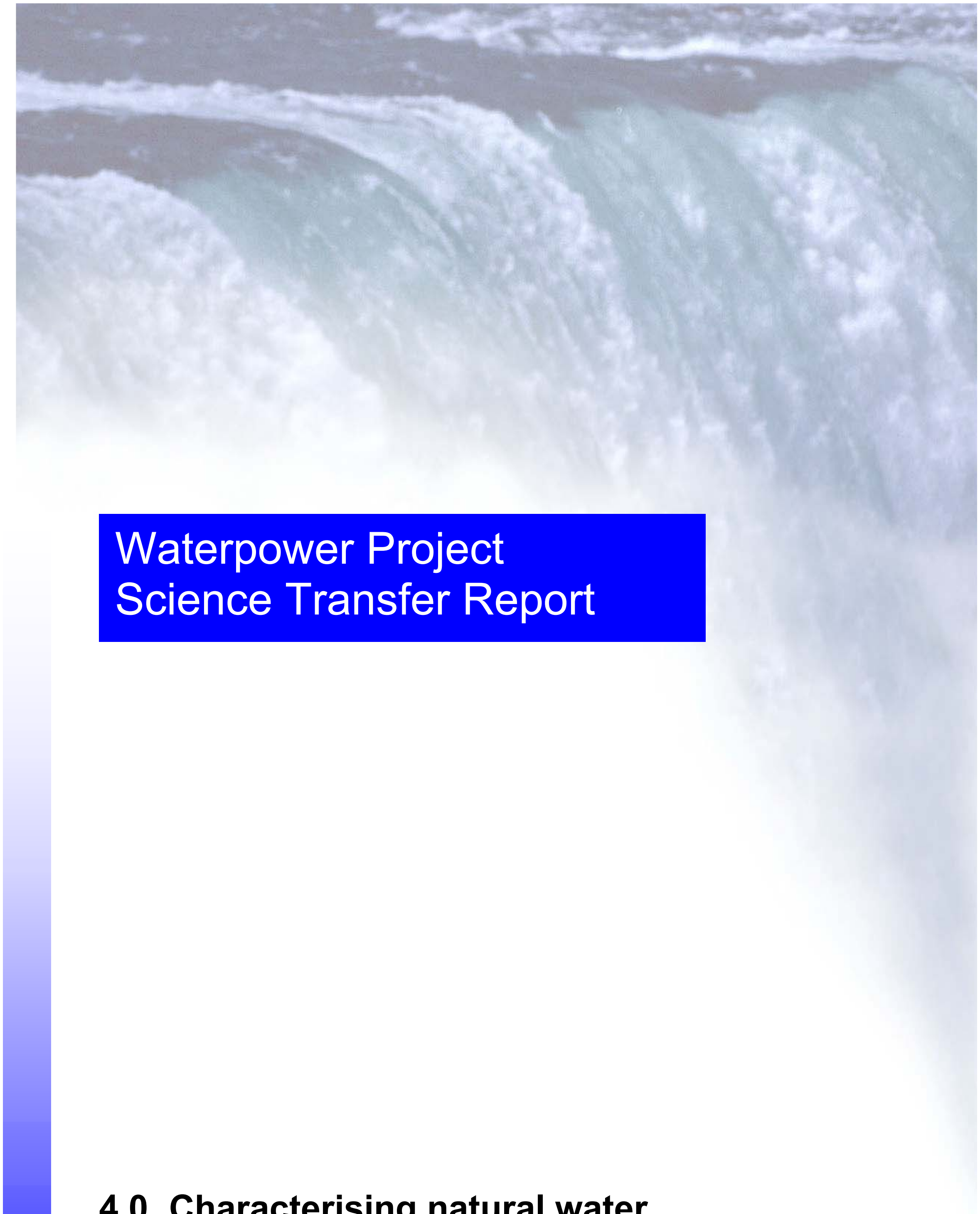

Waterpower Project Science Transfer Report

4.0 Characterising natural water level fluctuations on inland lakes in Ontario

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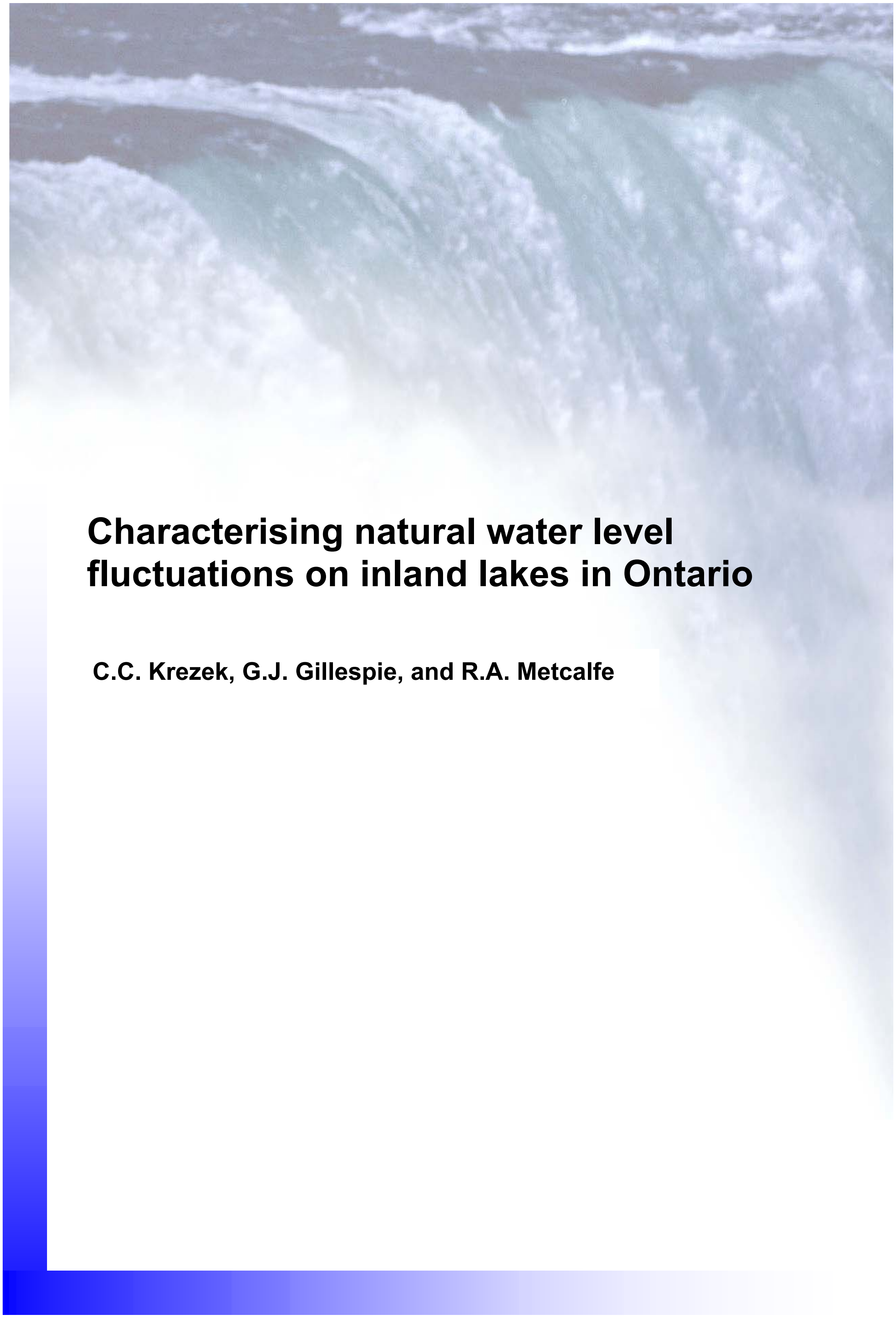


Characterising natural water level fluctuations on inland lakes in Ontario

C.C. Krezek, G.J. Gillespie, and R.A. Metcalfe

1.0 INTRODUCTION

Understanding spatial and temporal patterns of regional water level fluctuations is important for prescriptive management of water levels in Ontario lakes and reservoirs. Waterpower development has affected many Ontario waterbodies through the management of water levels for power production that are often different from naturally occurring water level patterns. Lakes have been shown to be more productive when operated to mimic the water level patterns in natural systems, where local species and communities evolved (Hill et al 1998; Kallemeyn 2000). Understanding the natural variability associated with water level fluctuation in lakes is the first step in adopting aquatic ecosystem approaches for the management of Ontario lakes and reservoirs.

Maintaining natural water level regimes while meeting seasonal power demands, as well as other recreational and socio-economic values, is a long-term goal of water management. In natural temperate lakes of Ontario, water levels are generally low during the winter, increase significantly in the spring with snowmelt, decline gradually into the dry summer months, and increase slightly during heavy fall rain events. The timing and magnitude of waterpower demand often conflicts with natural water availability in lakes. Demand for power is typically highest during times of the year when natural water levels are lowest (winter and summer). Although fluctuations in natural patterns do occur, those occurring in a managed system may be more abrupt or may take place at different times from the natural system (Kallemeyn and Cole 1990). The magnitude of these changes is a function of hydrological characteristics, waterpower management, and physical features of the waterbody, such as shoreline slope, depth, flushing time, and drawdown elevation.

Changes in the magnitude and timing of water level fluctuation can adversely alter water quality, substrate, riparian and littoral zones. For example, spawning sites located along the littoral zone or shoals are susceptible to the precise timing of lake filling. If filling occurs too late in the spring, fish may not have access to their spawning sites. If it occurs earlier, higher water levels may result in reduced littoral productivity by restricting light penetration to the lake bottom in cases of steep littoral slopes. Abrupt water level fluctuation is more detrimental to aquatic invertebrates since they are unable to adjust to receding water levels (Sharp and Keddy 1993). The rapid changes could also displace or strand fish (Bradford 1995). Regulated lakes or reservoirs also trap sediments (Gray and Ward 1982), alter water temperature (Webb and Walling 1995) and water quality (Lovejoy et al. 1997), and are barriers to native fish migration (Bergkamp et al. 2000). Recent reviews and reports by House (2001), MNR (2002) and MNR (2003) provide extensive information on impacts of managed water level fluctuations on lacustrine environments. Information on the natural variability in water levels in Ontario and how that variability can be quantified and applied to support healthy aquatic ecosystems is still needed.

