fish requirements. The WSP reduces the time required in the field and is applicable to other

Table 2. Predicted velocities compared with measured velocities in f/s, Tongue River, Viall Section at flows of 100, 150, 200, 260 and 390 cfs.

	TRANSECT 1	2	3	4	5
Flow = 100 cfs					
Program	1.91	2.18	1.55	.87	1.47
Actual	1.54	1.45	1.40	1.32	.90
Absolute deviation	.37	.73	.15	.45	.57
No significant difference $p > .20$					
Flow = 150 cfs					
Program	2.00	2.36	1.82	1.10	1.66
Actual	1.80	1.68	1.82	.91	1.32
Absolute deviation	.20	.68	.00	.19	.34
Significant difference $p < .20$					
Flow = 200 cfs					
Program	2.07	2.48	2.00	1.39	1.78
Actual	2.01	1.90	1.91	1.49	1.64
Absolute deviation	.06	.58	.09	.10	.14
No significant difference $p > .20$					
Flow = 260 cfs					
Program	2.19	2.58	2.14	1.58	1.93
Actual	1.87	2.09	2.46	2.10	2.00
Absolute deviation	.32	.49	.32	.52	.07
No significant difference $p > .5$					
Flow = 390 cfs					
Program	2.49	2.81	2.45	2.00	2.28
Actual	2.55	2.46	2.67	2.23	2.58
Absolute deviation	.06	.35	.22	.23	.30
No significant difference $p > .5$					

aspects of flow determination. Research needs remain in data collection on environmental requirements of the organisms involved.

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USE OF THE WATER SURFACE PROFILE PROGRAM IN DETERMINING INSTREAM FLOW NEEDS IN SIXTEENMILE CREEK, MONTANA

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ABSTRACT

The Water Surface Profile program was used to determine instream flow needs in Sixteenmile Creek, because there were no historical flow records available. Conveyance area, wetted perimeter and water velocity were parameters chosen from the Water Surface Profile data to use in evaluating changes in trout habitat with changes in flows. Graphs of conveyance area and wetted perimeter showed an accelerated rate of loss in these two parameters when flows were reduced below 50 cfs and they identified a critical point at 25 cfs.

Water velocity would be adequate to supply the needs of trout and food producing organisms if flows could be maintained at levels which would provide needed space and wetted perimeter.

Inadequacies in our ability to predict the consequences of a particular flow in numbers of trout produced were discussed.

INTRODUCTION

With ever increasing demands being placed on our aquatic resources by society, it is important that we become competent in determining and defending the needs of aquatic organisms. These needs have been recognized by new laws which require that consideration be given to environmental quality; the laws are evidence that conservationists will no longer listen to the rhetoric or the lip service being given to environmental quality. They demand action, answers and factual data derived from the application of the scientific method of problem solving.

The 1973 Montana Water Use Act recognizes fish and wildlife as beneficial users of water, equal to other water users. In addition, it provides for the reservation of water in streams and lakes for the use of fish and wildlife. The monumental task of determining and defending water needs has become our single highest priority, in our attempt to provide fisheries for future generations to enjoy.

Excellent reviews of instream flow needs and methodologies used in determining aquatic needs have been published in recent years (Bishop and

Scott, 1972;[1/] Hooper, 1973;[2/] Giger, 1973;[3/] and Bovee, 1974[4/]). Our task now is to refine what is known about the needs of aquatic organisms, and then to bring about a peaceful marriage between the biological needs and water use demands.

The purpose of this report is to demonstrate the use of the Water Surface Profile Program as a technique to use in determining and defending requests for instream flows to insure the perpetuation of a wild trout fishery.

STUDY AREA

Sixteenmile Creek orginates in the Crazy Mountains northeast of Livingston, Montana and flows southwesterly through sagebrush-grassland hills and rugged limestone canyons to its confluence with the Missouri River east of Townsend, Montana (Figure 1). Its gradient was 28.8 feet per mile through the study area and during the summer its average width and depth were 32 and 1.25 feet, respectively.

For the purpose of reserving stream flows, three different reaches were identified based upon gradient, channel characteristics and habitat type. One of the three stream reaches, the Francis Section, was chosen for this presentation to illustrate the use of the Water Surface Profile. This technique was employed primarily because no historical records of stream flow existed.

METHODS

Forty-seven cross sections were surveyed in a 3,954 foot-long section of Sixteenmile Creek. The U.S. Bureau of Reclamation's Water Surface Profile (WSP) program was used to analyze the data. In the original computer analysis, each cross section was broken down into 2 or 3 segments. Later, 21 of the 47 cross sections were broken down into as many as 9 segments each, to more precisely define conditions at a given point along the transect line.

1/ Bishop, Robert A. and James W. Scott. 1972. Instream Flow Methodology Workshop Proceedings, State of Washington, Dept. of Ecology.

2/ Hooper, Douglas R. 1973. Evaluation of the effects of flows on trout stream ecology, Pacific Gas & Electric, Dept. of Engineering Research.

3/ Giger, Richard D. 1973. Streamflow requirements of salmonids, Oregon Wildlife Commission, AFS, 62-1.

4/ Bovee, Ken D. 1974. The determination, assessment and design of "In-Stream Value" studies for the Northern Great Plains Region, University of Montana, unpublished thesis.

The data presented in this paper were taken from these 21 cross sections.

The WSP program determined that 500 cfs was the maximum amount of water the channel could transport (i.e., bankfull flow). The amount of wetted perimeter (wp) and conveyance area (ca) at 500 cfs were considered maximum (100%) and the amount of wp and ca at all other flows were calculated as a percentage of the maximum. These percentages were plotted on the y axis with cfs on the x axis. The slope of each line was designated as the ratio of change in y with changes in x. Wetted perimeter was calculated from the WSP data by dividing conveyance area by hydraulic radii.

Stream flow was measured with a Gurley "double A" current meter on a hand-held wading rod using methods described by the U.S. Geological Survey (Carter & Davidian, 1968[5/]). Stream flow was measured at the head of the study section once each month in six different months during the 1975 and 1976 water years. The flow measurements were plotted by month to construct a hydrograph.

RESULTS

Water Surface Profile

The Water Surface Profile (WSP) was employed to fill the information gap and make possible an evaluation of various flows on paper. Conveyance area (ca), wetted perimeter (wp) and water velocity were parameters selected from the WSP data as being most important in trout production.

Conveyance area, the total water area in a cross section, represents the space available to fish in the channel. In Sixteenmile Creek, conveyance area changed at a ratio of 0.8 ca units to 5 cfs for flows ranging from 50 to 500 cfs (Figure 2). The rate of change in conveyance area was 1.2 ca to 5 cfs for flows from 25 to 50 cfs and 2.75 ca to 5 cfs for flows less than 25 cfs. Nearly 50% of the maximum conveyance area would be provided by 175 cfs flow but at 25 cfs only 23% of the maximum would remain (Figure 2). These data indicate an acceleration in the loss of space available to fish with reductions in flow and it also indicates that flows less than 175 cfs provide a major portion of the space available to trout.

5/ Carter, R.W. and Jacob Davidian, 1968. Techniques of water-resources investigations of the United States Geological Survey, Book 3, Chapter A6.

Wetted perimeter, the linear feet of channel sides and bottom along a transect line that are wet at a given flow, displayed a pattern similar to conveyance area. From 50 to 500 cfs, the ratio of change in wetted perimeter to flow was 0.6 wp units to 5 cfs and the ratio was 1.8 wp and 2.75 wp to 5 cfs for flows between 25 and 50 and less than 25 cfs, respectively. Fifty-five percent of the wetted perimeter would be provided by 100 cfs and 39% would remain at 25 cfs (Figure 2).

In reviewing these data, an accelerated loss occurred for both parameters between 25 and 50 cfs with a greater change occurring with flows less than 25 cfs.

Average water velocity in the main channel ranged from 4.65 ft/sec at 500 cfs to 0.51 ft/sec at 5 cfs. The extreme low, which occurred in a pool area was 0.25 ft/sec at 5 cfs and the high was 6.85 ft/sec at 500 cfs, in a riffle (Figure 3). The range of average and extreme water velocities at each of the various flows was a reflection of the relatively high gradient of 28.8 ft/mi through the study section. Water velocity would probably not become a limiting factor if flows were sufficient to maintain adequate space and wetted perimeter. This was substantiated by studies which indicate that velocities ranging from 1.0 to 3.0 ft/sec generally provide for the needs of trout and food producing organisms (Hooper, 1973;[6/] Giger, 1973[7/]).

Hydrograph

Timing and magnitude of seasonal flows probably have a strong influence on the success of the trout population in Sixteenmile Creek. The hydrograph was constructed as a guide to insure that requested flows would follow the natural seasonal patterns. In 1975, the lowest stream flow (25.3 cfs) was measured in February, during the time when the creek was at its base flow. The highest flow was estimated at 500 cfs in May, 1975.

The summer months are a potentially critical period of low flow. In 1975, summer flows proved to be adequate with 234 cfs measured in June, 175 and 60 cfs measured in July and August, respectively. Irrigation demands on Sixteenmile Creek did not appear to affect critically low flows; however, 1975 was a year of abundant water in most Montana watersheds.

Peak flows coincided with snow melt. The period of time with flows over

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6/ op. cit. 2/, page 2.
7/ op. cit. 3/, page 2.

200 cfs, an approximate mean flow, would be nearly three months. With flows over 200 cfs, average water velocities along the thalweg would exceed 3 ft/sec and the minimum velocity would exceed 1.5 ft/sec. The riffles would be subjected to velocities as high as 6 ft/sec (Figure 3).

SUMMARY AND DISCUSSION

Because there were no historical stream flow records for the Francis Section of Sixteenmile Creek, identification of instream flow needs was difficult. The WSP program and hydrograph has helped us identify a potentially critical range of low flows and the approximate duration of the low flows. Using WSP data, cross sectional drawings and the hydrograph, we can determine the flows necessary to meet the needs of the fishery and the intergravel environment during the seasons of intermediate and high flows. In order to realize the maximum benefit from this technique and the information it provides, we must be able to predict the consequences of a given flow in terms of the number of trout produced for the fishery. We do not understand the relationship between hydrology and biology well enough to answer the following questions. Will a low flow of 35 cfs produce more fish than 25 cfs? How many trout does each percent of wetted perimeter or conveyance area represent? How many acre feet of water must flow through the Francis Section during May and June to maintain a clear intergravel environment? We must be able to answer these questions before we can be confident that our reservations will be defendable and will provide the necessary flows to perpetuate our fisheries.

As demands for water increase, our task of defending instream flow needs will become more difficult. If our abilities in this area do not improve before the demand for water outside the stream requires the last possible drop, the consequence will be degradation or loss of sport fishing.

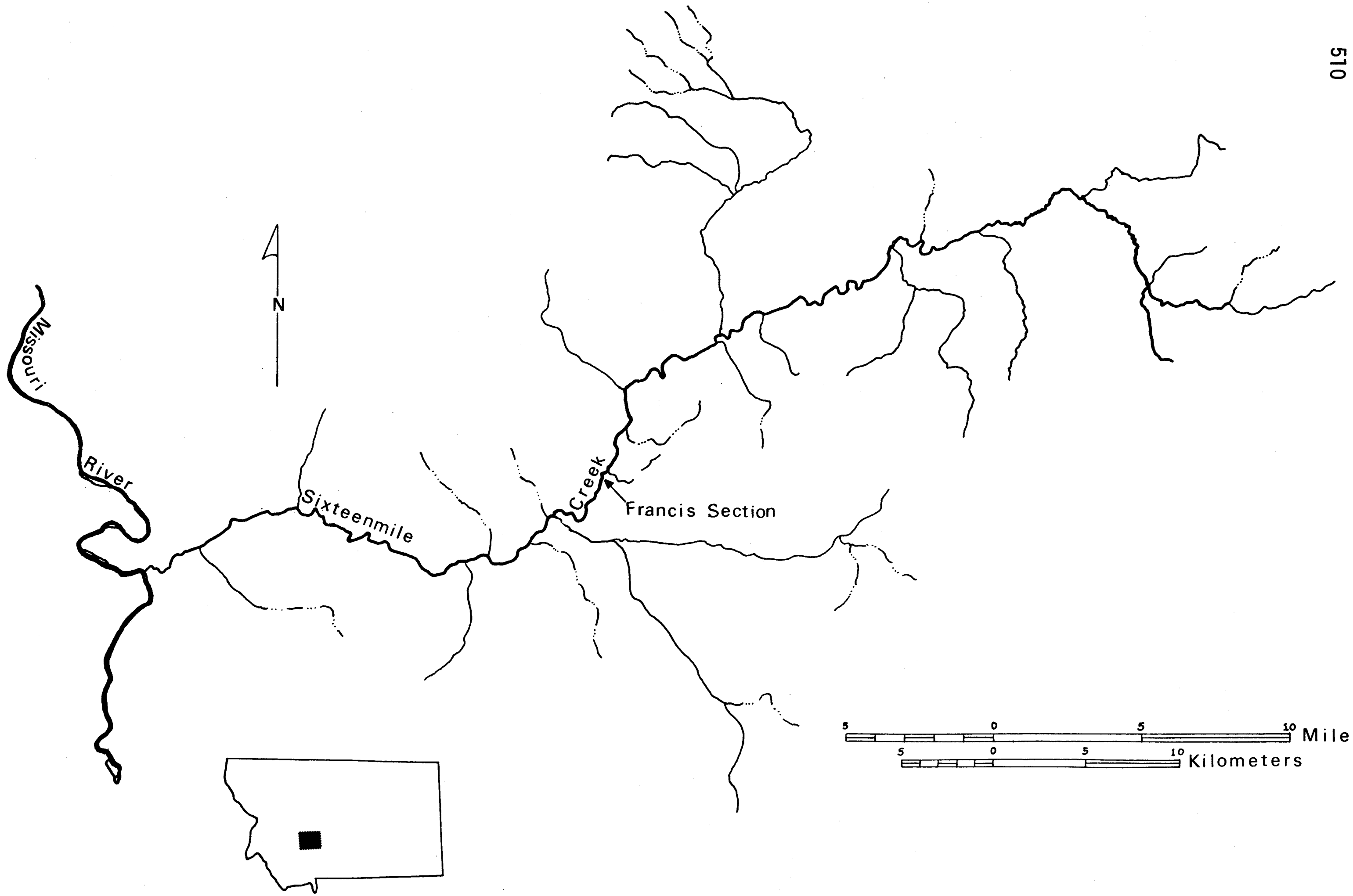

Fig. 1. Map of Sixteenmile Creek Showing the Francis Study Section

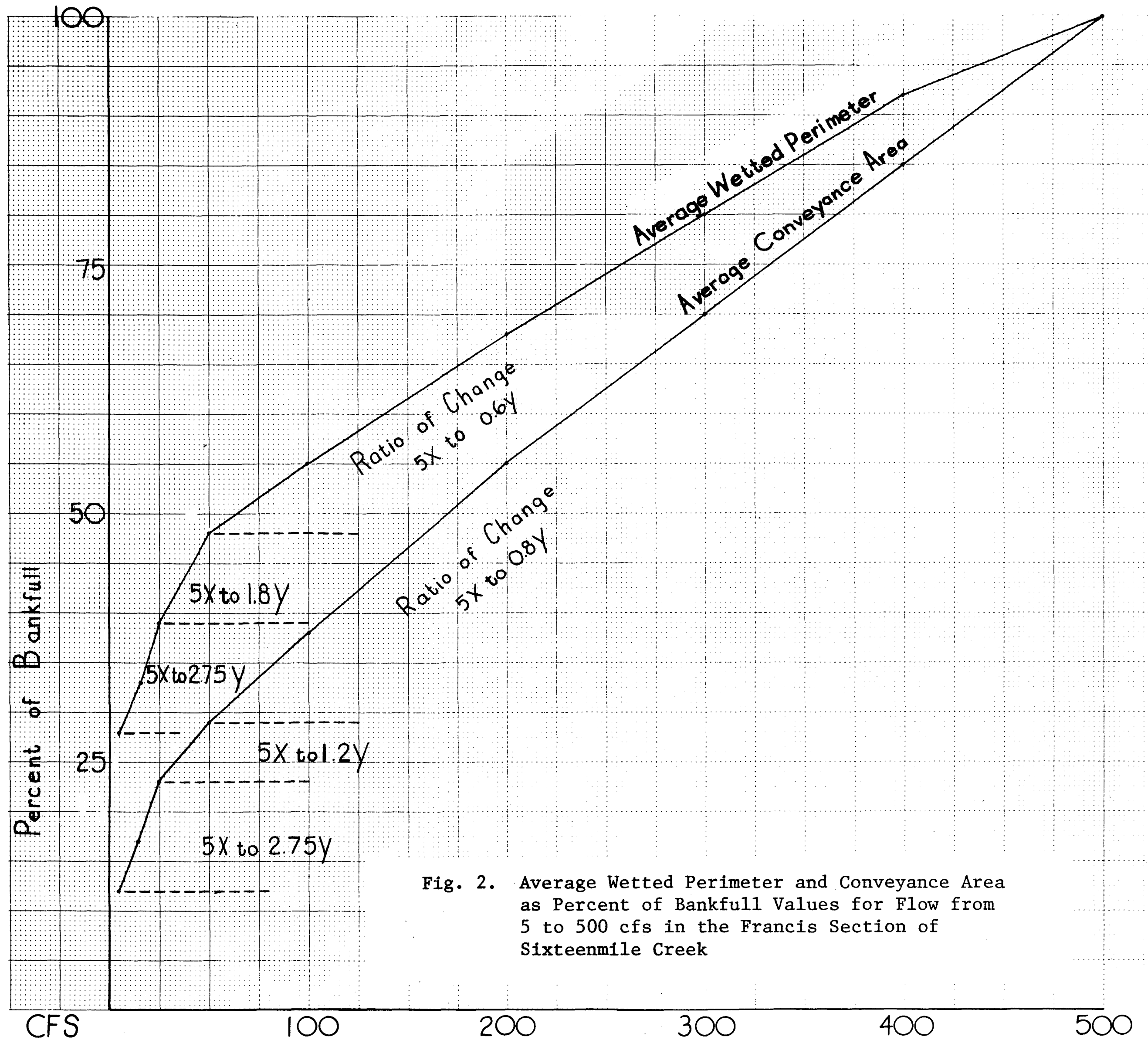

Fig. 2. Average Wetted Perimeter and Conveyance Area as Percent of Bankfull Values for Flow from 5 to 500 cfs in the Francis Section of Sixteenmile Creek

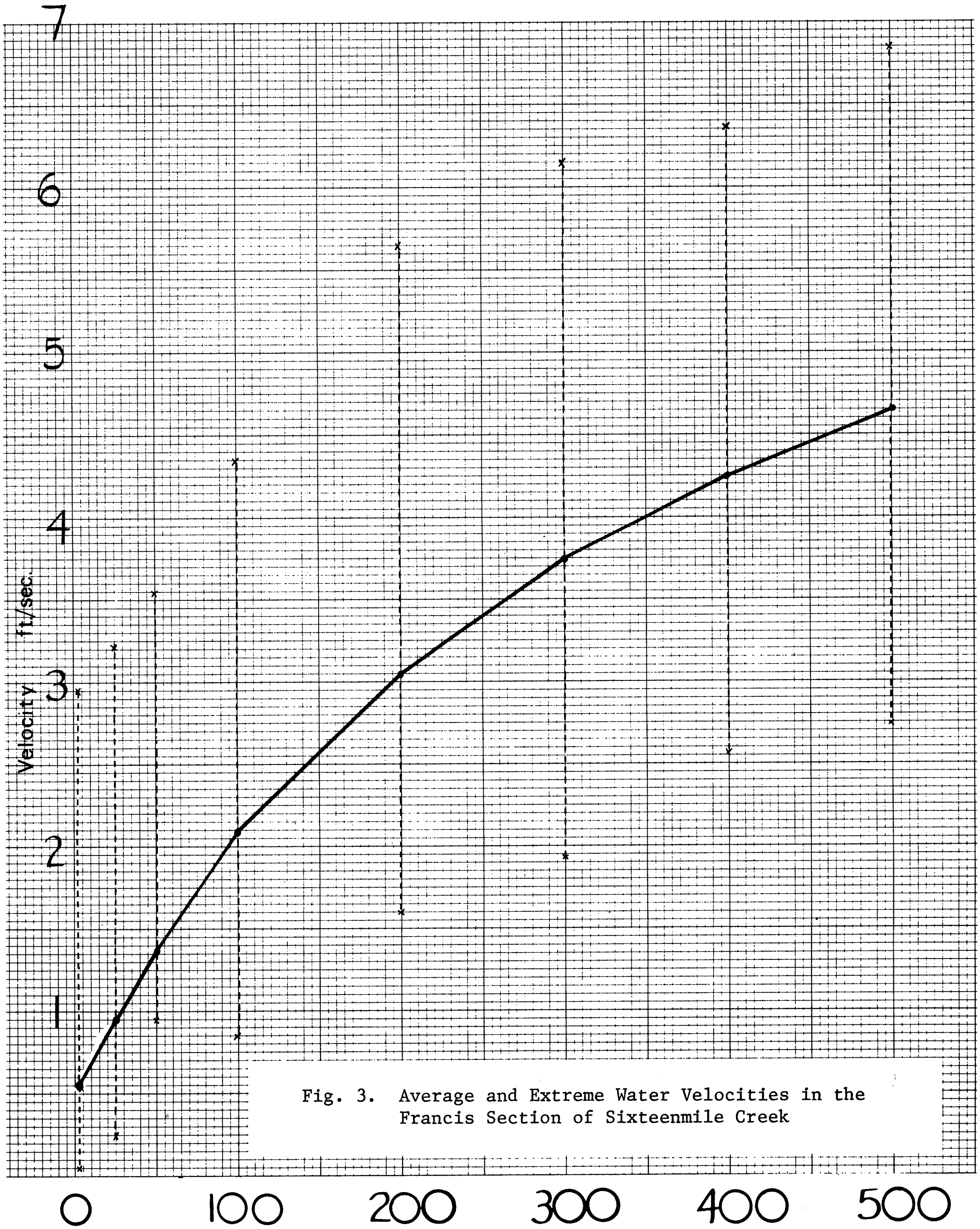

Fig. 3. Average and Extreme Water Velocities in the Francis Section of Sixteenmile Creek

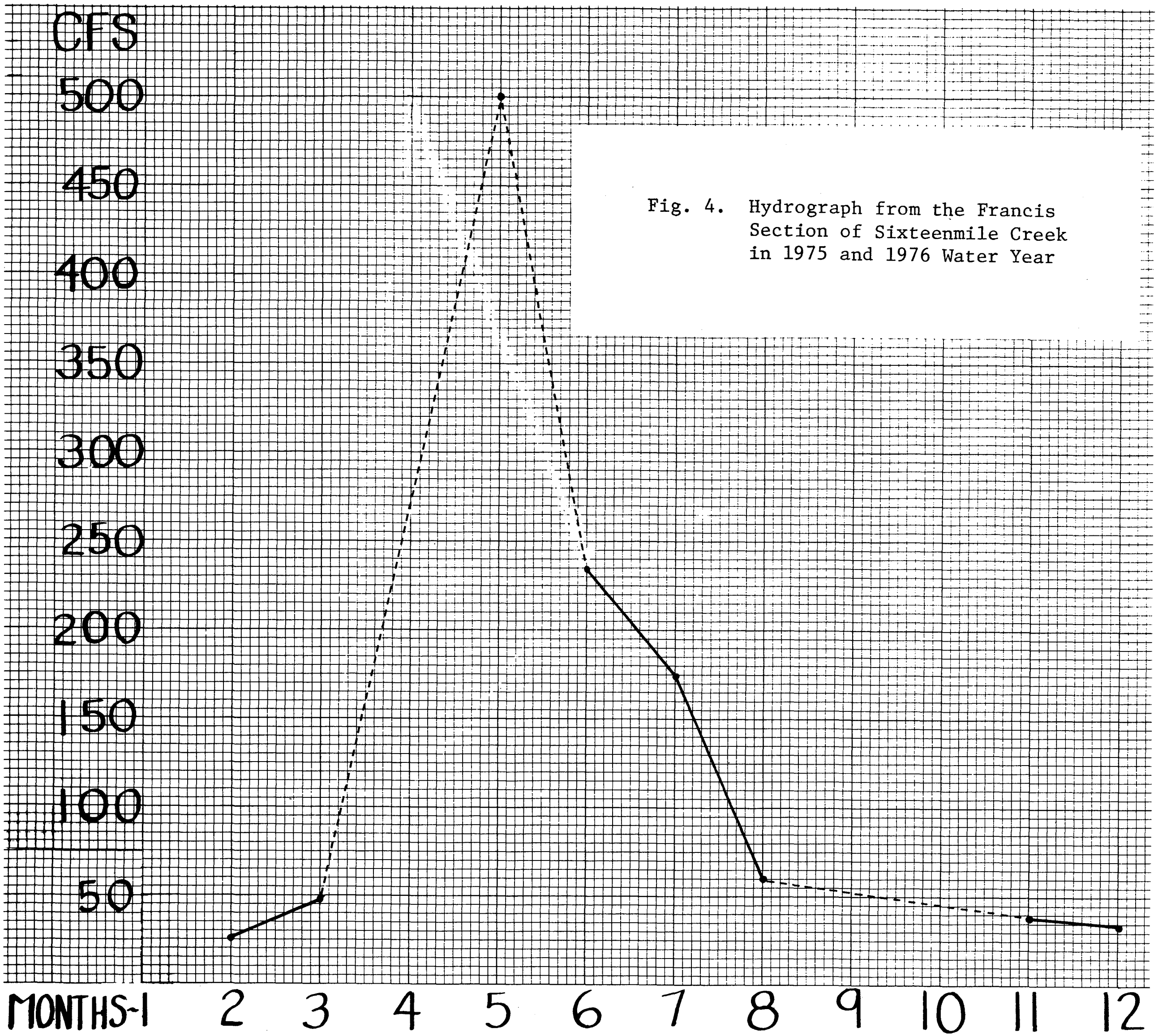

Fig. 4. Hydrograph from the Francis Section of Sixteenmile Creek in 1975 and 1976 Water Year

TOPIC V-F.

WSP PROGRAM FOR DETERMINING IFN

Summary Discussion

Discussion centered around data input and output from the WSP Program. It was asked whether velocities were predicted at a point on the transect. It was answered that velocities were average values, not point values. Currently it is believed that velocity is calculated as the average velocity occurring along a thread of flow between one transect and the next one upstream. However, upon further consideration, this may not be true and this point needs clarification.

Manning's roughness coefficient ("n" value) was discussed briefly. Manning's "n" has been a point of discussion for some time among hydrologists. The question here concerned the adequacy of the WSP Program in arriving at a proper "n" value. In the WSP Program, "n" is initially estimated from a description of bottom types and photos of the cross sections provided by the investigator. Then the "n" value is adjusted, if necessary, until the predicted water surface elevations match the observed elevations at the measured flow. If simply adjusting the "n" values does not calibrate the program, the Bureau will introduce additional cross sections in the case the calibration problem is due to a missed flow control point. However, if too much adjustment in "n" is required to match the elevations, or the problem cannot be corrected by cross-sectional adjustment, the field data is assumed to be in error and the program is not run. The data is returned to the investigator for corrective measures.

There was general agreement among those present that the Bureau of Reclamation's WSP Program properly utilizes "n" within current capabilities, and realization that the "n" value is not always precise.

There was also some discussion of how WSP accounts for changes in "n" in the calculation of the predicted flows, i.e., those flows above or below the measured flow used to determine "n". The answer was that WSP predicts flows without regard to changes which may occur in "n". Although it was realized that this is a fault of the program, it is not practical to correct due to lack of knowledge about expected changes in the "n" value in the streams under study. Research would have to be done on each stream studied to determine changes in "n" at different flows, and this would negate the utility of the WSP Program.

One person questioned the use of less than nine segments in a transect. It was pointed out that the Bureau of Reclamation in Billings frequently runs the program with as little as three segments per transect, although it can be run with as many as nine segments if desired. The current program could be modified to include a greater number.

Notes by panel moderator: Liter E. Spence, Montant Dept. of Fish and Game, Helena, MT

MATHEMATICAL MODELING OF SEDIMENT TRANSPORT AS A METHODOLOGY FOR DETERMINING INSTREAM FLOW REQUIREMENTS

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ABSTRACT

Although sediment transport in rivers has historically been considered a physical problem it also plays an important role in the chemical and biological interactions of aquatic systems. For example, during construction of the dam forming Electric Lake on Huntington Creek in Utah, a large amount of fine sediment was deposited in the streambed downstream. Huntington Creek is a prime trout fishery and sediment acculumation in the microhabitat of the stream apparently has eliminated some of the potential for secondary productivity. Attempts to flush the fines have not been successful because they are entrapped among the boulders and cobbles or matted in biological film.

A mathematical model is described which can be used to predict the sediment transport capabilities of a stream. Models of this type could assist in a management practice to limit the supply rate of particles within the transport capabilities of the stream during construction rather than to attempt to flush the particles at a later time. Also, models can be used to estimate the minimum flows required to transport the accretion load after the reservoir is in operation.

INTRODUCTION

Sediment Transport and Stream Ecosystems

Sediment transport has historically been considered as a physical problem for rivers and reservoirs; either because of deposition and shoaling or because of undesired erosion. Sediments also play an important role in the chemical and biological interactions of aquatic systems. Sediments act as sorption sites for biologically and chemically important molecules so that the rates of reactions may be affected by the amount, size, and location of sediment in the stream. By reducing light transmission sediments can reduce primary productivity. Also they reduce insect and fish habitat by filling crevices and holes, reducing surface area as well as reducing habitat having low stream velocity. Therefore, the feeding and propagation of fish may be disrupted by changes in sediment transport patterns. Sludge banks downstream from wastewater treatment plant outfalls act as long term habitat and biochemical substrate for bacteria and fungi. This reduces oxygen levels in the streams and alters benthic community composition to become dominated by microaerophilic detritivores resulting in fishery changes.

<u>Effects of Reduced Flow on Sediment Transport</u>

Construction of dams or other flow altering structures to guarantee flow for power projects, irrigation flows, flood control, municipal and industrial water supply and other water uses has at least two major impacts on sediment transport in streams: 1) sediment generated by the dam construction during low flow conditions when especially fine sediments (fines) are usually desposited in the streambed and may or may not become "cemented" between rocks, in pools, and other relatively quiescent areas; these sediments are extremely difficult to dislodge and become a permanent part of the stream ecosystem, especially because of the lower peak stream flows which occur after the flow is controlled; 2) transport of sediments input to the stream from lesser order uncontrolled streams entering the main channel downstream of the dam (accretion flows) may not be feasible because lower peak stream flows occur under conditions of controlled flow. These two impacts suggest several key issues which need to be addressed <u>prior</u> to construction and also suggest several possible approaches for ameliorating some of the effects of the sediment transport impacts. In this paper we illustrate the impacts and feasible solutions by considering the sediment transport problems which occurred as a result of the construction of the Utah Power and Light dam on the Right Fork of Huntington Creek forming Electric Lake for the Huntington Power Plant in Emery County, Utah (Figure 1).

Huntington Creek is a prime trout fishery in Utah and sediment accumulation in the microhabitat of the stream apparently has eliminated some of the potential for secondary productivity. Cementing of fines deposited in Huntington Creek is enhanced by rapid growth of algae on the deposited sediments. These algae bind the small particles together to make larger particles effectively increasing the critical velocity necessary to suspend them. Also dislodging of smaller sediment particles requires flows sufficient to disturb cobble and boulders so that the critical velocity can actually be achieved in the vicinity of the deposited sediments. This flow level usually requires impractical if not impossible releases from the storage reservoir.

Mathematical modeling techniques can be used to estimate the stream carrying capacity for sediments, and help to answer the questions: 1) How much sediment can be produced during dam construction and still minimize input and enlodging of fine sediments within the stream ecosystem? 2) For a given sediment loading rate due to accretion, what minimum flows should be maintained in the channel to prevent additional sedimentation?

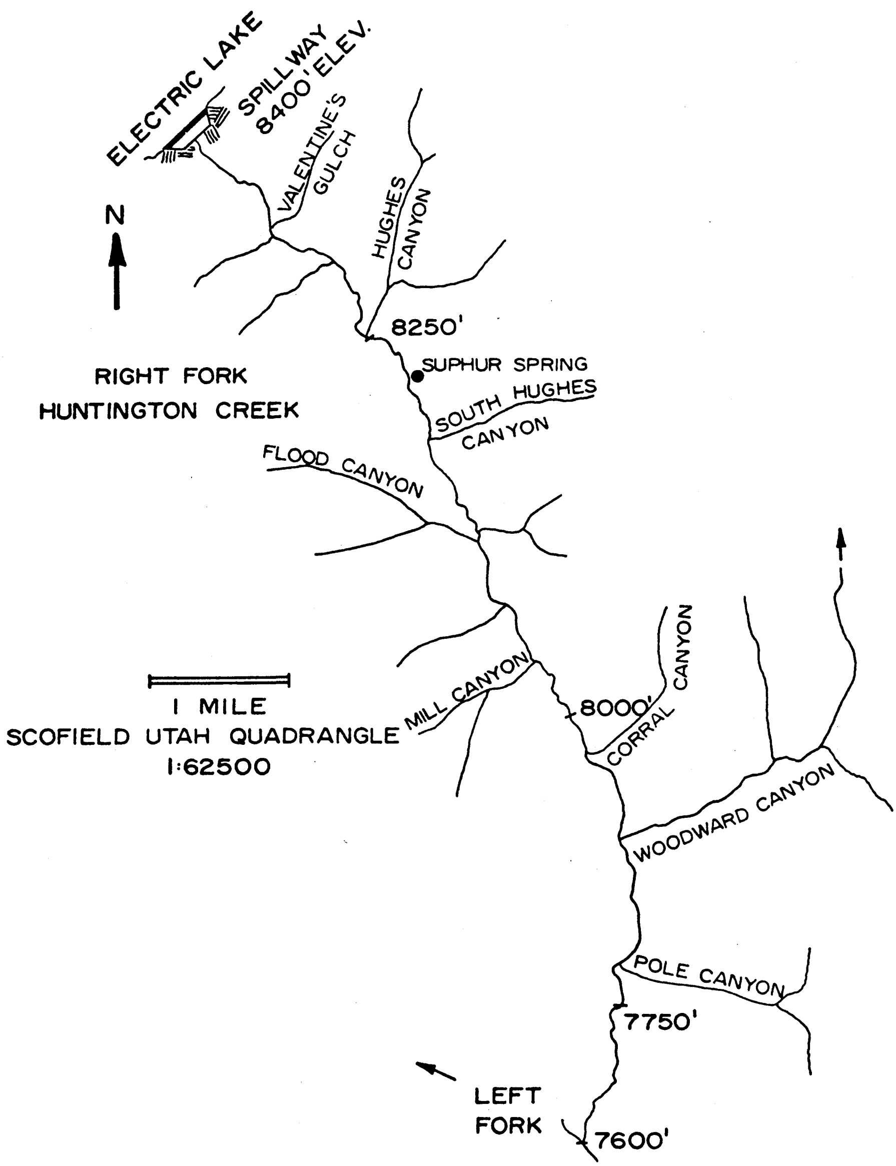

Fig. 1. Right Fork Huntington Creek

MODEL CONCEPTS

Suspended sediment loads may be classified in two ways: 1) the mode of transport and 2) the source from which they are derived. The classical definitions are shown in Figure 2 (a). Sediment particles are transported in the stream channel by one or more of the following mechanisms: 1) Suspension (suspended and supported by the surrounding fluid during its entire motion); 2) saltation (leaping into the flow and then resting on the bed); and 3) surface creep (rolling or sliding on the bed). Sediments moving as surface creep and saltation are supported by the river bed and therefore are referred to as "bed load." The sediments traveling in suspension are supported by flow and are referred to as "suspended load." The summation of the bed load and the suspended load is referred to as "total sediment load." Unfortunately there is no clear division among sediments traveling as bed load and suspended load in real rivers. During a specified time in a river reach a particular particle can move in suspension for awhile, along the bed of the river for another period, and not at all for the remaining time. However the definitions are useful for delimiting the two types of hydraulic mechanisms transporting the material.

The particles (both bed and suspended load) derived from erosion of the channel bed material make up the "bed material load." The part of the suspended load which consists of grain sizes finer than the bulk of the bed material is referred to as the "washload." The washload rate can be related to the available supply of solid particles within the watershed; it enters the watercourse by sheet wash, bank caving, etc. Because of its small size fractions, it moves readily in suspension and is merely washed through the channel. The sum of bed material load and washload equals the total sediment load.

The solid line in Figure 3 shows the relationship between stream transport capabilities (p) and sediment size (d) for a given stream flow in a particular river (Shen, 1971). The broken line represents the rate of supply (s) of various sediment sizes from the upslope area for the same river discharge. Let d* represent the grain size at the intersection of the two lines. For sediment sizes greater than d* the available supply rate is greater than the river can carry and, therefore, only a portion of these particle sizes will be transported. The remainder will be deposited in the upstream reaches. For sediment sizes less than d* the supply rate (s) is less than the river transport capability (p) and the actual amount of sediment transported is limited by the rate of upslope supply.

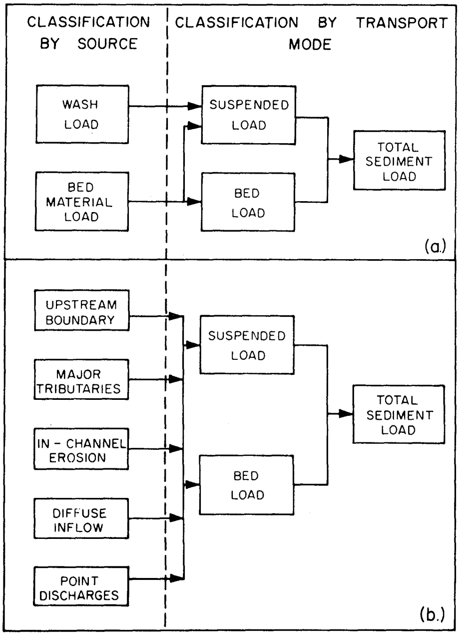

Fig. 2. Classification of Sediment by Source and Transport Mode

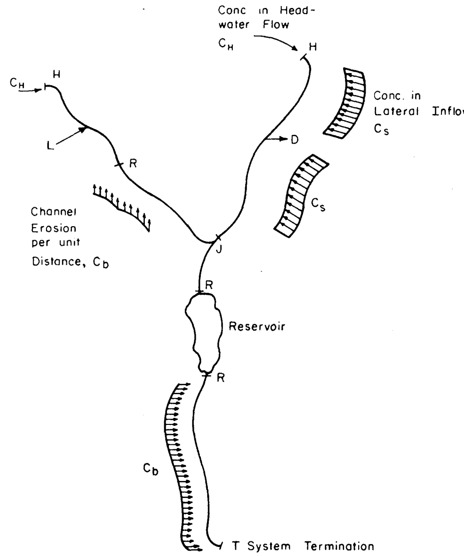

Fig. 4. System Structure and Boundary Conditions for the Mathematical Model

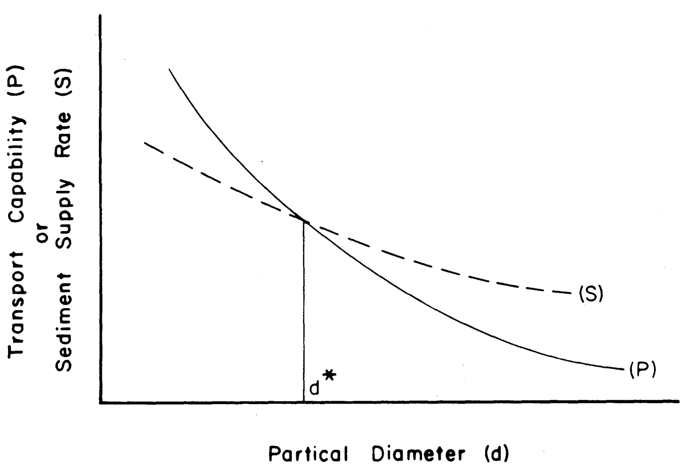

Fig. 3. Stream Transport Capacity (Solid Line) and Watershed Supply Rate (Dashed Line) Versus Sediment Size for a Given Flow Condition

A decreasing flow in the stream represented in Figure 3 would result in a general downward shift in the transport capability curve and increased deposition would occur. An increasing flow would shift the capability curve upward resulting in greater sediment transport. The wide fluctuations in natural streamflow result in alternate periods of deposition and flushing. The phenomena represented by the two curves in Figure 3 are not independent. Usually periods of high transport capabilities are associated with high supply rates and vice versa.

