Estimating the longitudinal extent of hydrologic alteration downstream of a waterpower facility.

Preface

The methods described in this document provide a technical approach for estimating the longitudinal extent of hydrologic alteration downstream of a waterpower facility. The document is scientific information and is not to be interpreted as policy.

Background

Methods are required to determine how far downstream from a proposed waterpower facility we would expect to see a change (alteration) in the flow regime of a river from the currently observed flow regime (i.e. pre-project regime) as a result of the construction and operation of a facility. This is the longitudinal extent of the hydrologic alteration and is only one piece of information used to define a project's zone of influence, within which potential effects of a project are assessed.

The purpose of this document is to establish a methodology to determine how far downstream the pre- and post-flow regimes are expected to be different. Whether the difference in flow regimes between the pre- and post-periods (i.e. the degree of alteration) has an effect on a specific value (ie. social, recreational, aquatic ecosystem values) is a separate question and is only discussed insofar as to distinguish between these two planning objectives (i.e. determining the extent of influence vs determining possible effects). Information on the expected degree of hydrologic alteration downstream of a project will help identify where potential effects may occur. Given the assumption that the hydrologic alteration will decrease with distance downstream, the longitudinal extent where possible effects might be anticipated may differ from the extent of the hydrologic alteration.

The approach discussed in this document assumes that streamflow data (observed or estimated) are available to characterise the pre-project flow regime (current condition) and a hydraulic model has been developed of the operating regime for the proposed facility to provide estimates of the proposed condition flow regime at specific cross sections downstream.

Conceptual approach

A flow regime can be described in terms of its magnitude, duration, frequency, timing and rate of change. Some or all of these characteristics may change when a flow regime is altered and can be used to estimate the extent of hydrologic alteration. This assessment requires information on the current flow regime (current condition) at the site and that of the proposed operational regime (proposed condition). The information required will depend on the type of facility and the types of alteration to be expected.

For a waterpower facility that will be operating to meet daily peak energy demands (in full or in part), the hydrologic alteration should be assessed by examining potential changes to the total distribution of flows and the diel range of flow, on a monthly basis. At a specific site on a river for any given month, the assessment evaluates if there will be a change in the range and frequency of observed flows or in the daily range of flows? Hourly, or finer resolution, streamflow data would be required to characterise differences in this pattern, particularly in the altered flow regime. If the current condition is a natural flow regime, daily data could be used for the analysis recognising that the estimates of daily variability may be underestimated. The underestimation will be greater in smaller basins that respond quickly to hydrologic inputs as opposed to larger basins with larger baseflow contributions that have less ‘flashy’ flow regimes.

If the current condition is a natural flow regime, a minimum of twenty years of data (assuming stationarity) is needed to adequately characterise variability in the streamflow. If only shorter, data records are available (i.e. < 20 years) the record should be evaluated carefully to ensure that it captures the range of variability expected at the site. This can be assessed by examining the next closest streamgauges (i.e. gauging stations in neighbouring basins with similar flow regimes to the proposed site) where the same period can be assessed within the context of a longer historical record (i.e. the last 20 years) to see if the range of flows are represented in the shorter period. The degree of representation could also be assessed by examining local climate data for trends. Longer time series or twenty year time series not immediately preceding the current date are not recommended as the simulated flow regime may incorporate past anomalous climate trends or basin conditions which no longer exist.

Time series for the current flow regime (observed or estimated) can be used directly to synthesise a flow regime at specific cross sections downstream of the proposed facility using proration or spatial interpolation methods. Alternatively, time series data estimated for the site where the facility is to be located can be used as input to a hydraulic model developed for the proposed project (eg. HEC-RAS) to estimate corresponding discharges and water level values at downstream cross sections. The same input data can then be used with a model of the operating regime for the proposed facility to provide estimates of the proposed condition flow regime at the same cross sections. Summaries for the variable of interest for the two distributions (current condition and the proposed condition) can then be compared to determine the degree of alteration. The downstream extent of the hydrologic alteration would end when the pre- and post alteration distributions are not statistically different. If it is not possible to model a continuous post construction time series over many years, typical operational flow and water availability scenarios (i.e. using the longterm monthly median flow to represent ‘typical’ water conditions) can be used to model expected post construction operation flows for each month.

