Rehabilitating the Aquatic Ecosystem of Rainy Lake and Namakan Reservoir by Restoration of a More Natural Hydrologic Regime

by

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Abstract. The 38,600-km^2 Rainy Lake watershed, part of the Hudson Bay drainage, contains a complex network of lakes, ponds, and connecting rivers and streams. Hydrologic conditions in Rainy Lake-Namakan Reservoir have been regulated by dams since the early 1900's. Regulation has altered the magnitude and timing of water level fluctuations and has removed much of the hydrologic variability the lakes would experience under natural conditions. The controlled water levels adversely affect key elements of the aquatic ecosystem: littoral vegetation, benthic organisms, fish, aquatic birds, and furbearers. Specific water levels, particularly spawning season levels, and annual fluctuations of water levels influence fish densities and spawning success. Simulation models indicate that phytoplankton biomass and primary production may also be affected by the regulatory program. As part of a Federal Energy Regulatory Commission licensing action, and based on recent research, alternative water level regulations were developed by various user groups. Regulations that emulate natural fluctuations in water levels, including annual and long-term variability, may overcome the adverse biological effects of the present program. Whereas conflicting needs of water users may prevent implementation of such alternatives and may preclude complete restoration of the Rainy Lake-Namakan Reservoir system, a regulatory program that is more ecologically sound seems possible, given our understanding of relations between the hydrologic regime and the various biological components. That knowledge, and information on other users' needs, has been used by a committee representing private

and public interests to develop a compromise regulatory program that provides for human and biological needs.

The aquatic ecosystem of the Rainy Lake basin has a long history of use by humans. Native Americans were sustained by its resources for thousands of years (Martin et al. 1947). Europeans, who first entered the region in the 1660's, traded with the Indians for furs, fish, and wild rice which were harvested from area waters (Nute 1941; Holzkamm et al. 1988). In the past 100 years, human influences on the aquatic ecosystem increased substantially. The principal effects were associated with commercial and recreational fishing, the introduction of nonnative fish species, and manipulation of water levels by the construction of dams at the outlets of Rainy and Namakan lakes.

In this paper, we focus on the effect of water level regulation because it can affect all components of the ecosystem. Water level regulation can change energy flow through the system and can alter biological communities (Benson 1973; Baxter 1977; Kimmel and Groeger 1986; Prosser 1986). Our objectives are to summarize the results of studies conducted to determine effects of water regulation on selected species and communities, present a method for developing and evaluating alternative regulatory procedures for reducing those effects, and describe how the method is being used by a group representing private and public interests to select a more environmentally favorable regulatory program.

Study Area

The 38,600-km^2 Rainy Lake basin forms part of the headwaters of the Hudson Bay watershed. About 70% of the basin is in Ontario, and the remainder is in Minnesota (Fig. 1). In general, the