The model is structured to analyze a river system, beginning at the headwaters and proceeding downstream, reach by reach. Both the rate of sediment supply (s in Figure 3) and the transport capability (p in Figure 3) of the river are evaluated in each reach. Figure 2 (b) shows the classifications used in the model for the sources of supply and the transport modes. Sources of sediment supply to a reach include: 1) transport from the adjacent upstream reach (upstream boundary), 2) major tributaries entering the reach, 3) in-channel erosion, 4) diffuse inflow, and 5) point discharges (for example, wastewater treatment plants). Modes of transport (the river transport capability) include suspended load and bed load.

Sources of Supply and Stream Transport Capabilities

An example of a typical system layout is shown in Figure 4. There are two headwaters (H), one point load (L), one diversion (D), one junction (J), and six reaches delimited by the symbol "R". One of the reaches represents a small, unstratified reservoir. Steady, non-uniform flow in the system is the net accumulation of the flows from the headwaters (Q_H), the point loads (Q_L) diffuse surface flow (Q_S), diffuse groundwater flow (Q_G), point diversions (Q_D) and evaporation from the reservoir (Q_e). Each flow has a sediment load associated with it. Each of these sediment loads consist of the mass concentrations of fifteen distinct ranges of particle sizes. The concentrations associated with the boundary flows described above are C_H^i, C_L^i, C_S^i, and C_L^i respectively (the superscript "i" indicates particle size range). The concentration in a diversion (C_D^i) is equal to that of the river at the point of diversion. Groundwater does not carry sediment. Lateral surface flow for a reach may be either into or out of the river; when modeled as an outflow it carries the concentrations of the river.

A review of the literature (Mandavia, 1976) indicated several techniques available for estimating the stream transport capabilities. The model was structured so that any one of the techniques could be used with a minimum of reprogramming. For this application, the equations developed by Yang (1972, 1973) were used. These equations relate sediment transport capability to stream power: the product of velocity and slope. Coefficients in the equations have been estimated by statistical regression on a large number of data and represent a more or less general case. Techniques are available to adjust these coefficients in accordance with observed data for a specific application.

Model Procedure

The particle size distribution of the total sediment load is represented in the model by fifteen distinct classes. Calculations are performed independently for each of the classes and results are summed to obtain the total sediment concentration.

Each stream reach is subdivided into elements such that an element ends at each point where model output is desired. Commencing at one of the headwaters, the model evaluates conditions in the first element. A mass balance is conducted on the boundary flows (Q_H, Q_L, S_S, Q_G, Q_D, Q_e) and the associated concentrations (C^i_H, C^i_L, C^i_S) to obtain total flow and total sediment mass (in each size class) available for transport at the end of the element. An input parameter (C_B) is also available to represent sediment contributions from channel erosion in the element. The stream transport capability for each size class is then calculated at the end of the element based on the existing hydraulic properties. If the transport capability is greater than the rate of supply, all of the available sediment is transported through the element. If the rate of supply is greater than the transport capability, deposition occurs in the element.

The flow and sediment leaving an element becomes the upstream boundary conditions for the next downstream element. When a junction is encountered, the model jumps to the tributary headwater, proceeds downstream to the confluence, conducts a mass balance, and continues down the main channel.

RESULTS AND DISCUSSION

The model was applied to Huntington Creek between Electric Lake and the confluence with the Left Fork in order to estimate the carrying capacity of the stream under various flow regimes. Data on the physical characteristics of the channel were obtained from transects (McLaughlin, 1975) and relationships for flow, velocity, and hydraulic radii were developed as shown in Figure 5. Data were available only for flows up to 24 cfs, so model responses for flow greater

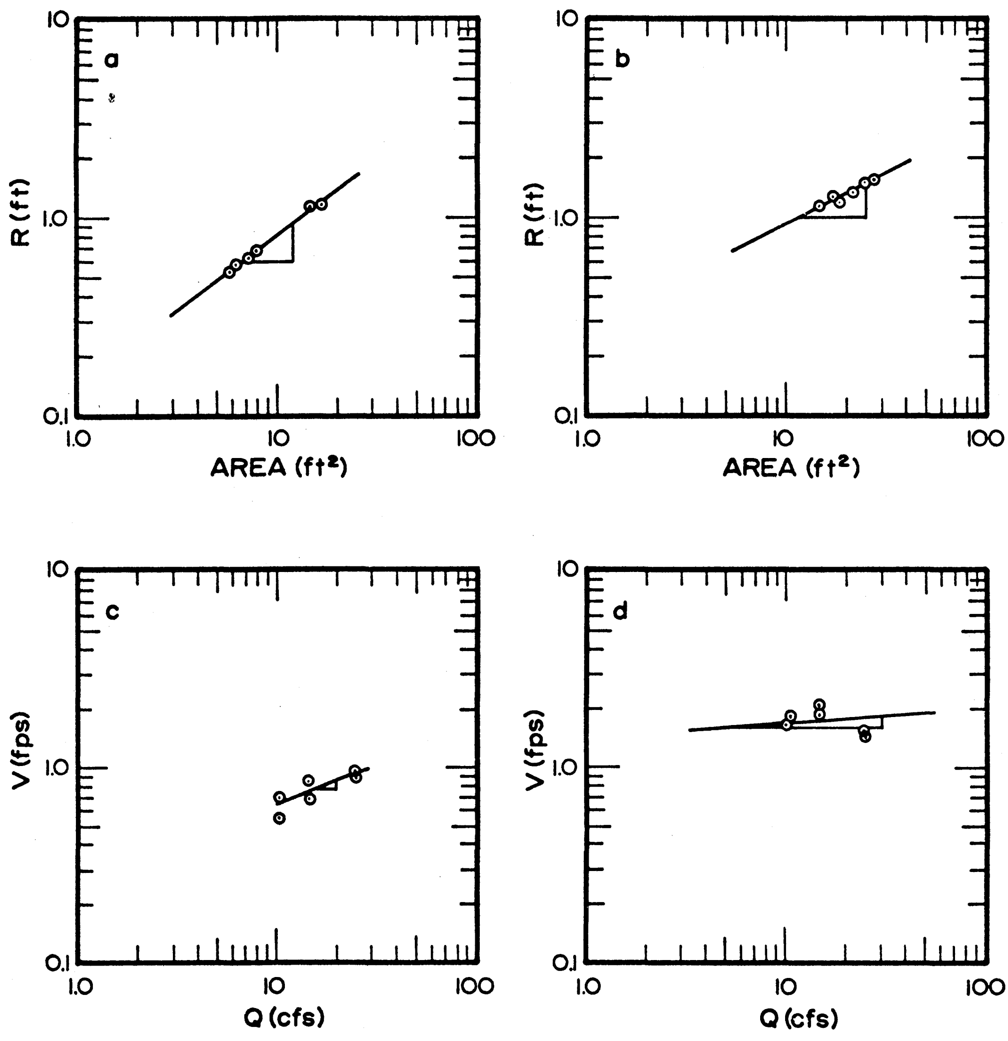

Fig. 5. Channel Characteristics for the Upper Reach (a) and (c) and the Lower Reach (b) and (d)

than this are based on the extension of these functions. The characteristics of the stream are such that velocity increases slowly with increasing flow. Average stream slopes were obtained from topographical maps with the upper and lower reaches of the section having average slopes of 0.010 and 0.013 respectively.

Figure 6 shows the relationship between theoretical transport capacity and stream velocity for two particle sizes according to the model using Yang's (1973) equations. The values shown are for the upper reach. The size of a particle has a significant effect on the ability of the stream to transport it. It is important, therefore, that data on size distribution of the sediment load be obtained as well as data on total sediment load. Good data are available on size distribution of the bed material in Huntington Creek (Winget, 1975) which ranges from about 15 to 35 percent fines (<0.841 mm) depending on the location. However, data are lacking for the accretion load.

In Figure 6 concentrations increase very rapidly up to velocities of about one fps and then additional increases in velocity result in only minor increases. The model predicts that even for velocities in excess of 1 fps the maximum concentrations of 0.062 mm and 0.25 mm particles which could be achieved are 800 and 40 mg/l respectively. Although velocity is the most important parameter, the concentration is also affected by stream depth. In general, for each particle size at a given velocity, there is some optimum depth that will produce a maximum concentration.

The solid lines in Figure 7 represent the theoretical stream carrying capacity for 4 particle sizes in the upper reach as a function of flow. Because velocities increase slowly with flow (Figure 5) and concentration varies with depth, the predicted concentrations for the reach do not attain the maximum potential indicated in Figure 6.

The general monotonically decreasing relationship between particle size and transport capability (p) is measured as number of particles transported. Since the mass of a spherical particle increases as the cube of its diameter, it is quite possible for larger particles, though fewer in number, to have a higher mass concentration than smaller particles. For example, Figure 7 indicates that the mass transport capability of the stream is greater for 1 mm particles than for either 0.062 mm or 0.25 mm. The number of 0.062 mm and 0.25 mm particles at a flow of 25 cfs are two thousand and ten times greater respectively than the number of 1.0 mm particles.

Several model runs were made at a stream slope of 0.005 in order to demonstrate the effect of slope on transport capacity. The results of these runs

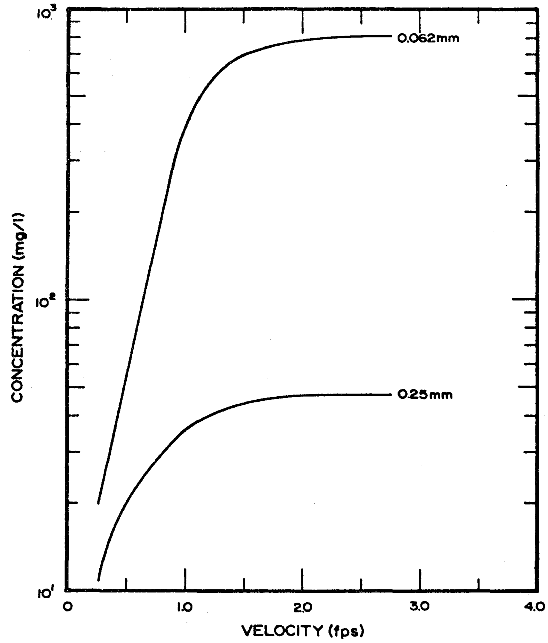

Fig. 6. Relationship Between Sediment Concentration and Particle Size

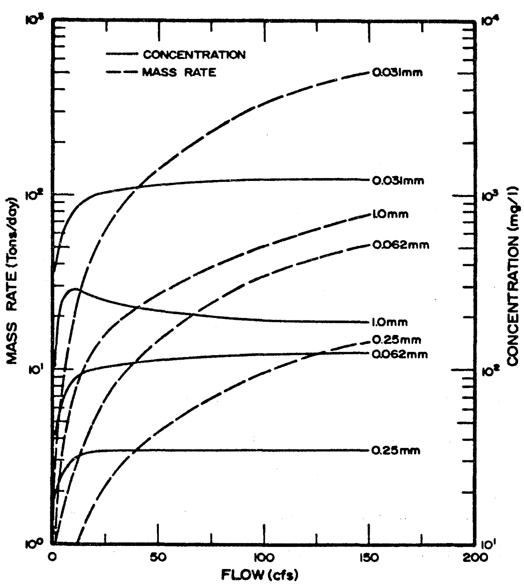

Fig. 7. Concentration (Solid Line) and Mass Transport Rate (Dashed Line) as a Function of Flow in the Upper Reach (Slope = 0.010)

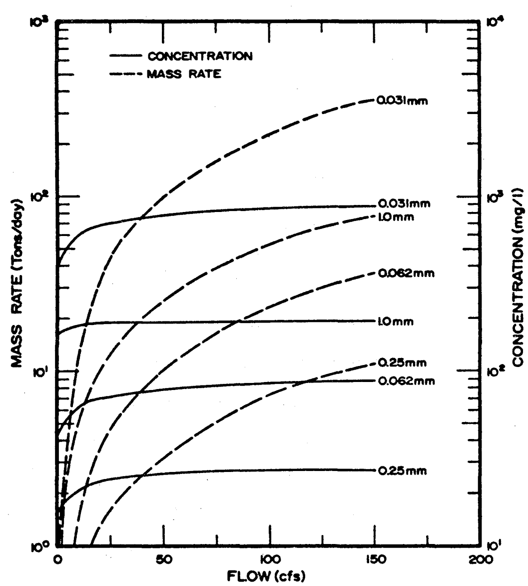

Fig. 8. Concentration (Solid Line) and Mass Transport Rate (Dashed Line) as a Function of Flow for a Channel Slope of 0.005

are shown in Figure 8. Figures 7 and 8 at the same flow rate, concentrations (solid lines) are about 40% higher at the steeper slope. Since the natural stream is made up of short segiments having steeper or more gradual slopes than the mean value measured from a topographical map, it can be expected that significant variations in transport capability will occur throughout what might first appear to be a more or less uniform reach of stream. The mathematical model is well adapted for analysing the effects of gradient variations on sediment transport.

The dash lines in Figures 7 and 8 represent the mass transport in Figures 7 and 8 represent the mass transport rate (the product of flow and concentration) in tons per day. The fact that sufficient transport capacity exists in the stream does not insure that particles in the bed material will be transported. They may be entrapped in the relatively tranquil voids among cobbles and boulders or matted in biological film. This situation apparently exists in Huntington Creek as evidenced by direct examination, field measurements (Winget, 1975), and by observing the release and subsequent transport of fines when the streambed is disturbed. The estimation of flows required to agitate the large bottom sediments sufficiently to flush the fines is beyond the range of reliable estimating techniques. An attempt is made to maintain a nominal flow of 10 to 15 cfs in the stream. Except in the case of storms which cause accretion, the total sediment load in the stream is in the neighborhood of 10 to 100 mg/l. In July of 1974 and again in July of 1975 flows in the range of 70 to 100 cfs were released in an attempt to dislodge the fines from the streambed. These high flows resulted in concentrations (estimated from turbidity measurements) reaching 10,000 mg/l or more for a short period of time (4 to 6 hours) and then tailing off into the hundreds after a day or so even with the continued high flow.

The model responses shown in Figures 6 through 8 are based on average model coefficients obtained from statistical regression of a large amount of data. More accurate model responses could be obtained if data were available for the particle size distribution of the sediment load in Huntington Creek. Such responses could have been used to estimate the permissable sediment loading to the stream during construction and, hence, the extent of preventive measures necessary to avoid choking the stream. A determination of particle size distributions in the accretion load and an estimate of the supply rate could be integrated into the model to predict the minimum flows necessary to maintain the status quo.

CONCLUSIONS

During the construction of the Electric Lake Dam fine sediments (less than 0.841 mm) were deposited in the bed of Huntington Creek downstream from the site. Now, even when the stream carrying capacity exists these particles are not available for transport because they are entrapped in the relatively tranquil voids among cobbles and boulders or in biological film. Once a particle is deposited on the bottom it may become very difficult to dislodge during future events. It would be a much more effective management practice to limit the supply rate of particles within the transport capabilities of the stream during construction rather than attempt to flush the particles at a later time. Mathematical models can provide estimates of the stream carrying capacity at various flow regimes to assist in assessing permissable loadings. Also, they can be used to estimate the minimum flows required to transport the accretion load after the reservoir is in operation. Because the transport capacity of the stream is closely related to the particle size, the size distribution of the sediment load is an important data requirement for this analysis.

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STREAM TEMPERATURE MODELING

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and Inge Dirmhirn[2]

ABSTRACT

Water temperature is an important quality parameter for the assessment of flow needs required to maintain certain aquatic habitats. A review of state-of-the-art mathematical models indicated a need for research and development concerning heat transfer mechanisms at the streambed. A field study was conducted on Spawn Creek, a small mountain stream near Logan, Utah.

Temperature probes were implanted in the gravel streambed and temperature variations were recorded. Meteorological, water temperature, and flow data were also recorded. A mathematical model was developed and verified which includes the traditional heat transfer processes plus a new component for streambed conduction and is capable of modeling unsteady flow conditions.

INTRODUCTION

Water temperature is an important quality parameter for the assessment of flow needs required to maintain certain aquatic habitats (McKee and Wolf, 1963). The field of water quality management and environmental protection is becoming more dependent on the use of valid and reliable predictive techniques in the form of mathematical models. A valid and reliable model of a natural physical phenomenon must be based upon an understanding of the basic processes involved.

Streamwater temperature is effected by heat transfer: 1) across stream boundaries by influent waters of different temperatures, 2) across the water surface, 3) with the streambed, and 4) by the hydraulic transport of the streamflow. Water entering the stream as point or diffuse loads will tend to warm or cool the receiving water in direct proportion to the relative temperatures and flows. The components of heat transfer across the surface and streambed are shown in Figure 1. Net radiation, ϕ_R, refers to the light energy penetrating the water surface. In clear shallow streams a portion of the energy reaches and is absorbed by the streambed. Long wave radiation, ϕ_B, is radiated from the water surface back to the atmosphere.

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Evaporation and convection are usually considered as a single process, ϕ_E, which is responsive to wind velocity, relative humidity, and temperature. Surface conduction, ϕ_H, refers to the transfer of heat across the water surface because of the temperature difference between the air and water, with the heat flux always flowing in the direction of the cooler temperature. Groundwater inflow may be a predominant heat transfer mechanism at the streambed. Cooler groundwater will, of course, have a tendency to cool (dilute the temperature) the stream. The thermal conduction of heat between the streamwater and the streambed material may also have an important effect on water temperature.

Hydraulic transport by flowing water in the stream channel is most frequently represented by the one-dimensional mass transport equation:

$$\frac{\partial AT}{dt} = - \frac{\partial(UAT)}{\partial X} + \frac{\partial}{\partial X}\left[AD_{\ell}\frac{\partial T}{\partial X}\right] + S \quad . \quad . \quad . \quad . \quad . \quad (1)$$

in which T is temperature, t is time, X is distance along the channel, A is average cross-sectional area. U is the mean stream velocity, and D_{ℓ} is the longitudinal dispersion coefficient. The first term on the right-hand side of Equation (1) accounts for advection in the channel. The second term (dispersion) represents spreading along the channel due to longitudinal mixing. The third term, S, represents the source-sink terms which link the heat transfer processes shown in Figure 1 to the hydraulic transport process.

A review of state-of-the-art temperature model was conducted (Comer, 1976) to determine the most current techniques being applied to model the heat transfer processes. Table 1 includes a summary of these techniques (definitions of symbols are included in Appendix A). The review indicated that additional research and development was needed to adequately describe the streambed conduction phenomenon and to provide a model which was capable of representing unsteady flow conditions. This study resulted in a mathematical model (Dynamic Stream Temperature Model; DSTEMP) which includes the traditional heat transfer processes plus a new component for streambed conduction and is capable of modeling unsteady flow conditions (Bowles, Comer, and Grenney, 1975).

MODEL APPLICATION TO SPAWN CREEK, UTAH

Watershed Description

Spawn Creek is a tributary to the Logan River and is located approximately 25 km northeast of Logan, Utah, in the Wasatch National Forest. The

Spawn Creek Watershed (Figure 2) has an approximate area of 15 square km. Data stations were located at three points in the system where continuous records of discharge and water temperature were obtained using calibrated hydraulic flumes and recording thermometers. Temperature probes were implanted in the gravel streambed near the lower end of the watershed to record temperatures at depths of 3 cm, 16 cm, 40 cm, and 100 cm (Comer, 1976). Meteorological data including global radiation, wind velocity, air temperature, and relative humidity were also recorded continuously. Spawn Creek, fed by a spring at its headwater and groundwater, contributes significantly to the total flow throughout the study reach. The creek has an average discharge of 15 m^3/min, average width of about 2.5 m, and an average depth of 20 cm.

Results

Figure 3 is a plot of the temperatures at various depths in the streambed for a 24-hour period in May, 1975. The temperature at the 3 cm depth closely follows the water temperature and that at 100 cm depth is nearly constant. Temperature variations at the intermediate depths are damped in magnitude and exhibit a noticeable time lag. When the water temperature is cooler than the streambed, net heat conduction must be from the bed into the water.

Figure 4 shows the variations in other important parameters during the same period of time in May including global radiation, wind velocity, and air temperature. The center plot in Figure 4 compares the total net heat exchange across the water surface with that across the streambed as calculated from the temperature profiles. Surface exchange is into the water (positive in Figure 4) during the day when the sun is up, and out of the water (negative) at night when the air temperature is cooler than the water. The bed exchange is into the water when the streambed is warmer than the water. The heat flux in bed conduction is of the same order of magnitude as the flux at the surface and, therefore, represents a significant process effecting stream temperature.

Figure 5 shows the DSTEMP model response (dash) compared with the observed streamwater temperature data (solid) at the downstream point in the watershed. The model was run using the meteorological parameters shown in Figure 4 and provides a good simulation of the observed data. The model was also applied for periods in August, September, October, November, April, and May with similar results.

CONCLUSIONS

Heat transfer processes in the streambed of Spawn Creek were observed to exchange significant amounts of heat with the stream. The streambed was observed to act as a heat sink during the daylight periods and a heat source during the night when stored heat was conducted into the stream. The mathematical model (DSTEMP) developed during the study was capable of adequately simulating water temperature fluctuations caused by variations in meteorological parameters.

ACKNOWLEDGMENTS

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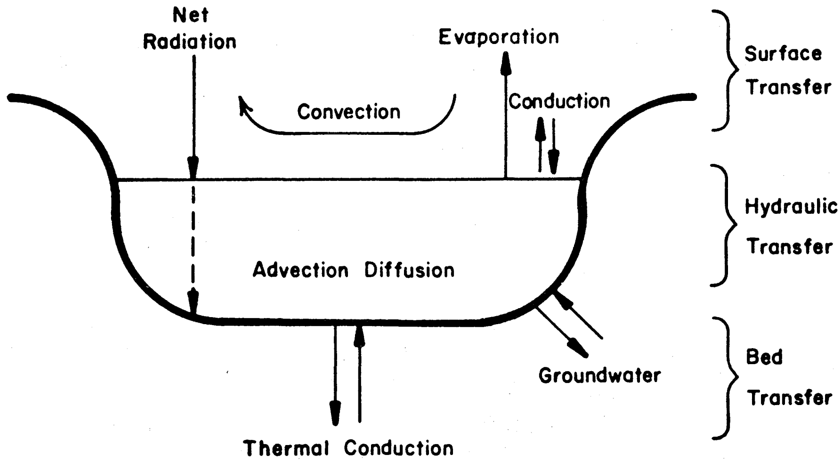

Fig. 1. Components of Heat Transfer on a Flowing Stream

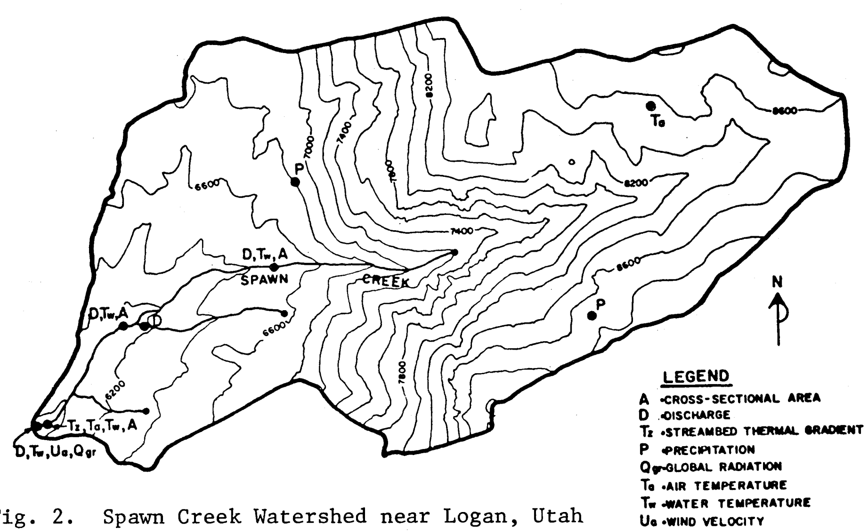

Fig. 2. Spawn Creek Watershed near Logan, Utah

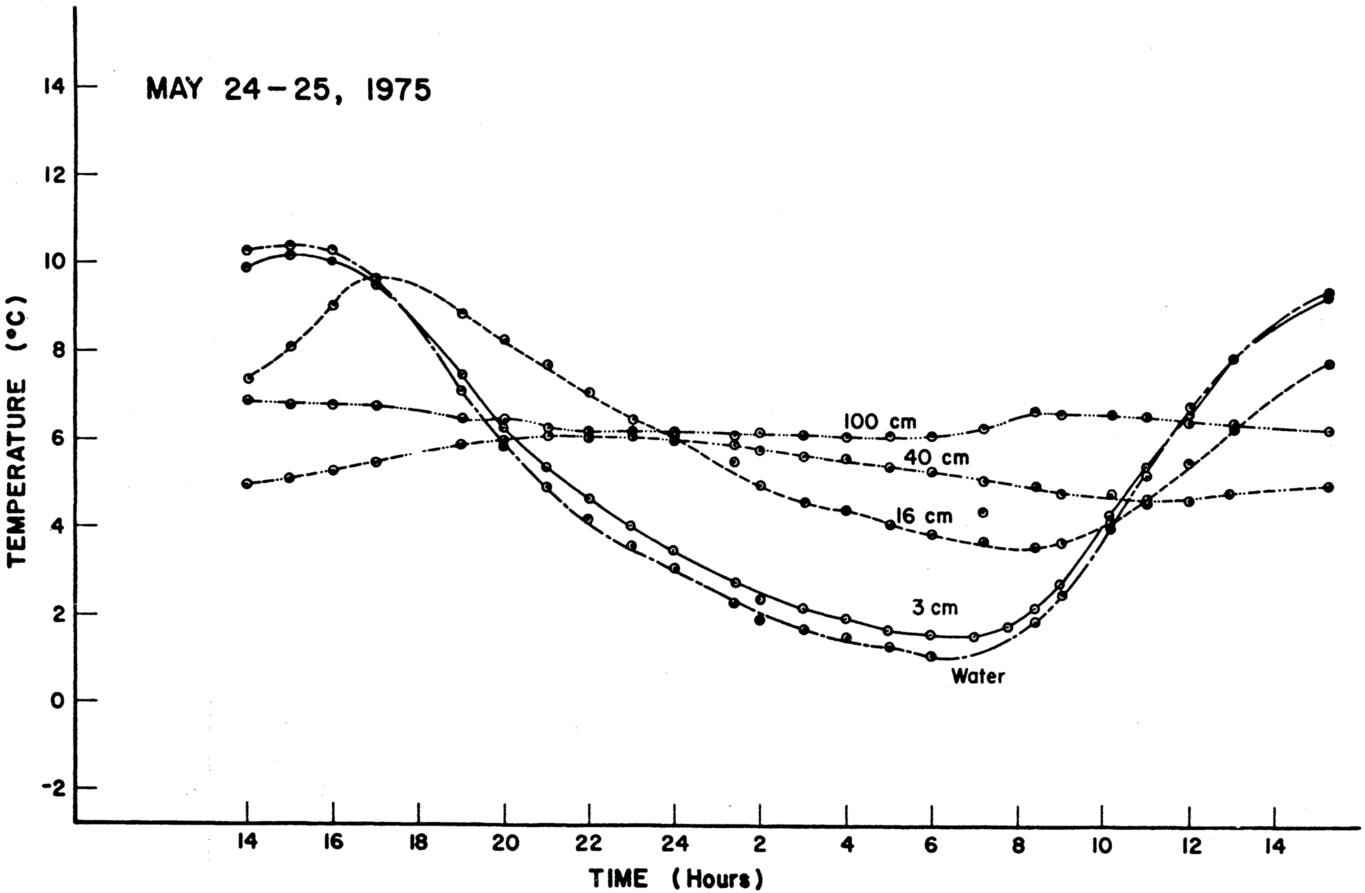

Fig. 3. Variations in Temperature at Four Depths in the Streambed Over a 24-Hour Period

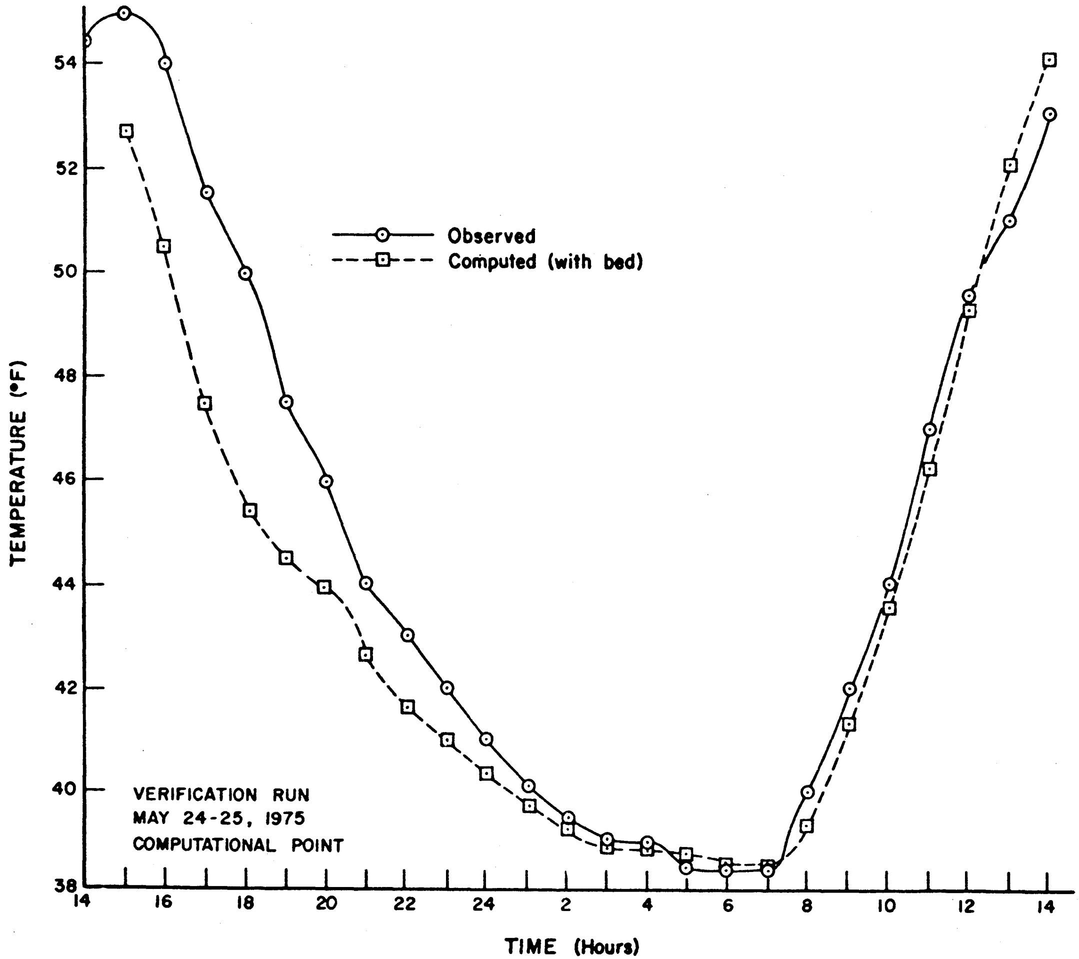

Fig. 5. Comparison of Model Simulation and Observed Data at the Downstream Point in the Watershed for May 24-25, 1975

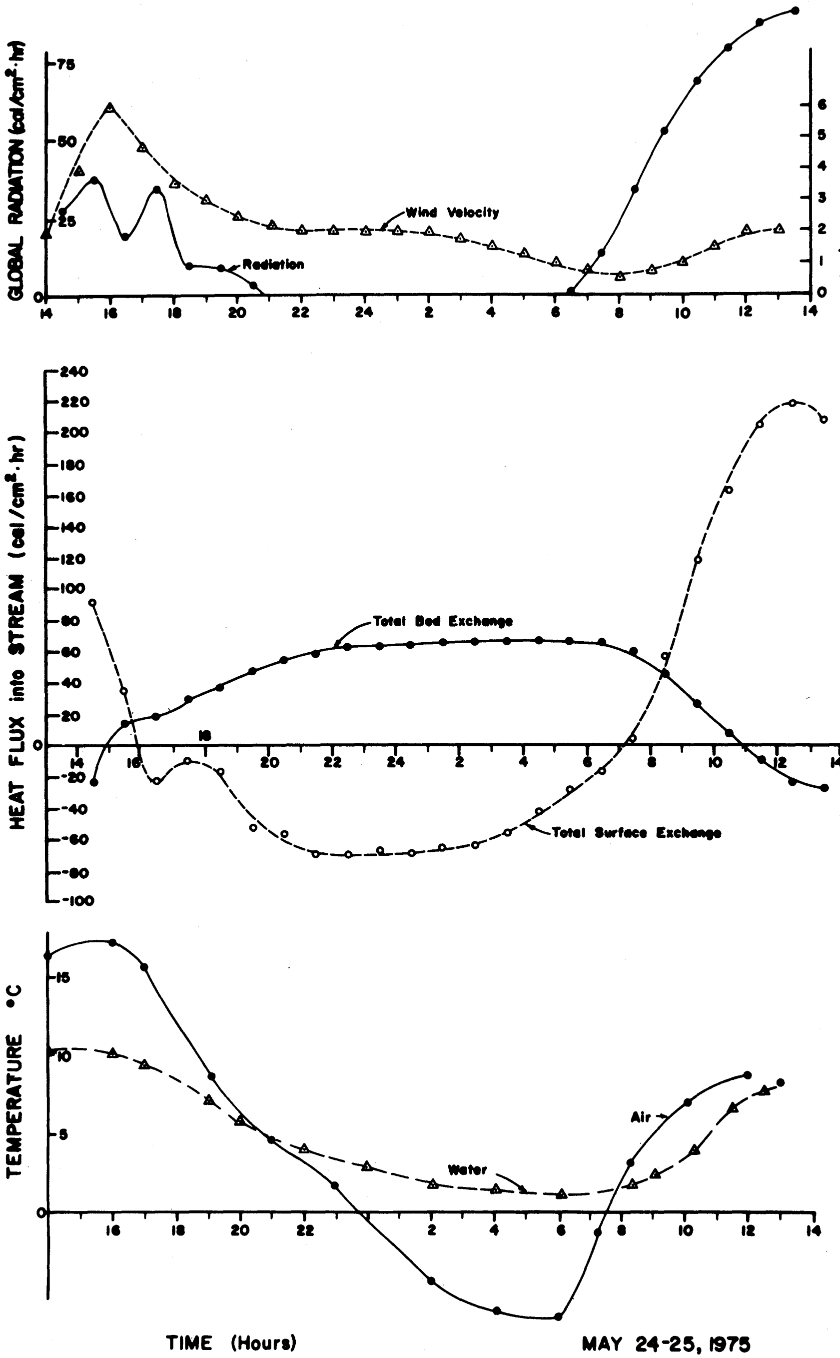

Fig. 4. Variations in Meteorological Parameters and Heat Flux at Spawn Creek, May 24-25, 1975

Table 1. Water Temperature Model.

QUAL-1 (Texas Water Development Board) (12)	
General Equation	$A \frac{\partial T}{\partial t} = \frac{\partial \left(A\ E_L\ \frac{\partial T}{\partial x}\right)}{\partial x} - \frac{\partial (A\ U\ T)}{\partial x} \pm \frac{A\phi_T}{\gamma C_p h}$
Energy Budget (Heat Balance)	$\phi_T = \phi_R + \phi_a - (\phi_B \pm \phi_H + \phi_E)$
Solar Radiation, ϕ_R	$\phi_R = \phi_{RI}\ a_t(1 - R)\ (1 - 0.65\ C^2)$
Evaporation, ϕ_E	$\phi_E = \gamma L\ (a + bU)\ (e_s - e_a)$
Back Radiation, ϕ_B	$\phi_B = \sigma(T_s + 460)^4$
Conduction, ϕ_H	$\phi_C = \phi_E(0.01\ R)$ WHERE $R = \frac{P}{29.92}\ \frac{(T_s - T_a)}{(e_s - e_a)}$
Streambed Heat Transfer, ϕ_{SB}	Considered groundwater heat input but conduction relatively insignificant compared to ϕ_T
Other Terms	$\phi_a = (2.89 \times 10^{-6})\ \sigma\ (T_a + 460)^6\ (1 + 0.17C^2)$ $(1 - .03)$
	Complete mixing, variable cross-section, variable dispersion coefficient
Bowles et al. (1)	
General Equation	$\frac{\partial}{\partial t}(AT) + \frac{\partial}{\partial x}(QT) = \frac{\phi_{TS}\ w}{\rho c_p} + \frac{\phi_{SB}\ W}{\rho c_p} + Q_\ell T_\ell + q_g T_g W + q_r T_r w - q_e T_w$
	$\phi_{TS} = C_1 + C_2\ T$
	$\phi_{SB} = C_3 + C_4\ T$
Energy Budget (Heat Balance)	$\phi_{TS} = (\phi_{RI} - \phi_{RR}) + (\phi_v - \phi_{rr})\ (\phi_a - \phi_{ar}) - \phi_{bs} - \phi_E + \phi_H - \phi_s - \phi_W$
	$\phi_{SB} = \phi_{sb} + \phi_{bb} + \phi_{cb}$

Table 1. Continued.