Standard statistical methods can be used to describe the range of variability observed in the current condition for an indicator variable and to establish assessment criteria to evaluate the degree of hydrologic alteration. Assuming the data does not follow a normal distribution, the median is used to estimate the most commonly observed conditions and percentiles (or % exceedances) used to describe the ‘spread’ of values, or variability, around the median. One method to determine if two distributions are **not** significantly different is to determine if the median value of the proposed condition falls within the 95% confidence interval for the median of the current condition (Figure 1). However, the magnitude of the confidence interval is dependent on sample size. Alternatively, the distribution around the median can be summarised into ‘levels’ of alteration based on increasing distance from the median. This is measured using percentiles (or % exceedances) which are independent of sample size, assuming the sample size is adequate to represent the distribution, and are simpler to calculate (Figure 1). In this example, the range between the 38^{th} and 62^{nd} % exceedance is used to test whether two distributions are different. Similarly, distributions are **not considered** different if values of the proposed condition fall within the range between these two % exceedances for the current condition.

Specific methodologies

To minimise the number of cross sections to be analysed, a trial and error approach can be used with both methodologies described below, starting the analysis at a location estimated to be the downstream boundary of hydrologic alteration. Additional sites can then be assessed upstream and downstream of this site until the downstream extent of the hydrologic alteration is identified.

Characterising the current condition and proposed condition

1) Diel range

This metric is used to assess change in short-term fluctuations in flow.

Current condition

i) Calculate the absolute diel range in streamflow ($m^3\ s^{-1}$) (i.e. the maximum observed value minus the minimum observed value in a 24hr period for hourly data starting at 00:00hrs). If hourly flow data is not available, daily values are used to calculate the diel range. For example Day 2 – Day 1 = absolute diel range for Day 2.
ii) Bin all of the diel range values for a given month across all years together and calculate the frequency distribution. For example, all diel range values for the month of June for 20 years of data would result in 20 years multiplied by the 30 values in the month resulting in 600 values for June.
iii) Summarise the distribution for each month using the four exceedance values shown in Figure 1 that demarcate quantile boundaries. An example of a cumulative frequency distribution is shown in Figure 2. The discharge values for the quantile boundaries can be extracted from this distribution and summarised (e.g. table 1) as shown in Figure 3.

Proposed condition

i) Replicate the steps outlined above for the current condition but where typical flow scenarios were used to model post construction monthly flows using the longterm monthly median flow, simply bin these values to calculate a typical frequency distribution for that month.

2) Flow distribution

This metric assesses change in the entire flow distribution, that is, the proportion of time streamflow is at specific magnitudes. It is directly related to water levels and thus habitat availability.

Current condition

i) Bin all streamflow data for each month for all years of record and produce a flow duration curve (FDC) for each. Thus, 20 years of data would result in 20 FDCs for the month of August.
ii) Bin the values for the same percent exceedance point on each FDC for the same month and calculate the median, 13th, 38th, 62nd, and 87th percentiles (i.e the median of the 20 50% exceedance values for the month of August etc.).
iii) Since the sample size for the calculations in (i) and (ii) will be small (i.e. equal to the number of days in a month for [i] and to the number of years of data for [ii]), the Harrell-Davis quantile estimator should be used (Harrell and Davis, 1982) to calculate the percentiles listed because of its increased efficiency. The use of this estimator in relation to flow duration curves is discussed in Vogel and Fennessey (1994).
iv) Plot the resulting median FDC and the associated levels of dispersion (13th, 38th, 62nd, and 87th percentiles) (Figure 4).

Proposed condition

i) Bin all streamflow data for each month and produce a period-of-record flow duration curve (FDC) for each. If a continuous post construction time series is available, bin all streamflow data for each month over all years (e.g. all August streamflows). Where typical flow scenarios were used to model post construction monthly flows using the longterm monthly median flow, simply bin these values to calculate a typical period-of-record FDC for that month.