The Ontario Ministry of Natural Resources (OMNR) has developed Water Management Planning Guidelines (WMPG's) to address multiple objectives associated with the operation of waterpower facilities and water control structures. The goal of these guidelines is to balance the range of environmental, social, and economic values placed on the water resource. The WMPG's include Aquatic Ecosystem Guidelines (AEGs), which provide direction to protect and enhance the aquatic ecosystem and to ensure waterpower resources are managed in an ecological sustainable manner. The AEGs have identified the magnitude, duration and timing of water level fluctuations as important hydrologic features that need to be quantified, both temporally and in Water Management Plans (WMPs) to support aquatic ecosystem recommendations.

This report addresses the need for greater understanding of natural water level regimes and their application to water management planning. Information on water level management and methodologies for quantifying water level regimes are provided. A case study of the work on the Rainy Lake – Namakan Reservoir by the International Joint Commission is presented to illustrate the impacts of managed water levels, important issues in reservoir management and methods for incorporating natural water level patterns into managed regimes. Lastly, the report presents an analysis of natural water levels in Ontario, based on available data to elucidate regional water level patterns that may assist water management planning.

1.1 WATER LEVEL MANAGEMENT

Water levels are managed to store flows from upstream and moderate the release of water downstream for the benefit of waterpower generation and/or flood control. The management of water levels for power generation is largely dependent on the type of waterpower facility and storage capacity of the associated water body. Three facility types have been identified in Ontario: Run-of-the-river, Intermediate, and Peaking (House 2001; MNR 2002). Run-of-the-river facilities are usually located on small dams with or without small head ponds, thus have very limited storage capacity. These types of facilities operate based on the availability of upstream flows and can store water for short periods (e.g. daily). Peaking facilities are located on large dams with large capacity reservoirs that can store water for several days. Release of water from the reservoir is controlled to meet peak power demands. Finally, Intermediate facilities are run-of-the-river with some peaking capabilities. These facilities have greater storage capacity than a run-of-the-river facility allowing them to store a portion of the daily inflow by discharging less water during off-peak periods and allowing greater flow during peak energy demands.

Reservoirs are often created from large lakes upstream of the waterpower facility. In other cases riverine sections are flooded to create head ponds or small reservoirs. Under the latter conditions the newly created lacustrine environment has new physical and biological conditions that often do not develop the same complex littoral environments as a lake (MNR 2002) and are often highly influenced by constantly changing water levels, which impede the evolution of biological and aquatic communities (Kraft 1988; Smith and Peterson 1991; Thurber et al. 1991; Wilcox and Meeker 1991).

Most commonly in Ontario, reservoirs are managed by using operating rules, which specify an operating range of water level elevations (examples are given in the case study below). The type of facility, the storage capacities of the reservoir, and site-specific water level restrictions that may be applied to the system (to protect specific species or other values) define these curves. To date, mitigation of ecological impacts caused by water level regulation has focused primarily on lucrative sport fisheries (Smith 1993). Recently, the emphasis has changed to a more holistic approach to sustain the full biodiversity and integrity of a lacustrine system.

1.2 RAINY LAKE – NAMAKAN RESERVOIR CASE STUDY

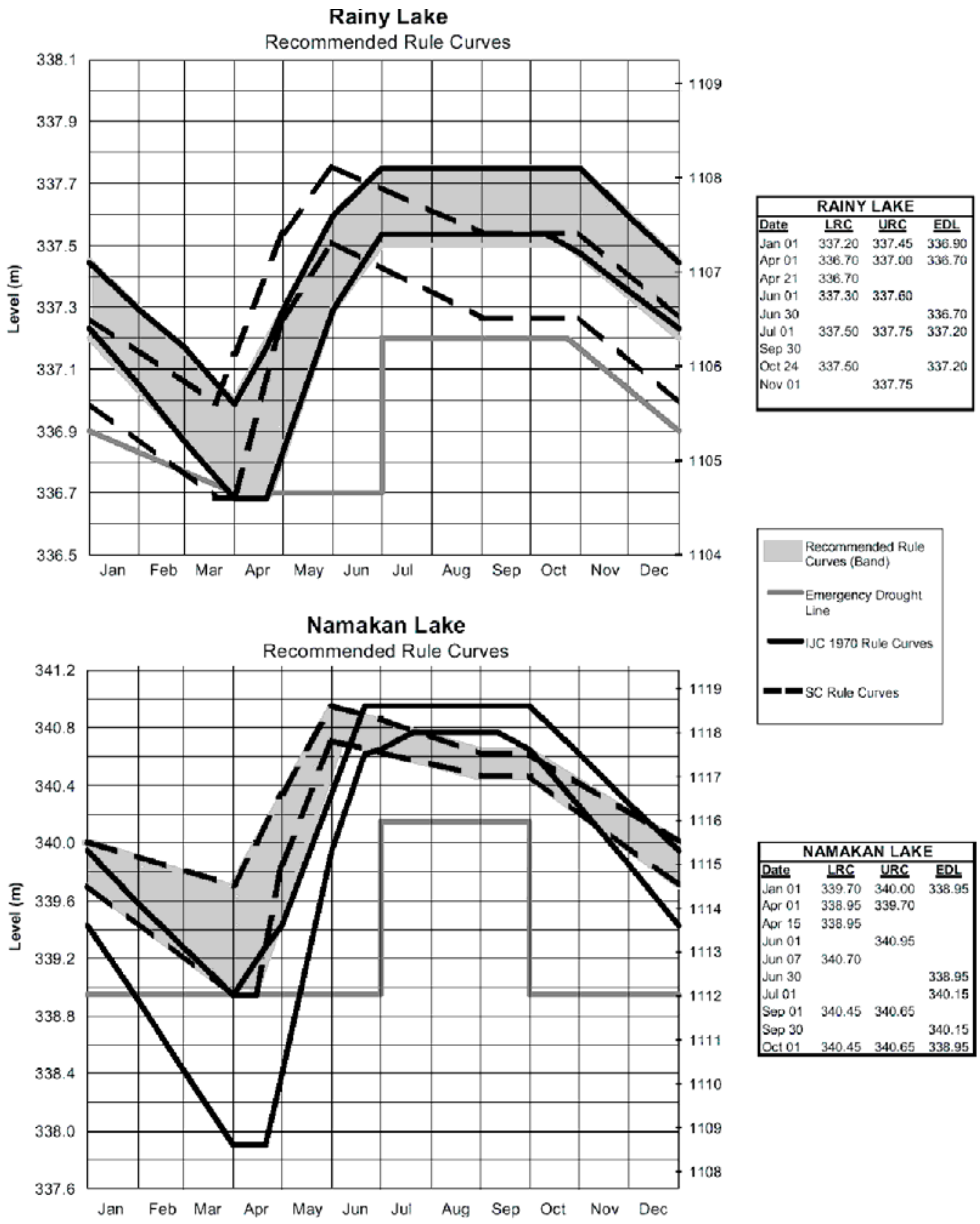
Perhaps the most intensely studied reservoir in Ontario is the Rainy Lake - Namakan Reservoir located in Northwestern Ontario within the Winnipeg River basin, covering an area of 38,600 km^2 (Kallemeyn et al. 1993). The five lake basins that are encompassed by the Namakan Reservoir all existed as natural lake basins prior to construction. These include: Namakan, Kabetogama, Crane, Sand Point, and Little Vermilion lakes. The reservoir is controlled by two dams located at the outlet, which drains into Rainy Lake that eventually empties into Rainy River. A dam on the Rainy River controls Rainy Lake water levels.

The Rainy Lake - Namakan Reservoir is managed by the International Joint Commission (IJC), an organization established to resolve disputes over the use of waters along the United States-Canada border. In making water management decisions the IJC uses rule curves defining permitted high and low water levels. A 1970 order issued by the IJC established 'all-gates-open' levels to deal with extreme high water conditions. By implementing the 1970 rule curves, larger than natural fluctuations in lake levels on Namakan Reservoir were used to maintain a constant head on Rainy Lake for waterpower generation, which resulted in less-than-natural-fluctuations on that lake. Investigation of these regulated levels by Flug (1986) found the following three major differences from natural conditions:

1. The magnitude of annual water level fluctuations, under 1970 regulated conditions, ranged from a maximum of 3.05 m on the Namakan Reservoir to 1.07 m on Rainy Lake. Estimates of natural or pre-dam fluctuation for the whole system, using hydrologic modeling, was determined to be 1.85 m.
2. Regulated annual water level fluctuations were characterized by higher summer and fall water levels and an average over winter drawdown of 2.3 m, compared to natural water level fluctuations in the range of 0.6 – 0.9 m.
3. The timing of regulated peak water levels generally ranged from mid-June to early July, which was determined to be much later than the estimated natural timing of late May/early June, depending on local climate and runoff conditions.

Research completed in the mid-80's on Rainy Lake - Namakan Reservoir showed that the 1970 rule curves adversely affected species composition, distribution, and diversity in several biological communities. Wilcox and Meeker (1991) showed that too little disturbance from water level fluctuations in Rainy Lake and too much disturbance in Namakan Reservoir reduced diversity in macrophyte communities. Kraft (1988) found that the benthic invertebrates were commonly found dead, or stranded during the increased winter drawdown in Namakan Reservoir lakes as compared to Rainy Lake with its lesser drawdown. Winter water drawdowns left beaver and muskrat lodges high, dry, and isolated from food caches at critical times of year (Smith and Peterson 1991; Thurber et al. 1991). Smith and Peterson (1991) concluded winter drawdown should not exceed 0.7 m. Female otters were found to shift their home range from shoreline to deeper water during winter drawdown on Namakan Reservoir reducing foraging availability (Route and Peterson 1988). Delayed springtime peaking of lake levels created early summer flooding of loon and grebe nests, resulting in as much as 45% net loss (Reiser 1988). At the same time northern pike (*Esox* lucius) and walleye (*Stizostedion vitreum*) were restricted access to preferred spawning sites reducing fisheries production (Kallemeyn et al. 1993). By combining topographic maps of the spawning areas and vegetative cover type surveys, Kallemeyn et al. (1993) were able to show that a 2 m rise in the lake level earlier in the spring was critical in increasing fisheries reproductive success. The gradual decrease of the 2 m rise over the balance of the year is shown in Figure 1.