Bowles et al. (1) (Continued)	
Solar Radiation, ϕ_R	$\phi_R = f(\alpha, R_g, R, d_p, C)$ (Wunderlich (19))
	or by probalic distribution of observed solar radiation between sunrise and sunset
	or by direct use of observed solar radiation
Vegetative Radiation, ϕ_v	$\phi_v = \sigma(T_a + 460)^4$ (Pluhowski (20))
	$\phi_{rr} = R_\ell \phi_v$
Atmospheric Radiation, ϕ_a	$\phi_a = \beta \sigma(T_a + 460)^4$ (Raphael (21))
	$\phi_a = R_\ell \phi_a$
Back Radiation, ϕ_{bs}	$\phi_{bs} = 0.97 \sigma(T + 460)^4$ (Anderson (22))
Evaporation, ϕ_E	$\phi_E = \rho L K_E U_a (e_s - e_a)$ (Wunderlich (19))
Conduction, ϕ_H	$\phi_H = 0.217 (T - T_a) P \rho L K_H U_a$ (Bowen (23))
Melting Snow, ϕ_s	$\phi_s = q_r \rho[L_f + c_s (T - T_r)]$
Surface Layout Renewal, ϕ_w	$\phi_w = 3.96 \times 10^4 K_w \left(\frac{U}{h}\right)^{0.33} (T_s - T)$
	(Novotny and Krenkel (8))
Streambed Solar Radiation, ϕ_{sb}	$\phi_{sb} = 0.4 (1 - R_b) \phi_R \exp(-zh)$
Streambed Back Radiation, ϕ_{bb}	$\phi_{bb} = \varepsilon \sigma (T_b + 460)^4$
Streambed Conduction, ϕ_{cb}	$\phi_{cb} = \alpha_1 + \alpha_2 \phi_{sb} + \alpha_3 T_g + \alpha_4 T$ (Comer et al. (24))
Other Terms	Point Loads $T_B = \frac{Q T + Q_{in} T_{in}}{Q + Q_{in}}$
	Unsteady flow from Implicit Dynamic Routing Program (Fread (18)), variable cross-sections, tributaries, point and diffuse thermal loads, variable meteorologic data across stream system, dynamic representation of temperature, dispersion neglected

APPENDIX A

NOTATION FOR TABLE 1

A	=	Cross-sectional area of channel	ℓ^2
A''	=	Quadratic coefficient (Morse, 1970).	
A_s	=	Surface area	ℓ^2
a,b	=	Long-wave radiation constants, a function of cloud height	
a_t	=	Atmospheric transmission	
B''	=	Linear coefficient (Morse, 1970).	
C	=	Cloud cover in tenths	
C''	=	Constant (Morse, 1970)	
c_i	=	Specific heat of ice	$Hm^{-1}T^{-1}$
c_p	=	Specific heat of water	$Hm^{-1}T^{-1}$
$\frac{dT}{dz}$	=	Streambed temperature gradient	$T\ell^{-1}$
E_L	=	Longitudinal dispersion coeffient	
e_a	=	Vapor pressure of ambient air	
e_s	=	Saturation vapor pressure of air	
$f(U)$	=	Wind speed function for heat flux (energy/area•time•time•p)	
h	=	Mean depth of flow	ℓ
v	=	Vapor-transfer coefficient in air boundary layer . . .	ℓt^{-1}
k	=	Coefficient of thermal diffusion	
K	=	Overall heat transfer coefficient	ℓt^{-1}
K_a	=	Vapor-transfer coefficient in boundary layer	ℓt^{-1}
K_E	=	Evaporation heat-transfer coefficient	ℓt^{-1}
K_H	=	Convection heat-transfer coefficient	
K_{SB}	=	Thermal conductivity of streambed material	
L	=	Heat of vaporization	
P	=	Pressure	$m\ell^{-2}$
Q	=	Mean stream discharge	ℓ^3t^{-1}
Q_{in}	=	Discharge of tributary or point load	ℓ^3t^{-1}
R	=	Albedo of the water surface to short-wave radiation . .	
S	=	Thermal energy source-sink term	
T	=	Water bulk temperature	T
T_a	=	Air temperature	T
T_B	=	Boundary temperature found by mass balance	T
T_E	=	Equilibrium	T
ΔT_E	=	$(T - T_E)$	T

ΔT_{PR}	=	Predicted temperature	T
T_s	=	Water surface temperature	T
T_w	=	Water temperature	T
THD	=	Tributary heat discharge	
U	=	Mean stream velocity	ℓt^{-1}
U_a	=	Wind velocity	ℓt^{-1}
v	=	Visibility	ℓ
WHD	=	Waste heat discharge	
X	=	Distance downstream	ℓ
α	=	Solar altitude	
β	=	Raphael's coefficient for long-wave radiation computation .	
γ	=	Specific weight of water	
ρ	=	Density of water	$m\ell^{-3}$
ε	=	Heat exchange coefficient	
η	=	Base heat exchange rate	
σ	=	Stefan-Boltzman constant	
ϕ_a	=	Incoming long-wave radiation	$H\ell^{-2}t^{-1}$
ϕ_{ar}	=	Reflected long-wave radiation	$H\ell^{-2}t^{-1}$
ϕ_B	=	Back radiation heat flux	$H\ell^{-2}t^{-1}$
ϕ_{bs}	=	Long-wave radiation for water surface	$H\ell^{-2}t^{-1}$
ϕ_E	=	Evaporation heat flux	$H\ell^{-2}t^{-1}$
ϕ_H	=	Conductive heat flux	$H\ell^{-2}t^{-1}$
ϕ_R	=	Short-wave radiation heat flux	$H\ell^{-2}t^{-1}$
ϕ_{RI}	=	Incident short-wave radiation	$H\ell^{-2}t^{-1}$
ϕ_{RR}	=	Reflected short-wave radiation	$H\ell^{-2}t^{-1}$
ϕ_s	=	Heat transfer during melting snow	$H\ell^{-2}t^{-1}$
ϕ_{SB}	=	Streambed heat transfer	$H\ell^{-2}t^{-1}$
ϕ_T	=	Total heat flux	$H\ell^{-2}t^{-1}$

MODEL OF INSTREAM FLOWS

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ABSTRACT

Modeling of instream flows is one method of evaluating various riverflows and the resultant water quality. Models that allow more elaborate evaluations usually have a need for considerable data.

The model being developed for the Snake River from Milner pool to C.J. Strike Reservoir will be used to study instream flow needs and assess different alternatives of water resource management. The sampling appears adequate for model testing. With the data collected in September and the additional data collected in March, 1976, there will be two sets of data for model calibration and verification. This tool being developed is anticipated to be very valuable in water resource management.

INTRODUCTION

Modeling of instream flow is the use of mathematical relationships to predict the resultant flow and water quality from a given set of conditions. The types of models available vary from one water quality and flow models to multiple parameter and flow calculation models. The more complex models allow more indepth evaluation of flow conditions but require more data for calibration. These models are restricted in application because of the cost of collecting data. The simple models cost less to implement but do not allow a direct evaluation of a flow condition.

MODEL DESCRIPTION

The water resource planner must then select a model that can be calibrated with minimal cost but allows the needed evaluation of the water resource. The model selected is a multiple parameter model with considerable data needs. The analysis data will be used to simulate a one-day period. This assumes a steady state condition.

MODEL APPLICATION

The application of a model to the Snake River involved 150 miles of river from Milner pool to C.J. Strike Reservoir. The objectives of this application are to study instream flow needs in conjunction with Idaho Department of Fish and Game resource maintenance flow studies and to assess different water resource planning alternatives.

The Snake Plain aquifer and the Snake River are the most important water resources in Idaho. The Snake Plain aquifer discharges to the Snake River in this study area. This discharge is important for Snake River flow augmentation, aquaculture, aesthetics, fish and wildlife. The aquifer discharge and flow past Milner Dam dictates the flow downstream to the mouth of the Boise River. The quality of surface return water, Snake River, and aquifer discharge dictates the quality of the Snake River to the mouth of the Boise River.

Water samples were first collected in this reach of the Snake River on September 15-19, 1975. This sampling was done in cooperation with the Idaho Department of Fish and Game. Samples were collected and flows were measured, where possible, on all major inflows of the Snake River in this reach. The Snake River was sampled where access allowed.

Figure 1 is a plot of air temperature versus time at the Twin Falls weather station. Along with the daily variation temperature, there was a general decrease in temperature. This decrease is important if water temperature also changes with time. Figure 2 is a plot of 12:00 noon water temperatures, of the Snake River at King Hill, with time. The water temperature was constant except for a slight decrease in temperature the last sampling day. A plot of 12:00 noon specific conductance of the Snake River at King Hill with time (Figure 3) shows that the conductance increased about 5 μmohs during the sampling period. The measured Snake River water temperatures taken at different places and different times (Figure 4) indicate that the water temperature which decreased slightly was fairly constant with time. The assumption that the river was in a steady state regime during the sampling period was valid. This allows the data to be used in the model.

Table 1 lists the dissolved oxygen, specific conductance and nitrate measured at the respective river mile. The change in the three water quality parameters do not correspond with each other. Without knowledge of the river and the types of tributaries, interpretation based on one parameter may be erroneous. This indicates the need for a multiparameter model for this reach of the Snake River.

TABLE 1. SNAKE RIVER WATER QUALITY

on September 15-19, 1975

River Mile	Dissolved Oxygen (mg/l)	Specific Conductance (μmohs)	Nitrate (mg/l-N)
524.3	9.9	430	0.76
539.4	9.3	430	0.64
565.8	8.8	450	0.91
583.0	9.2	430	0.86
597.2	8.6	530	1.58
610.1	10.0	480	1.30
630.9	8.7	360	0.54
653.9	8.1	380	0.32
673.7	8.6	360	0.36

SUMMARY

The modeling of the Snake River is difficult. It requires a multiple parameter model which requires extensive data collection. The tool being developed is intended to be used to study present instream flow needs, to be a predictive tool to assess future instream flow needs and to evaluate alternatives to water resource management.

The need for additional data was apparent. This data needs to be in a completely different flow regime. Such data was collected in an extensive effort by IDWR, USGS, and IDHW in March. Using both sets of data from September, 1975, and March, 1976, the model can be calibrated and tested, thus increasing the confidence in the tool as a predictive and useful tool for water resource planning.

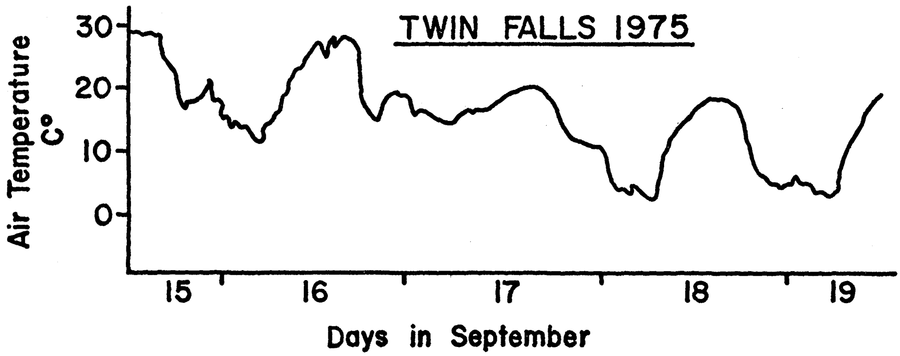

Fig. 1. Air Temperature of the Twin Falls Area During September, 1975. (Data made available by the Agricultur Research Station, Kimberly, Idaho.)

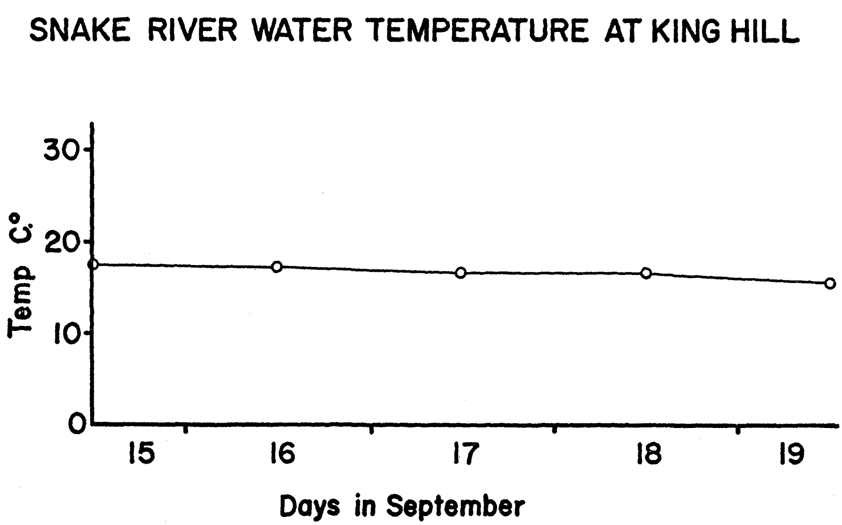

Fig. 2. The Water Temperature of the Snake River Measured at 12 noon at the USGS Gaging Location near King Hill, Idaho. (Date made available by USGS Water Resources Division, Boise, Idaho.)

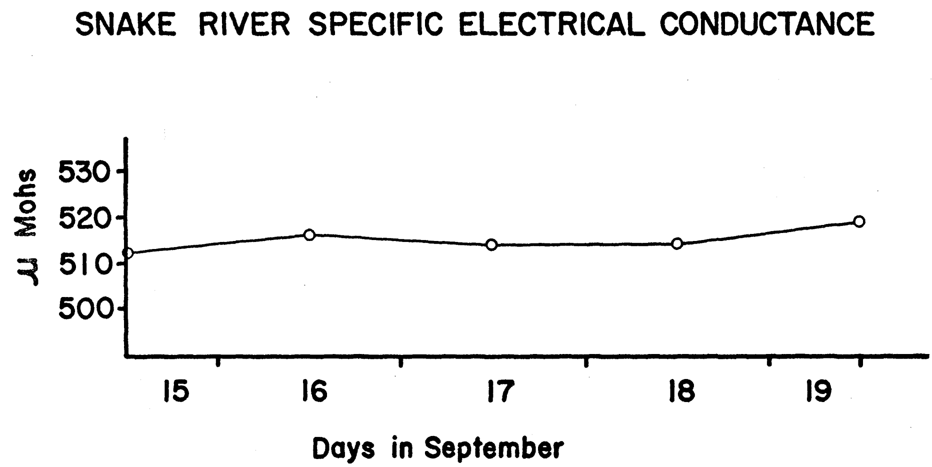

Fig. 3. The Specific Conductance of the Snake River Measured at 12 noon at the USGS Gaging Location near King Hill, Idaho. (Date made available by USGS Water Resources Division, Boise, Idaho.)

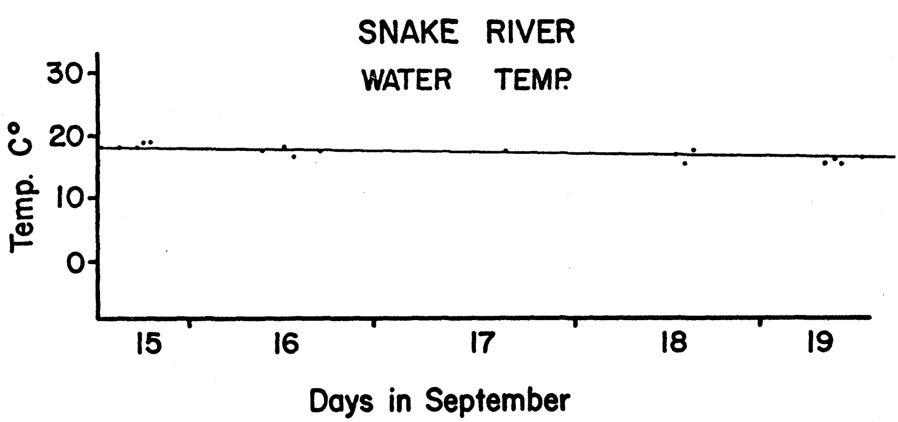

Fig. 4. Measured Water Temperatures of the Snake River at Different Locations During the Study Period

RELATING FISH PRODUCTION TO STREAMFLOW LEVELS USING FISH AND WATER MANAGEMENT MODELS

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ABSTRACT

The Cedar River is the water supply source for about 600,000 people in the Seattle Metropolitan Area. This river also serves as the spawning grounds for a large sockeye salmon run. In order to assess the relationship between Cedar River streamflow levels and sockeye salmon production, a fish production model was formulated which included a factor for instantaneous flood peaks and spawning streamflow levels.

This model was used together with a water resource model to determine the effect of spawning flows, flood flows and water facilities (i.e. dams and diversions) on sockeye salmon production. Results indicate that spawning flows have a relatively small effect on fish production unless they are reduced to very low levels which would be expected to occur during drought conditions. In contrast, flood flows have a very significant adverse effect on fish production.

The increase in river diversion for water supply was found to have very little effect on fish production levels. A water supply diversion of 150 M.G.D., the maximum capacity of the existing system, was determined to be the level of river diversion that maximized net benefits.

A variable minimum streamflow guideline was developed for the Cedar River based on an analysis of fish production, economics, and availability of water.

INTRODUCTION

In the Pacific Northwest, there has always been a relative abundance of water resources. This bountiful supply of water provided for high levels of fish production which served as the major source of sustenance for the original natives of the area. As the life style and number of the inhabitants changed, there was a great increase in the competition among various uses for naturally occurring streamflows.

In some instances, most notably on the Columbia River, this competition has proved detrimental to fish production. If a reduction in fish production accompanies a water resource development, it usually occurs because either, 1) some other water use was deemed to be of greater value than that derived from leaving the water in the stream for fish; or 2) the developers did not realize the effect of their project on fish production. This latter reason is the one most frequently used to explain reduced levels of fish populations in post-project years. As a result, a considerable amount of research has been undertaken to rectify this situation.

In spite of this research, there is still a lack of information specifically relating various streamflow levels to fish production. Most of the fish-related streamflow analysis up to this point has been to relate discharge levels to spawning area. Unfortunately, spawning area is not readily converted to fish production.

But, assuming that fish production levels can be related to streamflow levels, there still remains the problem of evaluating the worth of this fish production relative to other competing water uses. This involves determining the dollar value of fish caught since most other water uses (e.g. power, water supply) can be quantified in monetary terms.

The basic purpose of this paper is to describe a methodology that was developed by the author[1] for answering the two questions raised above. That is: 1) what is the relationship between streamflow levels and fish production and 2) what is the value of this fish production relative to other water uses?

The Cedar River, a western Washington stream draining into Puget Sound via Lake Washington at Seattle, was used as an example for development of the proposed methodology. This river which has an average discharge of about 1000 cfs has several water uses (e.g. water supply and power generation) which compete for water with the anadromous and resident fish populations which are supported by the river.

BACKGROUND

Seattle, a port city located in western Washington on Puget Sound, forms the core of what is generally referred to as the Seattle Metropolitan Area. (See Figure 1.) This area has a population of about 1 million, half of whom

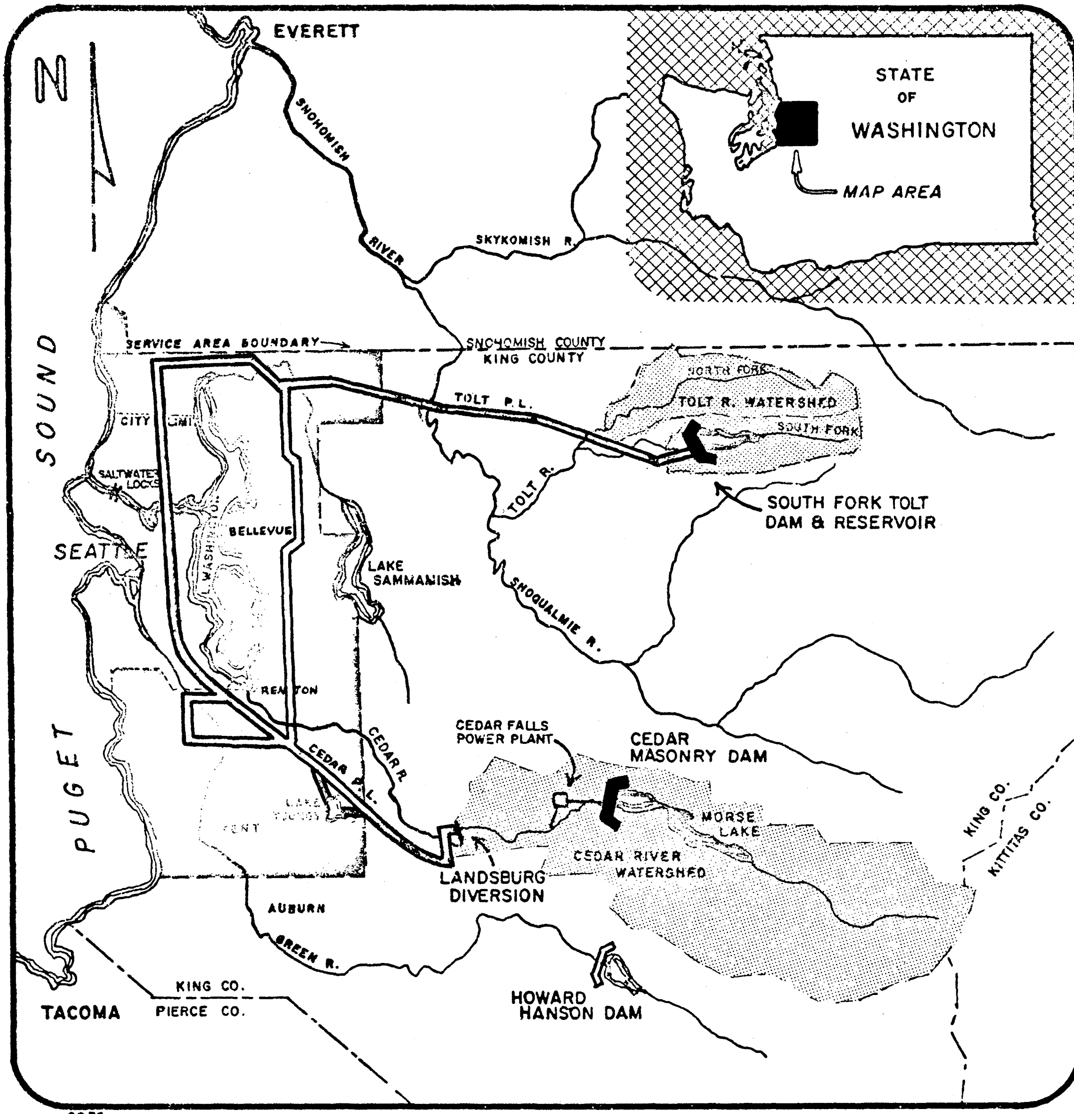


Fig. 1. Seattle Metropolitan Water System

reside in the city proper.

The City of Seattle Water Department serves as the regional municipal and industrial (M & I) water supplier for this area. It diverts water for water supply from both the Cedar and Tolt Rivers which originate in the Cascade Mountains east of Seattle. This water enters large pipelines which are inter-tied in Seattle and east of Lake Washington to form a dual supply gravity system. (See Figure 1.) Normally 70% of the 155 M.G.D. (240 cfs) average demand on this system is provided by the Cedar River. This requires an annual average diversion of 170 cfs which takes place at Landsburg, about halfway down the Cedar River.

Water is stored behind the Cedar Masonry Dam in the upper Cedar River for power generation and water supply purposes. One of the most unique water uses of the Cedar River is a sockeye salmon run which is the largest in continental United States. This run returns from sea through the Salt water locks and Lake Washington and spawns in the lower Cedar River. A high of 365,000 spawners returned to the Cedar River in 1967. Because of this large fish run and the competing uses of Cedar River water, in 1971 the Washington State Department of Ecology established minimum streamflow levels for the Cedar River pursuant to the State Minimum Streamflow Act of 1969. (This is the only instance in the State of Washington that this has been done.) The method used to set these minimum levels is commonly referred to as the "Washington" method and is described by Collings (1971).[2] Basically, this involves determining the discharge at which peak spawnable area occurs.

While this method is fine for arriving at possible streamflow levels to accommodate fish needs it leaves several important questions unanswered:

1) What is the effect on fish production if these flow levels are not met?

2) How do these flow levels relate to the availability of water?

3) What is the effect on other water uses of meeting these flow levels?

The methodology described herein involves the use of fish production and water models and economic evaluation of water use benefits to answer these questions thereby providing a rational approach to establishing minimum streamflow guidelines.

FISH PRODUCTION MODEL

In order to relate streamflow to fish production, a relationship between flow and a fish's survival rate during its life in the stream has to be developed. This then must be translated to a fish production level which is dependent on survival rates during the entire life cycle of the fish. This can be done only by developing a model or equation for the life cycle of the fish that would relate the number of recruits or progency produced by spawning salmon to the number of spawning salmon and various environmental conditions. This relationship is commonly referred to as a spawner-recruit equation or curve.

The simplest version of spawner-recruit equation is:

$$R_t = C \circ S \circ SR_{(0,t)} \tag{1}$$

where:
- C = Constant relating to number of eggs per female and sex ratio of spawners
- S = Number of spawners returning or escaping to the river
- $SR_{(0,t)}$ = Survival rate of progency from time 0 to t
- t = Length of life cycle (4 years for Cedar sockeye)
- R_t = Number of recruits or fish produced at time t

Since $SR_{(0,t)}$ covers the entire life cycle, it must be broken down into several factors in order to determine the effect of different environments through which a typical fish would pass during its life. These may be included in the spawner-recruit equations as multiplicative factors. (Paulik and Greenough, 1966).[3] This is done in equation 2:

$$R_t = C \circ S \circ (SR_Q \circ SR_F \circ SR_D \circ SR_M) \tag{2}$$

where:
- SR_Q = survival rate related to spawning flows
- SR_F = survival rate related to flood flows
- SR_D = survival rate related to density of fish
- SR_M = survival rate related to marine life of the fish

The first two survival rates, SR_Q and SR_F, are of primary interest relative to streamflows. Ricker (1954)[4] has found that the sockeye salmon density-related survival rate, SR_D, can be expressed as an exponential function of the form:

$$SR_D = ae^{-bS}$$

where: a and b are appropriate constants
e is the base of natural logarithms
S = the number of spawners

The marine survival rate, SR_M, can be determined from fish counts of fish leaving and returning to the fresh water environment. Some account has to be made for the number of fish caught at sea.

Several authors [5,6,7] have noted the reduction in salmon survival rates due to excessive flows during their incubation period (usually the winter months). From data collected by the Washington State Department of Fisheries, the relation between flood flows and survival rate, SR_F, was developed for the Cedar River sockeye. (See Figure 2.) This corresponds quite well with curves developed by Avey (1972)[7] for the Calapooia River in Oregon and by Lister and Walker (1966)[6] for the Big Qualicum on Vancouver Island.

The effect of spawning flows is much more difficult to detect. Low spawning flows reduce the amount of spawnable area thereby increasing the density of fish per spawnable area. In recent years, when fish counts have been made on the Cedar River, flows have not gotten low enough to show any noticeable effect on survival rates. As a result, a relationship used by Avey (1972)[7] was used for the Cedar River (See Figure 3). The spawner density at which no reduction in survival rate occurs was assumed to be 1.0 spawners per square yard of spawnable area based on information provided by Avey(1972)[7] and IPSFC (1966)[8].

In order to accurately determine the amount of spawnable area available at different discharge levels, an extensive amount of hydraulic and biological information of the Cedar was gathered and analyzed by Stober and Graybill (1974)[9]. As a result, the relationship shown in Figure 4 was developed.

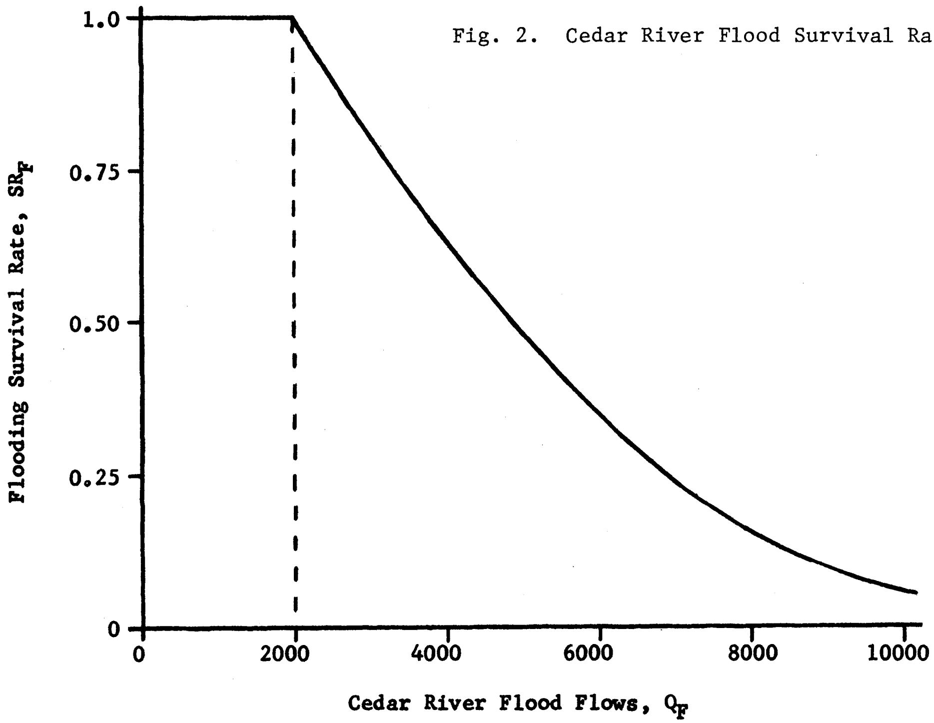


Fig. 2. Cedar River Flood Survival Rate

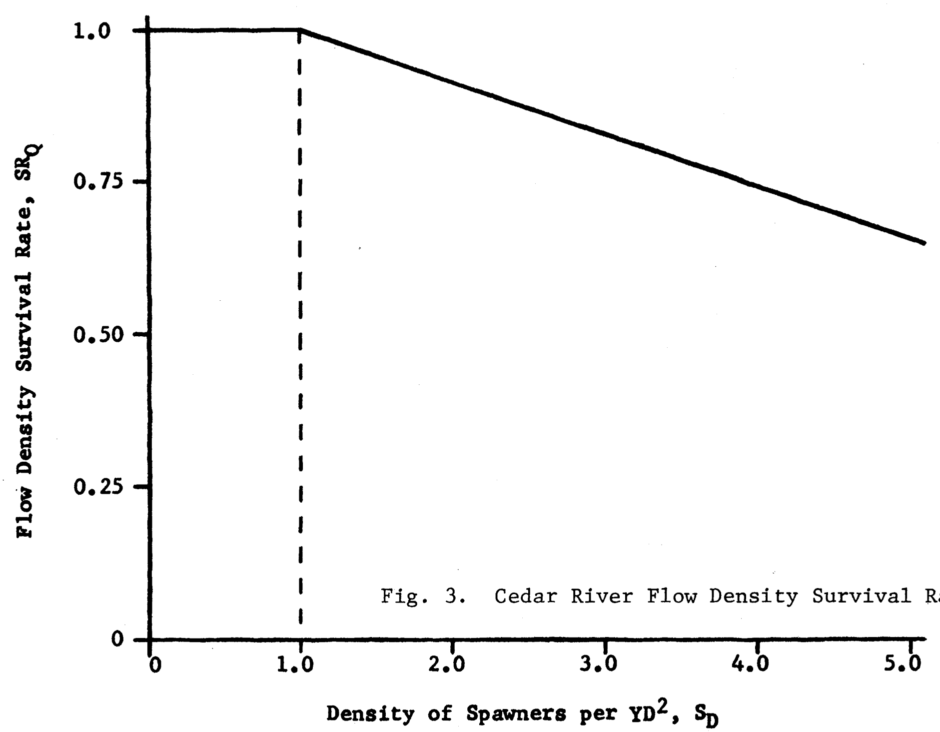


Fig. 3. Cedar River Flow Density Survival Rate

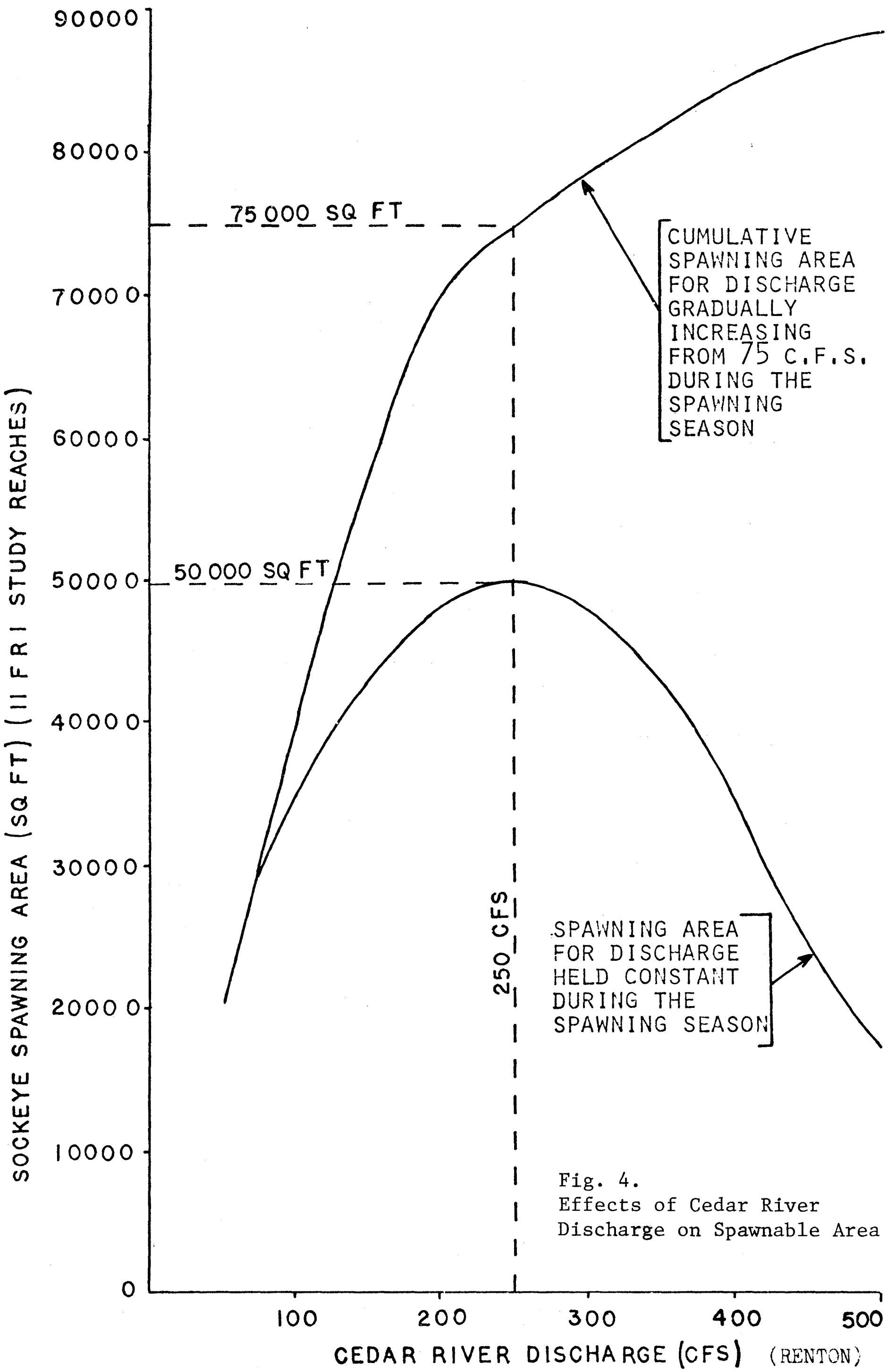


Fig. 4.
Effects of Cedar River
Discharge on Spawnable Area

Using the previously described relationships and Cedar River sockeye fish count data, the following spawner-recruit equation (plotted in Figure 5) was developed as the mathematical model of the Cedar River sockeye:

$$R = 2.6 \cdot S \cdot SR_F \cdot SR_Q \cdot e^{-.0014S} \quad (4)$$

WATER RESOURCE MODEL

The Seattle Water Department uses several water models in its management and analysis of the Cedar River (Miller, 1975)[10]. The water resource model used to simulate Cedar River streamflows under different conditions is called SEAT - 4. This model was developed by Howard (1976)[11]. It takes natural historical inflows computed earlier by Howard (1974)[12] and routes them through the Cedar River system which includes various water facilities and operating rules.

This model can be run under different sets of conditions. The resulting streamflows are then used by the fish production model to determine the effect of these conditions on fish production levels. For example, the Cedar River was "dereg-ulated" in order to determine the size of the Cedar River sockeye run if no storage facilities had existed on the Cedar River since the plant of the run in the early forties. Figure 6 shows the substantial lower fish production level that would have resulted because of higher flood peaks not being alternated by an upstream storage facility.

Predicting the next 25 years, the models indicated that a water supply diversion rate of 150 M.G.D., which is the capacity of the existing system, would result in the fish production level shown in Figure 6. In contrast, the natural fish production level would have remained quite low.

Of particular interest, in the case of the Cedar River, is the effect of increased river diversions for water supply on sockeye fish production levels. Combined use of the fish and water models produced the curve shown in Figure 7. This rather interesting result indicates that as river diversions increase

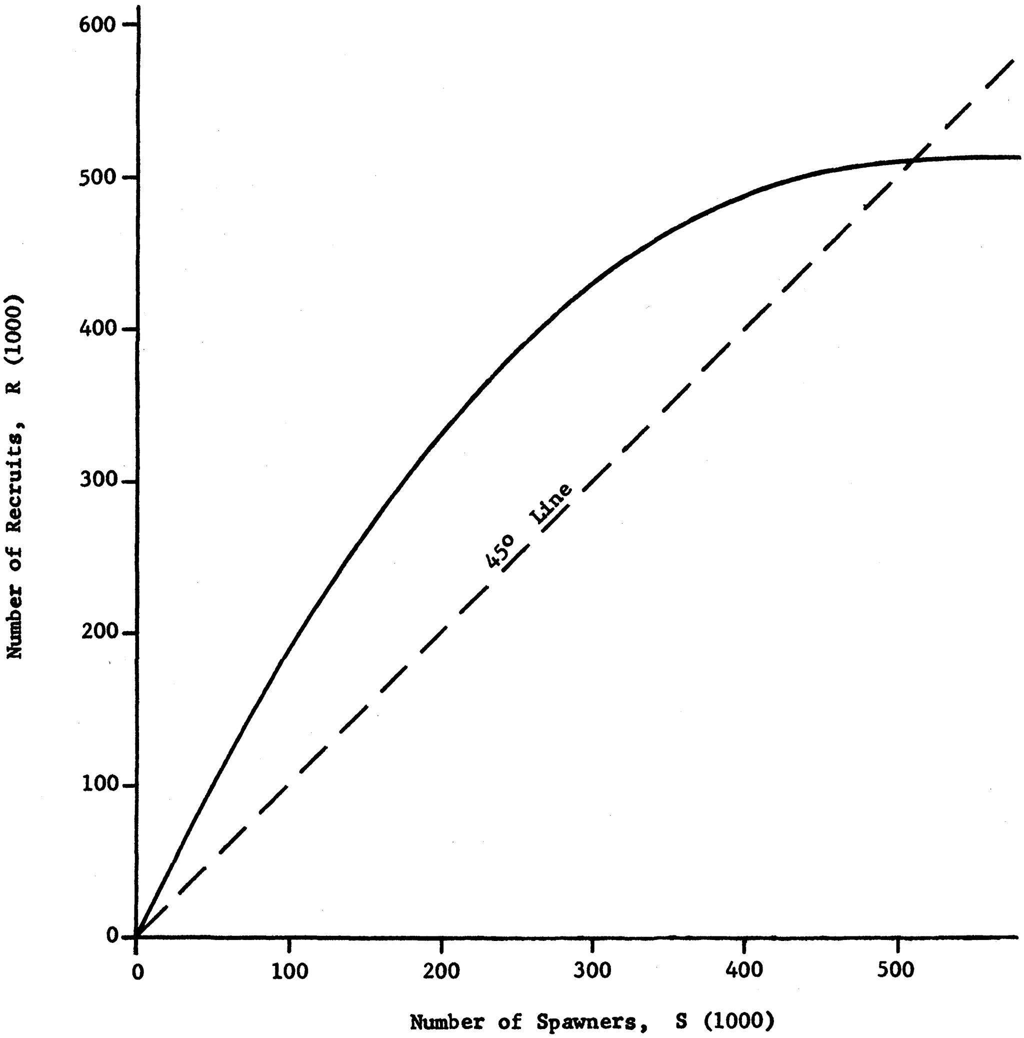


Fig. 5. Cedar River Spawner--Recruit Curve

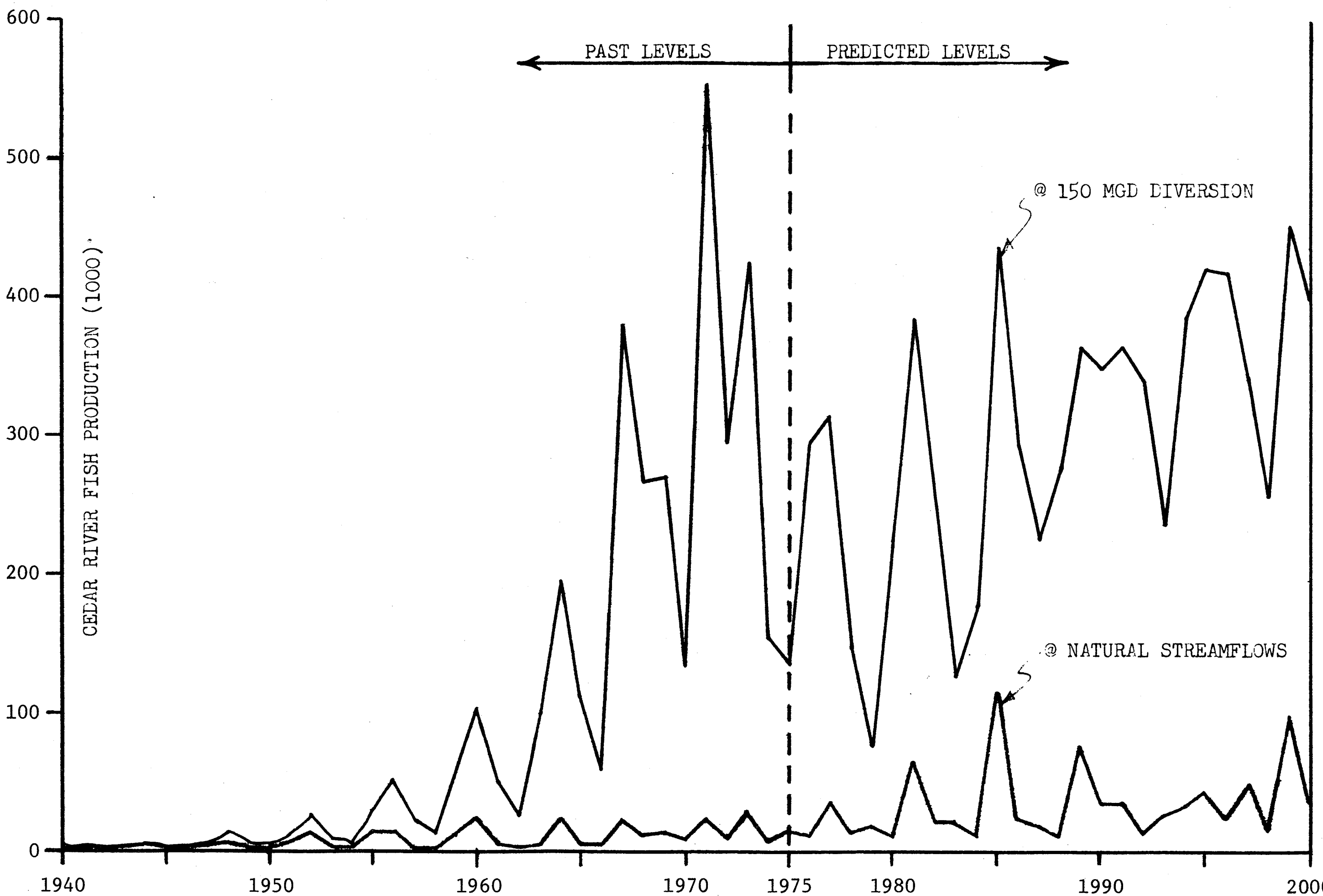


Fig. 6. Cedar River Sockeye Fish Production: Past and Predicted

there is actually a slight increase in fish production up to a point (i.e. 150 M.G.D.). The reason for this phenomenon is the increased flow control ability that higher river diversions provide during the spawning flow season. With this control, the starting spawning discharges can be kept down, then gradually increased to accumulate more spawnable area for the fish (See Figure 4).