<u>Criteria for comparing current and proposed conditions</u>

Diel range

i) If the monthly median absolute diel range of the proposed condition falls between the 38th and 62nd percent exceedance of the current condition (see Figure 3), the proposed condition is considered to be similar to the current condition and therefore the site is outside the longitudinal extent of hydrologic alteration.

Flow distribution

ii) If the entire monthly period-of-record FDC for the proposed condition falls within the area bounded by the 38th and 62nd exceedance curves of the current condition (see Figure 4), the proposed condition is considered to be similar to the current condition and therefore the site is outside the longitudinal extent of hydrologic alteration.

<u>Concurrence of the two methods</u>

Although results of the two methods will be highly correlated, the two metrics characterise different aspects of the flow regime and therefore may result in different estimates of the longitudinal extent of hydrologic alteration. In these cases, the cross-section associated with the longest estimated extent should be used to demarcate the downstream boundary.

How the longitudinal extent of hydrologic alteration is used in an assessment of potential effects

As stated in the background, methods to asses the effects of an alteration will not be discussed; however, it is important to clarify how delineation of the extent of hydrologic alteration relates to the subsequent boundary within which potential effects will be assessed, which may be different. Once the longitudinal extent of the hydrologic alteration is identified using the trial and error approach described above, the magnitude of the alteration through the length of this river extent is determined using a series of cross-sections. At each cross-section the alteration in discharge is used to calculate the alteration in water levels. The number and spacing of the cross sections should be sufficient to capture the shape of the downstream attenuation. This provides the necessary information to assess the potential effects of the alteration within this geographic boundary.

Three possible scenarios of hydrologic alteration downstream of a waterpower facility are shown in Figure 5. The longitudinal extent of the hydrologic alteration is delineated where the lines in each model reach the x-axis. At this location the post-project variability is considered to be within the range of the pre-project variability. Moving upstream from the lower boundary, one can assess at what point the increasing alteration might have possible effects (This requires information on the characteristics of interest along the river length and their sensitivity to the proposed alteration). For instance, in Figure 5 it might be determined that an alteration of alt_x will not have negative effects on the values of interest for this specific location on the river. Therefore, efforts to assess the effects of the alteration would be concentrated between d_0 and d_1 for Scenario 1, d_0 and d_2 for Scenario 2, and d_0 and d_3 for Scenario 3, all extents of which are only a portion of the total extent of the hydrologic alteration expected.