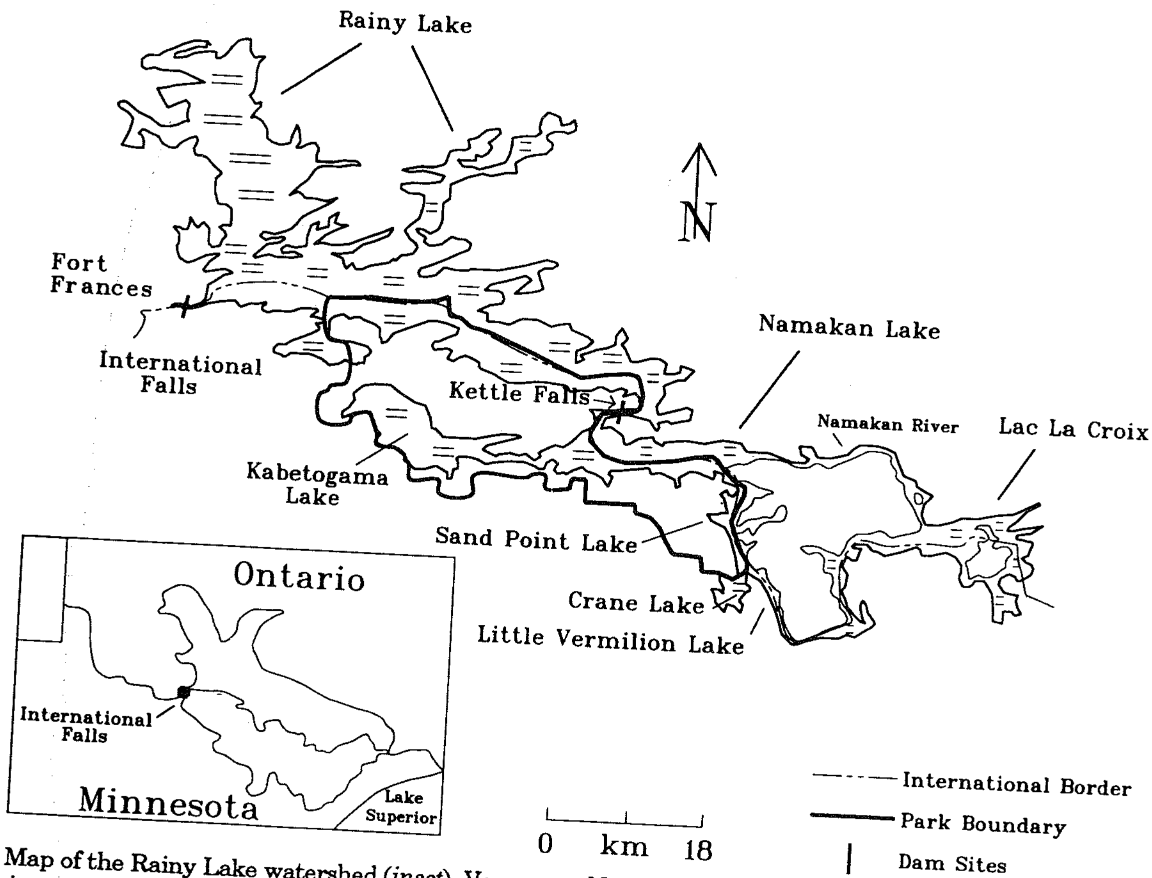

Fig. 1. Map of the Rainy Lake watershed (*inset*), Voyageurs National Park, and the lakes and reservoir discussed in this paper.

watershed is forested and characterized by thin soils, frequent outcrops of Precambrian rocks, and numerous lakes, ponds, and interconnecting rivers and streams. Parks and wilderness areas compose 25% of the basin; the major units are the Quetico Provincial Park in Ontario and the Boundary Waters Canoe Area and Voyageurs National Park in Minnesota.

Flow through the basin is generally northwesterly along the International Boundary. Changes in flow initiated at the headwaters take about 21 days, under average flow conditions, to reach the outlet of Rainy Lake. In traveling the 338 km between these two points, the waters drop about 135 m. Average flow at the outlet of Rainy Lake from 1905 to 1979 was 277 m^3/s; extremes ranged from 1 to 1,360 m^3/s. The highest flows in the major rivers typically occur during the spring freshet, which extends from April through June.

Rainy Lake, the largest lake in the basin, has a surface area of 858 km^2, 75% of which is in Ontario. The lake has a rocky, irregular shoreline and three distinct basins: the North Arm, Redgut Bay, and the South Arm. Namakan Reservoir lies immediately upstream of Rainy Lake and encompasses Namakan, Kabetogama, Sand Point, Crane, and Little Vermilion lakes. The reservoir has a surface area of 260 km^2, 77% of which is in Minnesota.

The area has a continental climate, characterized by moderately warm summers and long, cold winters (National Oceanic and Atmospheric Administration 1991). The frost-free season ranges from 110 to 130 days. Lakes are typically ice covered 5–6 months of the year. Average annual precipitation is about 68 cm, 30% of which comes in the form of snow. Precipitation is usually heaviest from June through August. Annual evaporation from all surfaces in the basin averages 49 cm, evaporation from lake surfaces averages 63 cm.

Water Level Regulation

The water level in Rainy Lake has been controlled since 1909 by a hydroelectric dam on its outlet, the Rainy River at International Falls, Minnesota and Fort Frances, Ontario (Fig. 1). Two dams at the outlets of Namakan Lake have controlled the water levels of Namakan Reservoir since 1914 (Fig. 1). Because Rainy Lake and Namakan Reservoir are border waters shared by the two countries, the dams and lakes are regulated by the International Joint Commission. The dams and lake levels are managed for the authorized purposes of power production, navigation, domestic water supply, sanitation, recreation, and other public purposes. Although regulated by the International Joint Commission, the dams have always been owned and operated by private industry. Their day-to-day operation is usually left to the industry, the International Joint Commission becoming involved only if its rules are not, or cannot be, followed.