Other studies on the reservoir have examined ways to mitigate the impacts described above. Cole (1982) conducted an analysis of historical regulated flows and seasonal reservoir water level changes compared to natural variability in lake levels of unregulated lakes and found that small changes in the timing of water level drawdowns could enhance habitat conditions for several native species. Flug (1986) developed a hydrological simulation model (MODSIM) to analyze and evaluate alternative reservoir operating rule curves.



RAINY LAKE

Date	LRC	URC	EDL
Jan 01	337.20	337.45	336.90
Apr 01	336.70	337.00	336.70
Apr 21	336.70		
Jun 01	337.30	337.60	
Jun 30			336.70
Jul 01	337.50	337.75	337.20
Sep 30			
Oct 24	337.50		337.20
Nov 01		337.75	

NAMAKAN LAKE

Date	LRC	URC	EDL
Jan 01	339.70	340.00	338.95
Apr 01	338.95	339.70	
Apr 15	338.95		
Jun 01		340.95	
Jun 07	340.70		
Jun 30			338.95
Jul 01			340.15
Sep 01	340.45	340.65	
Sep 30			340.15
Oct 01	340.45	340.65	338.95

Figure 1 Comparison of 1970 rule curves and suggested Steering Committee (SC) 2000 rule curves (EDL = emergency drought line, LRC = lower rule curve, and URC = upper rule curve (adapted from Kimmett et al. 1999).

Kallemeyn et al. (1993) described methods of introducing new rules curves that may restore natural conditions to the Rainy Lake - Namakan Reservoir. The first step in this process was to determine optimized water levels for managed lake regimes by:

1. Mapping lake districts.
2. Using hydrometric data to derive level parameters.

3. Examining changes in magnitude, duration and timing of water level fluctuations on a daily basis.
4. Identifying biological and aquatic species and evaluate the sensitivities regarding related habitat.
5. Identification of species at risk – plants or wildlife at risk that will have to be given special consideration.
6. Evaluating the natural water level regime and determine the impacts on hydro generation and power costs.
7. Considering recreational activities – lakes may be managed to forego drawdowns during the summer that can interfere with activities (i.e. navigation, fishing etc.).
8. Considering private property along the shoreline. Avoid impacting shore erosion, docks, boat ramps and water intake pipes.

The second step used these criteria to develop an impact assessment matrix relating the results of the environmental studies and hydrological analysis to potential impacts. The scientific literature was searched to develop ranking factors for those variables addressed in the studies considered significant to the area affected by changes in rule curves. The ranking factors were then used to evaluate effects of alternatives on those attributes with the results entered into the matrix. This matrix was used to facilitate discussion among various water users. A description of a weighted average multi-criteria procedure to quantify and evaluate the resource attributes using their ranking factors is given by Flug and Ahmed (1990). Lastly, Flug (1986) used MODSIM to assess alternative regulatory options. The model simulated the multi-lake system beginning with inflows to Namakan Reservoir and ending with outflows from Lake of the Woods, located 130 km downstream of Rainy Lake. By analyzing alternative regulatory programs this hydrological model was able to determine which water level regime the reservoir system could accommodate under normal, extreme high- and low-flow hydrologic conditions.

After reviewing the biological and modeling results, the IJC issued a supplementary 2000 Order to restore a more natural variation in the regulated water level regime of the reservoir (Figure 1). Among other things, it recommended:

1. A wider band in the rule curves during the spring refill period for Namakan Lake with an approximately 2 m drawdown over the summer and fall period;
2. A slightly wider band during the spring refill period and a modest amount of drawdown in the late summer and fall period for Rainy Lake;
3. The requirement for dam owners to target water level operations to the middle of the rule curve under natural conditions.

The 2000 Order altered the annual magnitude and timing of lake level fluctuations and dampened the amplitude of yearly fluctuations in water levels to mimic a natural water level regime. The task now is to implement an adaptive management approach that will provide information needed to determine if the rule curve changes have resulted in the hypothesized gains or losses to be reviewed after 15 years.

The long-term study of the Rainy Lake – Namakan Reservoir reveals several detrimental effects of regulated water level regimes on aquatic ecosystems. In doing so it makes a sound basis for prescribing more natural water level regimes on regulated reservoirs and suggests a framework for monitoring the effectiveness of achieving aquatic ecosystem objectives. Thus, the results of this work provide valuable insight for water management planning with respect to reservoirs. Unfortunately, few waterpower facilities in Ontario have reservoirs that have been the focus of similar levels of research activity or have historical hydrometric data. Elucidating linkages between water level fluctuations and ecosystem structure and function at intensively studied sites and identifying regional variation in lake level fluctuations provides important information for prescribing meaningful water level regimes on regulated reservoirs to achieve aquatic ecosystem objectives.

1.3 REGIONALIZATION OF NATURAL WATER LEVELS

Regionalization of ecological systems is a pragmatic way to manage natural resources in the absence of long-term biophysical data. Many jurisdictions use regionalization methods to manage aquatic systems, including freshwater lakes (Omernik et al. 1991; Harding and Winterbourn 1997; Johnson 1999; Gronskaya 2000; Jenerette et al. 2002; Quinlan et al. 2003). This broadscale, holistic approach delineates areas of similar characteristics into homogeneous areas of similar ecosystem function, such that traits within the delineated area are more similar within compared to those outside of it. This shift from micro-scale to the broader-scale focuses on spatial patterns and relationships between ecosystem attributes, permitting the extrapolation of results to data-poor regions.

Limnologists and hydrologist now recognize the advantages of studying spatial patterning among lakes at larger scales by using techniques such as reference sites (Johnson 1999), ecoregion delineations (Hughes et al. 1994; Omernik et al. 1991), ecological organization among lake districts (Benson et al. 2000) and landscape position (Kratz et al. 1997). Harding and Winterbourn (1997) group these methods into two strategies for the regional classification of ecosystems. The first strategy is similar to that commonly used in regional limnology, where large quantities of geographical, chemical, physical, and biological attributes are collected for a series of lakes across a geographic area. These data are then grouped based on similarities and related landscape properties. This approach is often used to group small numbers of lakes into districts (Quinlan et al. 2003; Webster et al 2000), but has also been used to define larger areas where large lake databases exist (Gronskaya 2000). The second strategy uses ecoregions, where areas are defined by known physical determinants of ecosystem structure and function (Harding and Winterbourn 1997). This strategy is more holistic than the other type of regionalisation and may require less site-specific information. This strategy assumes that ecosystems and their components show regional differentiation in the attribute of interest.

Regionalization methodologies are becoming widely used in limnological studies. In addition to determining similarities in biological, chemical and physical characteristics of lakes, the spatial position of lakes in the landscape can also be considered in the designation of lake districts (Magnuson and Kratz 2000). Kratz et al (1998) studied seven northern Wisconsin lakes and showed that temporal coherence (a pattern of synchronous variation across lakes in a region) was high for physical variables such as water level and water temperature. They concluded that it would be possible to extrapolate general trends from a small subset of lakes to an entire lake district since these physical factors are directly influenced by climatic events. Gronskaya (2000) grouped 50 lakes in Northwestern Russia into four lake districts based on similarities in geology, soils, and climate. Within these four regions high levels of coherence were found between water level regimes (mean annual lake level and maximum annual difference in level). Lake district studies have also been conducted in northwestern Ontario (Webster et al. 2000) and southcentral Ontario (Webster et al. 2000; Quinlan et al. 2003) that have found coherence in physical attributes of lakes within areas of similar hydrogeology. This type of regionalization has provided important findings on the controls of limnological characteristics, including lake levels, but is very data intensive, requiring extensive biological, physical and chemical characteristics of lakes.

At a larger scale, ecoregion classifications are often based on broad patterns in climate, geology, vegetation, soils and land use. Landscapes are commonly broken down into a hierarchy of nested units, enabling the selection of the appropriate scale for the particular application. Numerous studies have conducted similarity analyses using lake/stream attributes to test the validity of using ecoregions for regional boundaries (Johnson 1999; Hughes et al. 1993; Omernik et al. 1991). For example Johnson (1999) used an ecoregion approach to establish reference lakes in Sweden for monitoring water quality. Lakes within the five ecoregion delineations were found to have similar characteristics, validating the delineations for aquatic resource management. According to Omernik and Bailey (1997) ecoregions provide a common spatial infrastructure from which one can determine various regional resources and anthropogenic uses. However, it may not be the best framework to address all aquatic management problems. The physical drivers of the response variable in question must be represented in the delineation of the ecoregions. Many ecoregion delineations are based on terrestrial ecosystems and not aquatic, therefore caution should be used to ensure the aquatic ecosystem characteristic of interest is represented.

2.0 REGIONALIZATION OF ONTARIO LAKE LEVELS

Hydrological regionalisation of streamflows has been used to partition the Ontario Landscape into meaningful hydrological classes based on low flows (Figure 2) and flood flows (Figure 3). Numerous hydrologic gauges with long-term records on unregulated (natural) rivers across the province permit this type of analysis. These studies show that regional hydrologic patterns exist within the province (MNR 2000; MOEE 1995; Moin and Shaw 1985).

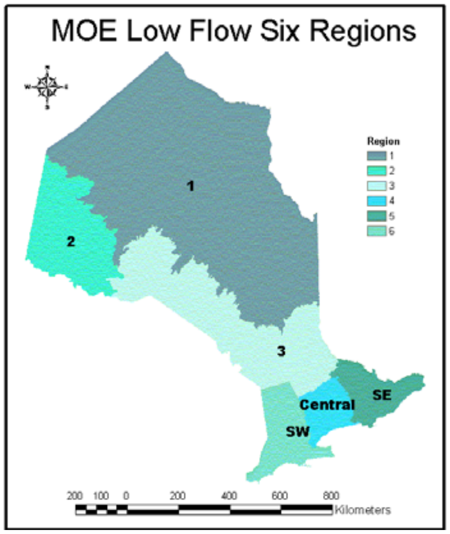


Figure 2 Ontario Low Flow regions (MOEE 1995)(Source: Chang et al. 2002)

Compared to the provincial stream gauge network, water level records are sparse in Ontario. Although, water levels on the Great Lakes have been well documented and monitored over time, data is lacking for smaller inland lakes. Optimally the regionalization of water levels requires numerous gauged lakes that are spatially distributed throughout the province, with quality long-term datasets encompassing a range of climate conditions. For direct comparison these data should be for the same period. However, a comparable dataset is not available for lakes in Ontario making qualitative regionalization methods impractical. Thus, an investigation of ecoregion approaches was necessary.