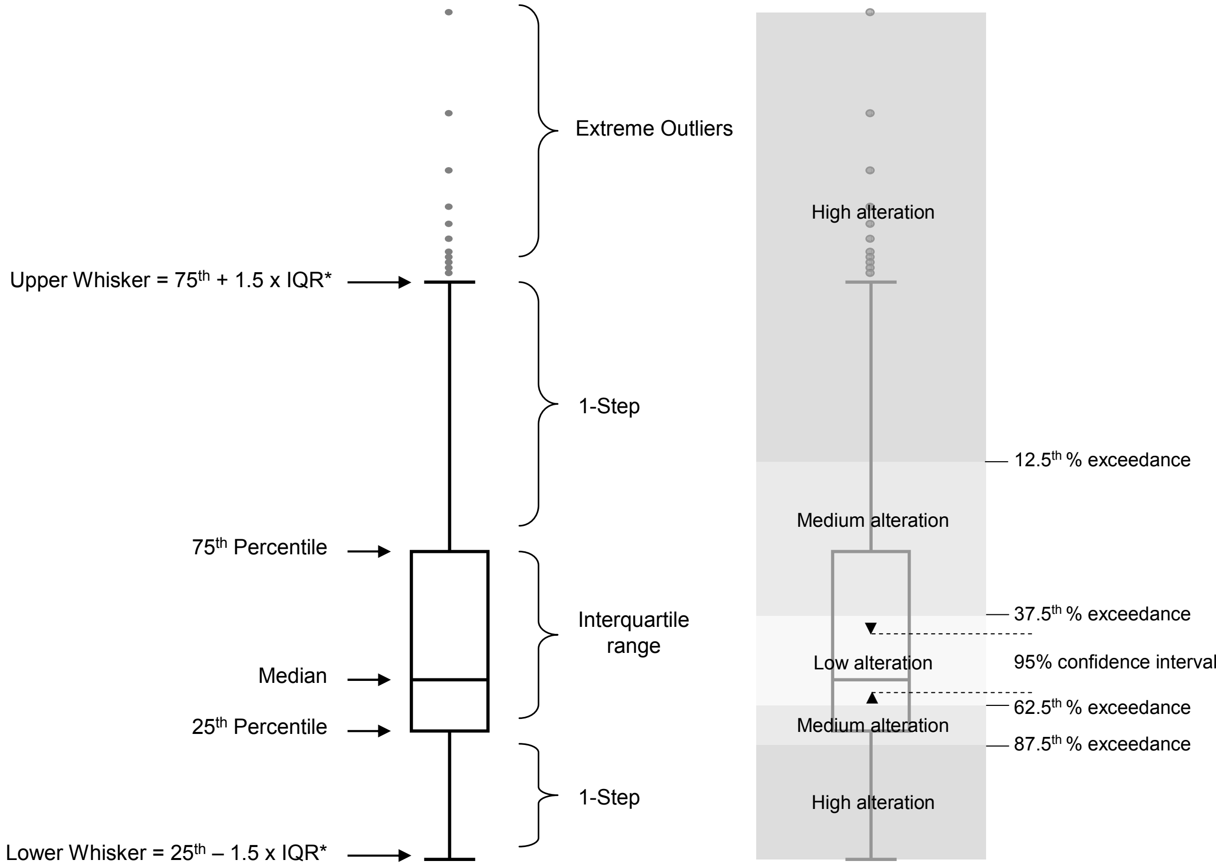

Figure 1 A box plot and how it is used to summarise a distribution and assess alteration. Measures of dispersion around the median are shown as percent exceedances, a common convention in hydrology when analysing flow duration curves (FDCs). Percent exceedances are rounded toward the median (i.e. 13th, 38th, 62nd, 87th) for simplification.

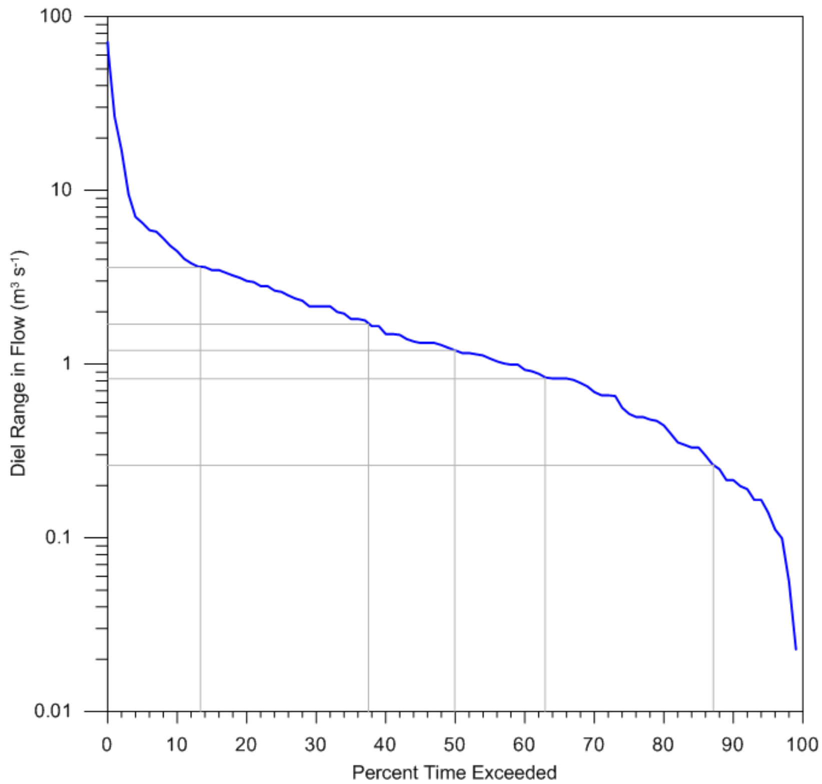

Figure 2 An example of the cumulative frequency distribution for June. The percentile limits shown in Figure (1) are shown here as vertical lines off of the x axis. The associated flow for each percentile is read off the y axis. This process was repeated for each month to derive Figure 3.