The International Joint Commission's water management programs, which are commonly referred to as "rule curves," use larger than natural fluctuations in lake levels on Namakan Reservoir to maintain less than natural fluctuations on Rainy Lake. The rule curves require that water levels be within a defined band of lake elevations at any time of the year (Fig. 2). Additionally, the program for Rainy Lake requires minimum discharges for pollution abatement to the Rainy River of 113 m^3/s between sunrise and sunset in the months of May to October and 93.4 m^3/s at all other times.

Under the current rule curves, which have been in effect since 1970, annual water level fluctuations have averaged 2.7 m on Namakan Reservoir and 1.1 m on Rainy Lake. Namakan Reservoir's fluctuation is about 0.9 m greater than the estimated natural or predam fluctuation, whereas Rainy Lake's is 0.8 m less (Fig. 2; Flug 1986). Namakan Reservoir's overwinter (October to April) drawdown under the 1970 rule curve has averaged 2.3 m, which is 2.0 m greater than the estimated natural fluctuation for this period. Rainy Lake's overwinter drawdown has averaged 0.8 m, which is similar to the 0.7 m estimated natural fluctuation. The timing of the fluctuations has also been altered under the regulated system, particularly on Namakan Reservoir. Regulated lake levels usually peak in late June or early July rather than late May or early June, as they did before dam construction, and they remain stable throughout the summer rather than gradually declining. Thus, the International Joint Commission's rule curves have altered both the annual magnitude and timing of lake level fluctuations, and dampened the amplitude of yearly fluctuations in water levels (Figs. 2 and 3).

Environmental Concerns

Concern about the effects of water level regulation on the aquatic biota has existed since the