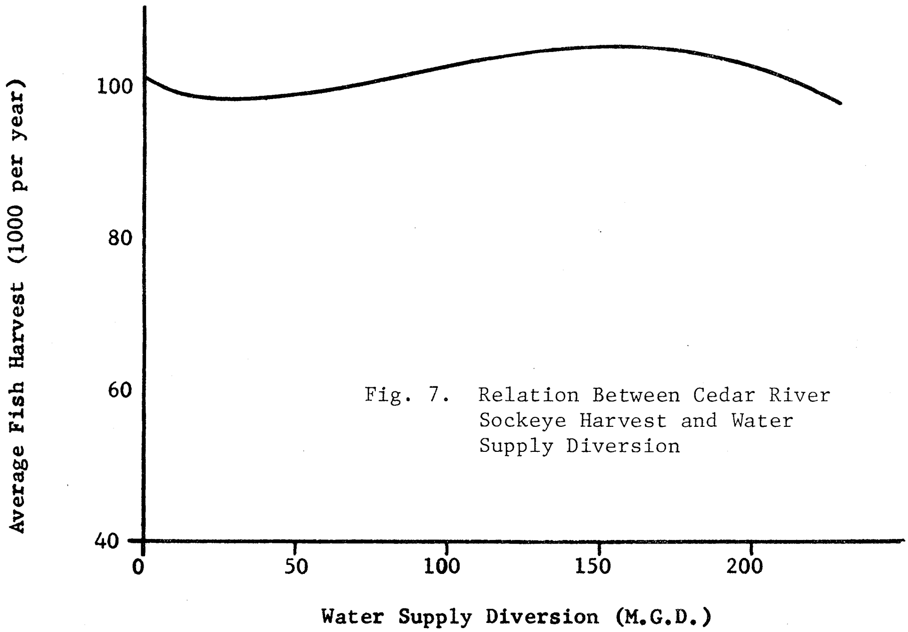
Because of the relationship shown in Figure 7, an economic analysis of the value of water for alternate uses (e.g. water supply and fish production) becomes somewhat of a moot point. At 150 M.G.D. diversion, the maximum capacity of the existing water facilities, the fish production level is also a maximum. The net economic value of Cedar River Sockeye salmon was estimated to be about $13 per fish caught assuming 75% of these were harvested commercially. This value is useful in determining the benefits of additional flood control on the Cedar River.

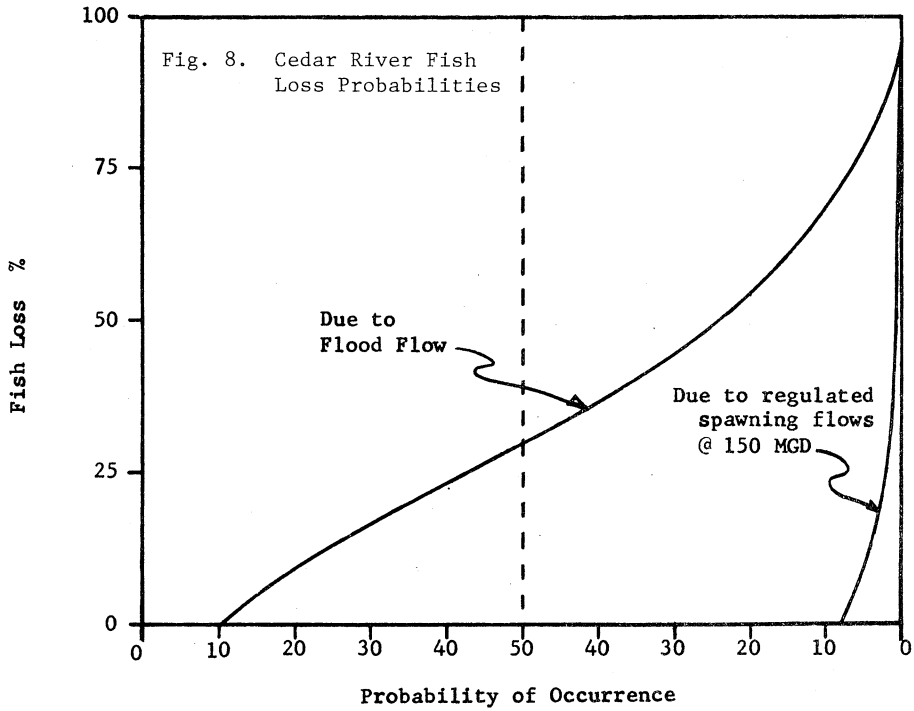
In order to put the effects of low and high streamflows on fish production into their proper perspective, Figure 8 is presented. This figure was developed from the output of the water and fish models. As can be seen, flood flows have a significant effect on fish losses while loss resulting from low spawning flows will occur only during extreme drought conditions.

MINIMUM STREAMFLOW GUIDELINE

One of the questions raised at the outset of this paper was: How does fish production relate to streamflow? Figure 9, based on the fish production model, answers this question for the Cedar River. Spawning flows have to get very low before there will be much of an effect on fish production. Normally (over 50% of the time) the flow at the end of the spawning season would be over 500 cfs. Figure 9 shows the minimum flow originally requested by the Department of Ecology (DOE) and that indicated by the Fishery Research Institute (FRI) after more extensive studies.[9]

The end result of the modeling exercise described in this paper is to


Average Fish Harvest (1000 per year)
100
80
60
40
0
50
100
150
200
Water Supply Diversion (M.G.D.)
Fig. 7. Relation Between Cedar River Sockeye Harvest and Water Supply Diversion


Fish Loss %
100
75
50
25
0
Fig. 8. Cedar River Fish Loss Probabilities
Due to Flood Flow
Due to regulated spawning flows @ 150 MGD
0
10
20
30
40
50
40
30
20
10
0
Probability of Occurrence

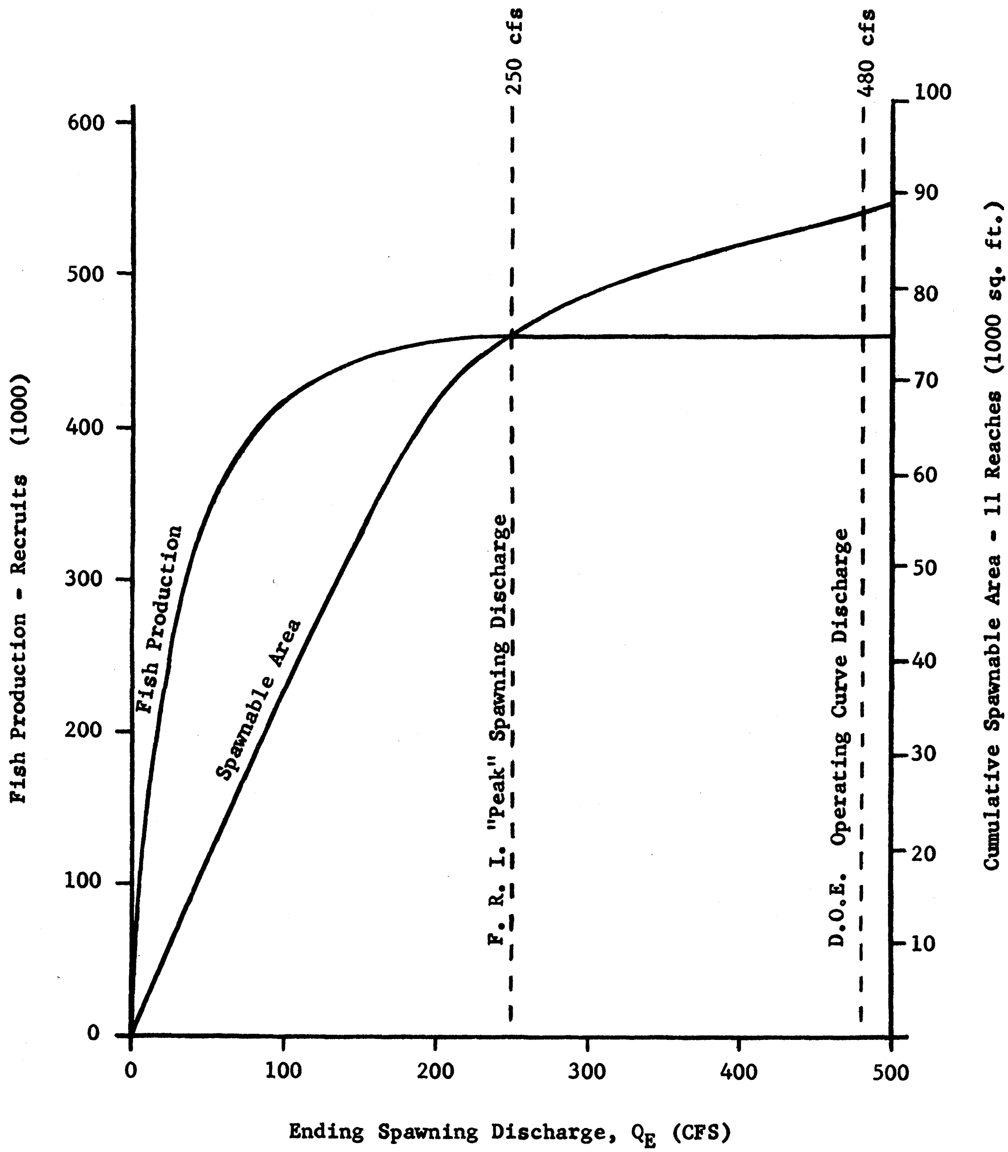
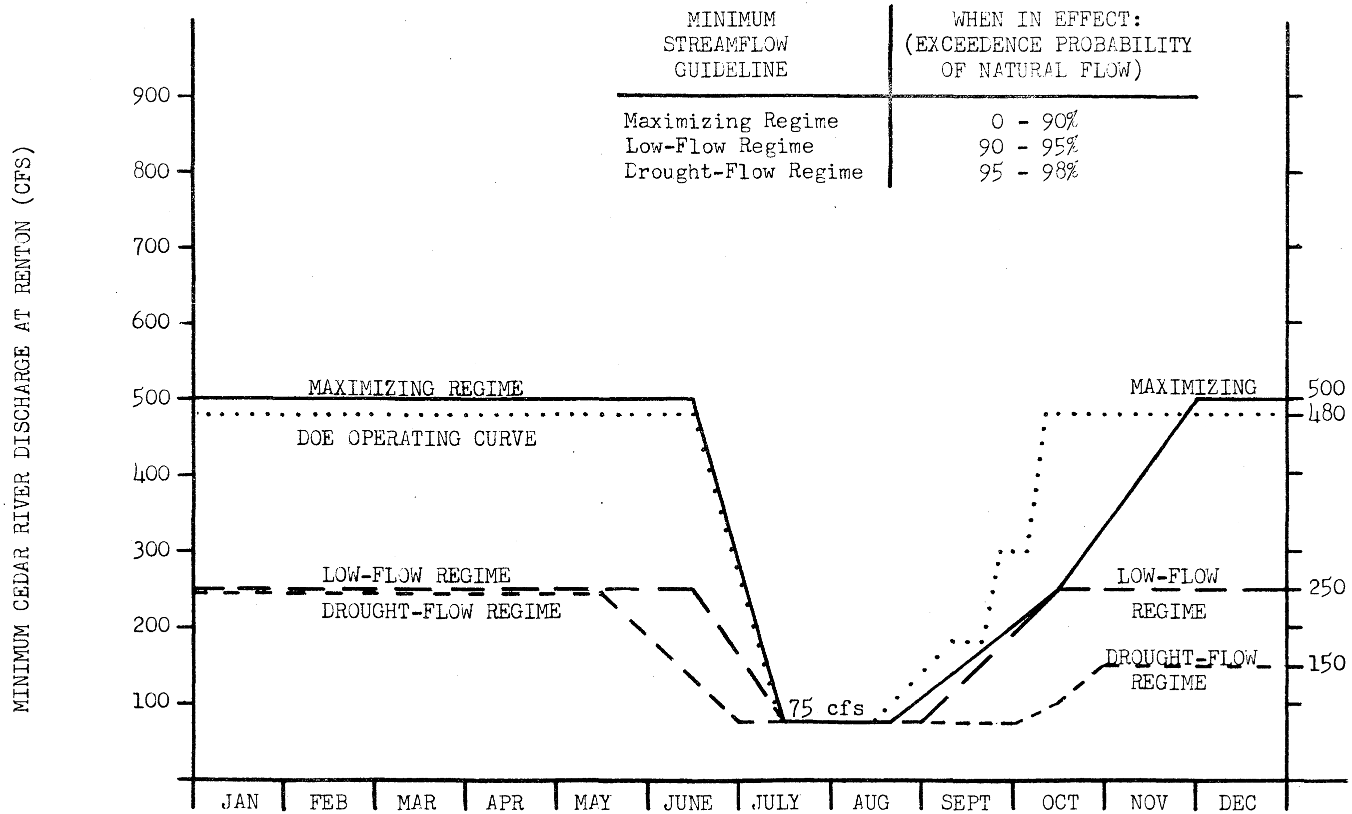


Fig. 9. Cedar River Streamflow--Fish Production Relationship

develop some rational guidelines for regulating river flows to insure instream as well as out-of-stream uses are accomodated. After a probability analysis of the availability of water and regulated streamflows, and an analysis of water supply capacity and fish production levels, the minimum streamflow guidelines shown in Figure 10 were recommended. There are actually three different guidelines depending on the severity of drought flow conditions. Establishment of only one minimum streamflow level, as has been proposed by some, is not practical in western streams, such as the Cedar, that have a high variability of streamflow.



Note: Minimum streamflow guidelines are based on a firm yield of 150 MGD and existing storage on Cedar River.

Fig. 10. Recommended Minimum Streamflow Guidelines for Cedar River

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TOPIC V-G.

MATHEMATICAL MODELING

Summary Discussion

Mr. Grenney was asked:

Question: Is matching of quantity and quality model time resolution necessary?

Response: They do not have to match, but you are limited by a more gross resolution, and you can consider some reactives as instantaneous and others as rate dependent.

Question: Can stream bank erosion be modelled?

Response: Not enough data available to construct good models.

Question: Do you need quantity model for attack of low flow problems?

Response: Stream quantity models are needed to generate such stream characteristics as temperature and velocity. Problems of resolution are important, and 7-day low flow data can be used for steady state low flow analysis.

Question: How can a model be used when you lack data for validation?

Response: The model is used as a tool to integrate facts, and as a framework to test new ideas, not necessary to believe the results. Sensitivity is tested by examining changes in parameters. Process models are better than compartment models for this use.

Mr. Comer was asked:

Question: For temperature modeling of a small stream, how much heat loss is to subsurface?

Response: About 20 percent of incident heat is lost to the subsurface.

Question: Any impact of turbidity?

Response: Although the model stream is clear, turbidity would be an important factor.

Mr. Clapp was asked:

Question: Are there any problems with fish hatchery wastes?

Response: Some data have been obtained and some problems noted in connection with fish hatchery wastes. High BOD is a basic problem, but if cleaning is occurring, the discharge is very high. Also, the cyclic discharge of industrial waste is a problem.

Question: What caused the oxygen peak in the river?

Response: It was caused by a drop in elevation and large falls which provide natural reaeration.

Mr. Miller was asked:

Question: What about low flow after spawning?

Response: There is a need to save water after spawning for incubation, therefore it is better to keep spawning flows slightly lower to insure adequate flows for incubation.

Question: Compare the spawners to returners data on the Cedar River to the Fraser River Sockeye productivity.

Response: The Cedar River is more like the Columbia, and the returners per spawners are much lower than the Fraser system. This may be due to cleaning up of Lake Washington and lack of food.

Question: There seems to have been good success relating one biological parameter to quantity; can this work for resident fish?

Response: It is quite a different game for resident fish, and the lack of information on the life cycle may limit model development.

Question: Is there any change in water quality due to flow regulation?

Response: Not much change is caused in water quality by regulation. Fish seem to be acclimated to higher temperatures because the river is very flat and more flow does not improve temperature significantly.

Question: Do you need many years of fish production data?

Response: Many years of data are needed for calibration of the model. It is hard to build a model without these data and you can only justify extensive measurement of stream bed characteristics by adequate correlation with fish data. It is better to iterate and make models only as complex as the data permit.

Notes by panel moderator: Brian Mar, Dept. of Civil Engineering, Univ. of Washington, Seattle, WA

REVIEW OF THE CURRENT STATUS OF AGENCY ACTIVITIES IN MONITORING OF WATER QUALITY IN THE FORT UNION COAL REGION

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INTRODUCTION

Energy needs of the Nation are increasing faster than development. Coal in the Fort Union Coal Region is believed to be one of the most important sources of energy.

Water is needed for conversion of coal to other forms of energy. It is anticipated that much of the coal will be mined for use or conversion near the source.

Studies are needed to answer questions as to dam and reservoir competency, storage capacities and costs, instream flow requirements, alternative water uses.

If energy is to be extracted from the Northern Great Plains, water has to be made available within 5 or 6 years.

We must have reliable water data before making any logical decision on leasing and extracting energy minerals. In addition to the obvious land changes normally associated with strip mining, changes in the ground water and surface water systems will occur.

An intensified system of hydrologic data collection in the coal areas of the Northern Plains states, designed to supplement the ongoing data collection programs of the U.S. Geological Survey (USGS) with special attention to the coal leasing, environmental and land resource management, is being provided. Hydrologic data are to include surface water discharge, chemical quality of surface and ground water, and ground water levels.

STUDY NEEDED

Many separate agencies are involved in the program. Each one has its own responsibility and is staffed with employees having the special skills and training needed to carry out its particular assignment. Problems and needs of the public cannot always be solved by assignments. Over the years this has been all too apparent. It becomes necessary for representatives to meet together as frequently as needed for the purpose of giving the best possible joint effort in serving the public. One of the vehicles for accomplishing this is a symposium such as this one. The instream flow needs is an important problem for a symposium. Someone has to keep things going--to keep the action alive. If he isn't assigned this responsibility, he must assume it. There are not many competent agency employees today whose time is under employed. Assuming new responsibilities means changing priorities. Another facet that is needed is administrative sanction and direction so that agency employees know that multi-agency problem-solving is part of their responsibilities. Those imaginary "fences" must be destroyed; teamwork with other agencies must be recognized as an essential part of job performance. Employees cannot change their priorities without administrative support.

Voluminous data are required to determine instream flow requirements. Responsibilities for determining instream flow needs for recreation, fish and wildlife water quality, aesthetics, and aquatic life are dispersed in many state and federal agencies.

With certain exceptions the data base for fish and wildlife resources as compared to water resources data are quite limited, as are methodologies for projecting or simulating the possible effects on fish and wildlife from various proposed actions. However, to date little has been done by federal and state impacts to obtain facts.

MONTANA

The Montana Water Use Act of 1973 provides for the use, development and conservation of the water with the least possible degradation of the natural aquatic ecosystems. In pursuit of the policy the State encourages the development of facilities which store and conserve water for the stabilization of stream flows. The priority between appropriators is based on first-in-time is first-in-right, with no provisions for priorities between beneficial users. Beneficial users in Montana included but are not limited to agricultural (including stock water), domestic, fish and wildlife, industrial, irrigation, mining, municipal, power, and recreational uses. Under the Montana Water Use Act of 1973, the Montana Department of Fish and Game requested a 7.1-million acre-feet reservation at Sidney for instream flow protection in the Yellowstone River. To date the Board of Natural Resources and Conservation have not acted on the request. The Missouri Basin Commission has recognized that it needs additional study on the Yellowstone and has proposed a technical Ad Hoc Committee on instream flow requirements.

The Director of Montana State Geological Survey, Sid Groft, had the foresight to recognize the potential water quality problems before mining started and hired Wayne Van Voast, a very capable expert, to carry on water quality studies. Wayne has carried on the monitoring around the strip mines at times almost single-handed. He has the respect and confidence of coal company employees as well as his fellow hydrologists. He has been financed by private grants, Environmental Protection Agency (EPA), Bureau of Land Management (BLM), and USGS. Figures 3 and 4 show results of his 5-year study of mine effluent and ground water samples. This was taken from his latest bulletin, No. 97, published by Montana Bureau of Mines and Geology.

DATA COLLECTION

The Bureau of Land Management (BLM) has turned to space age satellite technology in assessing the impacts of strip mining on surface and ground water in southeastern Montana. To gather hydrologic information, Montana State Office in Billings purchased equipment which collects, transmits, and disseminates environmental data. At least one message is collected every 12 hours by two instrument platforms located on the Tongue River as shown on the location map.

The National Aeronautics and Space Administration's (NASA) experimental polar orbiting Earth Resources Technology Satellite (ERTS) reported water level, temperature, dissolved oxygen content, flow rate, sediment content, and salinity of the Tongue River. The ERTS data originated from gauges on two key river locations. Each gauge sensed five measurements of the river and relayed this numeric information to the satellite orbiting about 500 miles above the earth's surface. ERTS in turn relayed the reading to NASA operated, ground receiving station at Greenbelt, Maryland, which teletyped the data into the BLM Washington Office within 45 minutes of initial measurement. With this information, BLM was able to assess the detrimental environmental consequence of the Decker, Montana strip-mine teaching of spoil banks and coal-ash deposits from coal-fired power generation plants.

CONVENTIONAL

Hydrologic data is presently collected and relayed by ground survey, telephonic communication, or ground-based radio-relay. These methods possess a varying range of capabilities and limitations. Ground surveys provide precise measurement, however, the collection and transfer of information is too slow and consumes too much manpower for many management activities, especially those involving large or complex watershed systems. Telephonic data collection (where available) enables coverage to be expanded at low cost. Unfortunately such communication is subjected to interruption by natural disasters when the need for hydrologic data is greatest. Ground-based radio relay is the third method of BLM data collection. Radio relay systems utilize sensors integrated into a collection platform which converts transmission to a regional control center. Data received almost instantaneously provides the basis for implementing management decisions during critical periods. However, ground-based radio relay is subject to disadvantages caused by distance and type of terrain. Installation and maintenance of servicing equipment in remote hilly terrain are costly because of the large number of relays and repeaters necessary to transmit the radio signals to the central control facility.

SATELLITE

Relaying data by satellite possesses most advantages without the need for costly relays and repeaters. An additional benefit stems from the small size of the satellite platforms. Since they can be relocated at low cost, platforms may be added or deleted as necessary offering a new capability to support special or changing requirements. An ERTS data collection platform transmits a signal every three minutes; however, the signal is released only when the satellite is in view of both the platform and ground receiving station at the same time. At mid-latitude locations, the orbital path provides four to six daily opportunities for the relay of signals. This frequency could be increased by adding additional satellites. The present ERTS system, which is a test, can only accommodate about 1,000 data collection platforms. The National Oceanic and Atmospheric Administration's Geostationary Operational Environmental Satellite (GOES), was launched in May, 1974. The GOES system is capable of either interrogating individual stations or obtaining data at prescheduled intervals. The data is received at Wallups Island by the National Oceanic and Atmospheric Administration. It in turn, teletypes the data to the users.

INVESTIGATIONS

BLM, in cooperation with a Geological Survey Office, has been evaluating the ERTS data collection system for the past three years, from two locations in southeastern Montana. These studies help determine usefulness and economic feasibility of relaying hydrologic data by satellite, versus conventional ground-based techniques. The information is received at a Geological Survey Office by way of a teletype link with the NASA ground receiving station at Greenbelt, Maryland. To date, the experiment has demonstrated that data collection by satellite is reliable and economically feasible. We now know satellite systems can be more flexible and more easily maintained than can conventional ground-based data relay systems. Further studies will establish the satellite system types. As the complexity of managing resources increases, expansion of the number of data collection sites will be necessary. Data relay by satellite can upgrade water resources management.

USGS, Water Resources Division, Montana--Don Coffin--Summary of activity in MT

"The Geological Survey is currently involved in an extensive site-specific and regional coal hydrology program in Southeastern Montana. The objectives of this program are to collect baseline hydrological data and predict the effects of mining the shallow coal in eastern Montana."

NORTH DAKOTA

The state of North Dakota has a cooperative agreement with the Federal Energy Administration for fiscal year 1976 which will be a two-part program directed by the State Engineer of the North Dakota State Water Commission.

The second part of the fiscal 1976 program will relate to the energy resource development area and will involve the conducting of extra field test drilling in the areas around Beach, Amidon and Mott, North Dakota, which are projected areas to be affected by possible coal development. The basic program of data collecting is under way, but the state is lacking information from established ground water test holes to monitor the water quality and quantity studies in these possible impact areas. The areas proposed for this investigation are ones where major coal deposits are present and where the quality and quantity of water for industrial development and added community growth is unknown.

USGS, Water Resources Div., N. Dakota--Hugh Hudson--Summary of activity in ND

"Work in North Dakota consists of investigations of the steady state hydrology of Western North Dakota supplemented by site studies. Site studies include the ca. four-year ground water monitoring program at Gascoyne where salinity increases have been selected, Horsenose Butte which is being terminated, and a new start on the "Beulah Trench" area."

EPA on-going studies include the evaluation of surface and ground water at potential strip mines in North Dakota (Falkirk Mine).

SOUTH DAKOTA

The Federal Energy Administration had a cooperative water program with South Dakota.

COLORADO

The Federal Energy Administration has a cooperative program with Colorado, which is explained at this symposium by Bob Longenbaugh, Professor at Colorado State University.

WYOMING

USGS, Water Resources Div., Wyoming--Sam West--Summary of activity in WY

"Wyoming's contrasting geology, hydrology, and land use necessitates a more diverse and sometimes dilute effort to that which may be possible in Montana."

UTAH

USGS, Water Resources Div., Utah--Hugh Hudson--Summary of activity in UT

"Efforts in Utah involve two year reconnaissance studies at the Henry Mountains and Wasatch-Book Cliffs sites, surface and ground water investigations in the oil shale area of the Uintah Basin, with plans to drill a one degree hole in the Asphalt Washington area and the EMRIA related investigations in the Alton area."

SUMMARY AND CONCLUSIONS

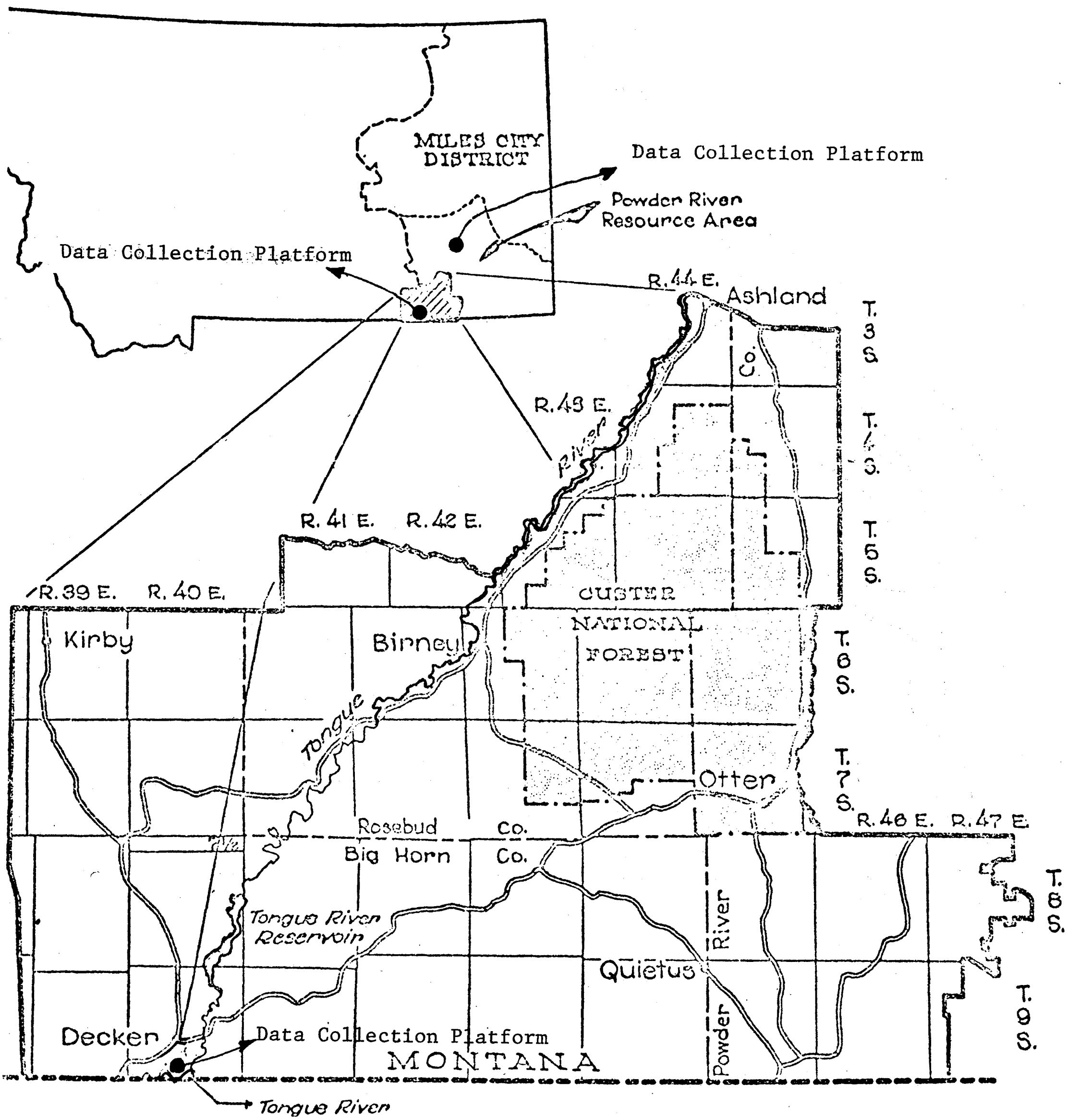
In the area of resource development, funding is available for the drilling and monitoring of water, but the increased activity in proposed coal development areas demands more complete data collecting. This additional work can only be conducted if outside sources of funding are available.

LITERATURE CITED

1. BAKER, A. A., 1929, The northward extension of the Sheridan coal field, Big Horn and Rosebud Counties, Montana: U. S. Geol. Survey Bull. 806-B, p. 1 -67.

Fig. 1.

DECKER - BIRNEY LOCATION MAP



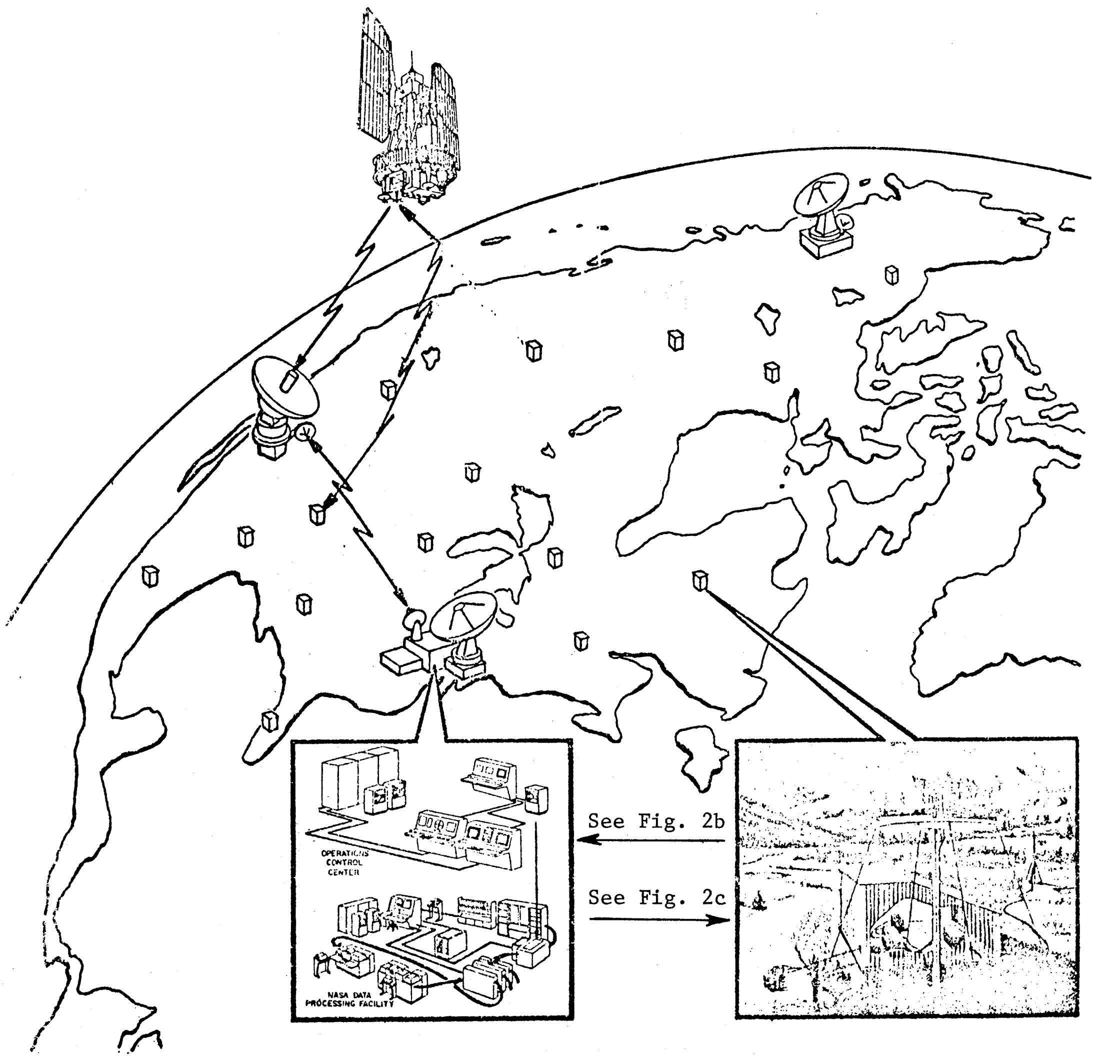


Fig. 2a. ERTS Data Collection System

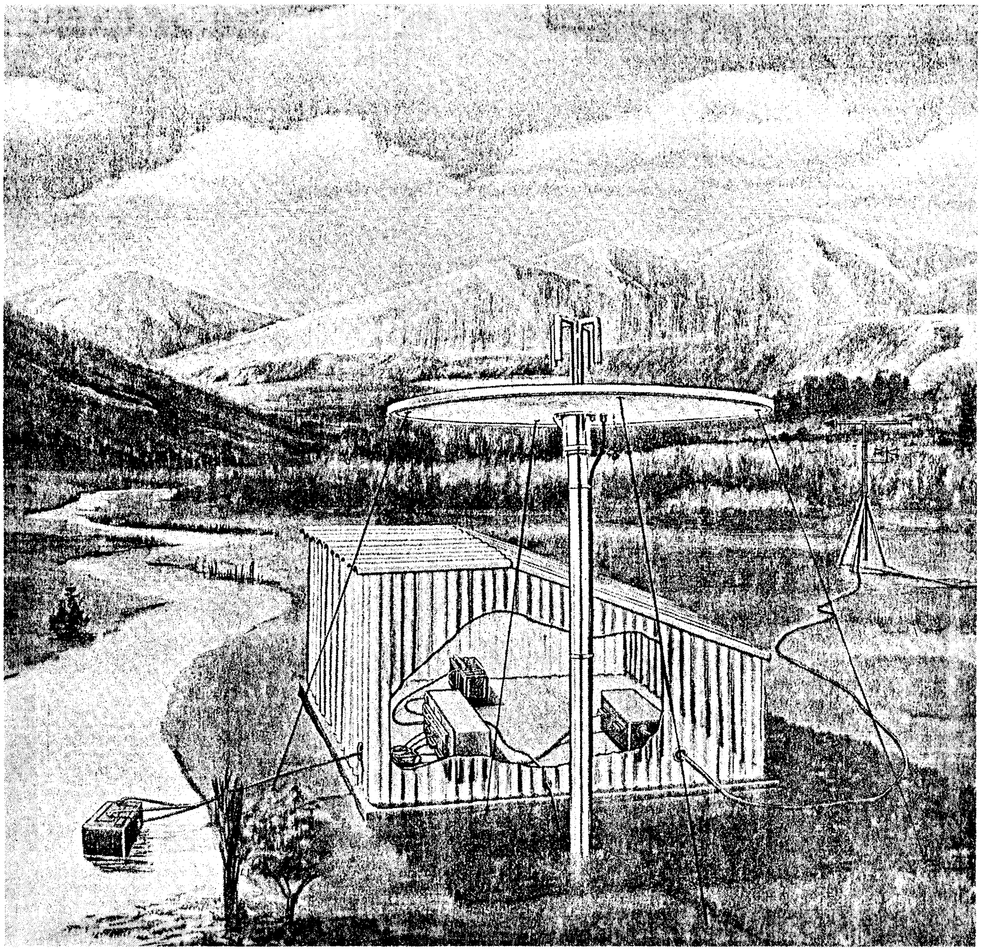


Fig. 2b. Typical Data Collection Platform Installation

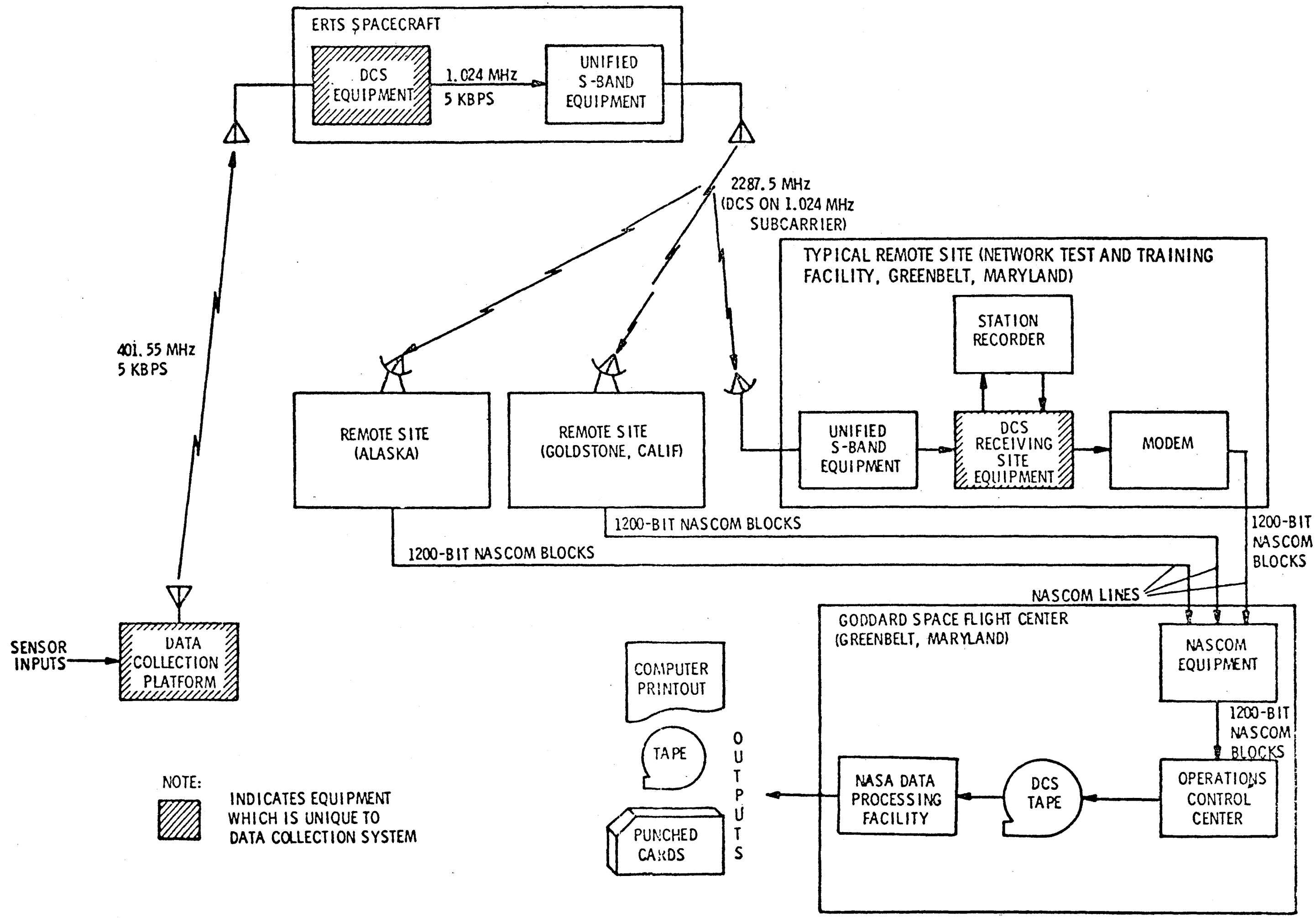


Fig. 2c. Data Collection System Data Flow

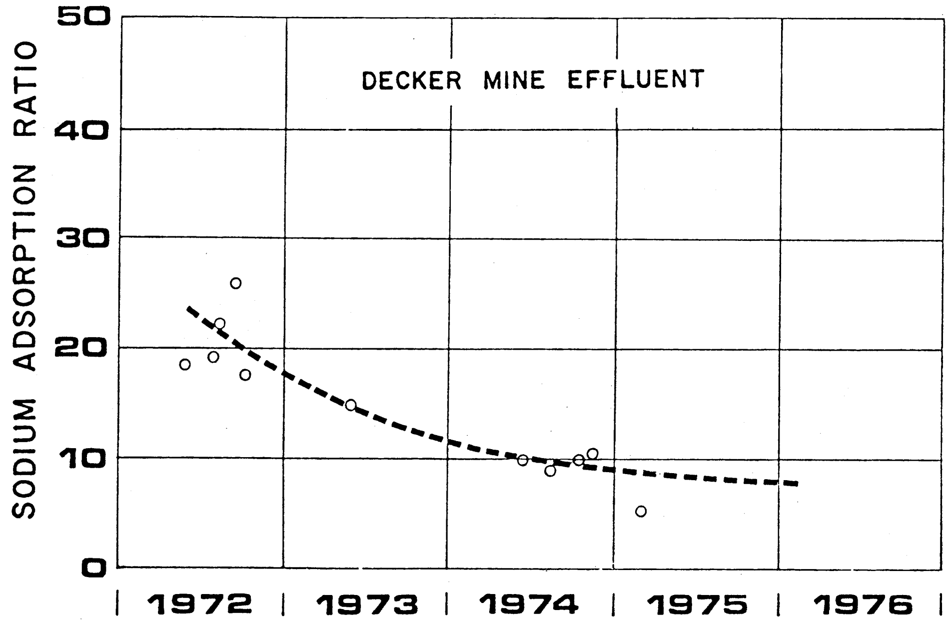


Fig. 3a. Sodium Adsorption Ratios Determined for Decker Mine Effluent Since Mining Began