Table 1 Summary of values used in Figure 3.

Month	DR_{13}	DR_{38}	DR_{50}	DR_{62}	DR_{87}	Upper 95%	Lower 95%
January	1.16	0.50	0.41	0.33	0.17	0.50	0.33
February	0.41	0.24	0.17	0.09	0.07	0.23	0.12
March	4.94	0.45	0.25	0.17	0.07	0.33	0.17
April	42.01	13.22	8.18	5.29	0.99	11.07	5.95
May	10.22	3.31	2.15	1.49	0.42	2.81	1.65
June	3.64	1.65	1.20	0.88	0.26	1.37	0.93
July	2.15	0.84	0.60	0.40	0.13	0.69	0.41
August	1.98	0.65	0.41	0.28	0.08	0.55	0.33
September	2.81	0.66	0.49	0.31	0.07	0.60	0.35
October	14.33	4.46	2.28	1.49	0.33	3.14	1.55
November	10.09	2.98	2.15	1.36	0.50	2.48	1.49
December	3.47	1.08	0.83	0.66	0.17	0.91	0.66

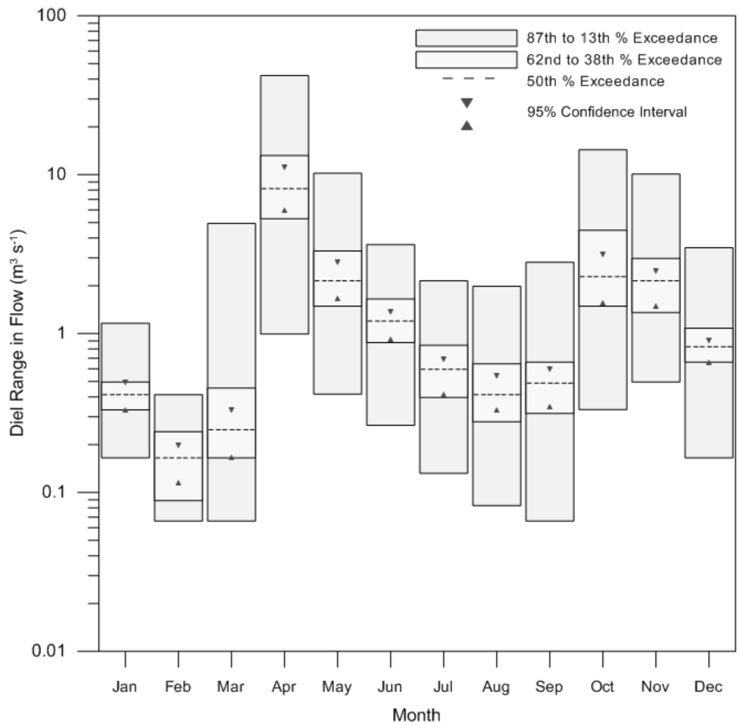

Figure 3 The monthly distributions of the diel range in flow observed at a cross section on a river with a natural flow regime.