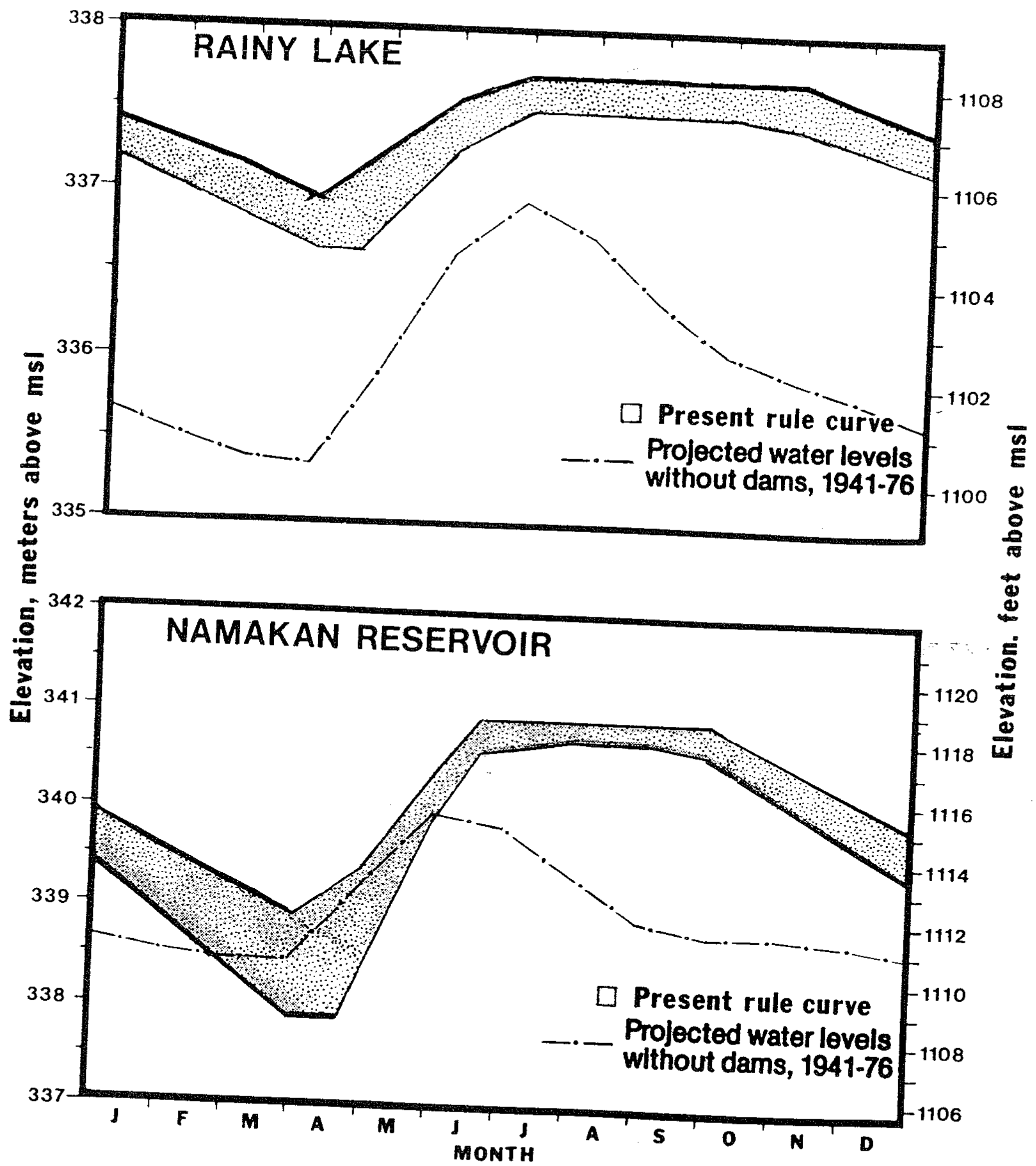

Fig. 2. Present water management programs (*rule curves*) and computed natural lake levels for Rainy Lake and Namakan Reservoir, Minnesota and Ontario. Elevations are given in meters and feet above mean sea level.

dams were constructed. The International Joint Commission's final report on the Rainy Lake Reference (1934) included statements from numerous parties expressing concerns about the possible effect of raising and regulating lake levels. The primary concern has been for the relation between lake levels and the fish community (Sharp 1941; Johnson et al. 1966; Chevalier 1977; Osborn et al. 1981).

The establishment of Voyageurs National Park in 1975, with its emphasis on restoring and preserving the natural environment, heightened concerns about effects of regulated lake levels on the aquatic ecosystem of Rainy Lake and Namakan Reservoir (Cole 1979, 1982). The effect of the fluctuating water levels on the littoral zone biota was a particular concern.

Further evidence of concern was the requirement in the Federal Energy Regulatory Commission's 1987 license for the International Falls dam that the dam owner "develop a water-level management plan for Rainy Lake to ensure the protection and enhancement of water quality, fish and wildlife, and recreational resources." This plan was to be based on studies conducted by Voyageurs National Park and any other studies conducted by the licensee after consultation with the U.S. Fish and Wildlife Service, the National Park

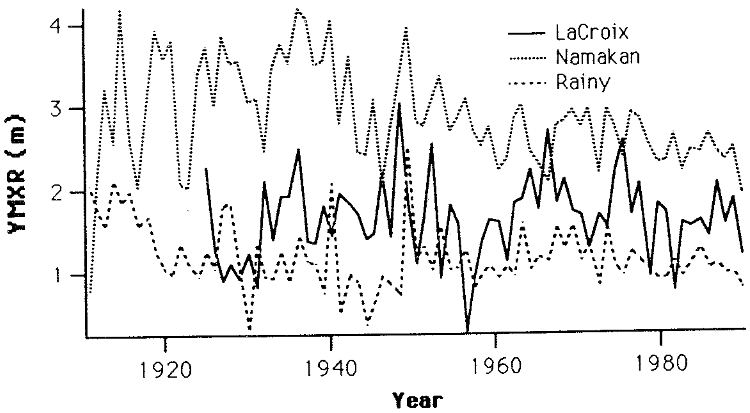

Fig. 3. Annual water level fluctuations (YMXR = maximum–minimum) in Rainy Lake, Namakan Reservoir, and Lac La Croix, 1911–90.

Service, and the Minnesota Department of Natural Resources.