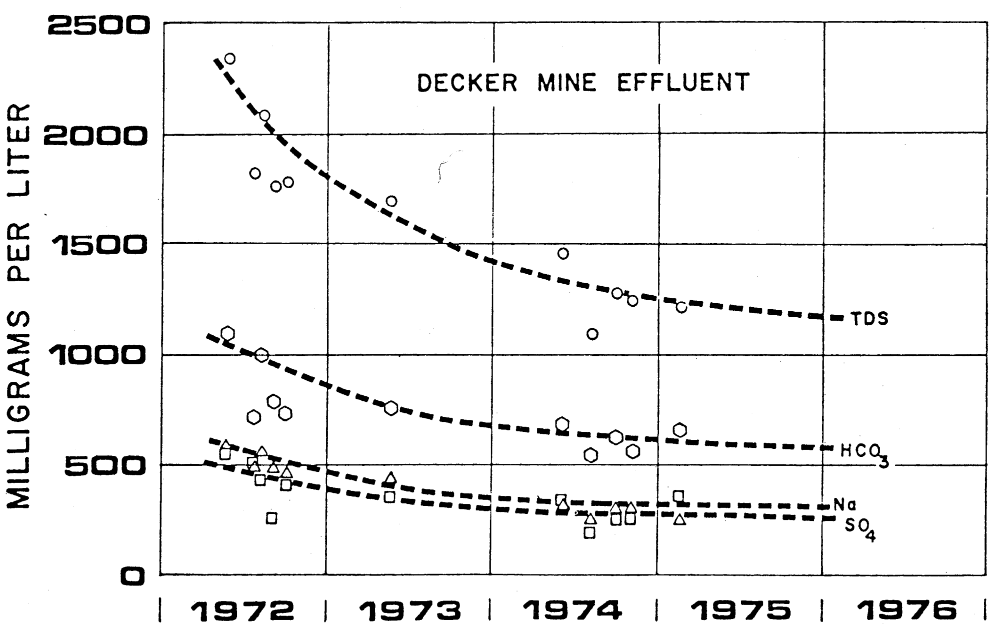


Fig. 3b. Concentration of Total Solids and Selected Constituents in Decker Mine Effluent Since Mining Began

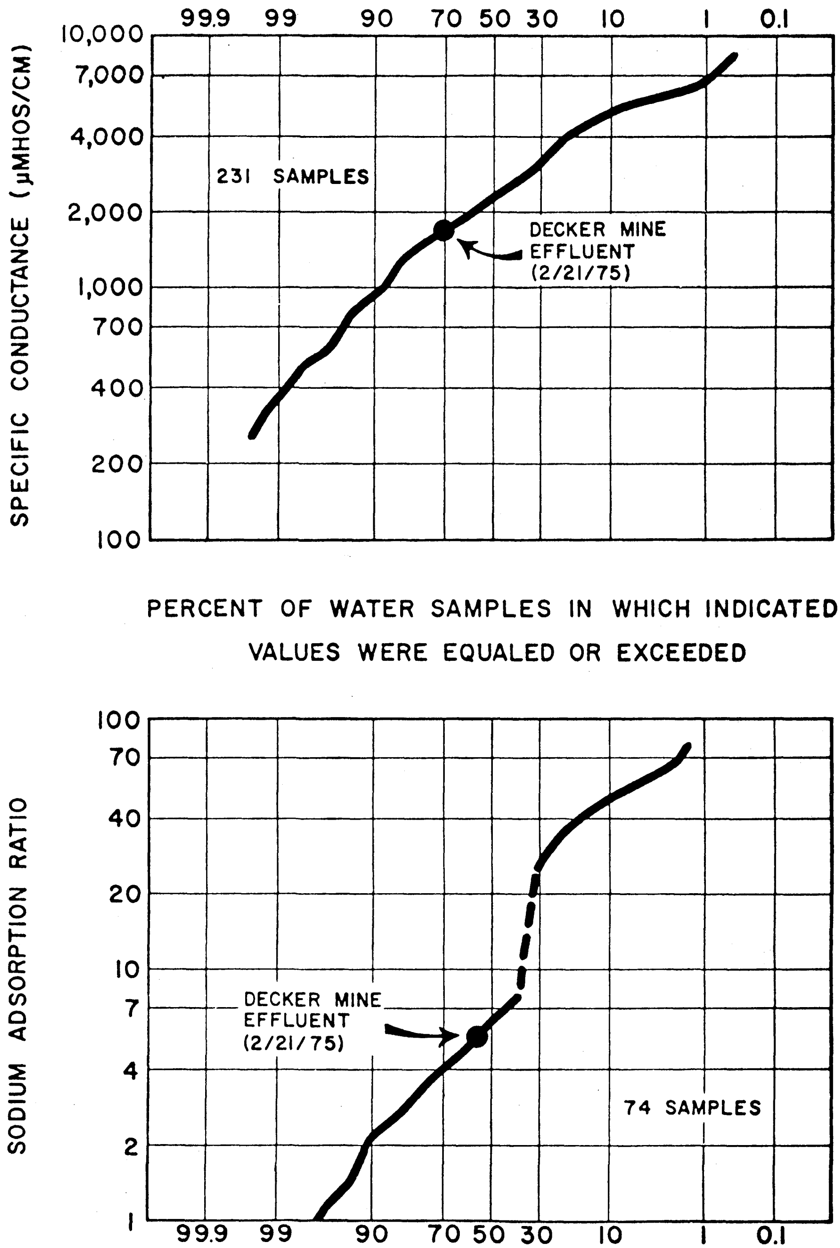


Fig. 4. Statistical Distributions of Water-Quality Parameters of Ground Water from the Birney-Decker Area, Southeastern Montana

LAHONTAN CUTTHROAT TROUT AND CUI-UI INSTREAM FLOW METHODOLOGY

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ABSTRACT

A fishery instream flow methodology for Lahontan cutthroat trout (Salmo clarki henshawi) and Cui-ui (Chasmistes cujas) is presented. The methodology includes such factors as: 1) river flow, 2) water temperature, 3) gravel composition, 4) hatching and emergence success and 5) competition and predation. The rationale behind the methodology and its application to fishery management in the Truckee River system is discussed.

INTRODUCTION

The Pyramid Lake-Truckee River system once supported enormous quantities of Lahontan cutthroat trout (Salmo clarki henshawi) and cui-ui (Chamistes cujus). These fish were the primary food of the Pyramid Lake Paiute Indians and formed the basis for trade with other tribes. As western civilization expanded, the sale of trout became a major source of revenue for the tribe from the 1860's into the 1930's and resulted in the establishment of a substantial commercial fishery (Sumner,1939). Records indicate that in the six-month period from October 1888 to April 1889, Wells Fargo Express and railroad freight lines shipped 100 tons of fish (Trelease, 1952). It was also during this period the lake gained national recognition as a tremendous sport fishery.

The trout population seemed able to adequately compensate for the large

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1. Sumner, F. H. 1939. The decline of the Pyramid Lake fishery. Trans. Amer. Fish . Soc. 69: pp 216-223

2. Trelease, T. H. 1952. The death of a lake. Field and Stream 56(10): pp 30-31, 109, 110-111.

harvest as long as it had access to spawning and rearing areas in the Truckee River, its tributaries and Lake Tahoe (Fig. 1). At the turn of the century, increased demands for Truckee River water led to the construction of numerous dams and irrigation diversions. The most significant, Derby Dam, annually diverted nearly half the water yield from the Truckee River. This diversion resulted in greatly decreased flows into Pyramid Lake and caused an 80 foot decline in the lake level between 1909 and 1968 and resulted in the formation of a delta at the mouth of the river around 1930. The delta and low flows prevented fish from ascending the river to spawn. The remaining trout population lived out their lives in the lake without being able to reproduce. The cui-ui spawned to some extent in the lake and probably on the river-lake interface and thereby maintained reduced population levels even though they were blocked from their primary spawning areas in the lower Truckee River.

The Washoe Project Act of Aug. 1, 1956 (70 Stat. 745) and recent court litigation initiated on behalf of the Pyramid Lake Paiute Indian Tribe has revived interest in the restoration of natural reproduction in the Truckee River, resulted in the construction of the Marble Bluff Dam and Fishway and Numana Dam fishladder, and current studies to determine stream flow requirements for spawning and rearing of Lahontan cutthroat trout and cui-ui in the Truckee River between Pyramid and Tahoe lakes.

GENERAL HYDROGEOGRAPHIC SETTING

The study area is dominated to the west by the Sierra Nevada and Lake Tahoe and to the east by the high desert country that is associated with Pyramid Lake. Lake Tahoe and Pyramid Lake are linked by the Truckee River which flows from Lake Tahoe and terminates 119 miles downstream in Pyramid Lake. Total area tributary to the river upstream from Pyramid Lake, including the Lake Tahoe basin, is about 1,900 square miles. The average annual flow at the state

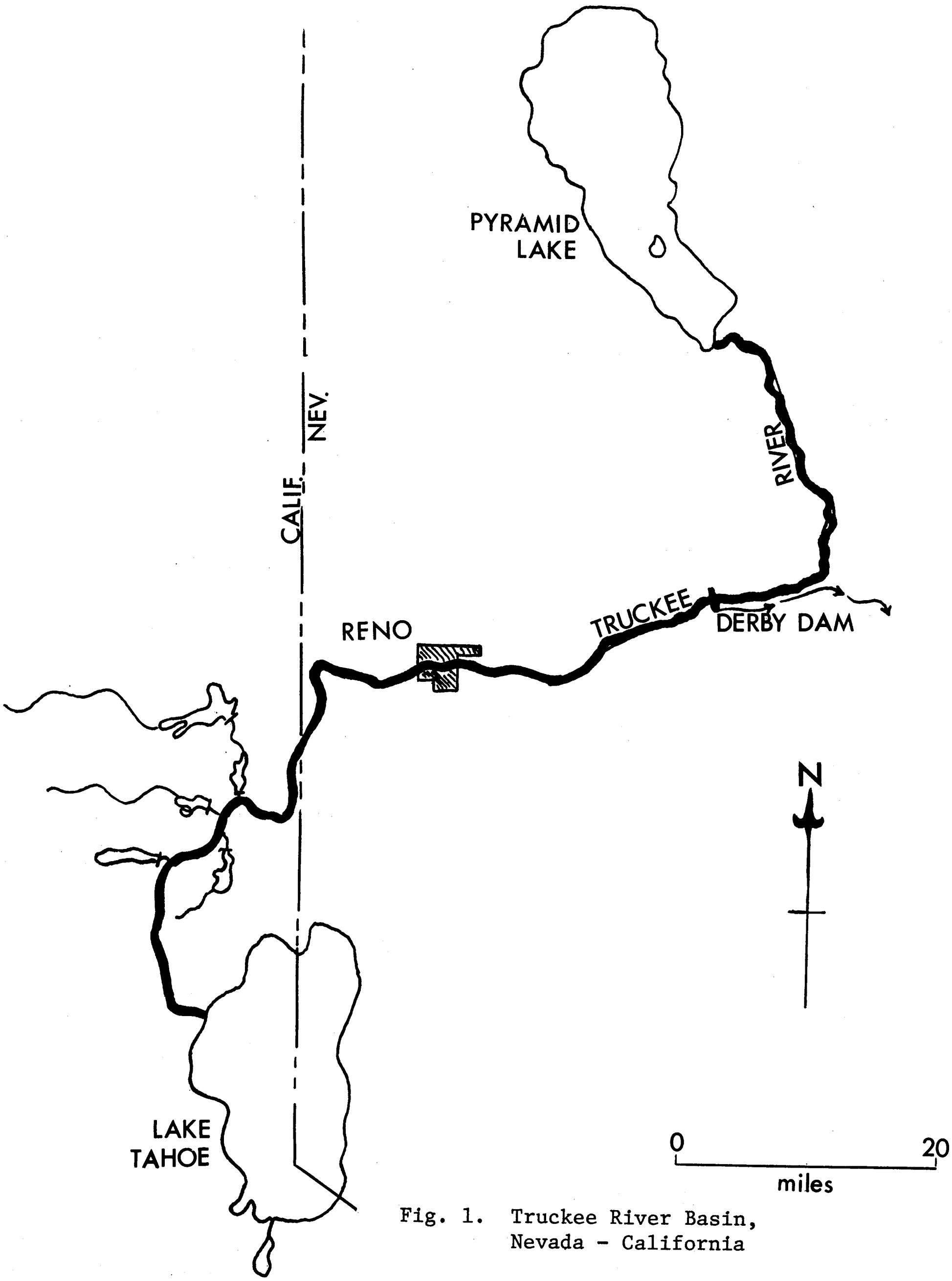

Fig. 1. Truckee River Basin,
Nevada - California

line between California and Nevada during 1919-69 was about 509,000 acre-feet, ranging from a low of 138,000 acre-feet in 1931 to a high of 1,300,000 acre-feet in 1952(Van Denburgh, et. al, 1973). During this same period average annual flow of 461,999 acre-feet arrived at Derby Dam with inflow into Pyramid Lake averaging 250,000 acre-feet.

Flow in the Truckee River is regulated according to a complex water-management program. Water is regulated from Lake Tahoe through a dam at the outlet. Water releases from Donner Lake and the major tributaries through Prosser Creek, Martis Creek, Stampede and Boca reservoirs are also man-controlled. Derby Dam, located about 25 miles below Reno, controls a transbasin diversion of Truckee River water to the Newlands Reclamation Project in the adjacent Carson River drainage. An additional 31 smaller diversion structures occur between Truckee, Calif. and Pyramid Lake and are utilized for power, domestic, industrial, and irrigation purposes (Ringo, 1975). At times, the total amount of water diverted exceeds the daily river flow by a magnitude of four, and attests to the reuse of water in the system and its importance in northwestern Nevada.

To define and evaluate the habitat conditions as they exist in the Truckee River today, and specify changes needed to reestablish and maintain natural spawning populations of Lahontan cutthroat trout and cui-ui, the following studies and methodology have been developed. The fishery instream flow methodology presented is unique when compared to other studies that have been conducted. This methodology incorporates other life history aspects not previously considered. The first major difference between this methodology and others from the Pacific Northwest is that it is being developed on a stream that does not have

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3. Van Denburgh, A.S., R. D. Lamke, J. L. Hughes. 1973. A brief water-resources appraisal of the Truckee River basin, western Nevada. U.S. Geological Survey Water Resources-Reconnaissance Series Report 57. 122 pp.
4. Ringo, R. D. 1975. A survey of Truckee River fish passage problems with emphasis on Lahontan cutthroat trout. U.S. Fish & Wildlife Service. 18 pp.

a natural Lahontan cutthroat trout or cui-ui population. All criteria for spawning and rearing depths and velocities must be obtained from other populations or from fish introcued into the Truckee River system. A second major difference is that this methodology is designed for a very comprehensive look at a single river system and is not being used in a statewide survey. The current program is expensive because of the detail that is needed in litigation. However, we feel our techniques can be applied on a more general basis to evaluate environmental degradation or monitor habitat conditions on other river systems. A third major difference is the development of a water temperature prediction model and several related studies that go beyond simple depth and velocity criteria. The basic components of our instream flow methodology for Lahontan cutthroat trout and cui-ui in the Truckee River is presented in Figure 2.

METHODOLOGY

Areas

The river will be divided into six major study area. Within each area depth and velocity stations will be established at five sites along the river. Each site will include a potential spawning riffle-pool area. These study sites will consist of a gridwork of sampling points where wetted perimeter, depth, and velocity will be evaluated at five different flows, including high, low and three intermediate values. Near bed velocity will be measured at 0.1 meter above the streambed (Chambers, et. al., 1955; Collings et. al., 1972).

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5. Chambers, J.S., Allen, G. H., Pressey, R. T. 1955. Research relating to study of spawning grounds in natural area. Annual Report to U.S. Army Corps of Engineers. Washington State Dept. Fisheries, 175 pp.
6. Collings, M. R., R. W. Smith, G. T. Higgins. 1972. The hydrology of four streams in western Washington as related to several Pacific salmon species. U.S. Geological Survey Water-Supply Paper No. 1968. 109 pp.

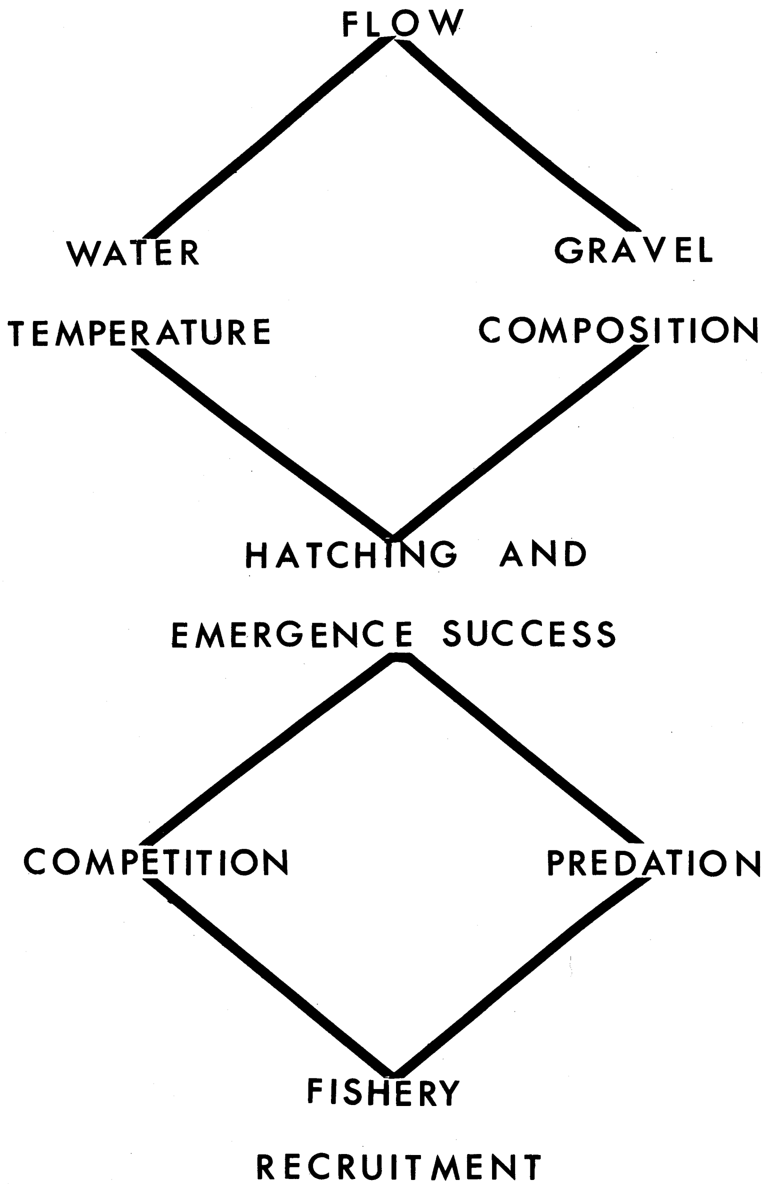

Fig. 2. Diagram of Fishery Instream Flow Methodology for Lahontan Cutthroat Trout and Cui-ui in the Truckee River, Nevada - California

The results will be mapped using a combination of techniques reported in Collings, et. al. (1972); Thompson (1972); Swift (1976). These techniques utilize a series of overlays of preferred depth and velocities and the development of criteria for spawning and rearing habitat. Areas of overlap will delineate preferred spawning and rearing areas or those areas where conditions are optimal.

Depth and velocity criteria for Lahontan cutthroat trout will be developed from two sources. Spawning depth and velocity criteria will be obtained from a natural spawning population in Mahogany Creek, a tributary to Summit Lake, Nevada. Additional spawning depth, velocity and transport velocity criteria will be developed from fish introduced into the Truckee River and fitted with radio transmitters. Adult migration patterns are being monitored from aircraft with redd location accomplished from the ground. Once a redd is located, extensive data measurements, including depths and velocities, are taken. Transport velocity criteria will be determined by evaluating the water velocities over irrigation diversions along the fish's migration route.

Depth and velocity criteria for the cui-ui presents a unique problem. The cui-ui is endemic to the Truckee River system but has not been allowed access to the lower river for 45 years. Adult cui-ui will be fitted with radio transmitters and released into the river below Derby Dam. Their migration patterns and eventual spawning sites will be monitored for depth, velocity and substrate preference. Data on these factors is not currently available.

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7. Collings, op cit.

8. Thompson, K. 1972. Determining stream flows for fish life. Pages 31-50 in Instream Flow Requirement Workshop, March, 1972. Pacific Northwest River Basins Commission, Vancouver, Wash.

9. Swift, C. H. 1976. Estimation of stream discharges preferred by steelhead trout for spawning and rearing in western Washington, U.S. Geological Survey Open-File Report 75 - 155. 50 pp.

Water Temperature

Water temperatures in various stretches of the river can be predicted using a temperature prediction model (Rowell, 1975). The model is based on a high, low or average daily maximum air temperature. In addition, hydrological input includes river mileage, average stream width, stream velocity, discharge, water temperatures at the beginning of each study section and effluent discharges and their temperatures. The model very closely approximates natural temperature conditions in the river. A five day forecast is also available. This forecast allows water releases to be regulated to maintain suitable water temperatures for spawning and rearing. In short, at any given flow and weather conditions, water temperatures in the Truckee may be accurately predicted.

Gravel Composition

Another major factor considered in our methodology is gravel size composition. The lower 64.4 Km (40 miles) of the river was once part of ancient Lake Lahontan. As a result, the river channel has cut through vast sediment deposits. Most of the fines in the spawning gravels are less than 0.84 mm in diameter. This fine silt acts like glue in cementing the gravel together.

In order to evaluate the spawning gravel composition in the river, the river was divided into six study areas. Area boundaries were chosen according to river topography, adjacent land uses, and water withdrawals. Each area was surveyed for potential spawning sites. A maximum of five sites were chosen in each area. At each site, two transects, consisting of ten core samples each were established. The methods of collection and analysis were similar to McNeil and Ahnell (1964). The core samples were dried and sifted through 10

10. Rowell, J. H. 1975. Truckee River temperature prediction study. U.S. Bureau of Reclamation, Sacramento. 56 pp.

11. McNeil, W. J. and W. H. Ahnell, 1964. Success of pink salmon relative to the size of spawning bed materials. U. S. Fish & Wildlife Service, SSR, Fish. No. 469. 15 pp.

standard sieves (58.8 mm opening to 0.10 mm). Volumes of larger sizes were obtained by displacement with volumes of finer material ($<$3.35mm) obtained by direct volumetric readings. Each size range was calculated as a percentage of the total sample volume.

Hatching and Emergence Success

Once gravel size composition is established, controlled laboratory and field studies can be initiated to determine potential hatching and fry emergence success. The laboratory studies consist of a series of small troughs filled with gravel. Sediment or fines will be added to duplicate: 1) "clean" gravels, 2) the highest percentage of fines found in the river, and 3) three intermediate values. The eggs are planted in Vibert egg boxes and embryonic survival is determined at the "green", "eyed" and alevin stage of development. Emergence success will be evaluated by placing eyed eggs in various mixtures of gravel and fines. Swim up fry will be counted as they emerge from the gravels. Intragravel flow, dissolved oxygen, and water temperature will be monitored twice weekly.

The field study sites will be located at various locations along the river. Artificial redds will be dug and eggs within Vibert egg boxes placed in the redds. The egg's embryonic development will be monitored at the same stages mentioned above. Intragravel flow, dissolved oxygen, heavy metals and water temperature will be monitored periodically.

Cui-ui studies will be limited to hatching success. Cui-ui are broadcast spawners so fry emergence need not be evaluated. Cui-ui eggs will be broadcast over various substrates ranging from rubble to silt. Substrates will also duplicate natural conditions in the lower river.

Competition and Predation

We are in the process of developing a study to determine how much, if any interspecific competition occurs between juvenile Lahontan cutthroat and brown and/or rainbow trout. The study would probably include placing adults into a small tributary stream under controlled conditions. The adults would be allowed to spawn naturally. The fry would be periodicallly placed, in known numbers, into a competitive situation with juvenile browns and/or rainbows. This mixed population would be sampled periodically to determine interspecific competition.

The predation aspects of the study are secondary in nature. An intensive fish population sampling is planned. We will examine stomachs from various predators captured to determine to what extent juvenile trout are utilized as prey organisms.

MANAGEMENT APPLICATIONS

The methodology outlined in this paper has one primary purpose. That purpose is to utilize all of the factors discussed above to allocate a limited stream flow in order to effectively manage one threatened and one endangered species. A brief review of the methodology outlines our rationale. At any given time in the river, the amount of flow is known. At a given flow, we will know the wetted perimeter, depths, near bed velocities and water temperatures at our major spawning riffles, rearing areas and migration barriers. If the wetted perimeter, depths and velocities over spawning areas are know, we can predict the amount of area suitable for spawning. In this area, we know the gravel size composition and particularly the amount of fines in the gravel. Our laboratory and field studies will give us an indication of potential hatching and emergence success that we might expect with a given gravel composition. Therefore, we can predict the number of fry emerging into the system. The competition and predation study will allow us to determine juvenile mortality. The end result is that we will have some idea what the recruitment to Pyramid Lake might be.

We must admit that this methodology is expensive and requires a lot of manpower to implement. However, when a stream is extremely important to an entire state, plagued by periodic water shortages, subjected to heavy water withdrawals and the only water source to one of the potentially finest quality trout fisheries in the world, then we feel the cost is justified. In addition, this river holds they key to success or failure of the endemic cui-ui. We feel that by properly allocating the flow in the Truckee River and minimizing water waste, we can satisfy all of the demands for the water without seriously affecting any single user group.

DEVELOPMENT OF METHODOLOGIES FOR EVALUATING INSTREAM FLOW NEEDS FOR SALMONID REARING

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ABSTRACT

A methodology is being developed that can be used in natural streams to estimate the influence of stream discharge on carrying capacity of salmonids. A habitat rating system has been developed for juvenile coho salmon which explains 72% of the variation recorded in fish biomass in six study sections at three different flow levels. Methods are proposed for evaluating instream flows for salmonid rearing which combines an evaluation of habitat quality and water quality over a range of flow levels.

INTRODUCTION

The maintenance of adequate instream flows to support aquatic life is recognized as a major problem. In Oregon the primary concern is the protection of resident and anadromous salmonids. The Oregon Department of Fish and Wildlife has recommended minimum and optimum flows by month for several hundred streams based on the passage, spawning, incubation and rearing requirements of the salmonid species present (1). Of these requirements, the relationship between rearing and flow is the least understood.

In 1968 the Environmental Management Section of the (then) Oregon Wildlife Commission requested that research be initiated to develop improved methods for recommending rearing flows for salmonids. As a result, a literature survey was initiated in 1971 (2) and preliminary investigations into possible research designs and methods were conducted on Elk Creek, a coastal stream, in the summers of 1973 (3) and 1974 (4). A study designed to measure and evaluate salmonid habitat and carrying capacity over a range of controlled constant flows was implemented in summer 1975.

METHODS

A wood piling weir and a 76 cm diameter corrugated metal pipe divert water from the North Fork of Elk Creek to the West Fork. A head gate provides control of flows through the study area. The weir is located on the North Fork 1.2 km upstream from its confluence with the West Fork.

Six 30 m study sections were established in the stream below the flow control facility. Each study section was separated from the remainder of the stream by screens and traps. Each section was stocked at a rate of 2 fish/m^2 with age 0+ coho salmon *(Oncorhynchus kisutch)* collected elsewhere in the stream.

Three constant discharge levels were studied during three two-week experiments. The flows were 84.9, 63.7, and 42.5 l/sec and represent the approximate 5-year recurrence interval, 7-day average low flow[1/] and 25% and 50% reductions from same. In each experiment, depths and velocities were measured on 22 cross-sectional transects (at 1-2 m intervals) in each study section. Substrate and cover types were evaluated for each transect in the first experiment. At the end of each experiment fish biomasses were estimated. Water chemistry and temperature were monitored weekly and continuously, respectively.

EVALUATION OF STREAM HABITAT FOR SALMONIDS

As a result of research conducted on Elk Creek in 1975 a system for evaluating coho salmon habitat has been developed. This system is based on a weighting of individual observations taken on cross-sectional transects. The weighting factor consists of a "habitat index" and a species-specific cover preference factor. The "habitat index" is the sum of values developed for a water type, cover, and substrate associated with each observation. These values are derived from a numerical ranking of specific types within each of the three categories (Table 1). The ranking is based on the relative value as coho salmon habitat of one type compared to other types in the same category.

Water Type

This category is used to rank depth and velocity at a given observation point in terms of the requirements for coho salmon habitat. Coho juveniles prefer depths >30 cm and velocities <30 cm/sec[2/]. Depth and velocity

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[1/] John F. Orsborn, personal communication.

[2/] Oregon Department of Fish and Wildlife, unpublished data.

Table 1. Criteria for rating the habitat of two different types of streams for two different salmonid species.

HABITAT INDEX CRITERIA	
A. Species: Coho Salmon - Age 0+	
Stream: Elk Creek	
Habitat Categories:	
Water Type	Value
Prime Depth >30 cm Velocity <30 cm/sec	2
Marginal Depth ≤ 30 cm Velocity <30 cm/sec	1
Cover Type	
Undercut banks and submerged roots	2
Overhanging cover and submerged logs and limbs	1
No cover	0
Substrate Type	
Cobble	2
Gravel	1
Sand, Silt or Clay	0
B. Species: Brown Trout - ≥ 15.2 cm (6 in.)	
Stream: Little Deschutes River	
Habitat Categories:	
Water Type	Value
Prime Depth >30 cm Velocity 12-21 cm/sec	2
Marginal Depth ≤ 30 cm Velocity ≤ 21 cm/sec	1
Cover Type	
Undercut banks, overhanging willows and submerged roots	2
Aquatic vegetation and submerged logs and limbs	1
No cover	0
Substrate Type	
Cobble	2
Gravel	1
Sand, Silt, Clay or Bedrock	0

combinations within these ranges are considered to be prime habitat and are given a value of "2". Depths <30 cm combined with velocities <30 cm/sec are considered marginal habitat and are given a value of "1". Locations with velocity observations of 30 cm/sec or greater are considered unsuitable habitat for coho salmon. Observations from locations unsuitable for coho salmon habitat receive a "habitat index" value of "0".

Cover

On streams without an overhead canopy of trees, streambank cover such as overhanging vegetation and undercut banks is an important source of shade, which salmonids prefer (5, 6). However, since much of Elk Creek has a full canopy of alder, cover is ranked on the basis of its value as a source of protection from avian predators rather than for its value as shade. Undercut banks and submerged root systems are judged to provide the best protection for juvenile coho and are given a value of "2". Overhanging cover within 1.5 meters of the surface and submerged logs and limbs are given a value of "1" and the absence of cover is given a value of "0". The value of substrate as cover will be discussed later. Individual observation points along a transect are given a cover rating based on the best cover within 30 cm.

The preference for cover of a given salmonid species is taken into consideration in the habitat rating system. Preference for cover is ranked as follows:

high preference for cover = 3;
medium preference for cover = 2; and
low preference for cover = 1.

Examples of species with each of these preferences are brown trout *(Salmo trutta)*, rainbow trout *(S.gairdneri)* and coho salmon, respectively.

Substrate

The substrate at each observation point is ranked on the basis of size. Cobble (>75 mm diameter) is given a value of "2" because it can provide cover (7, 8) and has a greater potential for food production compared to smaller substrate (9, 10). Gravel is given a value of "1" based on its potential for food production. Sand, silt and clay have little value as cover or for food production and therefore receive a value of "0".

Habitat Quality Rating

The habitat of a section of stream is evaluated on the basis of individual observations.

Let HI be the habitat index value which is equal to the sum of the water type value, the cover value and the substrate value and has a possible range of 1 to 6;

N be a species-specific constant which reflects the degree of preference of a given species for cover (e.g. for coho $N = 1$);

OB_{HI} be the number of observations having a value of HI; and

TOB be the total number of observations taken in the particular section of stream in question.

Then, the habitat quality (HQU) for the section of stream is calculated from the equation:

$$HQU = \sum_{HI=N}^{6} (HI - N) \left(\frac{OB_{HI}}{TOB} \right) \qquad (1)$$

An example of the calculation of HQU is presented in Table 2.

Table 2. Calculation of the habitat quality (HQU) for coho salmon of experimental section 1 at a flow of 5.1 m^3/sec. For coho the value of N is 1.

HI	$HI-N$	OB_{HI}	$\frac{OB_{HI}}{TOB}$	$(HI-N)\left(\frac{OB_{HI}}{TOB}\right)$
6	5	0	0.000	0.000
5	4	5	0.016	0.064
4	3	10	0.032	0.096
3	2	40	0.128	0.256
2	1	174	0.558	0.558
1	0	20	0.064	0.000
0		63		
		$TOB =$ 312		$HQU =$ 0.974

At present, the habitat rating system described above is specific for coho salmon in Elk Creek. The habitat quality ratings of the six Elk Creek study sections at three flow levels explained 72% of the variation in the coho salmon biomass of the sections (Fig. 1). Additional research is underway to determine its applicability to other streams and species. An example illustrating how the system could be applied to another stream and species is presented in Table 1.

When evaluating the habitat of a different type of stream for coho salmon, alterations must be made in the "cover" and "substrate" categories to include types not found in Elk Creek. For example, on the Little Deschutes River, (Table 1, B) which lacks the alder canopy found on Elk Creek, overhanging willow is an important source of cover. On Elk Creek overhanging cover is not as important. When evaluating the habitat for a different species, the depth and velocity preferences and the value of N in equation *(1)* must be adapted to the new species (e.g. for brown trout, $N = 3$).

A PROPOSED METHODOLOGY FOR EVALUATING INSTREAM FLOWS FOR SALMONID REARING

The proposed methodology for evaluating instream flows for salmonid rearing is based on the premise that the carrying capacity of a stream for a given species will change as the stream discharge changes. As the instream flow is reduced, changes which affect salmonid carrying capacity will take place not only in the habitat quality (in terms of *HQU*) but in water quality.

The important water quality parameters are water temperature and dissolved oxygen content. When the flow level drops in most streams the temperature increases and dissolved oxygen decreases. Temperatures of 22-25°C have been shown to be lethal to Pacific salmon *(Oncorhynchus spp.)* (11). Sublethal effects such as decreased growth also result from increased temperature (12). Davis (13) reports that if prolonged beyond a few hours, a dissolved oxygen level of 6.0 mg O_2/liter can result in some risk to a portion of an average freshwater salmonid population. A level of 4.16 mg O_2/liter can result in severe deleterious effects to the population. He considers a level of 7.85 mg O_2/liter to be a safe level.

There are some streams in which water quality would not be a factor limiting salmonid carrying capacity when the flow is reduced. In these streams the carrying capacity is controlled primarily by the habitat quality (Fig. 2).