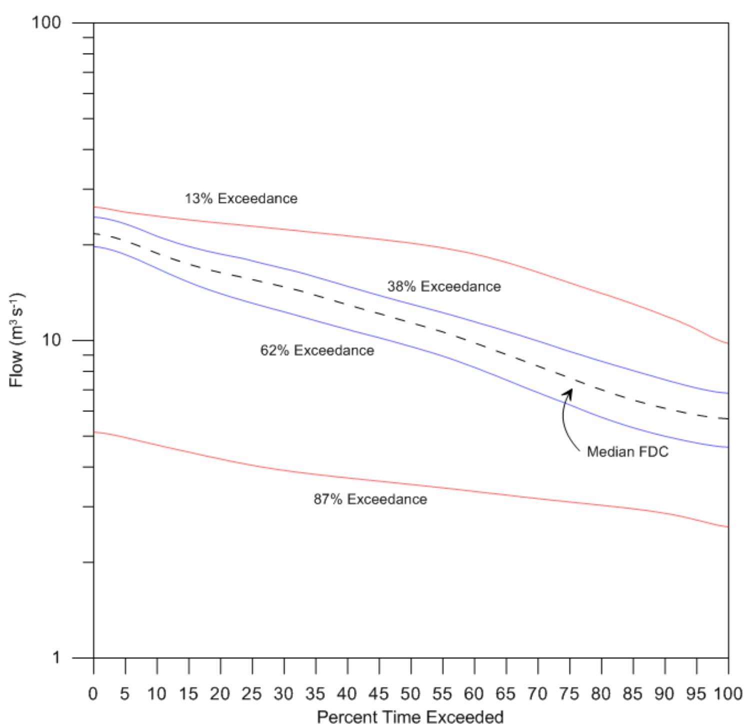

Figure 4 A median FDC and associated levels of dispersion.

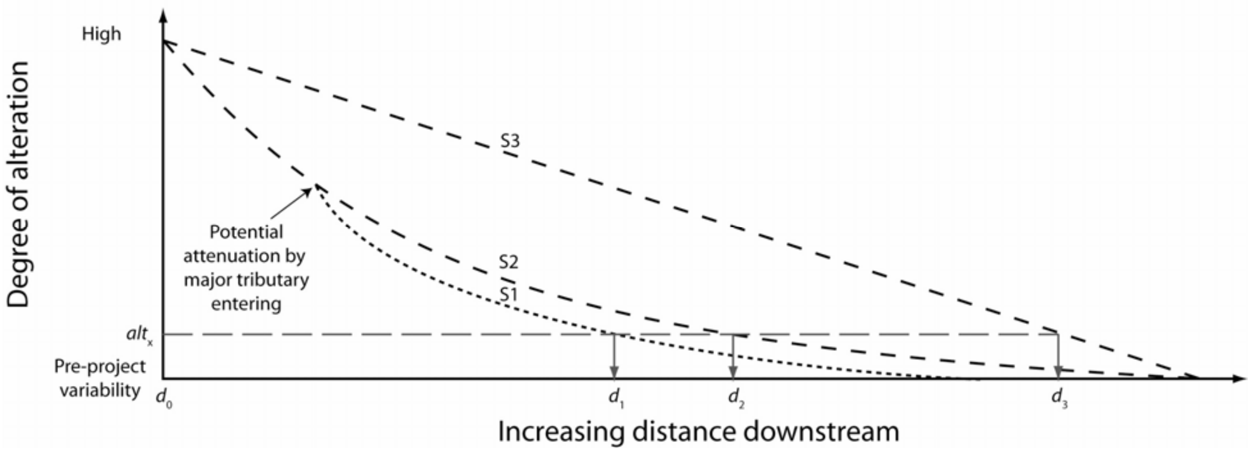

Figure 5 Possible scenarios of attenuation (S1, S2, S3) of the hydrologic alteration downstream of a waterpower facility. The longitudinal extent of the hydrologic alteration for a given flow metric is the location where the trajectory of the curve in each response model reaches the x-axis. This intersection point is the location where the post-project variability is considered to be within the range of the pre-project variability, delineating the longitudinal extent of the hydrologic alteration. See text for explanation of other annotations.

References

Harrell, F.E., and Davis, C.E., 1982. A new distribution-free quantile estimator. Biometrika, 69(3), pp. 635-640.

Vogel, R.M. and N. M. Fennessey, 1994. Flow Duration Curves I: A New Interpretation and Confidence Intervals. ASCE, Journal of Water Resources Planning and Management 120(4), pp. 485-504.

Appendix

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