To use the ecoregion approach, ecoregion delineation must reflect the degree of homogeneity in the drivers that are responsible for lake level patterns. Climate has been found to be an important driver of temporal variability in freshwater systems (Webster et al. 2000; Gronskaya 2000; Magnuson and Kratz 2000). Recent work in regional limnology has found that lakes within regions of

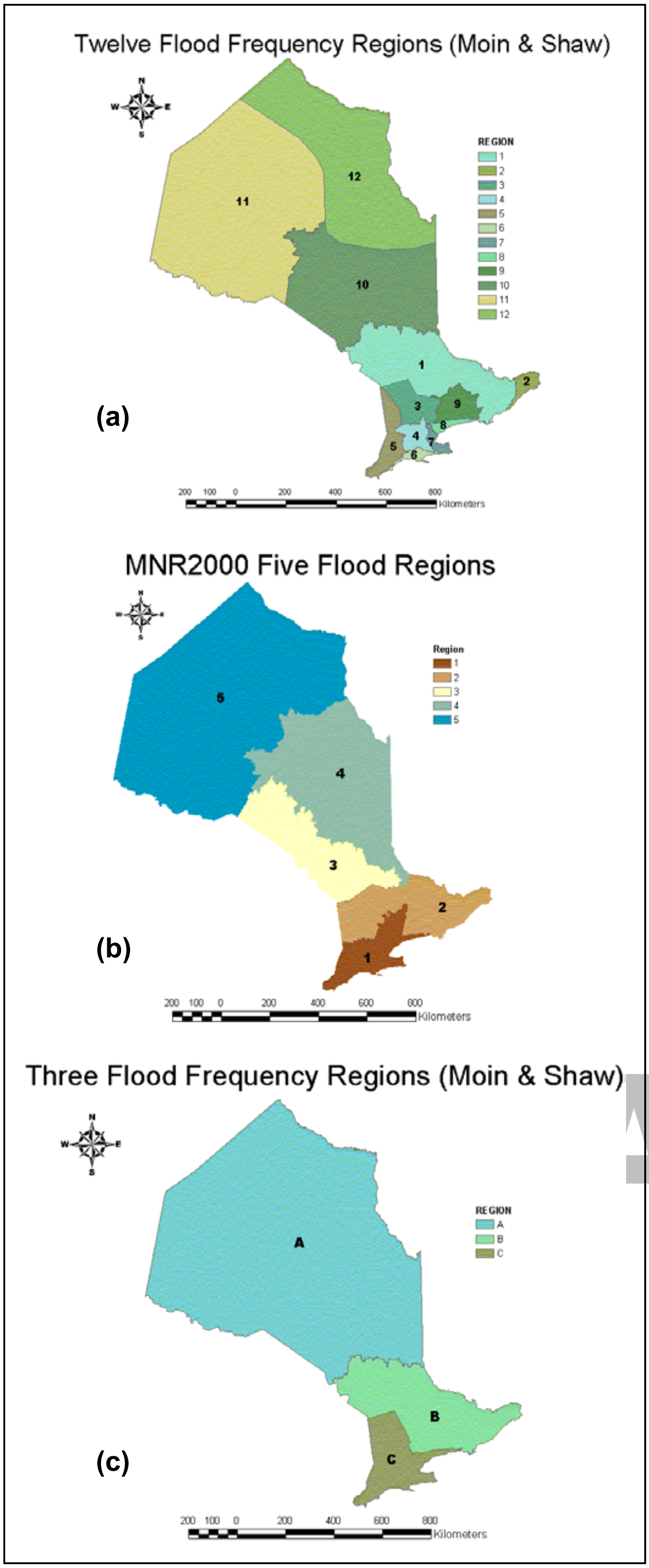


Figure 3 Flood regions for Ontario using a) an index flow method (Moin and Shaw 1985); b) a primary multiple regions method (Moin and Shaw 1985); and c) a multiple regression method (MNR 2000).

similar geology and climate influences show a high degree of temporal coherence in physical attributes, including lake level patterns (Webster et al. 2000; Magnuson and Kratz 2000; Gronskaya 2000; Kratz et al. 1998).

Within Ontario there are at least three ecoregion classifications: i) Ecoregions of Ontario: Modifications to Angus Hills' Site Regions and Districts (Crins and Uhlig 2000); ii) A National Ecological Framework for Canada by Marshall and Schut (1999); and iii) Ecoregions of Ontario by Wickware and Rubec (1989). The classification by Crins and Uhlig (2000) supersedes the classification of Wickware and Rubec and is very similar to the national framework with some refinements for Ontario (B. Crins pers. comm.). The classification of Crins and Uhlig (2000) is a revision of the original Ontario classification by Hills (1959). The classification has three levels of stratification partitioning the province into a hierarchy of ecozones, ecoregions and ecodistricts. Each lower unit is nested within its parent, with increasing scale of attributes from zones to districts. Ecozones are based on continental climatic patterns and major bedrock and/or physiognomic domains that influence broad scale flora and fauna. Ecoregions are focused on sub-continental climate patterns and divide areas based on climatic factors that influence primary productivity, biotic distribution and soil development. Ecodistricts have a landscape and bio-physiographic focus that represent patterns of landform, physiographic and topographic regimes as well as local climatic variation (Crins and Uhlig 2000).

Based on the classification for Ontario, the level of ecoregion should posses the required degree of heterogeneity in the primary factors that influence lake levels. Therefore, using this ecoregion classification and available lake level data the following objectives were set:

1) Characterize natural lakes across the province and determine any similarities in water level patterns that exist between lakes within the same ecozone and/or ecoregion. This includes: timing of maximum and minimum levels, magnitude of monthly and annual changes.
2) Make recommendations on additional data and analysis that would be required for a more thorough examination of natural water level patterns in Ontario.

2.1 METHODS

The predominant source of lake level data in the province is the HYDAT database (version 2.02 2001), which is an archive of hydrometric records for the country monitored by the Water Survey of Canada (WSC). Historic water level records from 89 lakes are archived in HYDAT. This includes 66 located on inland lakes/reservoirs and the remainder on the Great Lakes. Of these 66: 21 are natural (unregulated), 38 are regulated, and information is not available for the remaining seven. Of these seven lakes Salvesen Lake, Lake 979 and Lake 632 were determined to be unregulated (Scott Mcaughey pers. com.). Of the 24 natural lakes, 16 have at least five years of data, but four of these records have significant data gaps. Therefore, only 12 natural lakes, with at least five years of data, were available in HYDAT (Table 1).

Other sources of water level data for natural lakes are research sites. There are four lake-based research sites within the province with available lake level data: i) The Turkey Lakes, led by Environment Canada; ii) Coldwater Lakes (CWL), led by the Centre for Northern Forest Ecosystem Research (CNFER); iii) Experimental Lakes Area (ELA), led by Fisheries and Oceans Canada (DFO); and iv) Dorset Lakes Research Centre, led by the Ontario Ministry of Environment and Energy (MOEE). There are three gauged lakes in the CWL area, which are unregulated but periodically regulated by beaver dams (R. Steedman pers. comm.). The Turkey Lakes Watershed Project operated by the National Water Research Institute (NWRI) and WSC (R. Semkin per. comm.), monitors water levels on three lakes, Batchawana, Little Turkey and Turkey Lake. The Dorset Environmental Research Centre monitors seven lakes in the Muskoka/Haliburton region. Water levels for ten of the ELA lakes are in HYDAT, seven of which are included in this analysis.

Based on these data, a total of 23 lakes were suitable and available for analysis: 12 lakes from HYDAT, one from the Turkey Lakes, seven lakes from Dorset and three lakes from CWL (Table 2). The HYDAT lake data are annual time series of mean daily water levels for all lakes excluding Lakes 304, 303, 227, 223, 302, and 114 from ELA, which are seasonal time series (April to October). The CWL data are seasonal, collected weekly during the summer season and monthly during the fall and winter, but were interpolated to create a daily seasonal time series (R. Steedman pers. comm.). For Turkey Lake, water levels are an annual series of daily mean water levels. The Dorset Lakes data are collected weekly to monthly, April to December for all lakes except Harp Lake (R. Girard pers. comm.). Harp Lake data are an annual time series of weekly water level measurements.

Table 1. Summary of all potential natural lakes within the HYDAT database (N= Natural, NA=Unknown).