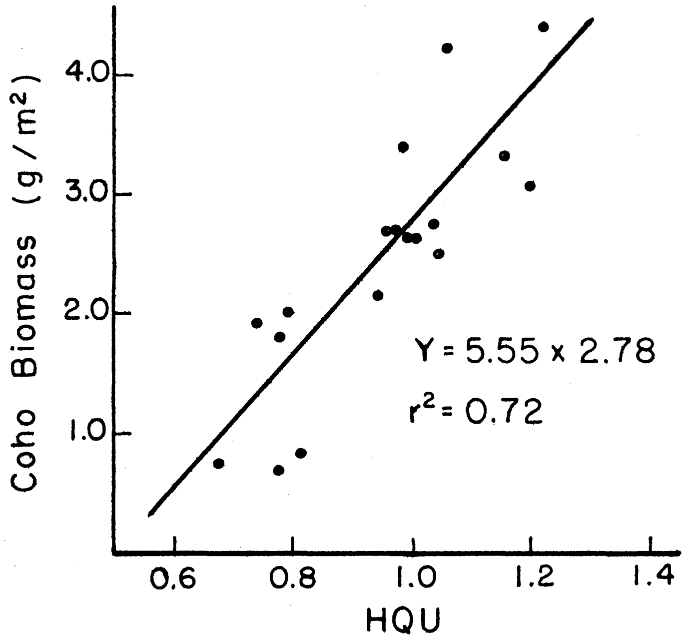

Fig. 1. The Relationship Between Habitat Quality (HQU) and Coho Salmon Biomass in Six Elk Creek Study Sections at Flows of 84.9, 63.7 and 42.5 l/sec.

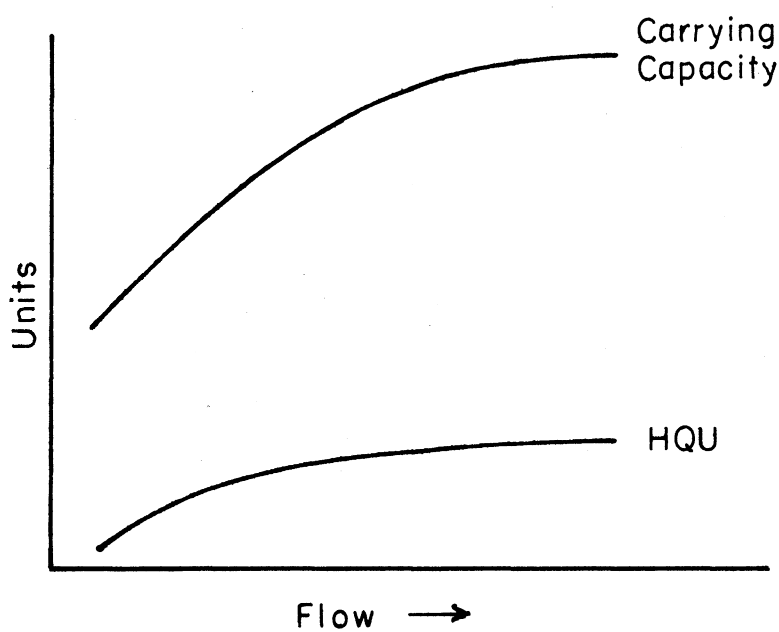

Fig. 2. A Hypothetical Example of Flow Reduction Decreasing Carrying Capacity Through Changes in Habitat Quality (HQU)

However, for many streams there will be a critical flow level above which carrying capacity will be determined primarily by habitat quality and below which carrying capacity will be limited by water quality (Fig. 3). This critical flow level might, for example, be the flow which results in a reduction of the dissolved oxygen content of the stream to 6.0 mg O_2/liter or an increase in temperature fo 22°C.

The methodology proposed consists of two parts. The first part is the identification of the critical flow level of a stream determined by monitoring water quality over a range of flows. The second part is to evaluate the habitat of a typical section of stream for the species of interest over the same range of flows using the habitat rating system described. The carrying capacity of the stream at flows above the critical level could be estimated from the habitat quality using species-specific relationships as presented in Fig. 1. The minimum flow recommendation would then be the flow which yields the lowest acceptable carrying capacity.

It should be remembered that this is a proposed methodology and has not been tested. We are continuing our work to refine the techniques employed in the methodology and to test its applicability to streams of different sizes and geographic locations.

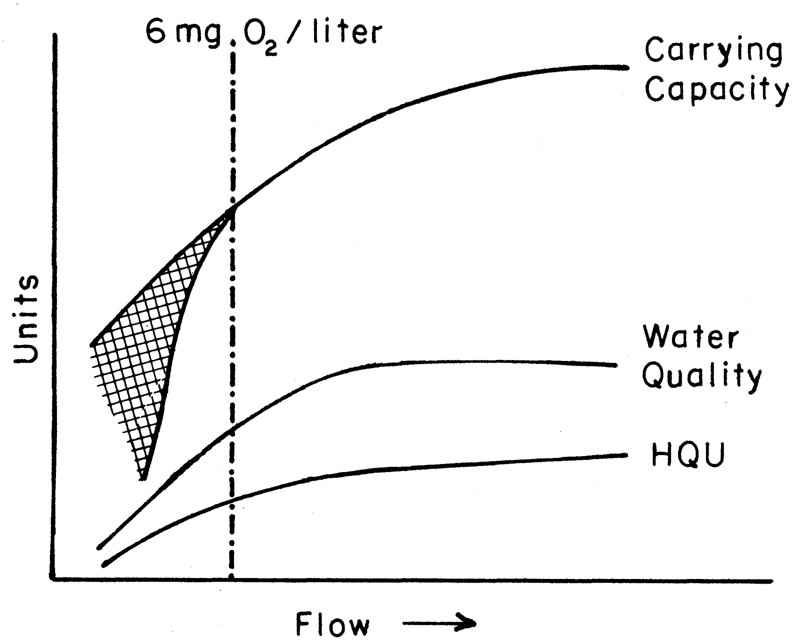

Fig. 3. A Hypothetical Example of Flow Reduction Decreasing Carrying Capacity Through Changes in Habitat Quality (HQU) and Then Below Some Critical Flow Level Through Changes in Water Quality. (Cross-hatched areas indicate decrease in carrying capacity due to water quality.)

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RELATIONSHIP OF TROUT ABUNDANCE TO STREAM FLOW IN MIDWESTERN STREAMS

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ABSTRACT

Most Midwestern trout streams are located in Wisconsin and Michigan, as climate and groundwater geology are most favorable in these states. There is concern that surface and groundwater withdrawal for irrigation and other uses in this region will reduce streamflow quantity and stability and that this will adversely affect trout populations.

Literature on hydrology and trout in the region is reviewed. New analyses of the relationship of streamflow discharge to abundance of young trout and to trout population biomass are presented, using data from six streams.

Streams with the most stable flow generally support the most trout. January-February discharge (believed to represent winter base flow) was more often a significant variable than was June-through-August discharge, winter high water or spring high water. However, in streams subject to severe flooding, spring and especially winter high water were negatively related to trout abundance.

It is inferred that in Midwestern streams, maintaining base flow is important to maintaining trout populations and that trout abundance can be increased by enhancing base flow.

INTRODUCTION

The Midwest is "water-rich" compared to most of the western U.S. and has relatively uniform annual precipitation distribution compared to rainy parts of the West. The Lake States contain an amount of fresh surface water rivalling any region of the world. Michigan possesses more fresh water than any other state, if one includes her portion of 4 Great Lakes.

Only a small percentage of the Midwest's water is in the form of streams suitable for trout. The trout stream resource is concentrated in the north, central and west parts of Wisconsin and the Lower Peninsula of Michigan, and throughout Michigan's Upper Peninsula. There is a scattering of trout streams in eastern Minnesota and northeastern Iowa.

Most of the streams originate from aquifers in sandy-gravelly glacial deposits, while those in the unglaciated area of the Minnesota-Iowa-Wisconsin juncture arise as limestone springs, and some in Michigan's Upper Peninsula and along the Lake Superior shore of Minnesota flow over igneous bedrock. Much of the water termed "trout stream" in the Midwest is of marginal quality for trout. Many trout populations are isolated at least seasonally by water of unfavorable temperature or by downstream impoundments. The trout zones of several hundred streams might be considerably extended if impoundments such as 19th century mill ponds and antiquated power-generation flowages could be removed. But most of these have assumed the status of recreational lakes, and they disappear only when the dams fail and the owners cannot afford to rebuild. The typical Wisconsin trout stream is a small spring brook which loses its favorable temperatures 10 to 20 kilometers below the headwaters. The typical Michigan stream has a greater length of trout water. There are few large streams that merit designation as "trout rivers." About 6 exist in Wisconsin. Michigan has 10 or more in the Lower Peninsula--most of them radiating from two great heaps of porous glacial drift material over 230 m (750 ft) thick in the northeast part--and a few others are in the Upper Peninsula.

A relatively new threat to stream flow in the Upper Midwest is crop irrigation. Potatoes have been spray-irrigated for several decades in northeastern Wisconsin, and vegetables have been raised by this method in the central sand plain of that state for about 15 years. A good example of the impact of irrigation on midwestern trout streams is the history of Big Roche-a-Cri Creek. The Roche-a-Cri has, since about 1960, owed much of its flow variability to ground water pumpage for irrigation. By 1967, 31% of the basin above the study area gaging site was under irrigation. In years of average rainfall, the 1967 level of irrigation stood to reduce flow at the gage site by 20-30% and by greater percentages in dryer years. Had the irrigated acreage of 1967 existed during the severe drought of 1958, flow of the Roche-a-Cri near the midpoint of the study area would have been depleted by 60% (Weeks and Stangelund, 1971:79). In Fig. 1 is depicted the low water condition that would have occurred nearer the headwaters had the irrigation farming prevailed in 1958. Upstream of that point, much of the stream bed would have been dry (Hine, 1970:22). If the entire 71% of the basin which is in crops or pasture becomes developed for irrigation, depletion of normal-year flows will probably increase to 50-60%, and even with little increase in irrigation, flow of the main trout zone will virtually stop whenever drought as severe as that of 1958 again occurs (Weeks and Stangelund, 1971:87).

Irrigation farming may soon spread to Midwestern soils and crops not previously thought in need of artificial watering. As agricultural science pushes back such production barriers as soil fertility, plant genetics, planting schedules, harvest techniques and tillage practices, soil moisture increasingly forms the bottleneck to crop yield. Rain seldom falls just when the new high-yield crops most need it--even in the water-rich Midwest.

Nobody really "owns" the water of any stream in Wisconsin or Michigan. The States hold the streams in public trust. In Michigan since 1972, no alteration of the bed, banks or flow of streams (certain "county drains" excepted) may be done without a permit from the State Department of Natural Resources. This regulation pertains no matter how small the trickle may be, as long as it is connected by any surface route with water that is indeed navigable. Almost all running water in Michigan is connected with the Great Lakes which are eminently navigable.

In Wisconsin, there may be no alteration or diversion of a "navigable" stream. Navigability used to be defined in that state by the ability of the waterway to float a 10-inch diameter saw log. Some Wisconsin Conservation Department officials long considered as navigable any stream in which a trout could swim--even if it had to swim on its side to do so. In 1975 a Wisconsin court held that streams are navigable which will float the smallest sort of recreational craft at some time of year, even if that time is the spring flood. This definition includes many streams which are actually waterless for part of the year and places them under protection of the State permit procedure. Essentially, the public as the right to navigate or otherwise use these waters non-consumptively.

Riparian owners of the region have certain closely controlled special rights to use of stream water. The concept prevails under a "reasonable use" doctrine that riparians may withdraw (or by impoundment, withhold) only such water as is <u>surplus</u> to that needed for maintaining conditions in the stream which are in the public interest.

Sustaining fish populations for recreational fishing is considered to be in the public interest. In general, even the riparian must not take away such water as would diminish the stream's capacity for sustaining fish. This, and the recognized detriment to navigability and other uses, restricts what people can remove directly from the stream, but not what may be pumped from the groundwater that feeds the stream. Legal control of groundwater withdrawal may develop as conflict over the supply intensifies.

The question that arises when someone wishes to take water from an Upper Midwestern stream--and in the future perhaps in regard to groundwater pumping--is: How much water can be withdrawn without adversely affecting the fish? Put more simply: What water is "surplus" to a fish or fish population?

METHODS

Data were compiled from streams where electrofishing mark-and-recapture estimates of trout populations had been conducted for several consecutive years and where applicable streamflow records existed. Published data, as well as original data from the files of the authors and others were used. In particular, data from 6 streams (Table 1, Fig. 2) were analysed:

Table 1. Characteristics of study streams.

Stream, Study Sections	Total Study Area Length (km)	Annual Mean Discharge (cfs) Avg.	Annual Mean Discharge (cfs) Range	Unit Area Discharge (cfsm)	Kind of Trout
Wisconsin Streams					
Big Roche-a-Cri Cr. A-D	11.0	9	7-13	0.7	Brook, few brown
Lawrence Cr. A-D	5.4	17	16-19	2 (est)	Brook
Black Earth Cr. A-D	9.0	27	18-42	0.4	Brown
Michigan Streams					
Pigeon R. A-D	9.7	77	53-80	1.2	Brook, brown
Hunt Cr. B, C	1.7	24	19-27	2.2	Brook
North Branch AuSable R.	0.4	200	?	1.0	Brook, brown

Although a much longer record of trout population inventories exists at Hunt Creek, 1966-75 was selected for analysis, as angling was prohibited in the study area during this period. Previously, the study area had been subject to periodic experimental changes in angling regulations. Sections B, C were selected from the total area (Z,A,B,C) because B,C served during 1966-75 as an unaltered control in a test of effects of sand injection into Z,A.

Such selection of data record periods or subsections of the study areas was not done on the other streams, even though most of them underwent considerable experimental manipulation of angling regulations and/or habitat during the periods of observation. In all cases other than Hunt Creek, the stream sections included in analysis were those for which the longest period of observation existed.

Biomass estimates were made by the following methods: 1) In Big Roche-a-Cri and Lawrence Creeks, most of the fish had been individually weighed during the electrofishing for each population estimate. The point estimate of the number of fish in each inch group of each species within each subsection of the study area was then multiplied by the appropriate mean weight and the inch-group biomasses totaled. 2) At the Pigeon River, the mean length-weight relationship for each species obtained in 1950-51 was applied to the inch-group numerical estimates of each year. 3) At Hunt Creek a length-weight relationship of brook trout obtained from the North Branch of the AuSable River was applied to inch-group estimates for each year.

Streamflow discharge data were available from gaging stations within the trout population study areas at Big Roche-a-Cri Creek, Lawrence Creek and the Pigeon River, whereas at Black Earth Creek the gaging station was ca. 3 km downstream from the lower end of the study area and for Hunt Creek and the North Branch of the AuSable River flow records from much more distant stations were used in our analyses (Table 2).

Table 2. Sources of streamflow discharge data.

Stream	Gaging Station
Big Roche-a-Cri Cr.	USGS gage #5-4015.1 (Hancock, Wis.) near center of study area, also previous Wis. Dept. Natural Resources gage at same site. Certain values for missing data from modeling of this station's flow by Weeks & Stangelund (1971).
Lawrence Cr.	Wis. Dept. Natural Resources gage near center of study area.
Black Earth Cr.	USGS gage #5-4065 (Black Earth, Wis.) ca. 3 km below lower end of study area.
Pigeon R.	USGS gage #4-1290 (Vanderbilt, Mich.) within study area.

Table 2 (cont.)

Stream	Gaging Station
Hunt Cr.	a) USGS gage #4-1335 (Bolton, Mich.) on Thunder Bay R. ca. 50 km downstream from study area. b) USGS gage #4-1356 on E. Branch AuSable R. (see below) ca. 50 km southwest of study area.
North Branch of AuSable R.	USGS gage #4-1356 (Grayling, Mich.) on E. Branch AuSable R. ca. 20 km west of study area.

Simple and multiple regression anaylses were used to examine for possible influence of streamflow variables on number of age-0 trout (young-of-the-year) present in fall and on standing crop (kg per stream-km) of the trout population in spring and fall. The major streamflow variables used were: 1) the January-February mean discharge in cfs, believed to generally represent winter base flow; 2) the maximum cfs-day between November 1 and March 10, as an indicator of the severity of winter high flow; 3) the maximum cfs-day for the period March 11-May 31, as the extreme of the spring runoff; and 4) the June-August mean discharge, taken to represent summer flow. September data were not considered in summer flow, as discharge often increases substantially in September, and the base flow influence may be proportionally less in that month. Certain trout populations were also used as independent variables in some of the analyses. Tables 3 and 4 list which variables were used in each analysis.

RELATIONSHIP OF FLOW TO NUMBER OF YOUNG TROUT

Pigeon River

A direct linear correlation between autumn number of age-0 brook trout and groundwater level was reported for the 9 years, 1949-57, in each of two segments (section B and sections C,D) comprising 5.6 km of the Pigeon River (Latta, 1965). Groundwater level appeared to account for more than 70% of variability in number of age-0 brook trout. Brown trout did not show the same relationship. Latta inferred that higher groundwater levels caused greater baseflow discharge in the river, resulting in survival of greater numbers of brook trout fry during the critical few weeks after emergence from the stream bed. He speculated that baseflow benefitted the young brook trout by enhancing food supply. We would add that greater baseflow may produce more favorable temperature and, owing to higher water level in the stream, there would be more space for territories and perhaps more hiding cover in vegetation of the stream edge. Also, in years of lower flow and less space (and food?), many young trout may have emigrated from the area. Emigration may often be confused with mortality in such population studies.

In contrast to the implications of Latta's analysis, we find in using the 17 years of observations now available (1949-65) that no significant relationship is evident between age-0 brook trout abundance and streamflow variables, including winter and summer discharges which may roughly represent base flow (Table 3). Also in contrast, number of brown trout young does appear to be related to flow variables--positively with Jan-Feb discharge and inversely with Jun-Aug discharge (Table 3). The regression model accounts for only 37% of observed variation in number of young brown trout, and the inverse relation with Jun-Aug flow is puzzling.

North Branch of AuSable River

From the regression model in Table 3, we infer that for age-0 trout (brook and brown together) to be abundant in this stream, there must be substantial winter base flow, lack of severe spring floods and plentiful summer flow. The model accounts for 95% of observed variation in total age-0 population, with 99.9% confidence that these variables explain the variability in age-0 brook trout population (P=.001).

Taken as separate populations, no significant relationship of brook trout young to the same flow variables was found, and number of age-0 brown trout appeared to be proportional to Jan-Feb flow and inverse to Jun-Aug flow--as in the case of Pigeon River age-0 brown trout--with the model accounting for 83% of variation.

Hunt Creek

No significant relationships were evident when using the data for the 10-year period, 1966-75 (Table 3). However, if 1975 is deleted from the analysis, a strong negative correlation between age-0 brook trout abundance and winter high water occurance emerges, with 82% of variability explained with 99.9% confidence (P=.001). That the 1975 data departed from this strong relationship may somehow be attributable to the fact that the maximum winter cfs-day that year was even lower than mean flow of the lowflow month in most winters. Moreover, 1975 Jan-Feb discharge was the lowest of the period of observation. It is quite

Table 3. Multiple regression analyses (backward elimination procedure) of autumn age-0 trout populations (Y) on streamflow variables and on spring age-I population.

X_1 = max cfs day, Nov 1-Mar 10
X_2 = mean cfs, Jan-Feb
X_3 = max cfs-day, Mar 11-May 31
X_4 = mean cfs, Jun-Aug
X_5 = peak momentary cfs, Nov 1-Mar 10
X_6 = peak momentary cfs, Mar 11-May 31
X_7 = number of age-I brook trout in April

Stream, Years, Trout Spp.	Variables Entered	F for Removal from Regression	Regression Model	R^2	P
Pigeon River 1949-65 (n=17)					
Brook	X_1 X_2 X_3 X_4	3.2	none*		
Brown	X_1 X_2 X_3 X_4	3.2	$Y = 3967 + 118X_2 - 163X_4$ (F=3.46, F=8.00)	37%	.040
Brook+brown	X_1 X_2 X_3 X_4	3.2	none*		
North Branch AuSable River 1959-67 (n=9)					
Brook	X_1 X_2 X_3 X_4	4.5	none*		
Brown	X_1 X_2 X_3 X_4	4.5	$Y = 1105 + 105X_2 - 77X_4$ (F=30.1, F=9.80)	83%	.004
Brook+brown	X_1 X_2 X_3 X_4	4.5	$Y = 1598 + 75X_2 - 21X_3 + 63X_4$ (F=44.3, F=15.7, F=5.8)	95%	.001
Hunt Creek (on Bolton gage flow)					
Brook	X_1 X_2 X_3 X_4 X_7**	4.1	none*		
1966-74 (n = 9--1975 omitted)					
Brook	X_1 X_2 X_3 X_4 X_7**	4.1	$Y = 3977 - .897X_1$ (F=32.2)	82%	.001
Big Roche-a-Cri Creek 1957-65 (n=9)					
Brook	X_2 X_4 X_7	4.1	none*		
Black Earth Creek 1955-63 (n=9)					
Brown (mean cfs of water-yr)			$Y = -1183 + 67.3X$ (F=13.8)	66%	.007
Brown	X_1 X_2 X_3 X_4	4.2	$Y = -1989 - 5.3X_1 + 141X_2$ (F=7.79, F=17.3)	75%	.017
Brown	X_2 X_4 X_5 X_6	4.2	$Y = -1924 - 3.4X_5 + 142X_2$ (F=14.4, F=28.8)	83%	.005

* No variable meets F-criteria
** Number of fish in 5 and 6-inch groups taken as estimate of spring age-I population.

possible that extremely low winter base flow (and attendant poor groundwater upwelling?) adversely affected the eggs and/or fry--even though Jan-Feb flow did not generally seem to correlate with number of young brook trout in this stream.

Big Roche-a-Cri Creek

Number of age-0 brook trout was regressed on Jan-Feb flow, Jun-Aug flow and springtime abundance of age-I brook trout without emergence of evidence of significant relationships. Data on winter and spring maximum flows did not exist for many years on this stream. Springtime age-I abundance was included as an independent variable, as White and Hunt (1969) had found inverse correlation of fall age-0 and spring age-I brook trout populations in Lawrence Creek and suggestions of the same relationship in Big Roche-a-Cri Creek. The best model to result from multiple regression backward elimination indicated inverse relationship to spring age-I and direct relationship to Jun-Aug flow (R^2 = 41%, P = .209). Perhaps with inclusion of a variable to account for change in hiding the cover, the model could be improved, as most of the study area underwent intensive habitat management during the period of observation (White, 1972, 1975).

Black Earth Creek

The best model found for the relationship of number of age-0 brown trout in Black Earth Creek with flow variables was that involving peak momentary discharge during winter and Jan-Feb flow (Table 3). This combination explained 83% of variation in age-0 brown trout population with 99.5% confidence of prediction. The relationship with the combination of winter maximum cfs-day and Jan-Feb flow was somewhat less strong. We infer that severity of winter flooding diminishes populations of young brown trout (at the embryo, sacfry or fry stage) and that substantial winter base flow enhances survival of the young.

In Black Earth Creek, all the winter peaks occurred after February 9, except one which was on January 13. This contrasts with the Michigan streams, where winter peaks were distributed throughout the season. As the typically late winter peaks of Black Earth Creek were suspected to be a part of the onset of spring thaw (although some of the coldest weather can occur in mid-February), a tabulation was made of peaks for the period February 1 through April 15 and this variable entered with Jan-Feb flow and Jun-Aug flow. The result was a non-significant model.

Mean discharge for the October-September water-year predicts 66% of variation in autumn age-0 brown trout population with 99.3% confidence (Table 3).

This strong correlation had been found previously by Dunst (1971). The model involving winter peak flow and Jan-Feb flow appears to more closely describe the dependence of young brown trout on streamflow in Black Earth Creek.

Lawrence Creek

The relationship of abundance of young brook trout to stream flow was not investigated, as number of young during the long record for this stream is highly variable, and the relatively few years of flow data that existed did not have a great range of values. For a discussion of influences on age-0 abundance in Lawrence Creek, see White and Hunt (1969).

RELATIONSHIP OF FLOW TO TROUT BIOMASS OR STANDING CROP

Fish populations expand and contract not only by varying the number of individuals through birth, death and emigration/immigration but also by growing in body weight or by losing weight. Therefore, if changes in streamflow discharge affect trout populations, one of the major responses should be change in the total weight of the population, which is an expression both of numbers and of body weight. The total weight of a specified population is called its biomass. The weight of the population per unit stream area or stream length is termed standing crop.

Springtime Standing Crop

The spring abundance of wild animals can be an indication of the suitability of winter habitat and food supply. Stream-dwelling trout depend on flow to carry a large share of their food to them as drift. Streamflow discharge must also largely determine the size and shape of the space in which a trout lives (White, 1973). If streamflow favorable for trout survival and growth occurs during one winter, then one could expect greater spring biomass than in years when it is not as favorable.

What might be favorable features of the discharge regime in winter? Greater baseflow in winter should mean not only more space and food for the fish, but more moderate (warmer) water temperature and greater availability of stream-edge vegetation and overhangs as concealment during a time when vegetational cover is dwindling.

We have analyzed possible effects of winter base flow by examining the relationship of January-February mean discharge to spring biomass in the 3 brook trout streams: Big Roche-a-Cri Creek, Lawrence Creek and Hunt Creek. As discharge tends to diminish throughout winter, the mid-to-late winter period before most major thaws was used as an index of base flow and of the most severe low-flow that trout might have to endure each winter. White (1972, 1975) had found correlation of spring biomass and Jan-Feb mean discharge in Big Roche-a-Cri Creek, with indications that detrimental effects of low-flow were ameliorated in a stream section when its channel was artificially narrowed and deepened and more overhanging cover was produced.

Jan-Feb flow appeared to significantly affect spring standing crop in Big Roche-a-Cri and Hunt Creeks (Table 4 and Fig. 3). Fall standing crop played a strong role in the Hunt Creek models, but seemed to detract from the Roche-a-Cri model. At Lawrence Creek, neither winter flow nor fall standing crop could be seen to significantly influence spring standing crop over the rather narrow range of values for the independent variables during the relatively few years (6) of flow observation. In Fig. 4, a plot of points for Hunt Creek could not be shown, as flow data were not from within the trout population study area, however, a general area of the graph was designated in which Hunt Creek data would fall.

Fall Standing Crop

One would expect that autumn trout population biomass would tend to vary in proportion to summer base flow and, barring compensatory processes at relatively high and low population levels, to vary in proportion to spring biomass, as well. During summer, angling mortality could disrupt the relationship. We have not included angling mortality in our analysis, however, its effect can be ruled out at Hunt Creek.

At Hunt Creek, where there was no fishing, spring biomass appeared to predict 55% of variability in fall biomass, with summer flow not entering significantly into the models (Table 4). At the Roche-a-Cri, despite angling, a model involving direct correlation with summer flow and inverse correlation with spring biomass accounted for 94% of fall biomass variation with 99.9% confidence. No strong relationship of either variable was found for the Lawrence Creek data. At the Pigeon River, where spring biomass data existed for too few years (5) to allow analysis, backward multiple regression of fall standing crop on winter maximum flow, Jan-Feb flow, spring maximum flow and Jun-Aug flow resulted in emergence of Jan-Feb flow as the only significant variable. There is 98.6% confidence that Jan-Feb flow of the Pigeon River accounts for 34% of variability in fall biomass. In the backward elimination procedure, inclusion of Jun-Aug flow resulted in 95.3% confidence that the model explained 35% of fall biomass

Table 4. Multiple regression analyses (backward elimination procedure) of trout standing crop in kg per stream-km (Y) on streamflow variables and on initial stock densities.

X_1 = max cfs day, Nov 1-Mar 10
X_2 = mean cfs, Jan-Feb
X_3 = max cfs-day, Mar 11-May 31
X_4 = mean cfs, Jun-Aug
X_8 = Standing crop the previous fall in kg/km
X_9 = standing crop the previous spring in kg/km

Stream, Years, Trout Spp.	Variables Entered	F for Removal from Regression	Regression Model	R^2	P
			SPRING STANDING CROP		
Big Roche-a-Cri Creek 1957-59, 61-66 (n = 9)					
			F=21.2		
Brook + brown	X_2	--	$Y = 1.89 + 1.77X_2$	75%	.002
1958-59, 61-66 (n = 8)					
			F=6.02		
Brook + brown	X_2 X_8	4.1	$Y = 3.12 + 1.59X_2$	50%	.049
Hunt Creek Trout on Thunder Bay River Flow**1966-75 (n = 10)					
			F=3.13 F=15.1		
Brook	X_2 X_8	3.8	$Y = -10.6 + .124X_2 + .751X_8$	72%	.012
Hunt Creek Trout on East Branch AuSable Flow 1966-75 (n = 10)					
			F=3.77 F=12.7		
Brook	X_2 X_8	3.1	$Y = -16.3 + .382X_2 + .643X_8$	74%	.017
Lawrence Creek 1961-66 (n = 6)					
Brook	X_2 X_8	5.1	none*		
			FALL STANDING CROP		
Big Roche-a-Cri Creek 1957-59, 61-65 (n = 8)					
			F = 32.4 F=17.8		
Brook + brown	X_4 X_9	4.1	$Y = 10.8 + .887X_4 - .246X_9$	94%	.001
Hunt Creek Trout on Thunder Bay River Flow 1966-75 (n = 10)					
			F=8.53		
Brook	X_4 X_9	3.1	$Y = 11.4 + 1.05X_9$	55%	.002
Hunt Creek Trout on East Branch AuSable Flow 1966-75 (n = 10)					
			F=8.53		
Brook	X_4 X_9	3.1	$Y = 11.4 + 1.05X_9$	55%	.022
Lawrence Creek 1961-66 (n = 6)					
Brook	X_4 X_9	5.1	none*		
Pigeon River 1949-65 (n = 17)					
			F=7.77		
Brook + brown	X_1 X_2 X_3 X_4	3.2	$Y = -16.8 + .741X_2$	34%	.014

*No variable meets F-criteria.

variation, but the F-value for Jun-Aug flow was only .264 (P = .615). If a simple regression of fall standing crop on Jun-Aug flow is made, there is explanation of 14% of variation with 86% confidence (Fig. 4). It is probable that Pigeon River fall trout biomass was more influenced by spring biomass (for which we have insufficient data) than by summer flow during the 17 years studied, and that spring biomass was strongly dependent on winter base flow; Hence the significant relationship of fall biomass and Jan-Feb flow.

For Lawrence Creek, as in the case of spring biomass, no significant relationships were detected for the relatively short period of observation involving little variation in flow.

Biomass data for Black Earth Creek and the North Branch of the AuSable River were not available at the time of this analysis.

Fig. 4 illustrates the firm relationship of summer flow with fall standing crop in Big Roche-a-Cri Creek, the apparent poor relationship at Lawrence Creek, the loose but suggestive relationship at the Pigeon River, and the area in which values for Hunt Creek would likely fall if complete data were available for streamflow discharge within that study area.

Effects of Flow Variability and Discharge per Unit Drainage Area

A correlation analysis by Hendrickson and Doonan (1972:44) suggested a general relationship between an index of streamflow variability (ratio of 90%:10% duration discharges) and standing crop of trout (lb/acre) in 16 stream segments of Michigan's Lower Peninsula. The higher standing crops tended to occur in streams having more stable flow.

A similar study of 28 streams in Michigan's UP (Hendrickson, Knutilla and Doonan, 1973a) yielded similar results, although some of the standing crop estimates which were used may have been in error by 50% or more. Trout populations seemed to be limited chiefly by stream temperature and discharge per unit area of drainage basin. Streams having high discharge per unit area during base flow were generally those that discharged relatively large amounts of ground water. Such streams also tended to have more stable flow and be cooler in summer and warmer in winter than those with smaller low-flow discharge per unit area.

In a third study by the same authors (Hendrickson, Knutilla and Doonan, 1973b) analysing in more detail the hydrologic and recreational characteristics of 10 streams in Wisconsin, Michigan and New York, standing crop of trout seemed related primarily to flow variability and discharge per unit drainage area along with such factors as stream temperature, water hardness, bed materials and instream vegetation. They found that most individual hydrologic factors were more highly correlated with biomass per unit stream length than with biomass per unit of stream surface area. Variability of flow (expressed again as the ratio of 90%:10% duration discharges or as the ratio of mean discharge to average minimum 7-day low-flow) was a significant factor in several of the regressions against standing crop of trout. Standing crop was again inversely related to flow variability.

DISCUSSION

Jan-Feb discharge was the flow variable most frequently present in significant regression models of trout abundance in terms of fall age-0 and of standing crop of the total population. Jun-Aug flow often entered the models of fall age-0 (sometimes inversely) and fall standing crop. Winter high flow was sometimes inversely associated with age-0 abundance but did not contribute significantly to explanation of biomass variation. Spring high flows were not involved in any of the significant models for either age-0 or biomass. It can be inferred that especially the winter base flow and also summer base flow are very influential in determining trout abundance in Midwestern streams, and that winter floods, where they reach severe proportions, are detrimental to trout. Spring floods may have relatively little detrimental effect.

The strong inverse relationship of age-0 trout abundance and winter peak flows in Hunt Creek and Black Earth Creek could be related to greater sediment load associated with such flows. Sediment deposition in the upper layers of redds could hamper embryo survival or result in less vigorous fry. However, even with substantial embryo and sac-fry mortality, which is rarely the case, at least in the streams with rather stable flow (McFadden, 1969), there should usually be a surplus of emerging fry. The usual bottleneck to trout yearclass size is thought to occur during the one- to three-month period after emergence (Allen, 1951; Latta, 1962; LeCren, 1965) and to be related to food/space phenomena.

Lawrence Creek standing crop of brook trout far exceeded that of the other brook trout streams in most years (Fig. 3 and 4). Perhaps this is related to relatively stable flow and strong groundwater contribution (see cfsm, Table 1), as the review of hydrologic studies by Hendrickson et al. would suggest. Hunt Creek also has relatively stable flow and high discharge per unit drainage area (Table 1) but sustains a lower standing crop. Perhaps this is attributable to such factors as lower nutrient load and/or the more northerly location of Hunt Creek, implying a colder water temperature regime.

Such variables as stream fertility and water temperature could well be involved in much of the variation unexplained by our analyses. Precision and accuracy of our analyses were also limited by the fact that stream discharge data and fish population data were seldom available for the same section of stream. Better precision of measuring biomass might also have improved some of the correlations and made the regression models more predictive.

MANAGEMENT IMPLICATIONS

The relationships covered in this analysis lend support to findings of a considerable number of fisheries studies (review by White, 1973:71-72) that high, stable stream discharge is favorable and severe floods, especially those in winter, are unfavorable for fish.

The complexity of trout stream habitat management potentialities and limitations is depicted in Fig. 5. Increasing base flow shows more possible beneficial effects emanating from it than any other management. It has implications for increased living space, and pool space in particular, improved water temperature, increased stream-edge and instream hiding cover, creating greater food supply and enhancing reproduction.

However there may be few options for increasing or stabilizing base flow to improve conditions in Midwestern streams. Potential for reservoir impoundment and release of water for improving low flow conditions is exceedingly limited. Harmful aspects of impoundment may generally outweigh the benefits. Pumping groundwater into streams has been the subject of several experiments. While this may augment low flows in a crisis, it would be very energy demanding.

The relations presented in this paper point out the necessity of maintaining present stream discharges and flow stability if maintenance of present fish stocks is a management objective.

ACKNOWLEDGEMENTS

The authors wish to thank Robert L. Hunt of the Wisconsin Department of Natural Resources and W.C. Latta of the Michigan Dept. of Natural Resources for providing data from files and for various helpful comments. Walter H. Conley and John R. Craig of the MSU Dept. of Fisheries and Wildlife facilitated data processing and advised on statistical analysis.

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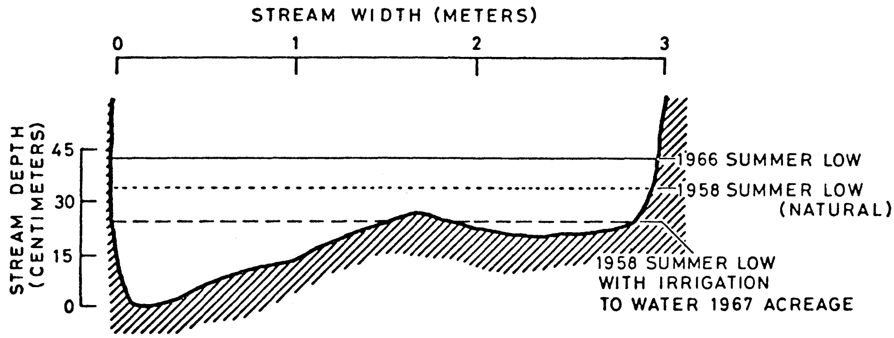


Fig. 1. Effects of flow depletion on stream stage in a cross-section of Big Roche-a-Cri Creek about 3 km below the headwaters. Vertical exaggeration is X2 (after Weeks and Stangelund, 1971).

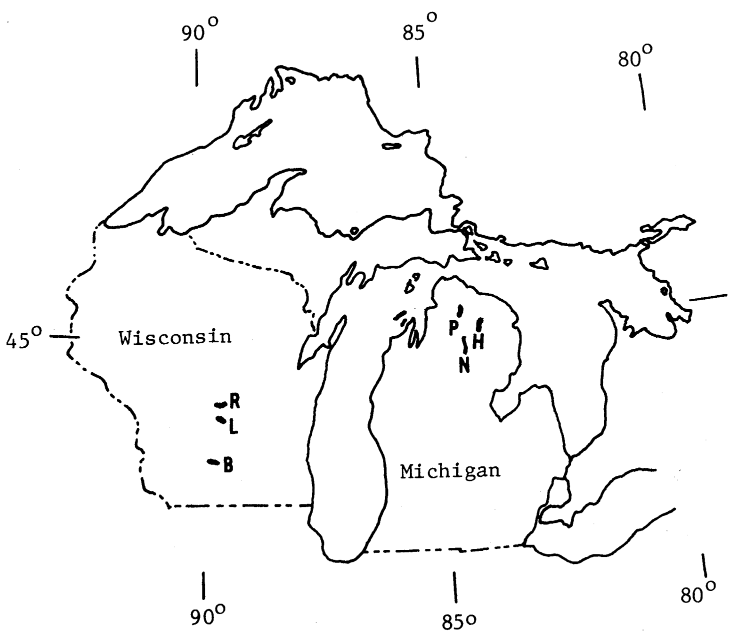


Fig. 2. Location of six trout streams on which analyses were made.

R = Big Roche-a-Cri Creek
L = Lawrence Creek
B = Black Earth Creek
P = Pigeon River
H = Hunt Creek
N = North Branch of AuSable River

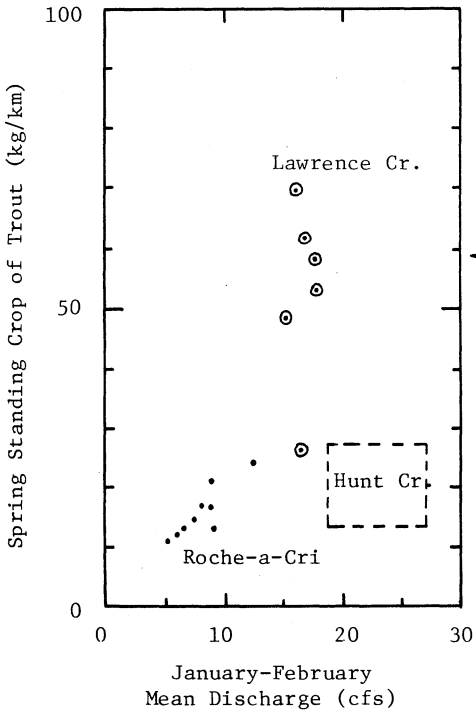
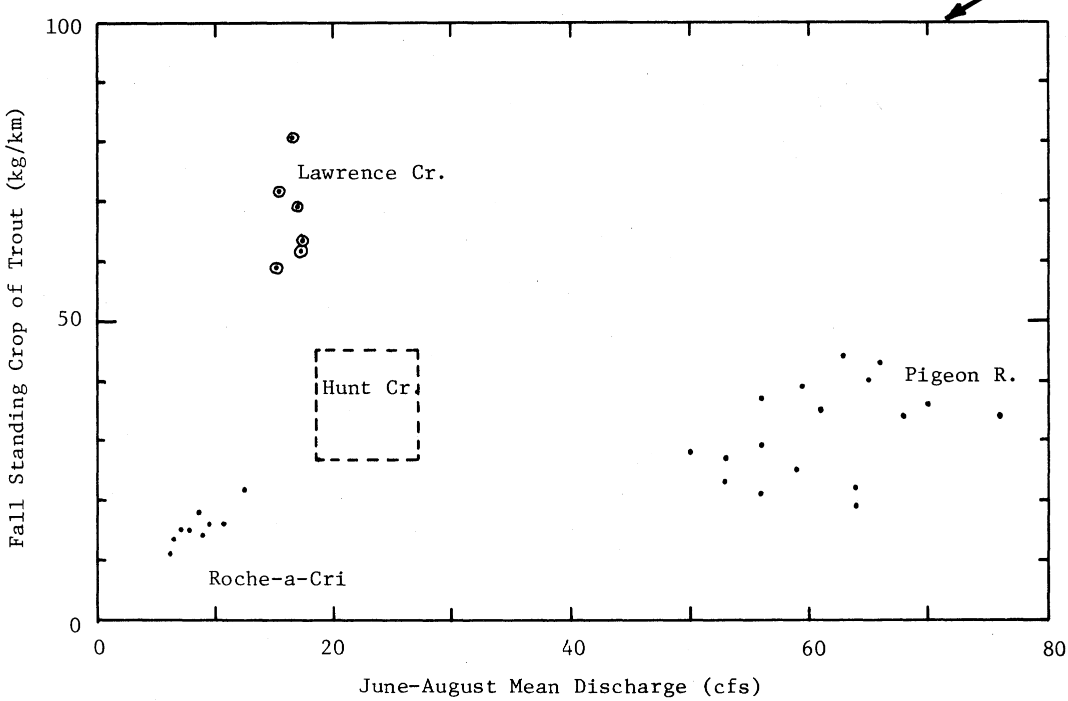


Fig. 3. Regressions of spring standing crops of trout (kg/km) on Jan.-Feb. mean streamflow discharge in study areas of three streams. Although estimates of Jan.-Feb. flow within the Hunt Creek study area are not sufficient for plotting individual points, an area of the graph is shown which covers the ranges of spring standing crop and of annual mean discharge a short distance below the study area.