Methods

General Approach

In the 1980's, the National Park Service, in response to these continued concerns, initiated a research program to (1) assess effects of regulated lake levels on the aquatic ecosystem of Rainy Lake and Namakan Reservoir, and (2) develop alternatives to the water management program (Kallemeyn 1983). The first component of the research program examined effects of the water management program (1970 rule curves) on selected species and communities thought to be sensitive to changes in water levels. The second component developed a hydrological model that could be used to assess alternative regulatory programs (Flug 1986). This model simulated the multi-lake system beginning with inflows to Namakan Reservoir and ending with outflows from Lake of the Woods, a large lake (3,850 km^2) located about 130 km downstream from Rainy Lake. To restrict the modeling effects to this area, outflows from Lake of the Woods were given priority and were forced to match actual historic releases. The model also provided for all legally mandated discharges for pollution abatement.

This program design was used because it would allow development and presentation of meaningful recommendations for alternative regulatory programs if research showed the water management program was adversely affecting the aquatic biota. It also allowed testing whether more natural water management scenarios could be used to reduce adverse effects on the biota without seriously conflicting with other authorized water uses (Cole 1982). Lastly, this information could serve as baseline data that could be used to evaluate the effects of any new water regulatory program that might be implemented.

Sampling Methods

Following are brief descriptions of the sampling methods used in the various National Park Service-supported studies and in another study sponsored by the Minnesota Department of Natural Resources, the Ontario Ministry of Natural Resources, and the dam owner in response to the Federal Energy Regulatory Commission license (Cohen and Radomski 1993). In 1992, the dam owner also sponsored the development of another hydrological model called SIMUL8, which mathematically simulates the operation of Rainy Lake and Namakan Reservoir (Acres International Limited 1993). Refer to the cited papers and reports for complete descriptions of the methods used.

Water quality in Rainy, Kabetogama, Namakan, and Sand Point lakes was monitored from 1977 to 1984 by Payne (1991) and in 1985 and 1986 by Kepner and Stottlemyer (1988). Payne's (1991) analysis was based on composite water samples, taken in May and August from the top, center, and bottom of a water column equal to twice the Secchi disk reading, that were analyzed using the methods described by Brown et al. (1970), Goerlitz and Brown (1972), and Skougstad et al. (1979). Kepner and Stottlemyer (1988) sampled monthly during the ice-free season. They measured primary production with the in situ ^{14}C method (Steemann-Nielsen 1952; Lind 1979; Wetzel and Likens 1979) and chlorophyll *a* spectrophotometrically, as outlined by the American Public Health Association (1980) and modified for dimethyl sulfoxide extraction per Burnison (1980).

Wilcox and Meeker (1991) compared aquatic macrophyte communities in Rainy and Namakan lakes with those in Lac La Croix, an unregulated lake located 32 km upstream from Namakan Lake (Fig. 1), to determine the effects of the altered hydrologic regimes. Lac La Croix's mean annual fluctuation of 1.6 m falls between those of Rainy (1.1 m) and Namakan (2.7 m) lakes. Also, its water level typically declines after early June, rather than remaining stable, and exhibits greater year-to-year variability (Fig. 3). In each lake, aquatic macrophytes were sampled along four depth contours selected to represent specific habitat types in the unregulated lake. Species identifications and percent cover estimations were made in twenty 1-m^2 quadrats on each transect. Importance values were calculated for each taxon as the sum of relative frequency and relative mean cover on each transect. The vegetation data were analyzed using standard summary statistics, Sorenson's index (Mueller-Dombois and Ellenburg 1974), and detrended correspondence analysis (McCune 1987).

Kraft (1988) compared benthic communities in Kabetogama, Namakan, and Sand Point lakes with those in Rainy Lake to assess the effect of the greater than natural overwinter drawdown on littoral zone macroinvertebrates in Namakan Reservoir. Invertebrates were collected with an Ekman grab with samples taken on transects at depths of 1, 2, 3, 4, and 5 m. Sampling was confined to summer except on Kabetogama Lake where samples were also collected throughout fall and winter. Invertebrates were identified to genus or higher taxonomic level and counted. A Shannon–Wiener diversity index and an equitability value (Krebs 1972) were determined for each sample. The Wilcoxon signed rank test or the Mann–Whitney U statistic was used to test for differences between lakes in number of invertebrates, taxa, selected taxa, and diversity.