HYDAT ID	Status	Years of Data	Name	Comment
05PA011	N	80	Lac La Croix at Campbell's Camp	Good record
05PB002	N	54	Little Turtle Lake Near Mine Centre	Good record
05PA010	N	37	French Lake Near Atikokan	Data problems pre-1985
05PD021	N	26	Lake 239 Near Kenora	Good record
04CE001	N	21	Big Trout Lake at Trout Lake	Missing extensive data
05PD018	N	21	Lake 304 Near Kenora	Data problems pre-1974, missing data
05PD020	N	21	Lake 303 Near Kenora	Seasonal, Apr – Oct
05QD009	N	21	Lake 227 Near Kenora	Missing data 1971-77, seasonal, Apr – Oct
04CA001	N	20	Sandy Lake at Sandy Lake	Data problems before 1968
05QD021	N	14	Lake 223 Near Kenora	Suspect data 1995, seasonal, Apr – Oct
05QD022	N	14	Lake 302 Near Kenora	Seasonal, Apr – Oct
05PD027	N	10	Lake 114 Near Kenora	Seasonal, Apr - Oct
04GC001	N	6	Eabamet Lake at Fort Hope	Missing data
04FB002	N	5	Attawapiskat at Lansdowne House	Missing data
04DA003	N	4	Winisk Lake at Webequi	Missing data
04BA001	N	2	Pipeston River at Karl Lake	Less than 5 years data
04DA004	N	2	Wunnummin Lake at Wunnummin	Less than 5 years data
04DB003	N	2	Kasabonika Lake at Kasabonika	Less than 5 years data
05QD007	N	2	Northern Light Lake at Outlet	Less than 5 years data
05QD007	N	2	Lake 305 Near Kenora	Less than 5 years data
05PA007	N	1	Crooked Lake Near Curtain Falls	Less than 5 years data
05QE011	NA	41	Salvesen Lake near Outlet	Unregulated, missing data pre-1979
05QC004	NA	6	Pakwash Lake Below Snake Falls	Regulated
05PD034	NA	5	Lake 979 Near Kenora	Unregulated, missing data
05QD020	NA	4	Clay Lake near Quibell	Less than 5 years data
05QD028	NA	1	Lake 632 Near Kenora	Unregulated, less than 5 years data
02EC015	NA	36	Lake Simcoe near Gamebridge	Regulated
04LC002	NA	1	Ivanhoe Lake near Foleyet	Less than 5 years data

For all data, years or months with anomalous data, or large periods of missing data were removed from the analysis. Mean monthly water levels and monthly standard deviations were calculated for the entire period of record, unless data problems existed (Table 2). Therefore, lakes were not analyzed for the same period of record, due to the limited availability of data. Analysis of HYDAT records was conducted using Streamflow Toolkit (Environment Canada, 1993), and was completed in Microsoft Excel for all other data. The change in lake level was calculated as the lake level of the present month minus the lake level of the previous month. The months of maximum and minimum levels were represented by the month of highest and lowest mean monthly lake level. The total annual change in lake level was calculated as the difference between the highest and lowest mean monthly lake level.

Table 2. Summary of natural lake level records used for analysis.

Lake	Latitude *(deg min sec)*	Longitude *(deg min sec)*	Data Extent	Scale	Source
Sandy Lake	53 03 03	93 20 15	1965–1984	daily, year round	HYDAT
Salvesen Lake	50 21 18	94 26 33	1960-1999	daily, year round	HYDAT
Lake 239	49 39 28	93 43 36	1965–1995	daily, year round	HYDAT
Lake 303	49 39 40	93 55 30	1969-1990	daily, Apr –Oct	HYDAT
Lake 304	49 39 27	93 44 53	1974-1990	daily, Apr - Oct	HYDAT
Lake 227	49 41 13	93 41 27	1969–1995	daily, Apr - Oct	HYDAT
Lake 223	49 41 55	93 42 40	1981-1995	daily, Apr – Oct	HYDAT
Lake 302	49 40 24	93 45 40	1981-1995	daily, Apr - Oct	HYDAT
Lake 114	49 40 10	93 45 30	1981-1990	daily, Apr – Oct	HYDAT
CWL L26	49 07 15	92 08 44	1992–2000	weekly to monthly	CNFER
CWL L39	49 05 38	92 09 58	1992-2000	weekly to monthly	CNFER
CWL L42	49 04 59	92 09 37	1992-2000	weekly to monthly	CNFER
Little Turtle	48 46 20	92 36 30	1914–1967	daily, year round	HYDAT
Lac La Croix	48 21 20	92 12 50	1921–2000	daily, year round	HYDAT
French Lake	48 40 20	91 08 06	1960–1998	daily, year round	HYDAT
Turkey Lake	47 02 05	84 22 50	1980-2000	daily, year round	NWRI
Harp Lake	45 23 00	79 07 00	1980–2002	weekly, year round	MOEE
Plastic Lake	45 11 00	78 50 00	1980–1998	weekly, Apr - Dec	MOEE
Red Chalk Lake	45 11 00	78 56 45	1980–1987	weekly, Apr - Dec	MOEE
Dickie Lake	45 09 00	79 05 00	1980-1998	weekly, Apr – Dec	MOEE
Crosson Lake	45 05 00	79 02 00	1982-1993	weekly, Apr – Dec	MOEE
Heney Lake	45 08 00	79 06 00	1982-1993	weekly, Apr - Dec	MOEE
Blue Chalk Lake	45 12 00	78 56 00	1980-1998	weekly, Apr – Dec	MOEE

Information on the physical characteristics of each lake, including surface area, perimeter, mean and maximum depth were gathered from literature, the Internet, taken from provincial maps, or were provided by the data contacts. Characteristics including: basin area, Mean Annual Runoff (MAR), Mean Annual Lake Evaporation (EVA), Mean Annual Precipitation (MAP), and Mean Annual Snowfall (MAS) were determined for the watershed of each lake using Ontario Flow Assessment Techniques (OFAT) (Version 1, 2002). Watersheds were extracted based on the outlet point of each lake, such that the information included the entire lake and the area that drains into it. Characteristics of Lac La Croix could not be determined using OFAT because the lake is located on the Ontario border and is not completely contained within the provincial data set. Instead values for a nearby watershed were used. The values generated in OFAT are from regional models; therefore one can assume watersheds within the same region will have similar characteristics.

2.2 SUMMARY OF LAKE CHARACTERISTICS IN ONTARIO

2.2.1 Spatial Distribution within Ontario Ecoregions

Within the province there are three ecozones, 14 ecoregions and 70 ecodistricts. All lakes used in the analysis fall within the Ontario Shield ecozone, which is located between the Northern Taiga and Lake Simcoe-Rideau ecoregions (Figure 4). There are no lakes within the other two ecozones, which is not a concern for the Northern Hudson Bay Lowlands ecozone, but is a concern for the Southern Mixedwood Plains ecozone, where a number of waterpower facilities

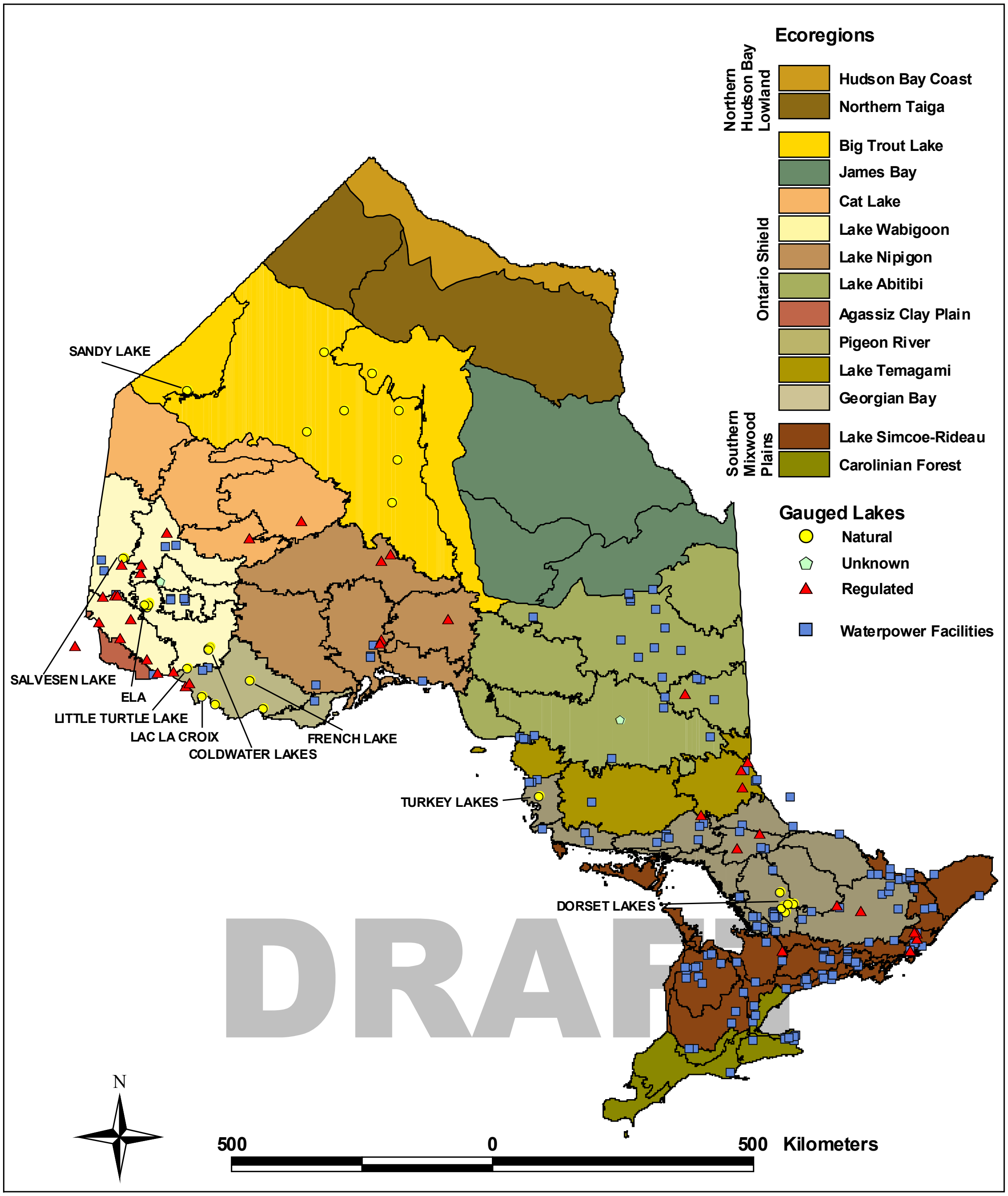


Figure 4 Location of lake gauges and their spatial distribution throughout the provinces fourteen ecoregions. The lines within each ecoregion indicate Ecodistrict divisions. Ecoregions within each Ecozone are defined in the legend. Lakes used in this report are labeled.

and regulated lakes are located (Figure 4). Within the Ontario Shield ecozone the lakes are distributed within four of the ecoregions and six of the ecodistricts (Figure 6, Table 3). ELA, Coldwater and Little Turtle Lakes are all located in the same ecoregion (Lake Wabigoon) and ecodistrict (Manitou) (Table 3). Salvesen Lake is also located in the Lake Wabigoon ecoregion, but is in the Sydney Lake ecodistrict. Lac La Croix and French Lake are in the same ecoregion (Pigeon River) and ecodistrict (Quetico). The Dorset Lakes and Turkey Lakes are both in the Georgian Bay ecoregion, but Turkey Lake is in the Batchawana ecodistrict and the Dorset lakes are in the Huntsville ecodistrict (Table 3). Sandy Lake is the only lake in the Big Trout Lake ecoregion and the Sandy Lake ecodistrict.