Fig. 4. Regressions of fall standing crops of trout (kg/km) on June-Aug. mean streamflow discharge in study areas of four streams. Although estimates of June-Aug. flow within the Hunt Creek study area are not sufficient for plotting of individual points, an area of the graph is shown which covers the ranges of spring standing crop and annual mean discharge a short distance below the study area.



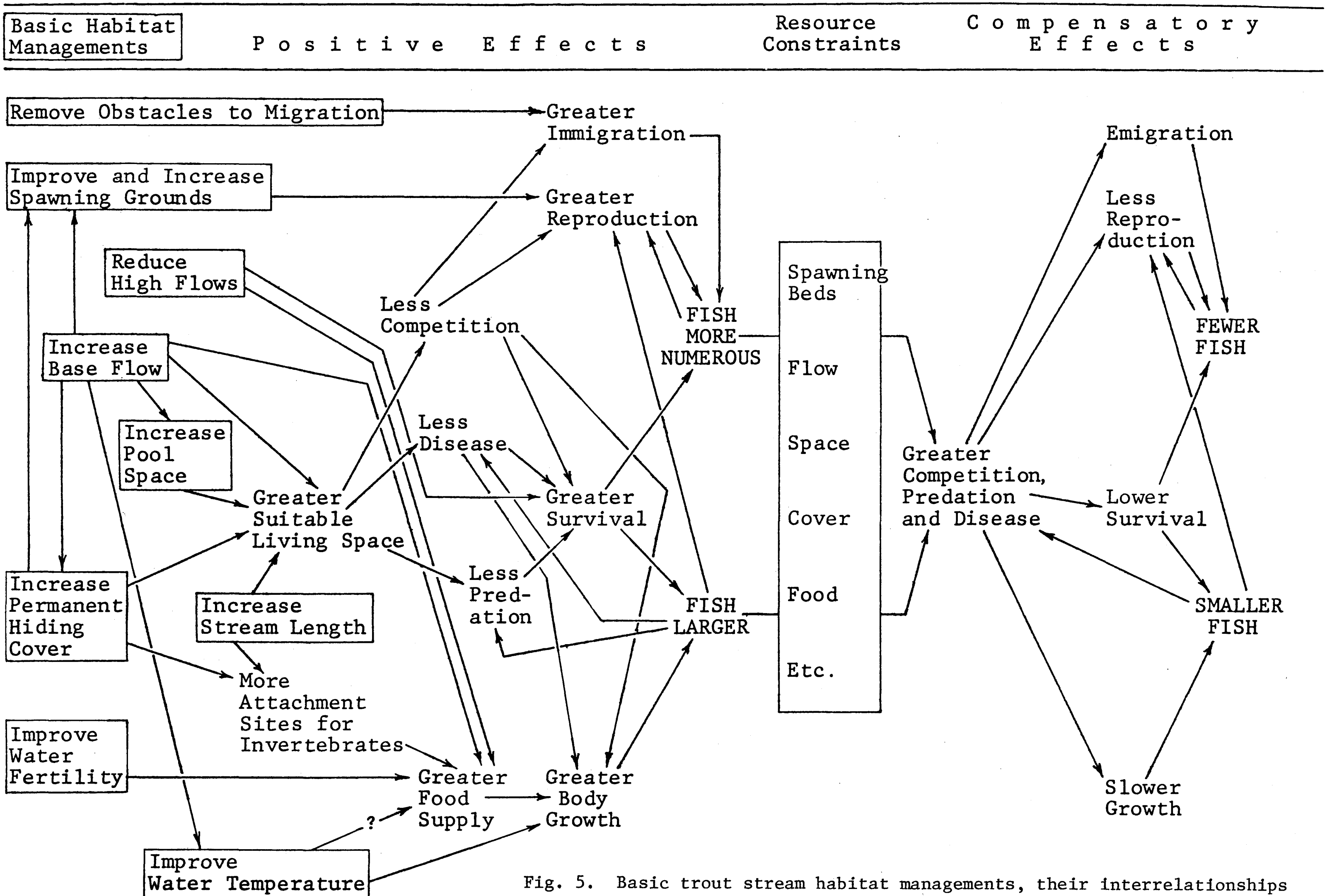


Fig. 5. Basic trout stream habitat managements, their interrelationships and pathways of effects and limitations (from White, 1976).

TOPIC V-I.

FISHERIES IFN METHODOLOGIES

Summary Discussion

Methodologies for determining instream flow needs of fish are the most numerous and refined of all instream flow needs, yet contain many flaws and lack the perfection for which fishery biologists are striving. In an effort to achieve a greater degree of sophistication in fisheries methodologies, emphasis continues to be placed on research and modification of existing techniques to meet special situations.

The U.S. Fish and Wildlife Service is adapting an intensive transect analysis technique on the Truckee River in Nevada to provide data on instream flow needs for various federal court litigations. Their project involves the development of flow needs criteria of Lahontan cutthroat trout and cui-ui, mapping spawning and rearing habitats, water temperature prediction studies, radio tracking, incubation success evaluation, and prediction study. Recruitment to Pyramid Lake can be predicted if flows, temperatures, stream bed composition, wetted perimeter, and hatching success are known. Their objective is to protect the lake level and maintain fish production in the Truckee River. The intensity and level of detail in the study have been influenced by attornies involved in the court litigations.

The Oregon Department of Fish and Wildlife is conducting research on the interrelationships of stream flow and the aquatic parameters affecting salmonid production. A habitat index rating system has been proposed as a methodology for translating specific criteria on habitat requirements into instream flow recommendations.

Midwestern streams achieve a degree of protection through their riparian doctrine of water resources management and allocation. Diversions of water from navigable streams are regulated in many areas by permit. The definition of navigability qualifies nearly all streams with important fish populations. The welfare of brook and brown trout populations in Wisconsin and Michigan are significantly influenced by impacts of consumptive water uses.

Notes by panel moderator: Ken Thompson
Steering Committee Member

NATURAL RESOURCES PERSPECTIVES

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It is fortunate that I can come back here to Boise and be with you because my history, as Frank Richardson has indicated, includes an interval in the city of Boise. It reveals something I should share with you.

Some years ago, I was responsible for conservation law enforcement in the western part of the United States. On one occasion it was incumbent upon me to come to Boise and lead my troops in qualification with the side arm, which is something all responsible law enforcement officers should do periodically. We came to Boise and went up to the police pistol range and spent the whole day qualifying. I participated--as leaders of men should--and while I don't share with you the details of my score, I will reveal that some time afterwards, a deputation of seasoned law enforcement officers from the Fish and Wildlife Service came to me and said, "You may get into all kinds of difficulty in the future in your career, but whatever you do to try to escape that difficulty, don't count on your prowess with a side arm to get you out of it." I think that was good advice. My recollection was that there was much sound and fury and very little performance on that day, but it was a delightful time in Boise, and one I will long remember.

I am pleased to be here and most especially pleased to see a purposeful convocation of people of differing persuasions and differing disciplines. It is most unusual to find engineers, attorneys, and biologists together--certainly without bloodshed. This, I think, portends of a particularly sanguine future for the effort. I think it was Mark Twain who said, "It is most remarkable to find an attorney who has his hands in his own pocket--for a change." I am not sure how appropriate that is to those barristers with us, but the fact that people can join on an occasion of this kind to deal with these kinds of problems, whether they be builders, biologists, attorneys, or water engineers, is important.

You have been wined and dined, and have enjoyed yourselves--now I think it is time for you to suffer the onslaught of the bureaucracy from Washington--represented by myself. I intend to share some serious thoughts with you. I should point out to you there are two microphones present--one to the PA system, the other connected to a tape recorder. I am one of the few Washington-based bureaucrats who is not afraid of a tape recorder. That says something for my naivete, perhaps.

I should say that I particularly appreciate Frank pointing out that I am not an easterner, certainly not one who has spent all of his life along the Potomac. I find some difficulty, many times, in dealing with some people who come to see me because they launch immediately into a long story about what life is like in the west or in the south or in some place other than Washington. They seem to conclude that somehow I have never been anywhere but along the Potomac. I don't mean this as denigration of the Ivy League, but they often seem to say to themselves that this man <u>has</u> to be a Harvard graduate. Perhaps it is the mustache that makes me appear to be an intellectual, but at least they begin with the assumption that I am totally unfamiliar with the real world.

You have been told in an indirect way that I do have some familiarity with the real world, wherever that may be. I want to talk a little bit about the real world and the perspectives I think are being derived from the kind of sessions that you have attended for the last two days. First of all, the really important fact is that various kinds of people have come together to discuss complex problems. The kind of problems you are dealing with--instream flow--may seem to be almost superficial and certainly not very important in the scheme of things. Not true. It is representative of the kinds of things that all of us, whether we are biologists or water users, attorneys, engineers, environmentalists--whatever they are--or society as a whole, are facing today. Fundamentally, we are having to make choices about how a diminishing set of resources is to be used in the future, whether that resource is water, coal, fish and wildlife, timber, or grazing. Society is confronted with the fact that choices have to be made about how resources are to be used and these choices are not easy to make. The demands on these resources are multitudinous and frequently they are at odds with one another. The real question then is: How are these choices to be made? What mechanisms do we use to decide how this nation will address these problems now and in the future? Instream flow preservation is a good example because water is critical to all our considerations--fish and wildlife, irrigation, power development, or recreation. Water is critical. There are more demands on water than there is water to go around. There are very complex problems associated with this issue. This is only a part of the basic problem that confronts us as we deal with the pressing issues of today--the use of natural resources in this nation. Natural resources that are renewable therefore can be perpetuated, and natural resources that are nonrenewable can be used but once and therefore must be used wisely. These resources are growing in value because they are becoming more scarce.

This morning you heard a speaker elaborate on the fact that resources become more valuable as they become less abundant. That is an immutable fact of economics, if economics has any immutable maxims. Sometimes the relative rarity of these resources results in the demands upon them becoming diametrically opposed. There is value in a forest because it is aesthetically appealing, it provides habitat for wildlife, and also represents timber in the sense of those things that man must and indeed has to use: lumber for construction, pulpwood for paper, grasslands for grazing. These values are all real, but it is the utilization--the management, if you will--of these values that are often at odds with one another.

Strong social and economic considerations surround resources values. We have only to regard the social implications as exemplified by the utilization of fisheries by Indians and non-Indians, the growing of Indian concern about their own rights as they relate to the rights of non-Indians to detect the ramifications of the issues to which I refer. All of you know of these kinds of problems and they point up the fact that there are strong and growing social issues developing in this country that do, in fact, affect natural resources. A decade or more ago, I'll bet nobody would believe that social issues could revolve around such things as anadromous fish. It is true--these are real issues today. They will not go away. They are growing--growing in importance. They are growing in their impact on the way society regards its resources and the way the Nation will respond in the years to come. These are extremely important kinds of considerations that we cannot possibly overlook.

Obviously, in any of these issues there is a factor that seems to run rampant even before any other consideration and that is emotion. People like hunting; people don't like hunting. People agree that trees should be cut; people think trees should never be cut. Wilderness versus utilization. Exploitation versus preservation. It is all around us and it is growing--it is evidence also of another phenomenon that has developed in the last ten years or so and that is the fact that nothing can ever be done in isolation anymore in the United States. That which occurs in Idaho, Montana or Nevada is known to people who live in New Jersey or North Carolina because they are interested. Few things can be done in any state that does not in some way make an impact on other nations in the world. How can it be that those people who are proprietors of the major part of the world's oil can affect the economy of the United States? We know how it can be--we saw it happen two years ago. How can it be that two mature and well developed and intelligent nations almost go to war because of a fish called the cod? Nothing can occur on the face of this globe without having impact elsewhere on the planet. That is a reality that cannot be denied. The world isn't shrinking--it's becoming more sophisticated. It's also being populated by a great many more people, which has something to do with the phenomenon.

Perhaps that is well because it is a classic example of how ecology is applied to the things with which we deal. Nothing happens in this quarter of the globe that does not cause a response on other quarters of the globe. It is important to note that the decisions that are made about instream flows or coal development, or how the continental shelf is developed, are not made in isolation and cannot be contained within the geographic area in which they occur. They affect the whole nation, indeed the whole world. People are interested, people are concerned.

In my business, the fish and wildlife business, we find that people have a growing interest and concern and an enlarging body of misinformation about fish and wildlife. Society's various pressure on administrators of fish and wildlife resources is incredible and all too often is based on gross misinformation. What is it that people know about fish and wildlife, for example? Most people know only what they have learned, and where do they learn it? You know where they learn it just as well as I do. They learn it from that device sitting in the family room that glows in multi colors. It explains to us how the real world works through Walt Disney and all of his imitators, and conveys to the general public the idea that fish and wildlife are not very different from us. They have big and appealing eyes and fur, and they live an interesting life. They can even be seen to scratch themselves in time to Chopin. That is the way the world is. It says so on the tube.

We have to recognize that most of the people in this growing nation of ours are at least two generations removed from the real world in terms of fish and wildlife. And their information is not altogether accurate. How many times on television have you seen the predator actually catch and consume his prey? Occasionally you see a kodiak bear take salmon, because that is dramatic and it is really not offensive because who cares about a salmon. But you almost never see a cheetah catch an ibex and almost never see a wolf take a deer. And yet we all know that this happens and that life out there in the real world is often cruel and that nature is not a benign, balanced, and delightful thing as it seems to be portrayed on the television tube--far from it.

The realities of the wild world are lost upon most people of this country and that is unfortunate because they develop their opinions based on what they see and read and too often are misinformed. This applies to all the other things that relate to natural resources. People are not well informed. They are willing to be committed to have strong advocacies one way or another but they are often ill-informed. And as a result, the diametrically opposed opinions develop. Hunters versus anti-hunters, developers versus preservationists, and the whole litany of issues that you all know about accrue to the decisions that must be made about natural resources in this nation.

It is important to also note that people's perceptions are in fact changing. They are concerned, albeit misinformed, but they are concerned, and this should be capitalized upon. People should be properly informed about what it is that faces this nation for the next couple of decades. The questions exemplified by the discussions that have gone on here for two days are good examples. People want to make the right decisions but they do not quite know how. They want to reach the right conclusions about the major issues--northern great plains coal or the Kaiparowitz power plant or the cross-Florida barge canal. They want to have decisions made but they do not know quite how to ascertain what it right.

Society also will demand a continuing growth in technology, the exploitation of the resources this nation has and at the same time, almost antithetically, will demand the preservation of the quality of life that is not fully understood but is desired. They want to be able to know that there are wild lands out there inhabited by wild creatures, not really understanding how this works or how this state of grace is achieved. They want to know that there are fish in the streams and at the same time to know that the nation is producing food at a proper level and in a proper economic framework so that this nation in its tricentennial year, a 100 years hence, will be as well off as it is today. That's a large order. That's the nub of the decisions that face all of us, particularly those of you represented during this symposium.

This is the era of not just the environmentalist--that's a bad term. I am not sure what an environmentalist is. It depends on to whom you speak, I think. Frequently it is a person whose heart is in the right place but who is misinformed about the issues. It is a person, perhaps, who wants to be able to leave to his children the kind of heritage that he was given or thinks he was given. It is incumbent upon specialists and professionals in this field to make sure that the right decisions are made in the nation's best interests. The public interest must be served, as has been said at earlier meetings. It is hard to identify the public interest. What is the public interest? It's hard to say. But somewhere there is a public interest that must be served.

It is abundantly clear to me that the time is upon us to begin to do these things because we do not get any second chances in this business. The utilization of water, or timber, or grazing, or fish and wildlife, or even the aesthetic appeal of a mountainside is not a thing you can give up and later recapture. You have to do it right the first time out. All of us represent those elements of society that are interested in doing this job and I submit that any one of us properly coached to write down what it is he would like to see the nation do in 15 or 20 years would come out with fundamentally the same kind of answer. An economically viable, progressive nation with a life style, a quality kind of life that is desirable and acceptable that includes all the things we find interesting and beneficial and, indeed, necessary to the perpetuation of the kind of enjoyment we have, whether it is being out-of-doors or just knowing it is there. I can recall an example of the idea that knowing that something there is akin to being satisfied. At a staff meeting I attended many years ago in the regional office where I was stationed, we were discussing what was then quite new--the wilderness act and the concept of wilderness. One of the staff people said, "I feel very strongly about wilderness even though I may never visit one of these areas. I want to know that people can enjoy that kind of resource, that it is there, and that it is preserved and is available, even though I may never ever to able to use it myself." One of the other participants responded, "That's strange--I feel the same way about Racquel Welch." So, it depends on your perspective. Everybody has the same thing in mind but couches it in different terms.

What can we do to assure the attainment of the kinds of things that we all pretty well agree upon--the attainment of a quality of life with an effective economic system for this nation and, indeed, for the world? One of the things we have to do to begin with, and I think this is being started at least in a small way at this symposium, is to agree that we have the same goals in mind. Nobody in his right mind wants to deny the kinds of things that we all recognize as being important. There ought to be wild lands and free-flowing water and fish and trees and all the rest and at the same time the assurance of being able to go into your living room and flip the light switch and have electricity produce illumination. These things have to occur. Society will demand it. Somehow we have to strike an accord with differing positions about these issues in order to attain the best of all possible worlds. That is a subject that has been addressed by philosophers for years. How do you attain the best of all possible worlds? They could philosophize about it because they didn't have to worry. Now _we_ can no longer simply philosophize because _we_ must do something.

I am convinced that this is not really the era of the environmentalist. This is the era of the practicing pragmatist, a person who can make these things happen. We don't have too much time. The onrush of events, the necessity for finding energy, for, if not feeding the world, at least redistributing the food resources of the globe. The necessity for coping with a growing population is upon us now--it will not wait. We have very little time, finding the way is a responsibility of this generation, not the next one. If we can agree that the objective is to arrive at a state of grace in which we have the virtues of wilderness and wildlands and all the things we like, and the development of a necessary and absolutely vital technology, then the question is how do we get there from here? How do we go down our separate roads to get to that happy end point? One of the things that we professionals, at least in the biological field, must do is to begin to overcome the deficiencies in our knowledge. We don't know a whole lot about varied streamflows and their effects on fish and aquatic wildlife. We don't know a great deal about the impacts of oil developments on the estuaries of the nation. We don't know very much at all about the mechanisms that move the ecological machinery that makes this earth's natural systems work properly. We have to overcome these deficiencies so that we can demonstrate what must be done in order to preserve these values. This is very important. We have operated for 40 years that I know of on the basis of the sketchiest possible information. Perhaps pretty good intuition, but intuition and 15¢ will generally get you a cup of coffee these days. We have to have more than that.

I think we have a moral obligation to give to our children a chance to make their own choice about resources and not make them all now in behalf of future generations. We have a few years in which to do it. We have the capability for making the right decisions, for moving into that arena in such a way that we can come out with the objectives attained.

I think what we have seen in the last two days here is a fine example of an attempt to attain those objectives. There needs to be more of it on a much broader scale. We see the Boise River outside this room. That river's instream flow problem is not at all serious, at least here in this fantastic valley. We see the surrounding mountains and all the remarkable natural attributes that are growing to be a rarity in the world. You don't find too many mountains, you certainly won't find a stream in the vicinity of Washington that is anything like the Boise River. If anything, the Potomac is dangerous--it erodes boats and tends to affect people's health...they even turned off the Lady Bird fountain, as you know, because it spewed the stuff into the air which was not where anyone wanted it. It should be in the river so it would go out to sea right away. That is a shame, considering Washington is the Nation's capital and this is the Bicentennial Year. The fountain has not squirted in several years because it may be a hazard to human health--like smoking. You in the West, the people who visit this delightful western town, are seeing among the last of what is left in its relatively natural state. I think these things are worth preserving. But it does not mean in order to have these values we have to give up electricity, or transportation, or energy, or lumber for housing. We can have them all, but it means we have to get together and understand each other and make these things happen.

If there is any message I would like to leave with you, it is that we do not have the luxury of time. We have to do it soon, and when I say "we," it is us. As Pogo Possum said, "We have met the enemy and he is us." Maybe that is true. I hear people talk about the light at the end of the tunnel. That was a delightful cliché during the Viet Nam era. The light at the end of the tunnel in the environmental age--nobody has stopped to think that the light you see at the end of the tunnel may be an express train coming your way.

I think we can do the things I have outlined. I am confident that we can bring off this rather formidable task of making the nation meld together, join together in its disparate views and achieve what it is that I think society wants over the long run. It is not going to be easy, but it is worth it because the alternative is intolerable.

Well, you have been wined and dined and moderately entertained. I shall not impose the bureaucracy on you to any greater degree, except to say that as a transplanted westerner who was never near Harvard until just a few months ago and then was asked to leave town, it is a pleasure to have had an opportunity to speak with you and to spend some delightful hours in this remarkable city. And I commend to you the idea that we can, in fact, do the things that all of us have been talking about. Ladies and gentlemen, it has been my pleasure, indeed. Good night.

POLICIES OF THE FOREST SERVICE IN DETERMINING INSTREAM FLOW NEEDS

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I am very pleased to have this opportunity to discuss instream flow needs. All of you are fully aware of the increased competition for water in the Western States, and the need for comprehensive water resource planning. Recognizing instream flow needs is the first step toward reaching a proper balance in water resource allocations. The ability to quantify the instream flow need and assess its significance is essential for the States to carry on meaningful water resource planning.

The National Forests play an important role in water resource planning in the eleven Western States by providing more than 50 percent of the water. But, our discussions this week have focused on the distribution of available water to competing uses, rather than on production. As you know, the National Forests have considerable impact on many State water planners and water users in general, because of the Forest Service claim for water under the Reservation Doctrine.

Mr. Kiechel, from the U.S. Department of Justice, and Mr. Turner from the Office of General Counsel, have already discussed the legal concepts of the Reservation Doctrine. Now, I would like to discuss what it means to the Forest Service. Under the Federal Reserved Right, the Forest Service claims sufficient water to meet the purposes for which the National Forests were reserved. It is said that the Federal Reserved Right is "cloaked in mystery," because it is unquantified and relates to purposes which are not clearly identified.

This morning, I would like to attempt to remove that "cloak," and outline a procedure to keep the mystery out of Forest Service reserved rights.

The Forest Service reserved water claim can be classified into two major categories: (1) diverted and storage use, and (2) instream flow needs. The diverted and storage uses include water for campgrounds, administrative sites, stock water, and road watering. Of course, the instream flow needs include fisheries, recreation, esthetics, stream-side vegetation, and so on.

Diverted and storage uses require only small quantities of water to meet current and foreseeable National Forest uses. Even when a reasonable factor is added to these estimates to compensate for the inability to fully foresee future needs, the total quantity of water required is still not large enough to be of concern by most water users. Of course, even this small amount is a major issue to those who resist the Federal Reserved Right in principle. But of greater concern is our claim for instream flows and natural water body levels necessary for National Forest purposes.

Perhaps the greatest unknown of the Reserved Right, at present, is the amount of water involved. Those who oppose the Federal reserved instream flow right have said that the amount is "unquantified" or "all the waters from National Forest System lands," or "unlimited and excessive."

However, the legal record shows that substantial efforts have been made to remove the "mysterious" aspects of reserved rights. These efforts include the actual quantification of certain types of water claims and a suggested means for quantifying our total water needs.

We are well along with the job of quantifying existing and foreseeable National Forest water use needs for diverted and storage uses. All State Engineers are aware of our efforts and have copies of our water needs inventories. Everybody agrees that these water needs are "de minimus," in legal parlance.

Some water users are far more concerned about our claim for instream flows. Our position has been to claim only those amounts of water reasonably necessary to fulfill the purposes of that reservation. I want to emphasize the words "reasonably necessary." We certainly are not making a claim to all water produced on the Forests. In addition, the water needs of National Forests are subject to appropriations made prior to the data of reservations.

We are a long way from being able to quantify the total amount of our reserved right. However, we intend to make those figures available in a reasonable, timely manner. There are obviously many uncertainties in providing such figures. However, the Forest Service will be conducting the analysis with state-of-the-art applied technology tempered by the constraint of accomplishing this enormous job. Nationally, we are talking about over 187 million acres of National Forest reserved lands which implies, by the very size of acreage, that this will be a costly and time-consuming job. However, we recognize the importance of quantifying these waters to allow completion of other Federal and State water resource planning, and to allow effective administration of existing appropriated water rights by the States.

I have said that the National Forest reserved right is that amount reasonably necessary to fulfill the purposes of that reservation. This statement surfaces two unknowns: first, what are the purposes for that reservation, and second, what is reasonably necessary.

The National Forests have always been managed under a multiple use policy for outdoor recreation, range, timber, watershed, and wildlife and fish. The intent to manage the original Forest reserves for these general purposes is manifest in the history of these lands even before the Forest Service was created. In a report to the Chief of the Division of Forestry following the Creative Act of 1891, and before the Organic Act of 1897, the purposes were identified as first, to assure a continuous forest cover for the purpose of preserving or equalizing water flow in the streams, and to assure a continuous supply of wood material. Secondary objectives are those of an esthetic nature, namely to preserve natural scenery, remarkable objects of interest, and to secure places of retreat for those in quest of health, recreation, and pleasure. The record leaves no doubt that the intent has always been to manage the National Forests under today's multiple use concepts. This intent can be found in historic documents of agency programs, congressional actions, and judicial recognition. Therefore, the Federal Reserved Right must include water in reasonable amounts to fulfill the following National Forest purposes:

1. Protection of watersheds and the maintenance of natural flow in streams below the watersheds.
2. Production of timber.
3. Production of forage for domestic animals.
4. Protection and propagation of fish and wildlife and their habitat.
5. Recreation for the general public.

The issue this symposium is really addressing is the role of instream flow needs in an equitable distribution of water resources. Instream flow needs must be recognized as a beneficial use of water when allocating our water resources.

To properly include instream flow needs in an equitable distribution of water resources, we must evaluate the benefits received from the water flowing through the natural streambed; as opposed to benefits received from the water being diverted away from the streambed for use at some other point. Two questions immediately arise. First, how much water is needed in a channel to meet the instream flow requirements of the various resources; and second, what are the social, economic, and environmental benefits received from that allocation? This symposium has already addressed these questions in detail.

But there is still another important consideration in the equitable distribution of water: Is the water used efficiently? Efficient use is particularly significant, but very complex, when we are talking about large-scale diversions for municipal-industrial purposes and certain types of agricultural irrigation. Water use must be as efficient as is practical to meet today's demand for the limited supply of water here in the West.

One of the primary purposes of the National Forest System is to secure favorable water flow conditions for both on-Forest and off-Forest uses. But what is a reasonable allocation of favorable flows for on-Forest and off-Forest uses? It is difficult to suggest an equitable distribution of water, but we do have some guidelines. The Forest Service believes that a reasonable claim for water must be a quantified volume, and must (will generally) represent some portion of the total available flow. Exceptions to this rule are wilderness areas, where the United States claims the total streamflow, except for any appropriations prior to the date of reservations. We also believe that, in most instances, a water claim should not dewater a stream on a National Forest.

The Forest Service does not claim to have a formula which will assure reasonable distribution of water. Nor does the Forest Service claim the authorization and responsibility to make allocations of water. We do, however, have extensive experience in allocating Forest land to competing uses to meet the demand for goods and services. We have evolved a land management planning process to facilitate decisions in this allocation effort.

National Forest land management planning seeks to balance allocations of use between the needs of people and the capabilities of the land. Land management planning must also comply with the National Environmental Policy Act of 1969, as well as the many other laws that apply to National Forest System lands. This planning relies heavily on interdisciplinary teams, public involvement, and new data handling and analysis tools. Our goal is to bring the most pertinent knowledge, the most advanced skills, and the best thinking to bear upon each Forest Service land management decision.

In the future, the Forest Service will incorporate instream water needs into the land management planning process. The Forest and Rangeland Renewable Resources Planning Act of 1974 directs the Secretary of Agriculture to periodically assess the national situation for forest and rangeland resources. This assessment includes the need for determining claims for instream water flow and natural water body levels. Through efforts such as this symposium, and research by Federal and State agencies and universities, all aspects of natural resource management are being more clearly recognized and defined. When natural resource decisions are being made by administrators and our Courts, it is very important to have well documented environmental, social, and economic information to assess possible alternatives. The ultimate decisions for an equitable distribution of water rest with the Court. This allows for further proceedings, with the right of appeal, for any water user affected by the United States water claim, to have his "day in court."

In summary, the purposes of the National Forests, since their inception, have been broad in scope, and include responsibilities for watershed, timber, range, fish and wildlife, and recreation. The Federal Reserved Right guarantees reasonable quantities of water needed for the management of these resources.

The Forest Service recognizes its responsibility to quantify its reserved right. This quantification will be costly and time consuming. But, it is necessary for a timely and equitable distribution of water in the Western United States, and for administering the rights of others.

The equitable distribution of waters in the Western United States can occur only when we analyze the benefits received from alternative allocations of water. Without any question, instream flow needs must be a part of this allocation.

A WRC NATIONAL PERSPECTIVE ON INSTREAM FLOW PROBLEMS

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ABSTRACT

Instream flow needs is a critical consideration in the conflicting demands on our water resources for economic development and environmental enhancement. In fulfilling the assignments of the 1965 Water Resources Planning Act, one of which is the establishment of principles, standards, and procedures for the evaluation and formulation of water and related land programs, the Council is involved in controversy between the conflicting demands and often lacks the necessary information for decision-making. The need for improved methodologies to determine instream requirements is essential to the implementation of the Principles and Standards and for the National Assessment program.

The WRC strongly supports the Cooperative Instream Flow Service Group, a multiagency, multidisciplinary team, being established by the U.S. Fish and Wildlife Service in hopes of providing data on instream flow needs for use in the evaluation and formulation of water and related land programs using the Principles and Standards concept.

The WRC is presently innovating a program, the water assessment and appraisal program, which will provide decision makers with a guide in setting national and regional priorities for meeting critical water requirements.

INTRODUCTION

The Water Resources Council (WRC) is pleased to participate in this Instream Flow Needs Conference cosponsored by the Western Division of the American Fisheries Society and the Power Division of the American Society of Civil Engineers. The subject of this conference is critical to the well-being of the Nation as we, as a Nation, choose courses of action which attempt to balance the oft conflicting demands placed on our water resources for economic development and environmental enhancement.

WRC Programs

Because of the role outlined for it in the 1965 Water Resources Planning Act the Council many times finds itself in the midst of controversy over conflicting use and many times without the basic information on which to recommend a resolution of such conflicts. Among other things, the Planning Act assigns, to the Council, the responsibility for (1) maintaining a continuing study and preparing an assessment of water supply availability and identification of critical water requirements; (2) maintaining a continuing study of regional or river basin plans; (3) appraising adequacy of existing and proposed policies and programs to meet future water requirements; and (4) with the approval of the President, establishing principles, standards, and procedures for the evaluation and formulation of Federal water and related land projects.

Need for Improved Methodologies for Instream Uses

The need for improved methodologies to determine instream requirements is essential to the implementation of the Principles and Standards; however, the urgency of this need is presently focused within the Council in the National Assessment program. In "The Nation's Water Resources" (the First National Assessment by WRC, published in 1968), the following quote is found on page 1-14:

> Instream Uses
>
> "In this First National Assessment water requirements for instream uses have not been compared with potential flows. Lack of comparable data on instream uses has prevented meaningful analyses and comparisons. In future assessments, a more complete analysis of the adequacy of flow for instream uses will be undertaken."

Presently the Council is preparing the second National Assessment which will be completed in 1977. After a period of 9 years, the Council could default in an analysis of instream uses compared with other competing uses and available flows by including a similar statement in the current Assessment. We are still plagued by a lack of data and acceptable methodology to give us adequate information on instream uses. Keith Bayha reported to you on the subject as part of the panel on Recognition of Instream Flow Needs in Changing Times.

We all are aware of the background of water programs leading up to the present situation requiring improved determination of instream uses. Historically, water in this Nation has been utilized to promote economic development. Water for irrigated agriculture was used very effectively as a tool in developing the West. Water has "greased the gears" of industry. In recent times, the values and priorities of our Nation have shifted placing increased emphasis on the quality of life.

This historic evolution of water programs emphasis has led to a great sophistication in the state-of-the-art as far as the quantitative analysis of water requirements. Except for the need for additional data on ground water and water rights information, this Nation has a relatively good reservoir of data on the quantum aspects of water. However, it is recognized that we are lacking data on quality consideration and associated information on the effects of stream flows on biological systems.

It is this disparity in data and methodology for analysis that has heightened the conflicts between user groups advocating conflicting environmental and economic patterns for water management. Without adequate knowledge as to the effects of stream flow depletions, the environmentalists have been forced to take the general position that--"We don't really know how much water is required or the minimum flow we can tolerate for instream requirements; therefore, for instream purposes, we require all that is remaining in the stream." This brings howls of protests from developers, who look upon such a stance as being totally unrealistic and no more than a ploy to stop projects.

Stemming from all of this, we have indeterminate delays and resulting decisions, which lead to further confusion and inefficiencies. We have projects and programs being implemented that are questionable, and we have projects and programs blocked that should be implemented. We, as professionals, cannot be satisfied with this situation.

This situation makes it extremely difficult for the U.S. Water Resources Council to operate effectively in resolving conflicts. The best we can do is to identify the conflicts and to indicate the potential implications of such conflicts. The 1975 Water Assessment is making an attempt to get better estimates of instream flow requirements as well as gross estimates of stream flow depletions. For example, the Assessment is utilizing the criteria of the so called Montana Method to measure the relative status of the Nation's streams with respect to the effects of the current level of depletions; look at where projected potential additional depletions will be the greatest; and, therefore, have the largest impact on the currently existing instream aquatic habitat. The Assessment's approach to this problem is only a start, but one which needs to be verified and further refined before publication of the report in 1977.

Instream Flow Service Group

The Council strongly supports the Fish and Wildlife Service effort to establish a Cooperative Instream Flow Service Group at Fort Collins, Colorado. We urge participation by both Federal and State agencies in financing and manning this long overdue program effort. We fully support Fish and Wildlife's desire to develop this group as a multiagency and multidisciplinary team. This group will serve a most valuable service if it develops, as I envision and trust it will, outputs on methodologies, data refinement and analysis, and effects information. These products will be of extreme value to all water planners and would be effectively used by the Council in future Council funded programs for comprehensive planning and the continuing water assessment.

The Council is not so naive as to believe that the efforts of the Cooperative Instream Flow Service Group will be a panacea and that all water use conflicts will disappear. However, output from this group will be of great value in the continued implementation of WRC's Principles and Standards and agencies procedures for the evaluation and formulation of water and related land programs and projects. The concept of WRC's Principles and Standards of developing alternative plans emphasizing economic and environmental objectives and the displaying of tradeoff effects in a system of accounts is a rational approach to water planning in today's situation. Improved information on instream uses is necessary in indicating tradeoffs among alternative plans under the Principles and Standards concept.

Water Assessment and Appraisal Program

In closing, I want to briefly explain to you the water assessment and appraisal program that is presently being implemented by the Council. The objective of this program is to give the Executive Branch of the Federal Government, through the Water Resources Council, an analytical mechanism for the appraisal of existing and proposed water and related land programs (see Attachment A). From the outputs of this program, the Council and its member agencies will be in a better position to make sound recommendations to the President and Congress on the allocation of limited Federal resources to meet the critical water requirements of the Nation.

This program builds upon State and regional plans as they compare to a continuing national assessment and to a data base relating to historic funding of federally financed water programs. The regional plans (CCJP's) will not only portray the programs, goals and objectives for the regions or basins, but they will also indicate requirements for Federal assistance and the relative priorities for such Federal assistance in implementing these plans. Inputs to these State and regional plans would include all levels of planning from a variety of sources (Federal, State, local and private).

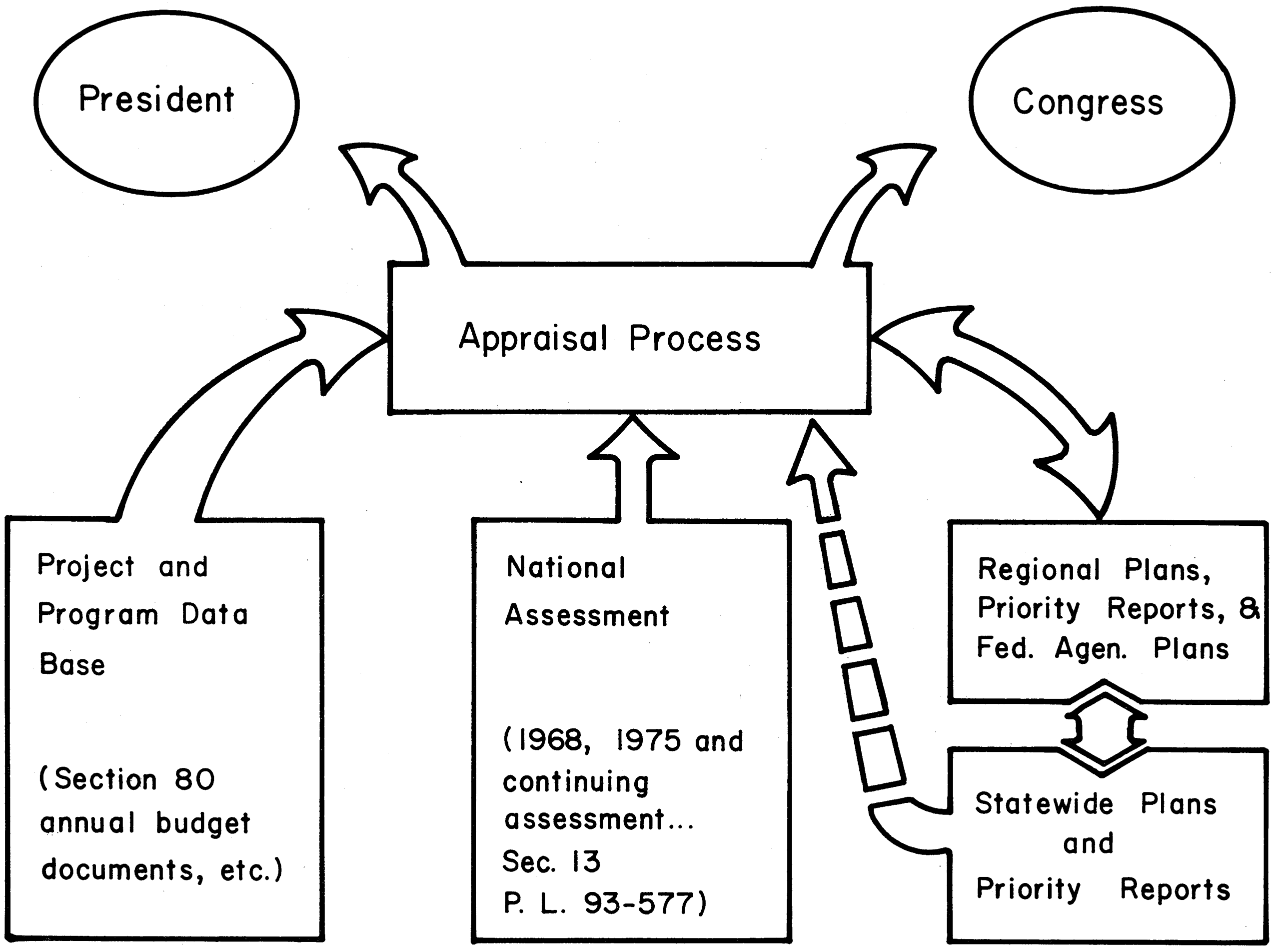
It will take time to perfect this system; its utility will be based upon experience, availability of inputs and the extent that users make of it. Notwithstanding this process, the Federal agencies will continue to set their priorities and submit their requests for funding and authorization through their normal reporting processes. State and local officials, as well as other organizations, will continue their direct contact with Congress to indicate their priorities and support for various programs. However, this integrated appraisal program of the Council will assemble meaningful information which can serve as a guide in setting national and regional priorities for meeting critical water requirements and as a tool for decision-makers in the allocation of scarce resources to meet these critical requirements.