Effects of regulated lake levels on common loon (*Gavia immer*) and other shore and marsh nesting birds were studied in Rainy Lake and Namakan Reservoir from 1983 to 1986 (Reiser 1988). Intensive shoreline searches were used to determine adult bird densities and to locate nests. Nests and resulting broods were monitored to determine hatching and fledging rates. Nesting habitat, climatological, hydrological, and lake characteristic data were collected for use in evaluating their effects on nesting and reproductive success.

Effects of regulated lake levels on the aquatic furbearers—beaver (*Castor canadensis*), muskrat (*Ondatra zibethicus*), and river otter (*Lutra canadensis*)—were evaluated by comparing densities, behavior, and standard morphological measurements of animals from Rainy Lake and Namakan Reservoir (Route and Peterson 1988; Smith and Peterson 1988, 1991; Thurber et al. 1991). Lodge counts provided indices of abundance for beaver, while animals that were livetrapped and radio-implanted were used to study behavior, movements, and mortality. Estimates of muskrat densities were obtained from house counts, live-trap catches, and recaptures of marked animals. Radio-implants, sign surveys, and visual counts of marked and unmarked animals were used in the river otter study.

Kallemeyn (1987a, 1987b) evaluated the relation between spawning season water levels and reproductive success of walleye (*Stizostedion vitreum*), yellow perch (*Perca flavescens*), and northern pike (*Esox lucius*) by comparing seine and trapnet catches of age-0 fish with spawning season water levels. The quantity and availability of northern pike spawning habitat was determined from topographic maps and vegetation cover surveys. Cohen and Radomski (1993) examined relations among the fish populations, the fishery, and water level regulation in Rainy Lake and Namakan Reservoir from the context of ecosystem processes. For an index of ecosystem processes, they used the annual fluctuation or the yearly maximum range of water levels (YMXR). They used spectral analysis to explore relations between YMXR and an index of fish abundance determined from commercial fish catches over time. Spectral analysis treats a time series, such as the water level and commercial fish data, as a sum of sine waves (i.e., cycles; Priestly 1981). The method can be used to investigate changes in a variable over time and to detect cycles in a series. Other researchers have applied spectral analysis to fisheries data (Cohen and Stone 1987; Stone and Cohen 1990; Pereira et al. 1992). The method uses Fourier transform to fit a sum of sine waves, sine waves of different amplitude and period, to the data (Bloomfield 1976).

Two measures produced by spectral analysis are power spectrum and coherency. The set of amplitudes of a time-series at each possible period (years per cycle) is quantified by the power spectrum. Thus, the measure exposes significant cycles and their periods. Coherency is a measure of the amount of correlation between the power spectrum of two time series. Analogous to the correlation coefficient, coherency indicates how closely two time series are fluctuating at a particular period. Coherency ranges from 0 to 1, where 1 represents perfect synchrony of fluctuations between two time series. A coherency is calculated for all periods explored in both time series. At each period then, the correlation between amplitudes of fluctuations gives the coherency. For example, high amplitudes at the same period in two time series would have high coherency at that period. For both measures some information is lost. Of importance here, information on phase relations or when the cycles peak is lost. The analysis ignores phase lags. For example, two time series composed of the same sine wave (same amplitude and period) could have different phases but still have a coherency of 1 at the period of that particular sine wave.

Results and Discussion

The results of the National Park Service research program and the Cohen and Radomski (1993) study are summarized in the following sections. Information gathered in earlier studies, which dealt almost exclusively with the fish community, and pertinent information from the literature are also included.

Water Quality and Primary Production

Water quality in Rainy Lake and the Kabetogama, Namakan, and Sand Point basins of Namakan Reservoir is good (Kepner and Stottlemyer 1988; Payne 1991). Rainy, Namakan, and Sand Point lakes, which receive most of their inflows from a large area of exposed bedrock and thin noncalcareous glacial drift, are oligotrophic to mesotrophic, having low dissolved solids and alkalinity (Table 1; Payne 1991). Kabetogama Lake receives much of its inflow from an area that is overlain by calcareous glacial drift and is eutrophic, having higher dissolved solids and alkalinity (Table 1; Payne 1991). Values for trophic state condition estimators (e.g., specific conductance, chlorophyll *a* concentrations, and carbon assimilation rates) from Kabetogama Lake are typically 2 to 3 times higher than those from the three less productive lakes (Table 1; Kepner and Stottlemyer 1988).