Table 3. Classification of lakes and lake areas into ecozone, ecoregion and ecodistricts for Ontario.

Lake or Lake Area	Ecozone	Ecoregion	Ecodistrict
Sandy Lake	Ontario Shield	Big Trout Lake	Sandy Lake
Salvesen	Ontario Shield	Lake Wabigoon	Sydney Lake
ELA	Ontario Shield	Lake Wabigoon	Manitou
CWL	Ontario Shield	Lake Wabigoon	Manitou
Little Turtle	Ontario Shield	Lake Wabigoon	Manitou
Lac La Croix	Ontario Shield	Pigeon River	Quetico
French Lake	Ontario Shield	Pigeon River	Quetico
Turkey Lakes	Ontario Shield	Georgian Bay	Batchawana
Dorset Lakes	Ontario Shield	Georgian Bay	Huntsville

2.2.2 Physical Characteristics

The natural lakes range from very small lakes in the ELA (5 to 56 ha) to very large lakes including Sandy Lake (50 700 ha), Lac La Croix (13 787 ha) and Little Turtle Lake (2 312 ha) (Table 4). Maximum depths range from 2.5 m on Lake 303 to 63.4 m at Turkey Lake. Salvesen Lake and Little Turtle Lake are relatively shallow for their large surface areas. Lake 239, L26, Turkey Lake, Red Chalk Lake and Harp Lake are all relatively deep compared to their small surface areas. All lakes are have well-defined outlets. In the Dorset lakes, Blue Chalk Lake drains into Red Chalk Lake. In the Coldwater Lakes, L39 drains into L42.

As expected, the patterns of climate, runoff and ecoregion distribution are similar in that lakes within the same ecoregions have similar MAR, EVA, MAP, and MAS values (Table 4). Due to their northern locations (See Figure 6) all lakes receive significant snowfall, ranging from 137 mm on the ELA lakes to 299 mm on the Turkey Lakes. The Dorset and Turkey Lakes are in the highest snowfall areas (Table 4). MAP is similar, with lowest values around the ELA lakes (~600 mm) and Salvesen Lake (596 mm), and highest in the Turkey Lakes (895 mm) and Dorset Lakes area (906 – 939 mm). Evaporation rates are highest also in the Dorset Lakes (664 – 698 mm) and lowest in the Sandy Lakes watershed (391 mm). Expectedly, MAR is lowest in the CWL area (210) and highest in the Dorset Lakes area (485 – 592 mm).

2.2.3 Hydrologic Attributes

It is important to reiterate that the water level data presented is not for the same period, therefore some differences may occur due to varying climatic influences in each period. Most sites do have some overlap, containing data through the 1980's into the 1990's, with the exception of Little Turtle Lake (Table 2). Therefore, the data does not permit exact comparisons but does

Table 4 Physical characteristics of the lakes, including climate information for their drainage basins. Lakes within the same ecoregion are grouped by colour, as indicated by the colours in Table 3 and Figure 2 (BA = Basin Area, SA = Surface Area, MAR = Mean Annual Runoff, EVA = Mean Annual Lake Evaporation, MAP = Mean Annual Precipitation, MAS = Mean Annual Snowfall).

Lake	**Surface Area** (ha)	**Mean Depth** (m)	**Perimeter** (km)	**Max Depth** (m)	**Basin Area** (km^2)	**BA/ SA**	**MAR** (mm)	**EVA** (mm)	**MAP** (mm)	**MAS** (mm)
Sandy Lake	50700.0	NA	NA	NA	7893.0	15.6	260	391	615	177
Salvesen Lake	575.5	5.6	40.2	14.6	1748.7	303.8	271	545	596	170
ELA Lake 239	56.1	10.5	3.9	30.4	4.5	8.0	246	585	599	137
ELA Lake 303	9.5	0.75	1.5	2.5	0.5	5.3	248	586	599	137
ELA Lake 304	3.4	NA	0.7	6.7	0.3	8.8	248	586	599	137
ELA Lake 227	5.0	3.0	0.8	10.0	0.4	8.0	245	582	600	137
ELA Lake 223	27.3	4.5	2.5	14.4	2.4	8.8	247	583	600	137
ELA Lake 302	23.7	5.7	3.3	13.8	1.0	4.2	250	586	600	137
ELA Lake 114	12.1	NA	1.9	5.0	0.6	4.9	250	587	599	136
CWL L26	29.3	11.5	2.6	37.0	1.1	3.7	210	565	646	144
CWL L39	39.2	12.7	3.0	23.0	1.0	3.4	210	566	647	144
CWL L42	26.4	12.7	2.3	18.0	2.0	7.6	210	566	647	144
Little Turtle Lake	2312.0	3.6	141.6	9.2	4751.0	205.5	216	565	648	147
Lac La Croix	13787.6	NA	295.0	51.2	1988.0	14.4	233	580	652	144
French Lake	284	12.5	12.6	25.9	173.0	60.9	235	554	672	158
Turkey Lake	52.0	12.2	5.9	63.4	8.0	15.4	560	525	895	299
Harp Lake	71.4	13.3	4.8	37.5	5.4	7.6	504	664	906	206
Plastic Lake	32.1	7.9	3.0	16.3	1.5	4.7	491	691	907	206
Red Chalk Lake	57.1	14.2	5.2	38.0	5.9	10.3	493	687	925	214
Dickie Lake	93.6	5.0	8.9	12.0	5.0	5.3	492	690	908	205
Crosson Lake	56.7	9.2	4.2	25.0	4.6	8.1	485	698	939	216
Heney Lake	21.4	3.3	2.7	5.8	1.1	5.1	492	691	909	205
Blue Chalk Lake	52.4	8.5	4.8	23	1.7	3.2	493	687	928	214

allow general natural patterns to be described. There is a general pattern in lake level changes, shown by the mean monthly change in water levels in Figure 5. All lakes exhibit small to moderate decreases in the winter months, followed by relatively large increases in the spring, and decreasing levels into the summer. In the fall, levels either continue to decline, but at a much slower rate (e.g. Little Turtle Lake, Sandy Lake, Lac La Croix) or they display small increases in water levels. Relatively large spring increases only last for one to two months on all lakes (Figure 5). The magnitude of change in mean monthly water levels is relatively small for all lakes (Figure 5) and the greatest magnitude of change is observed on the larger lakes and ranges from –0.04 m on Lake 303 to 0.83 m on Lac La Croix (Table 5).

The timing of monthly maximum and minimum mean water level varies across the province, influenced by climate and lake size. The month of the highest mean water level typically occurs in the spring, which ranges from April/May to early June (Table 5). The two largest lakes, Lac La Croix and Sandy Lake peak in June, later than the others, which could be attributed to their larger storage capacity, or in the case of Sandy Lake a combination of lake size and northern location. Minimum levels occur in late summer to early fall for all the smaller lakes, regardless of location, including those in ELA, Dorset and Turkey Lakes areas. In contrast, minimum levels occur prior to spring melt for all the larger lakes (Table 5). There is some surprising variability in the three CWL, despite their close location and linkages. This can be explained by the small variability between months for these lakes, which made it difficult to determine significantly

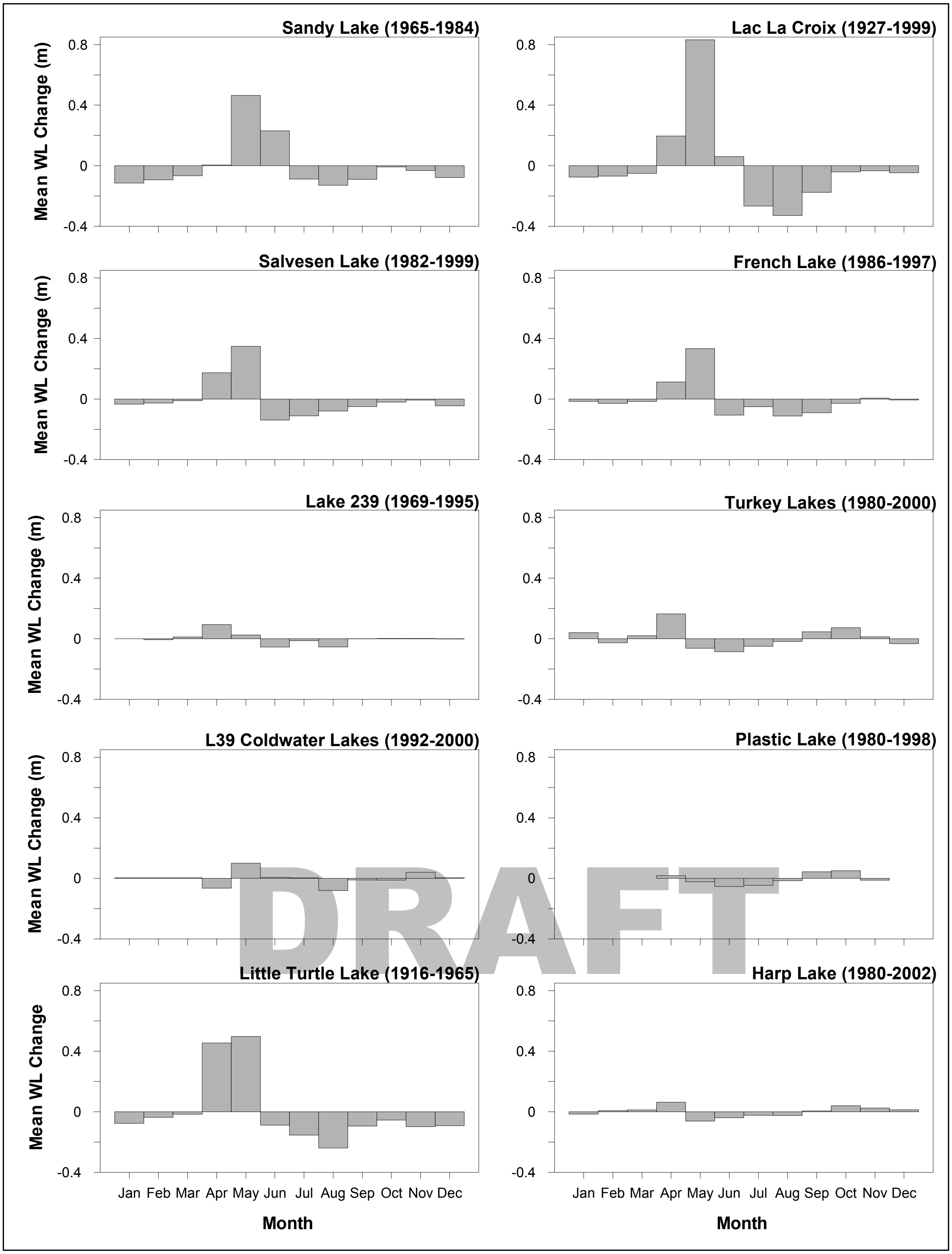


Figure 5 Mean monthly change in water level for a sub-sample of natural lakes.