Summary

The other day I read a statement made by Mr. Kenneth C. Bolding in Technology Review. To me it was the best justification I have seen for the water assessment and appraisal program and increased professionalism among water officials. It is something that we as water technicians need to keep in mind as we "do our thing" in making water assessments, determining instream requirements, and designing projects, or whatever we are doing. Mr. Bolding's statement follows:

> "The world moves into the future as a result of decisions, not as a result of plans. Plans are significant only insofar as they affect decisions. Planning may be defined in such a way that it is part of the decision-making process; but if it is not a part of the decision-making process, it is a bag of wind, a piece of paper and worthless diagrams."

WATER ASSESSMENT AND APPRAISAL PROGRAM



THE PLACE OF THE AQUATIC SPECIALIST IN THE INTERDISCIPLINARY APPROACH TO SOLVING STREAMFLOW PROBLEMS

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ABSTRACT

The interdisciplinary approach applies to a selected group of specialists who interact as a team from beginning to end to solve an assigned problem. The National Environmental Policy Act requires the utilization of a systematic interdisciplinary approach in planning and decisionmaking when the matter may have an impact on man's environment. An aquatic scientist, such as an aquatic ecologist, fishery biologist, or limnologist, on all interdisciplinary teams helps fulfill the requirements of this law.

The development of a streamflow problem analysis, leading to sound decisionmaking, is so complex that usually many disciplines will be required to work together with intergroup communication to find solutions. Aquatic scientists must fit in and be part of such an interacting team if the aquatic resource is to be protected and enhanced. No longer can the aquatic scientists continue to work by themselves, patting each other on the back, and reinforcing one another on what a great job they are doing, while talking to no one else. Either we fit into the team approach or we should get out and let someone else do the job. The resource is too valuable to mismanage. There are 10 separate steps or building blocks in which the aquatic specialist must have a strong commitment in order to function in an interdisciplinary manner. These building blocks, beginning with the identification of the problem and ending with management direction, are the vehicles for aquatic specialists to improve management of streamflows.

INTRODUCTION

The terms multidisciplinary and interdisciplinary are confusing, and to many people both terms mean the same thing. My definition of a multidisciplinary approach is perhaps limited, but one that is based on experience. It applies to a process where one person, acting as judge and jury, receives separate, fragmented data from assigned specialists. The specialists had little, if any, interaction. The report writer then meshes these uncoordinated data to form an analysis document for decisionmaking. The product usually represents one person's understanding rather than the understanding that can be derived from an interacting team. Yet, the best resource management decisions are based on how the evidence from all disciplines is evaluated, not on rank or title of the

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decisionmaker. Aquatic scientists have often found themselves functioning in a multidisciplinary manner, and the results are usually unproductive and disheartening.

An interdisciplinary approach, in my opinion, features a team of specialists representing various disciplines who interact from the time the team is assigned a problem through the decisionmaking and management directive stages (Fig. 1). This is the type of team effort aquatic scientists should associate with, because the total mix of interacting minds produces the best possible final product. This interdisciplinary definition, however, does allow for some planned, single-discipline activities during the team tenure for the sake of efficiency. It allows individual scientists to function independently in data collection and at the start of the first stage of data analysis. However, they have first interacted to determine what types and levels of data are to be collected for entrance into the final analysis.

From these definitions, the multidisciplinary approach resembles the dictatorial way of doing business, but the interdisciplinary approach is a more democratic way. Needless to say, this report will concern itself with the interdisciplinary approach. The National Environmental Policy Act (NEPA) requires a systematic, interdisciplinary approach to planning and decisionmaking in any matter that may affect the environment. An aquatic scientist on the interdisciplinary team helps fulfill the requirements of this law.

WHAT CAUSED THE INTERDISCIPLINARY APPROACH?

The historical approach to problem solving has been to reduce a large, complex situation to its component parts. Thus, we gained a partial understanding of parts of the whole, but lacked an understanding of the interrelationships within the situation.

In the past, this approach was used in the management of those resources that detrimentally impact aquatic resources. As a result, resource management was usually conducted by a single discipline using functional approaches. The timber specialist logged the riparian areas, the livestock manager allocated the streambanks to grazing, the engineer designed the culvert crossing, and the waterflow managers stored or diverted water to fit offsite uses. Any or all of these activities often occurred without proper consideration of the aquatic resources. The fishery biologist managed the resulting fishery resources with an incomplete understanding of why the fishery was declining and perhaps no understanding of the stresses coming from the watershed or within the stream itself.

The disciplines were not talking to each other and there was little attempt to coordinate their management programs. Even among aquatic biologists, Cummins (1966) found communication blocks affecting the ability to manage stream environments. Each biologist usually went his lonesome, independent way.

It was not uncommon a few years ago for a water management agency to manipulate riverflows while a biologist flew over the river in an airplane and, from this height, decided which flow was best for the fishery. Management decisions forced upon us in this manner, whether they be from a lack of commitment, a lack of money or time, a lack of understanding, or noncommunication among those involved in the decisionmaking, helped develop the thinking within the public sector that scientifically trained personnel are no more qualified than the general public to make management decisions.

Thanks to NEPA and the increasing awareness of the need for more comprehensive resource management, the functionalized, intuitive type of decisionmaking of the past was changed to a more comprehensive interdisciplinary approach. This direction came none too soon, because the burgeoning human population had accelerated water use and increased the demand for understanding streamflow needs.

Now that we are gaining an understanding of our functionalized findings within each discipline system, this single-system understanding must be meshed into the integrated system that in our case is an ecological system. This can be best accomplished through an interdisciplinary approach.

WHY AN INTERDISCIPLINARY APPROACH?

The management of streamflows is difficult and complex because of (1) the complexity of the stream environment, (2) the complexity of the stress applied by surrounding or upstream uses, (3) political restraints on water management, (4) inappropriate and confusing laws and regulations, (5) the numerous agencies that have authority to control or manage aquatic systems, and (6) the complexity of public desires. An understanding of the biological requirements and relationships of plants and animals within the stream is a complicated task by itself, without the requirement of relating it to these other important matters.

Resource managers lack understanding of the aquatic and surrounding environment as it relates to streamflow needs. The major reason for this is that no valid comprehensive analysis system has been developed to document, describe, evaluate, and fulfill aquatic needs and relate this to streamflow needs. This symposium was organized to address these problems, but the problems will only be solved when the aquatic scientist has complete participation on the interdisciplinary teams.

The development of a streamflow analysis leading to decisionmaking is so far reaching that not only will it take an interdisciplinary effort from engineers, hydrologists, aquatic ecologists, fishery biologists, soil scientists, landscape architects, wildlife biologists, range scientists, and others to build a proper procedure, but it will take interdisciplinary activity by administrators, land managers, politicians, lawyers, economists, and sociologists to sell it and apply it in the real world. Thus, a collection of talent, coordinated to provide synergism, will be needed to effectively solve streamflow problems. The mechanism must be developed so that all related disciplines, including the aquatic specialists, can work together, with intergroup communication, to find solutions to streamflow needs. The past has well demonstrated that the job is too big and too complex for separate functionalized approaches.

WHY DOES THE AQUATIC SCIENTIST HAVE TO FIT IN?

Most western States do not manage streamflows for the best or wisest utilization of water that will provide the most use and enjoyment for the greatest number of people, because water use (rights) is regulated mainly through a "first in time--first in right" appropriation law. Thus, the political process can disrupt the soundest functional approaches leading to decisionmaking for water management. If legislatures continue to ignore streamflow needs that can only be defined through a comprehensive interdisciplinary approach, then these laws and regulations will continue to do an inadequate job for the fisheries. Seldom does a single discipline have much success in influencing a political decisionmaking process. The interdisciplinary approach with all specialists working in a coordinated way will have much more success.

Water resource boards have the responsibility for identifying streamflows which will preserve the desired uses; fish and game commissioners have the authority to manage fish and wildlife in relation to streamflow needs; departments of health and welfare have the responsibility for water quality as affected by streamflows; State land boards control the beds of all navigable streams; the Environmental Protection Agency has some control of water quality requirements as affected by streamflows; and the U.S. Fish and Wildlife Service has authorities and memoranda of understanding to study and recommend streamflow needs. The U.S. Army Corps of Engineers, the Forest Service, and the Bureau of Land Management have certain authorities to manage waters on lands they administer or those controlled by their structures. Thus, the aquatic profession should have representation within each of these managing agencies to influence decisions that relate to aquatic environments.

Because many agencies do not have aquatic scientists, it becomes difficult or impossible for the scientist to not only fit into their problem analysis, but also to have authority to be represented in the agency's problem-solving and decisionmaking procedures. The public's desire for streamflow management is also as mixed as the political and managing agency attitudes. For streamflow management to be successful and protect and enhance our resources, it must have public support.

So, no longer can aquatic scientists keep meeting by themselves, patting each other on the back, and telling each other what a great job they are doing, while really talking to no one. Either we "fit in or get out" as the game is too complicated and the resource too valuable to go it alone. Through an interdisciplinary and an all-encompassing interagency approach, the aquatic professions can make sure that total aquatic needs are adequately identified and considered in every agency's planning and management.

Another beneficial spin-off that should not be overlooked in the interdisciplinary approach, especially when participating on interagency teams, is that it provides broad opportunity to keep up with the times in career development and offers job contacts that can lead to personal betterment.

HOW DOES THE AQUATIC SCIENTIST FIT IN?

The first prerequisite to fitting in is to have the background to perform well in your own field and have standing with your own colleagues. Then comes the ability to work with others and a desire to participate in a group venture. A difficulty arises here in that aquatic scientists in their educational and training development have acquired biases resulting in the tendency to be self-centered loners. Somewhere in our educational makeup, or in our adaptation to survive in the bureaucratic jungle, we have developed personalities that keep many of us from entering into managerial interdisciplinary problem solving. Our agencies, in complying with NEPA processes, have done wonders in breaking us out of this shell. Our disciplines are now acquiring a problem-solving focus and getting away from our once strong functionalized focus. Thus, with constant prodding, we are moving in the right direction.

One function of an interdisciplinary team is to resolve as many misunderstandings and misconceptions regarding the assigned problem as possible. To do this, the aquatic scientist must interact with each person on the team--challenging, learning from, and contributing to the understanding of all team members. The scientist must place less emphasis on functional loyalties and advance new approaches to old problems. We must also collaborate directly and fully in all phases of the team's work, from the design stage, through decisionmaking, and even into the decision-evaluation stage.

The break in functional loyalty is not easy, as our peers have deep-set notions on how we are to function in our position. Often, we are so highly sensitive to peer rewards that our personal behavior is guided more by their expectations than by any other factors. This causes difficulty in meeting new problems with new approaches, because the peer generation still has close ties to the old way of doing business, which often failed in the past and would fail completely to meet today's needs.

Scientists may have to give up some allegiance to their division or even their agency, if integrated problem solving is to be accomplished objectively. Objectivity is a necessity because in many cases the aquatic stress or change that is detrimental to the fishery is related to a major resource your agency is managing. Streamflow needs correlate closely with livestock management or logging in that the respective managing agencies are often very protective and jealous of their major resource responsibility and do not want an aquatic specialist informing them they are doing a poor job of management. As the scientist interjects the facts into team functions, he can be inviting career suicide and the rewards system soon lets you know the professional risks involved. With these constraints, the scientist still must voice his convictions without exciting the opposition, or creating hostility within the peer group. Saying this is difficult to do...is the understatement of the eons.

INTERDISCIPLINARY INVOLVEMENT STEPS

The aquatic scientist must have a sincere interest in all steps of the problem analysis and have a strong desire to solve each assigned problem in its respective order. The scientist must be on the team from start to finish. The procedure of being excused from team participation midway through the building block development, which has usually been the case in the past, needs to be eliminated. Many agencies fully involve scientists in the data-collection stage, but ignore their capability in the analysis, and especially in the decisionmaking stage. For proper interaction, the aquatic specialist must participate in each of the following steps:

Step 1 - Forming the Team

The specialist should join the team at the very beginning and develop a strong commitment to function in an interdisciplinary manner. Scientists who are dedicated to function solely toward the advancement of their own discipline can jeopardize the goals. However, even though the emphasis is now on developing a problem-solving frame of mind, sufficient discipline focus is needed to function as a professional. A proper balance is needed.

The scientist must be prepared to devote about half of his time to the team effort. Efficiency is lost if the scientist is on more than two teams at the same time. This restriction will enable the scientist to still work effectively under Parkinson's law which states, "work expands to fill all available time."

Some of us who participated on as many as 15 interdisciplinary teams at one time can vouch for the failures that resulted. In most land- and water-managing agencies, the number of scientists in each of the other disciplines overwhelms us and we find ourselves on team after team, matching contributions from members who have only been assigned to one team, so we must limit ourselves and define our interdisciplinary role and get to it while at the same time fulfilling our responsibilities to the development of team morale.

Discipline balance in the team is required as it relates to the degree of expertise and level of understanding of each individual specialist. To match an experienced specialist from one discipline with a slightly trained teammate with no experience in another discipline leads to biased decisions. The resulting mismatch derails the compromise method of reaching decisions.

Step 2 - Design of Problem Boundaries

The problem can be properly identified even without an interdisciplinary approach because any individual can delineate and describe a problem. The study and the problem boundaries should be small enough in scope so the necessary aquatic information can be handled with the time, money, and methods available. If the problem is too big to be handled, then it should be subdivided to fit the available resources. The problem must be well understood at this time, prior to the specialist's contribution to the setting of objectives.

Step 3 - Setting the Objectives

At the very beginning, discipline objectives must be established and then meshed into the team objectives. Also, the level or intensity of study must fit the objectives, and fulfillment of the objectives must lead to problem solution. This will test the objectives for meeting reality. The agency and team leadership often need a push from the team members in developing a new, bold approach to the realistic setting of objectives.

Step 4 - Identify Data Needs

The intensity levels and types of aquatic studies to fit the allotted time, the available dollars, and the needed accomplishment should be set immediately to guarantee that this information is available to all team members. This phase causes us much difficulty as usually the aquatic resources have not been documented or analyzed because of lack of trained people and money. Thus, we are often left behind at this step as the rest of the team moves ahead. We must obtain some flexibility in the amount of data needed for a proper analysis. "Overkill" should be prevented, as it is unrealistic to assume that all the needed information will be gained prior to study completion. Also, because most of the data available are use-oriented rather than environmentally orientated, a critique of available data plus that to be gathered will be needed. Team members need to be well aware in this step of how the aquatic data are going to fit in with the total team data. The data also need to fit the "rule" (a rule is the description of the environmental mosaic and how a set of conditions placed on this environmental mosaic will react) requirements so the defined rule will have answers. An applicable rule technique is being developed in ECOSYM by Utah State University in a project sponsored by the Forest Service SEAM (Surface Environment and Mining) Program.

Step 5 - Critical Path

The team must function as a unit, including the aquatic scientist. The aquatic work must be programed for an orderly movement, and coordinated with the team from beginning to end. Each team member should be made aware, early in the game, of your commitment to timing and any problems related to meeting any of the team deadlines.

Step 6 - Study Coordination

The individual studies and the resulting information should be coordinated with the complete team so all studies will complement each other. A common frame of reference is absolutely essential if we are to get away from the stacking of individual, functionalized scientists' reports which occurred in the past. Information bridges need to be built, early in the game, between the aquatic scientist and the other team members, so the combined information will fit together in the team report.

Step 7 - Report Completion and Analysis

From the integration of the individual discipline studies and analyses, the capabilities, compatibilities, and impacts from all resource uses are determined by the team. This understanding is then interjected into the interdiscipline report in a finalized form suitable for the decisionmaking processes. In this report, the rules for defining ecological process and the answer to the rules affecting ecological process must be defined.

The analysis stage takes an open mind and preconceived ideas are always open to modification during the integrating phase. In the crunch of analysis, everyone on the team will not agree all the time, and in reality, the final product is a compromised solution. However, the scientist cannot become isolated in this critical stage, as this is where any environmental gains will be made as the compromises lead to decision recommendations.

All alternatives must be identified and analyzed. Here come the trade-offs, as not one alternative will satisfy every team member. Often a combination of parts of the alternatives into a new alternative will develop a solution that the team can live with. Alternatives should be assigned priorities and trade-offs identified in selecting the final alternative. Special effort must prevent stronger groups of individuals from dominating and thus biasing the compromised team recommendations. Collectively, the team may reject any of the aquatic specialist's ideas as they relate to the analysis, but this is to be expected. Our profession can be of great value in this building step by continually interjecting sound ideas. The largest impact of the team will be in steps 1 through 7 where the most effective picture of the true value of the social-economic benefits must be brought into focus.

Step 8 - Decisionmaking

Decisionmaking, which allocates the streamflow, can be a weak link because usually aquatic scientists do not, will not, or are not allowed to enter into the decisionmaking processes. Someone has to make the final decision and, if the proper decision is not made, the aquatic resources will suffer. Scientists must develop stature and position to extend their influence beyond the traditional role of disciplinary data gatherers and into decisionmaking. Being present with stature and influence during this stage will make the final decision more defensible.

An effective interdisciplinary approach to decisionmaking requires balance and assures an understanding of how and why the recommended decision is made. Often it is not until the team effort has wound down and dissolved that a court suit or court injunction challenges the decision on lack of a true interdisciplinary approach, especially as it relates to aquatic values. The aquatic scientists cannot fail in their responsibilities associated with each interdisciplinary step. A look at the court track record shows that the managing agencies usually lose when a decision is challenged. If the aquatic specialist feels the final direction is not valid and will violate existing laws, or will detrimentally affect the aquatic resources, then the scientists should go on record with a dissenting minority report. This document may be valuable for future analysis, as today's game does not end--it goes on and on. This also allows an outlet for each team member and gives each a forum so no member is ignored.

Step 9 - Management Evaluation and Accountability

Wouldn't it be nice if we could get all the aquatic information needed into the management evaluation? How did the fish react to determined flows? Did the waterfowl adjust to the programed water diversions? Was the optimum flow decision favorable for white water floating?

Well, our disciplines can interpret this information if we are only allowed to continue into the management evaluation phase. To fully participate in management evaluation, however, the biologist must have first participated in all the interdisciplinary steps and been integrated with the team during its entire tenure. Even after the interdisciplinary effort is over, the aquatic specialist should constantly participate in evaluations and updating of the team findings for management accountability. All management can be improved upon and the directions from the decisions should always stand the test of evaluation with modifications as needed. The decisions should be constantly monitored to make sure the objectives behind the decisions are met.

CONCLUSIONS

The interdisciplinary approach can improve the management of streamflows, but this will take bold, aggressive, and imaginative teams with original thinking capability in the leadership. The aquatic scientist has failed to step into agency and team leadership positions, yet our discipline is essential. We are ecologists and understand life support systems and the interactions of life within the systems. We understand water and its relationship to the lands and how stress from the surroundings can affect living systems. We are short in understanding the socio-economic capabilities and constraints, but so are many of the other disciplines. Thus, if we will participate and gain an understanding of the managerial methods of working within an interdisciplinary process, then we will be in a much better position to gain leadership positions that will enable us to protect and enhance the aquatic resources. With total interaction and increasing involvement in interdisciplinary leadership, the aquatic scientist can best meet the needs of the aquatic user and the aquatic environment.

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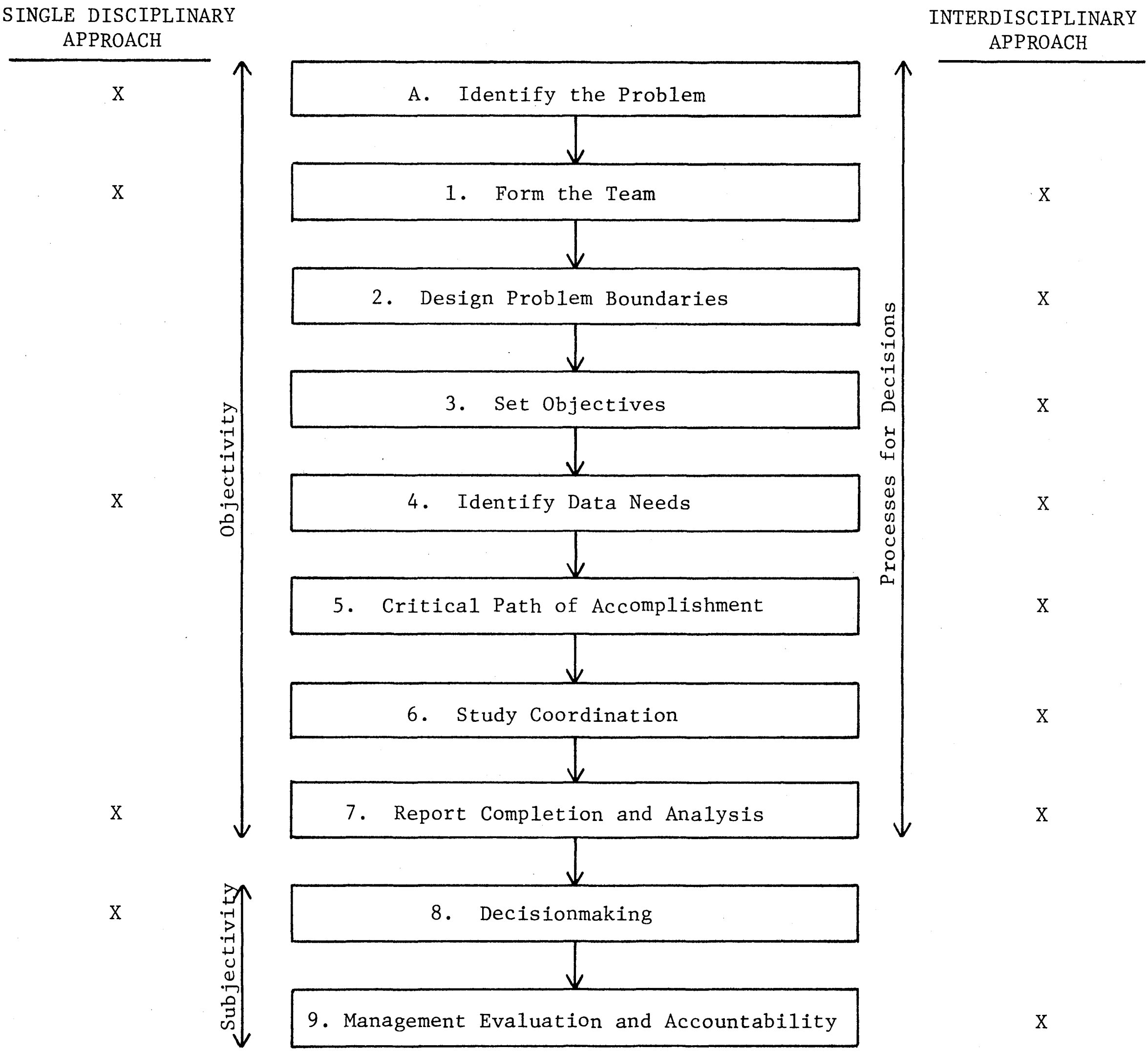

Fig. 1. Flow Chart Outlining the Consecutive Steps for the Interdisciplinary Team to Complete for Systematic Problem Solving and Resource Objective Fulfillment (from Platts 1973)

THE SPORTSMAN'S VIEWPOINT AND SOME SUGGESTIONS

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This subject is a difficult one because, like beauty, it is in the mind of the beholder--what is one man's piece of cake may be another's castor oil. If we put a dam on a plains river, fishermen rejoice while the waterfowler and small game hunter are outraged; a dam on a salmon river will bring the salmon angler down on a builder while the lake fisherman is all smiles. Diversion of water from a prime trout river will attract Trout Unlimited's wrath but the newly irrigated land may provide pheasant hunting and thus the bird hunters' support. Despite this large divergence of special interests it may be possible to establish perameters of opinion and define certain elements which would be common to the entire spectrum of sportsmen.

Who are these sportsmen whose viewpoint we are trying to understand? There are some 50 million of us from all walks of life and, as 25% of the U.S. population, fairly representative of it. A critical fact to remember is that for us hunting and fishing is avocational rather than vocational. Only a tiny percent of our number is involved in these sports on a professional basis. Because we hunt and fish for fun and relaxation, we do not want to spend our leisure hours fighting to preserve our sport--we'd rather participate in it. Yet if you kick a sleeping bear long enough he inevitably will rouse himself and do battle. So it is with sportsmen. We're beginning to wake up.

Fortunately for those who wish to work with sportsmen, there is a competent leadership emerging in some areas. The cold water fishery is led by T.U. and F.F.F., the waterfowlers by D.U. and overall the National Wildlife Federation is asserting itself more all the time. By and large sportsmen will follow the lead of these groups.

We sportsmen may not be very smart but we do know that fish will not live in a dry creek bottom, nor will wildlife long flourish along a stream course which has been denuded of its vegetation in the name of enhanced stream flow. An agency or private company that proposes a project which results in that type of thing invites the sportsman's wrath, impaired public relations and probably a lawsuit. We don't need anymore of that and neither does anyone else. The hard working sportsman's group would rather expend its efforts improving what we have than fighting what is proposed.

I believe that we have taken some significant steps toward cooperation and understanding during the last few years. The sportsman is far better informed than in the past--or at least his leadership is. We appreciate the fact that a stabilized instream flow may enhance a fishery; we realize that silt is probably the fisherman's worst enemy and thus may appreciate a dam's silt retention abilities. Conversely, poor land use, sloppy forestry practices and polluted return irrigation flow are properly identified as culprits to be dealt with. The better informed sportsman represents both a threat and an opportunity to those who wish to alter instream flows. A threat to those who do not recognize our needs and deal with them in the most equitable manner: an opportunity to those who are doing the best job possible to answer our needs and are willing to put forth the effort necessary to explain the problems and work toward equitable solutions.

The day when the sportsman could be treated as an ignorant slob to be pushed to the back of the bus is over. We have already lost more than we could afford and we will fight for what is left. Over, too, is the day when the sportsman has a negative knee jerk reaction to all projects and proposals to alter flow.

Let me be more specific. We do not want to lose another foot of free flowing river or the wildlife it sustains along its banks--yet inevitably we must. When we do, we want something in return. We can applaud a Lake Powell without equivocation. We applaud a Flaming Gorge but then must struggle over temperature control to preserve the downstream fishery. We applaud Fontenell and the tailrace fishing below it but we decry the necessity of the battle for a lousy 360 second feet to sustain one of the west's great brown trout spawning runs. We damn a Teton project without equivocation.

I note that in the title which was assigned to me by John Peters and Frank Richardson that I was given an opportunity to make some suggestions. I am certainly not going to let that opportunity pass by. In making these suggestions, I hope that they will also tend to clarify the sportsman's viewpoint.

I think two of my primary suggestions lead from one to the other: The Study of Alternatives and Innovation. Too often in the preparation of environmental impact statements the study of alternatives turns out to be nothing more than boiler plate and an exercise in adhering to the rules rather than an honest perusal of other alternative possibilities. I would take a small example in our own Colorado Rockies. On the Upper Colorado there is need for additional water storage. This for irrigation, power generation and what is always questionable in my mind--flood control. The proposal, of course, is to dam a narrow spot on the main stem of the Colorado River in Gore Canyon. Frankly, I could have chosen the spot myself just from the experience I have had in Trout Unlimited battling some ill-conceived projects throughout the country. We must ask those individuals who picked this site why it is such an automatic thing. Was the site picked because it was the best place for a dam, because it was the easiest, or because it was always done that way. Just upstream of the proposed damsite, a stream called Muddy Creek enters the Colorado River. It drains an area of unstable soils that I am sure provided natural pollution in the form of silt since time immemorial. This problem has been compounded by over-grazing, highway building and all the normal ills that seem to be pervasive in our high country. Would it not be possible to include a dam on Muddy Creek where there are ample sites for a project. It certainly has a heavy flow and a great part of the water rights which are projected for the Gore Canyon site are derived from the flow of the Muddy. Putting a dam on the muddy would cut the silt flow into the river thus improving the muddy itself from the sportsman's standpoint. It would certainly slow down the in-migration of silt to the new reservoir which in time, of course, would mitigate its ability to do the job for which it was designed. If it were not possible to include a dam on the Muddy in the project, maybe that is where the mitigation money should go. Mitigation money too often is just a fish thrown at the problem to get the sportsmen off the project sponsor's back. If the smallest possible dam were built in Gore Canyon and if a dam were built on the Muddy, the project sponsors could come to the sportsmen with a straight face and point out the good that their project was going to do for fish and wildlife. In that manner they could enlist the sportsmen to their side; and with their joint efforts the chance that the project would be built is almost 100%.

Before going on to my third suggestion, let us go back for a minute to the question of site selection for dams. I have already questioned the reason for them always being put on a main stem stream or major tributary and in a narrow spot. Let us suppose that you were a project engineer involved in a project to store water for power, irrigation or for some other reason. Wouldn't it be possible to put a small diversion structure in a river, take the water by gravity to a side canyon which was adaptable to damming, drop the water through a penstock, thus generating power, and repeat the procedure in the outflow process. You would have dammed a dry side canyon so typical to the west with very little loss of fish and wildlife values, created a reservoir fishery and yet done very little to alter the main stem stream itself. At the same time, by skimming the flows you would very possibly have enhanced the fishery in the main stem. This may be a simplistic example but it does, I believe, illustrate the kind of thinking that could go into projects which would make them do the job for which they were constructed while at the same time honestly enhancing the fish and wildlife resource. Again, the support of the sportsmen for the overall project would be almost guaranteed.

My third suggestion would be to design operating schedules and procedures with the fish and wildlife resource in mind. Certainly we sportsmen realize that the entire design and operation of a project cannot be done for our benefit. At the same time we believe that if fish and wildlife values are considered from the beginning of the planning function that much better projects can be designed from our standpoint. One of the most important aspects of the project as far as we are concerned is the very subject of this conference--instream flow. In general terms we would like to see the flow with as little variation as possible. This means variation on a daily basis as well as variation on a seasonal basis. One of the common problems to many projects is a situation where trout might be spawning on a gravel bar which is the right water depth, etc., the flow from the project may have been constant for a period of time during the winter and early spring, and now just about the time that the rainbows have spawned the gates are opened and down comes the great spring flood washing the spawn downstream to be lost forever. Conversely, if the instream flow has been running at a certain level for a period of time, a spawning has just taken place and the water level drops, the net result is the same. Not only is the flow important instream, but the water level in the reservoir itself is of concern to sportsmen. Very often it seems that the bass just get themselves in the mood, accomplish their spawning, and the reservoir is dropped five or six feet again leaving the spawn high and dry. I am convinced in my mind that this type of thing can, in great part, be avoided with proper prior planning.

Another concern to sportsmen regarding the instream flow is the temperature of that flow. Flaming Gorge Reservoir is an excellent example of this particular problem. As the reservoir was filling, the stream temperature in the Green River below the reservoir was excellent--trout growth was close to phenomenal and the fishery was one of the top ones in the west. Unfortunately, the outtake from the reservoir was in the bottom of the dam, and thus as the reservoir filled, the water temperature at that location became lower and lower. Finally, a couple of years ago the instream flow from Flaming Gorge Reservoir was literally liquid ice. This, of course, inhibited the growth of the fish in the stream below the dam and also changed the instream micro-climate on which the fish depends for his existence. Thanks to the efforts of Regional Director Dave Crandall of the Bureau of Reclamation, we will see a variable outtake installed on the dam during the next couple of years which will allow us to have ideal temperatures in the stream below the dam all year long. To have planned a variable release point for the reservoir in the planning stage would have been much less expensive and certainly would have alleviated what will be a five or six year problem for the fishery on the Green River. Hopefully, if fish and wildlife values are seriously considered during the planning of projects, we will be able to avoid this type of instream flow problem as well as others such as nitrogen super saturation which has plagued the Columbia River over the last few years and which probably is the greatest single factor responsible for the decline of the anadromous fishery in the Columbia River System.

Fourth, we must clean up our act. It certainly does no good to have proper instream flow if it cannot be used by fish and in some cases even by wildlife. The causes of traditional pollution, of course,are well known. The laws exist and the cleanup project is underway to improve our situation in this area. Less obvious are the problems of pollution from silt and return irrigation flow. Silt of course can be derived from bad land use of all types, but it is often associated with poor forestry practices and overgrazing. We must take steps to eliminate these problems and treat our watersheds more carefully. This, in turn, will benefit not only fish and wildlife but all who use water.

We suggest that something must be done to clean up irrigation return. Not only the silt, but the thermal pollution and, even more immediately, dangerous pesticide input into the streams. Additionally the irrigationists can expect to come under increasing attack if the sloppy practice which is so prevalent in the western states continues. It is very hard for the sportsman to tolerate the fact that his stream is de-watered when he sees incredible waste by those people who have title to the water. This bone of contention is destined to become a real point of conflict if something is not done.

Our fifth suggestion is that we learn to use what we have in the way of legal rights for instream flow for the protection of our fish and wildlife resource. At this very conference people have stated that in one northwestern state the Fish and Game Department is afraid to move because there are individuals in the statehouse who control the appropriations for Fish and Game and who are not concerned about the fisheries resource. In Colorado sportsmen struggled long and hard to have a stream protection law enacted only to find that the Division of Fish and Wildlife, which is responsible for enforcement of the law, is unwilling to knock heads with the Highway Department, among others.

With one exception we do not find that additional laws are necessary. It is necessary for us only to properly and fairly enforce what is already on the books in order to guarantee the quality and quantity of instream flow that we need. That one exception, of course, is the major one and revolves around western water law and the major river basins of the west. There is honest confusion of interpretation within the legal fraternity and it will probably be necessary for the Supreme Court to re-adjudicate the flow of the Colorado River, for one. The question of whether or not it is legal for instream flow to be set aside for fish and wildlife enhancement; the concerns of Wyoming, who is afraid that if they do not use the water they will lose it; the concerns of Mexico who, while it is receiving its proper share of water, is receiving it in such a quality that it is virtually unusable.

These questions and a great many others need to be clarified by the highest legal authority in the country in order that the necessary projects and programs pending for fish and wildlife, as well as irrigation, power and other uses, may go forward in an orderly and expeditious fashion.

Finally, we sportsmen feel it will be necessary in the long run to have a fish and wildlife Bill of Rights: stream protection, guaranteed instream flow for fish and wildlife, beneficial use being expanded to include fish and wildlife flows, equal rights for fish and wildlife in the use and planning of our water projects, and some prohibition against alternation of natural streams will all have to be addressed.

In summary, it can fairly be said that the sportsman wants clean, clear water, instream, at the right temperature and in enough quantity to sustain and enhance the fish and wildlife resource. Not necessarily the way it was in the beginning, but in a way that will guarantee our sport in the future. Consider, finally, that there are 50 million sportsmen. That number may not mean anything until you think in terms of what this could mean as a political force. Compare that to probably the largest political lobby in the United States--organized labor--which numbers less than 20 million members. If those individuals who desire to plan and develop the water resources of this country could consider and work with the sportsman, together we would represent an unstoppable political and social movement.

CONCLUDING REMARKS

by Fred Eiserman

And now we have completed four days of strenuous effort. We have had a working conference in every sense of the word. I am sure you will all agree that we have met the objectives of exposing and providing for multidisciplinary discussion of problems associated with the allocation of stream flows among competing and noncompeting uses. A proceedings will be published which, I am sure, will be of significant value to technical, legal, and political practitioners associated with instream flow problems. As part of this conference, we have reviewed in detail the problems, problem components, and the strategies for implementation of instream flow requirements. The state of the art on instream flow needs methodology has been updated. Legal foundations for instream flows and case studies have been reviewed. The important subject of land use planning as related to instream flows has been discussed. Short courses on law, hydrology, and other subjects have been conducted. Roundtable discussions on the real world associated with applying minimum flows have shown us that even with stream flow legislation and data to substantiate requirements, there is no guarantee that aquatic environments will not be dewatered. We have talked of mathematical modeling and finally this morning, we have heard from administrators, professionals, and private citizens with reference to their positions on the problems associated with increased competition for limited stream flows. The most impressive gathering of people on the subject of instream flows ever assembled has taken place here in Boise.

The end result of all this certainly has been in the understanding of our mutual problems, and I sincerely hope that our most significant accomplishment has been the setting up of guideposts which will permit us to proceed with the necessary decision-making process to balance the traditional uses of our streams and rivers with a program of enhancement and protection of these aquatic environments. I also sincerely hope that this symposium has stimulated and inspired the attendees to take with them a spirit of cooperation which will eventually improve the quality of our water planning efforts, and which the necessity of compromise becomes mutually inclusive for the benefits of future generations. As you all know, this symposium has been too encompassing to summarize each and every presentation, and it would be impossible to adequately remark on all of the topics. In fact, many, many weeks ago it was decided by the Steering Committee not to test the patience of the faithful who have remained to this final hour.

I do, however, have a few comments that concern future actions necessary to obtain some of our objectives in maintaining stream flows necessary if a measure of the lotic aquatic environment is to be preserved. As Warren Fairchild indicated, we are not decision makers, but we are in an excellent position to influence those who make decisions. In this democracy, the actions of decision makers are still tested at the polls--provided that the citizen is fully informed. At the roundtable discussions on applying minimum flows in the real world, I have heard that even with studies and laws on this subject, stream flows will not be maintained primarily because the rank and file citizen, thinking his rights are being protected, has not been informed to the contrary. And at this conference, one of the most important sessions, Topic II-E on public involvement, had only six people in attendance. I suggest that you read your proceedings on this topic. Doli Obee from the League of Women Voters of Idaho provided an excellent paper, as did other members of this panel.

I urge you all not to forget the dedicated professional citizen, become one yourself, and participate with these people. Perhaps a symposium for these people including the League of Women Voters, the Audubon Society, Trout Unlimited, the Sierra Club, Friends of the Earth, the Izaak Waltons, and others would be in order.

In addition to the possibilities for operations of systems for stream flow research, as Bob Scott reported on, I would suggest operating systems to motivate people into action where the results of a dewatered stream can be fully appreciated. And finally, I would suggest the formation of a permanent committee on this subject within the Western Division of the American Fisheries Society to keep alive this theme of getting together and developing action plans with all disciplines in water resource management. In any event, Frank Trelease's comment that "this is no sport for the short winded," is to be remembered.

It has been my pleasure and gain to have been part of this program, and I thank all of the speakers, the participants, the attendees, the Steering Committee, the staff, and the financial sponsors for making this symposium a success. I wish you all a safe journey home and with this the Instream Flow Needs Symposium and Specialty Conference is now officially closed.

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