Analysis with a total phosphorus mass-balance model indicated peak spring total phosphorus levels in Kabetogama Lake would be reduced from about 34 µg/L to 30 µg/L if the present rule curve were replaced by one approximating natural conditions (Kepner and Stottlemyer 1988). The authors attributed this to (1) a reduction in bottom areas exposed by drawdown and accompanying sediment-water interactions, (2) reduced nutrient inputs resulting from die-off of littoral vegetation, and (3) reduced nutrient concentrations because of volume changes. The authors, stressing the model was uncalibrated, concluded a return to natural fluctuations could reduce phytoplankton biomass and the accompanying primary production. These changes, in turn, could have ramifications throughout the food web.

Aquatic Vegetation

Naturally regulated Lac La Croix supported a more taxonomically and structurally diverse plant community at all depths; the greatest differences were evident in the plant assemblages from deeper water (Table 2; Wilcox and Meeker 1991). The effect of the less than natural water level fluctuation on

Table 1. Mean values for selected water quality and trophic state estimators for Kabetogama, Namakan, Sand Point, and Rainy lakes.

Variable	Lake			
	Kabetogama	Namakan	Sand Point	Rainy
Dissolved solids (mg/L)[a]	68.0	49.0	56.0	49.0
Total alkalinity (mg/L)[a]	40.0	15.0	17.0	15.0
Total P, August (µg/L)[a]	45.0	12.0	18.0	11.0
Conductance (µmhos/cm@25° C)[b]	84.0	45.0	50.0	47.0
Chlorophyll *a* (mg/m^3)[b]	9.3	2.7	4.0	3.3
Carbon assimilation (mg $C/m^3/4h$)[b]	29.4	13.2	13.8	12.9

[a] Payne (1991); mean concentrations for 1977–83.
[b] Kepner and Stottlemyer (1988); mean concentrations for 1985–86.

Table 2. Sums of the mean importance values for 26 of the most prominent plant taxa on transects 0.5, 1.25, and 1.75 m below the mean annual high water level of Lac La Croix, Rainy Lake, and Namakan Lake. Taxa were separated into morphologically similar groups (Wilcox and Meeker 1991).

Category	Lac La Croix			Rainy Lake			Namakan Lake		
	0.5	1.25	1.75	0.5	1.25	1.75	0.5	1.25	1.75
Thin-stem emergents	21.1	0.0	0.0	36.0	2.9	0.0	43.4	13.3	0.0
Mat-formers	25.4	0.0	0.0	8.9	7.2	0.0	33.6	46.4	12.4
Low rosettes	6.8	0.0	0.0	1.0	28.3	0.0	13.5	22.8	13.6
Low-growth aquatics	9.9	33.8	43.0	0.0	8.3	0.0	0.8	5.4	34.9
Erect aquatics	16.1	52.5	52.1	0.0	49.1	96.8	0.5	8.7	29.2
Total	79.3	86.3	95.1	45.9	95.8	96.8	91.8	96.6	90.1

Rainy Lake was most obvious on transects that were never dewatered. Only four plant taxa were present at that depth (1.75 m), and they were all erect aquatics (Table 2). On Namakan Lake, the effects were most apparent at the depth (1.25 m) that was exposed annually to the effects of desiccation and disturbance from ice formation in the sediments (Table 2). Those conditions favored the establishment of low rosette and mat-forming plant species, neither of which provides much structural diversity in the water column. Wilcox and Meeker (1991) concluded the macrophyte communities of both regulated lakes would benefit from a hydrological regime approximating that of Lac La Croix. They suggested such conditions would provide a more natural and structurally diverse macrophyte community that would provide more diverse habitats for aquatic fauna (Wilcox and Meeker 1992).

Benthos

Winter drawdown on Namakan Reservoir can dewater up to 25% of the reservoir bottom and can cause a massive layer of ice to be in contact with the substrate for periods exceeding 100 days (Kraft 1988). These effects typically extend to levels 2 to 3 m below summer pool elevation. Mean diversity values for invertebrates at depths of 1 and 2 m in Namakan Reservoir were significantly lower than in Rainy Lake (Wilcoxon Signed Ranks test $P \leq 0.05$) but were not significantly different at 3, 4, or 5 m (Table 3). Equitability values, which indicate the evenness of allotment of individuals among taxa, exhibited a similar pattern (Table 3). Stranding and subsequent mortality, which were observed frequently in the winter samples, would seem to be a major contributing factor to the observed differences. Stranding of organisms (Benson and Hudson 1975) through exposure of substrates to air or ice cover (Ioffe 1966; Paterson and Fernando 1969; Kaster and Jacobi 1978) can reduce or alter benthic communities.