Table 5 Timing of maximum and minimum monthly mean water levels and the magnitude of that change as represented by the total annual change in water level (maximum – minimum water level). Monthly maximum mean water level changes are also listed. Note: lakes marked with an asterix are based on seasonal records.

Lake	Month of Maximum Level	Month of Minimum Level	Total Annual Change in Level (m)	Maximum Monthly Change in Level (m)
Sandy Lake	June	March	0.70	0.46
Salvesen Lake	May	March	0.52	0.35
ELA Lake 239	May	September	0.12	0.09
ELA Lake 303 *	May	August	0.07	-0.04
ELA Lake 304 *	April	September	0.10	-0.06
ELA Lake 227 *	April/May	August	0.13	-0.05
ELA Lake 223 *	May	October	0.15	-0.06
ELA Lake 302 *	May	September	0.09	-0.06
ELA Lake 114 *	April	August	0.11	-0.05
CLW L26	May	September	0.15	0.08
CLW L39	July	April	0.11	0.10
CLW L42	April	September	0.05	-0.04
Little Turtle	May	March	0.95	0.50
Lac La Croix	June	March	1.09	0.83
French Lake	May	March	0.47	0.33
Turkey Lakes	April	August	0.22	0.16
Harp Lake	April	August	0.15	0.06
Plastic Lake **	May	September	0.14	-0.05
Red Chalk Lake **	April	August	0.32	0.12
Dickie Lake **	April	August	0.23	-0.08
Crosson Lake **	April	September	0.37	0.19
Heney Lake**	April	August	0.25	-0.11
Blue Chalk Lake **	May	August	0.13	-0.07

** April to October* *** April to December*

higher or lower months (i.e. for L39 the mean levels for July and May were 429.99m and 429.98m, and were 429.88m and 429.90m for April and September).

On an annual basis, the maximum change in water levels is also relatively small, ranging from 0.05m on L42, to 1.09m on Lac La Croix (Table 5). The larger lakes tend to have greater annual fluctuations in water levels compared to the smaller lakes. There is also relatively little variability in water levels over time, shown by the minimum and maximum water levels and standard deviations in Figure 6. Predictably the variability tends to be lowest in the winter months and highest in the spring and summer. L26 from the CWL has very little variability, which may be attributed to linear interpolation of weekly and/or monthly data into daily data in the raw data (R. Steedman pers. comm.). There is also little variation in levels on Plastic Lake, which may also be a result of the weekly to monthly water level recording.

2.3 DISCUSSION

All lakes are located on the Canadian Shield within the Ontario Shield ecozone, therefore share similar broad geological features (Table 3). The lakes range in size from very small lakes in the ELA area to very large lakes like Lac La Croix and Sandy Lake (Table 4). All the lakes in this ecozone share some general trends. First, all lakes exhibit a similar pattern of water level fluctuation with decreasing levels in the winter, increasing in the spring as a response to spring melt and declining in the summer with reduced precipitation inputs and evaporation losses (Figure 5 and 6). The greatest variability between lakes occurs in the fall. The second significant pattern to note is the magnitude of changes. The magnitude of monthly and annual changes varies with lake size but is generally small (Table 5). None of the lakes show any changes greater than 1.09 m (Table 5) between months or throughout the year. Also, none of the lakes show minimum levels in the winter months (Table 5). For those lakes that do have negative water level changes in the winter months the magnitude of change declines each month over the winter into the spring (Figure 5). Variability in these general trends appears to be influenced largely by lake size (Table 4). The larger the lake size the greater the magnitude of changes in lake levels (Table 5) and variability throughout the year (Figure 6).

This general pattern is significantly different from regulated reservoirs (Figure 7). Regulated reservoirs typically have large winter drawdowns that sometimes begin in the fall and increase in magnitude into the winter months (Figure 7). High spring flows are used to refill the reservoir following drawdown, the magnitude of which influences the timing and duration of maximum levels. Summer levels are often held constant and do not show the level of decline observed in the natural lakes. As well the magnitude of changes both annual and monthly are often larger on regulated systems (Wilton 1985; Jansen 2000; Kallemeyn et al. 1993) (see also Lake Timiskaming and Wanapitei, Figure 7).

Studies have recommended modifying the frequency, timing, magnitude and length of drawdown to replicate more natural patterns in reservoirs. Minor alterations to regimes have been shown to result in large benefits to fish and invertebrate populations (Jansen 2000). As mentioned in Section 1, the Internation Joint Commission (IJC) recently made such changes to the Namakan and Rainy Lakes management to improve the ecological and environmental values of those reservoirs while also attempting to satisfying water levels for recreation and waterpower production values (Kimmett et al. 1999).

Lake water levels are a physical attribute primarily driven by climate and geologic features of the landscape (Gronskaya 2000). The ecoregion classification partitions the Ontario landscape into areas that are exposed to similar climate and have similar geologic features. Knowing the driver of this attribute and its spatial extent allows inferences about water levels within a given ecoregion. Strong correlations have been found between ecoregion classifications and freshwater systems (Harding and Winterbourn 1987; Hughes et al. 1994; Gronskaya 2000; Johnson 1999). Gronskaya (2000) found similarities in lake levels over large regions in NW Russia, based on similarities in climate, soils and geology. Lakes in three Ontario Lake districts, including ELA, DORSET, Red Lake, and Muskokas were found to have strong coherence in physical attributes, including lake levels (Webster et al. 2000; Quinlan et al 2003). These lake districts are on the Canadian Shield in areas with shallow till, therefore the hydrogeologic connectivity is primarily through surface water (Webster et al. 2000; Magnuson and Kratz 2000). These lake districts were found to be spatially uniform such that lakes exposed to the same climate patterns were found to have similar response in physical attributes, including water levels. Therefore, in areas that are spatially uniform, information from nearby lakes with similar climate and hydrogeology can be used to make inferences on physical attributes like water levels. The results provide the scientific basis to allow inferences about lake levels for each ecoregion and provide a starting point for reservoir management.

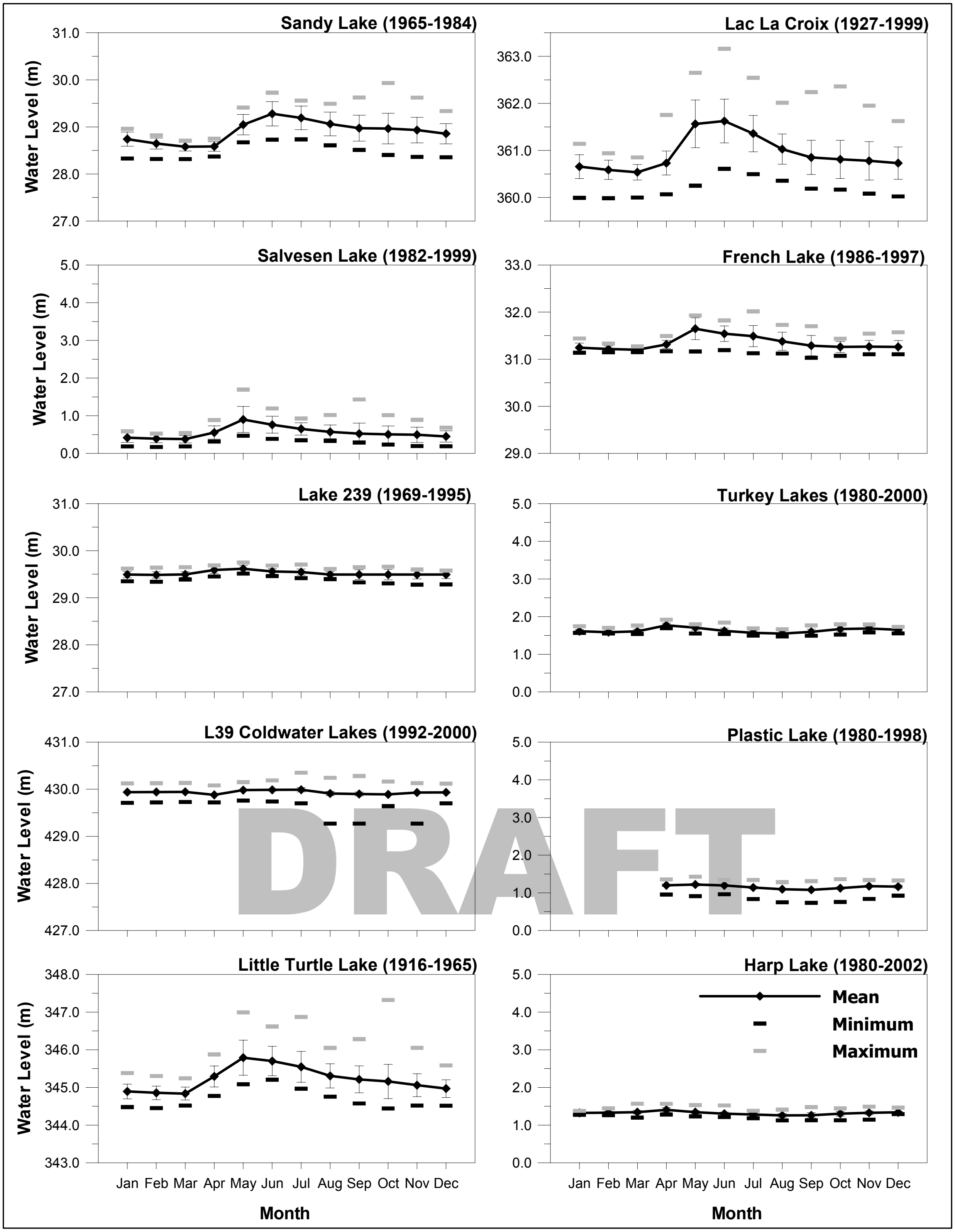


Figure 6 Monthly mean, minimum and maximum water levels for a sub-sample of natural lakes. Bars around the mean values represent standard deviations. Y-axis scales are not the same, but have the same range in values (5m).

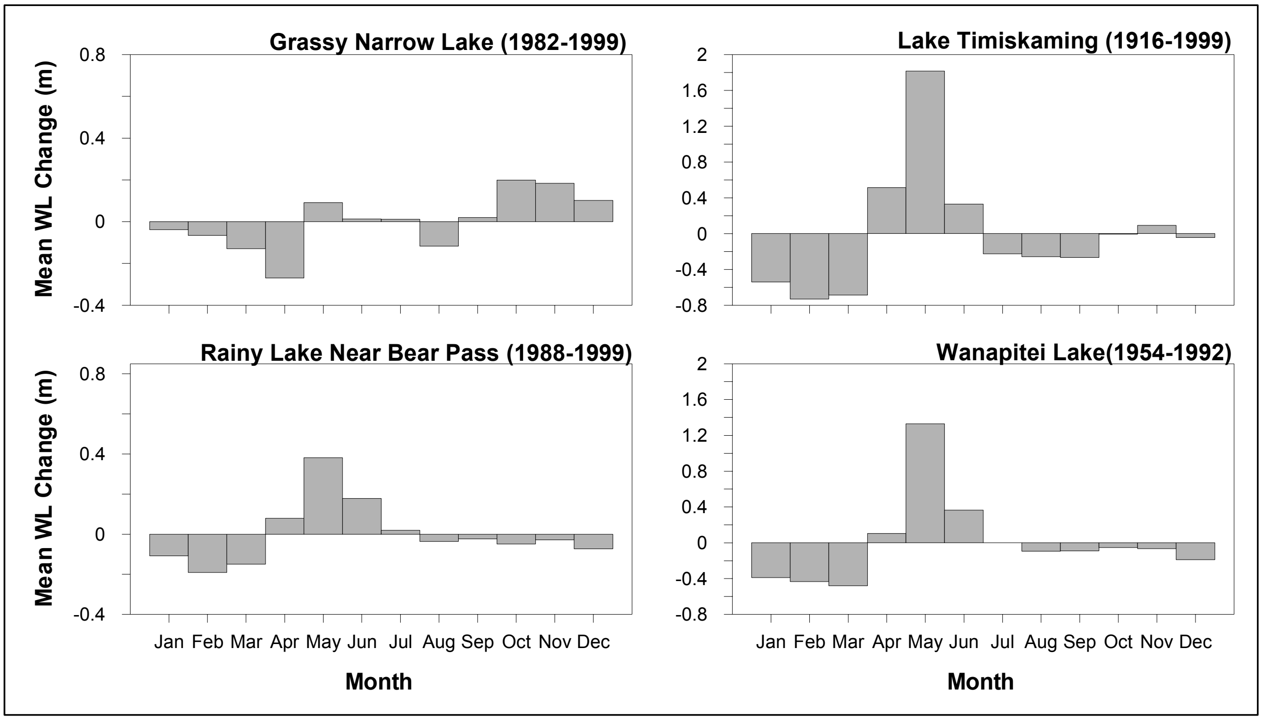


Figure 7 Mean monthly water level change for four regulated lakes. Grassy Narrow is in the Lake Wabigoon ecoregion, Rainy Lake and Namakan are in Pigeon River and Wanapitei Lake is in the Georgian Bay ecoregion.

In the Big Trout Lake ecoregion, represented only by Sandy Lake, maximum water levels are seen in June, with minimum levels in March and maximum changes in March. Although this is the only lake in this region, this pattern is similar to Salvesen Lake, which is the closest lake to Sandy Lake (Figure 3). Keeping in mind that Sandy Lake is a very large lake, which may respond differently than smaller lakes in the area.

In the Lake Wabigoon ecoregion the ELA, CWL, Little Turtle Lake and Salvesen Lake represent a large diversity of lake sizes that peak in April to May. Differences in lake response may be attributed to differences in the surface area to mean depth ratio, an index of a lakes exposure to the atmosphere (c.f. Kratz et al., 1998). The smaller lakes appear to be more impacted by relatively high evaporation rates (Table 4) resulting in minimum lake levels in August to October. These smaller lakes also show the greatest change in monthly levels which occur in August. The larger lakes (Lake Salvesen and Little Turtle) which also have large basin area to surface area ratios, have minimum levels in March, the result of continuing declining water levels over winter (Figure 6). The greatest monthly change in water levels for these two lakes occurs in May coinciding with the timing of spring snowmelt (Table 5). The Coldwater Lakes data are problematic; measurements are not continuous and beaver dams have artificially influenced the levels (R. Steedman CNFER, pers. comm.), making it difficult to ascertain the validity of these outliers.

Lac La Croix and French Lake make up the lakes in the Pigeon River ecoregion and are both in the same ecodistrict. Minimum levels occur in March for both lakes and the month of maximum change is May (Table 5). French Lake peaks in May followed by Lac La Croix in June (Figure 4), the large size of Lac La Croix and its large drainage area may influence this delayed peak.

Studies on the Namakan and Rainy Lakes, which are in the Pigeon River ecoregion, found that pre-dam peak levels also occurred in late May, early June (Kallemeyn 1992), consistent with other lakes in the ecoregion.

In the Georgian Bay ecoregion, peak water levels occur in spring (April to May) and lowest levels in the summer (August to September). Lakes in these areas have the highest MAP and MAS, and the Dorset Lakes have the highest EVA (Table 4). These high evaporation rates are likely the cause of the low summer levels. There is more variability in the month of maximum change in this region, ranging between April and May, as well as July and November. Important to note is all lakes in this region, with the exception of Turkey Lake and Harp Lake, have data that extends from April to December only. Since the calculation of monthly change for April requires data in the month of March, values for April cannot be calculated. Therefore, it is not possible to tell if these lakes would have greatest changes in April like the other two lakes with complete data.

3.0 CONCLUSION

Much has been learned about the influence of water level fluctuations on ecosystem processes. However, the extrapolation of this knowledge is difficult given the sparsity of water level gauges on interior lakes within the province with historical water level records and the bias toward clusters of research sites which precludes the statistical analyses necessary to regionalize water level properties. Nonetheless, given the available data, distinct patterns are discernable in natural lake level fluctuations that can be explained by physical, climatological, and locational attributes. Equally important are patterns/features not observed in any of the data from natural lakes that are characteristic of regulated reservoirs. Thus, patterns observed in natural lake water levels as presented here and existing research that links water level parameters to ecosystem processes, does allow for meaningful recommendations for water level regimes that would best achieve aquatic ecosystem objectives in water management planning. There are also opportunities to validate these patterns using site specific information on elevations associated with waterfowl nesting sites, denning locations, and spawning sites etc.

Clearly there is a need for more hydrometric stations to be located on interior lakes in the province to support research on lake ecosystem processes. The inherent bias in the hydrometric monitoring network towards stream gauges is explained by their traditional use for flood forecasting. However, recent emphasis on monitoring water quantities, watershed health, and impacts of climate change has highlighted the need to consider other needs in network design decisions. It is also important to locate hydrometric stations on lakes strategically to ensure greatest ecological representation of larger spatial units, that also integrates lake size, to ensure an optimal reference network.

Regional reference sites have been found useful for developing biological, physical and chemical criteria for lakes (Johnson 1999; Hughes et al. 1993; Biggs et al. 1990; Heiskary and Wilson 1989). Many authors agree that the selection of representative reference sites for these ecoregions should follow accepted protocols. A number of steps have been suggested to establish a reference network (after Hughes et al., 1994):

1. Define areas or regions of interest using map information and wherever possible use natural boundaries (i.e. drainage divides).

2. Define waterbody types (e.g. lakes), classes (within a type), and sizes of interest. Factors to consider include:
    - temperature (cold water vs. warm water);
    - size (area, depth, volume, discharge, and exchange rate);
    - bed materials (coarse, fine, and bedrock);
    - connectivity of stream and lakes; and
    - chemistry (alkalinity, acidity, turbidity, nutrient status and concentration of dissolved organic carbon).

3. Select candidate reference sites using available data, map information, aerial photos, local knowledge and expert opinion. The purpose of this step is to locate candidate sites that are minimally disturbed and likely to remain so. For example the following criteria would be identified on a map:
    - locate and reject lakes in disturbed areas;
    - public lands vs. private lands;
    - information on pollutant discharge, hazardous waste, farms etc.;
    - water resource data (i.e. channelization, dams, and water withdrawals); and
    - introduced species, fish stocking and harvesting data.

4. Conduct a field reconnaissance to locate potential sites. This step is essential to validate the spatial data used for the selection.

5. Determine the number of reference sites needed to attain the proper balance for estimating regional variability.

6. Quantitatively evaluate the biological health of reference sites.

Several ongoing initiatives such as Ontario's ecoregion classification and the Water Resources Information Project (WRIP) are producing spatial data sets that fulfill some the criteria suggested above. Information from these initiatives combined with the analysis of natural water level variability presented in this report provides important initial information for developing a reference lake network. The numerous water level records within HYDATA indicated as being regulated should also be examined to determine if the degree of regulation in fact masks the natural variability that would be observed at the site and precludes these gauges from further examination.

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