Individual taxa exhibited similar patterns, with densities of the alderfly (*Sialis* spp.), which is sensitive to lake level regulation (Grimas 1961), and mayfly (*Hexagenia* spp.) being lower in the drawdown zone in Namakan Reservoir than in Rainy Lake (Table 4). In contrast, chironomids, which quickly recolonize newly submerged areas (Cowell and Hudson 1968), were more abundant at the Namakan Reservoir sites than in Rainy Lake, particularly in the dewatered zone (Table 4). Isopods (*Asellus* spp.), which are also affected by regulation (Grimas 1961), were collected regularly in Rainy Lake but never in Namakan Reservoir.

Table 3. Mean diversity and equitability values for benthos samples from Rainy Lake and Namakan Reservoir on six common sampling dates, June 1984–June 1986 (Kraft 1988).

Depth (meters)	Diversity		Equitability	
	Rainy Lake	Namakan Reservoir	Rainy Lake	Namakan Reservoir
1	2.155	1.672	0.70	0.58
2	1.980	1.690	0.70	0.60
3	1.999	1.864	0.76	0.71
4	1.852	1.836	0.81	0.74
5	1.807	1.789	0.82	0.75

Results of a scuba survey of unionid mussels indicated the drawdown on Namakan Reservoir may have reduced their numbers and caused a shift in their distribution (W. L. Downing, Hamline University, St. Paul, Minnesota, personal communication). Mussel densities in Kabetogama and Namakan lakes were lower than in Rainy Lake and they occurred only at depths exceeding 4 m. In Rainy Lake, mussels were primarily found at depths of less than 4 m, which is more typical of bivalves (Pennak 1978). Conceivably, the drawdown could limit mussel populations either directly through death resulting from stranding or by forcing them to live in suboptimal habitats. Drawdown resulted in the stranding of large numbers of clams (Kaster and Jacobi 1978), and in Lake Sebasticook in Maine, drawdown caused two unionid mussel species to virtually disappear (Samad and Stanley 1986).

Shore and Marsh Nesting Birds

The large winter drawdown on Namakan Reservoir and the resultant low spring water levels make water level changes of more than 1 m necessary in May and June to reach the established summer levels. The June changes, in particular, adversely affected aquatic bird nesting success (Reiser 1988). During the period from 1983 to 1985, 47% of the attempted common loon nests on Namakan Reservoir were lost to flooding, while on Rainy Lake, 27% were lost. Red-necked grebes (*Podiceps grisegena*) were even more sensitive to lake level changes. From 1983 to 1985, 77% of the red-necked grebe nests on Namakan Reservoir were lost to flooding; on Rainy Lake 45% were lost.

Reproductive success of loons was significantly higher on Rainy Lake and Namakan Reservoir when the lake level rose less than 20 cm during June. On Rainy Lake, the mean productivity level for 3 years when the June lake level rise was less than 20 cm was 0.28 fledged young/adult; the comparable figure for 5 years when the rise was greater than 20 cm was 0.19. Reproductive success of common loons for the same time periods on the Namakan Reservoir lakes were 0.20 and 0.10 fledged young/adult. June lake level changes of less than 20 cm have occurred on Rainy Lake about 75% of the time since the 1970 rule curve went into effect, whereas on Namakan Reservoir such favorable conditions have only occurred about 20% of the time.

Similar relations were observed between lake level changes in June and the proportion of flooded nests of other marsh-nesting birds. Nest losses caused by flooding were higher for pied-billed grebes (*Podilymbus podiceps*) and black terns (*Chlidonias niger*), which nest on the water surface, than for red-winged blackbirds (*Agelaius phoeniceus*) and yellow-headed blackbirds (*A. xanthocephalus*), which nest above the water.

Aquatic Furbearers

High stable summer and early fall water levels caused beavers to build their lodges and food caches at elevations that left them susceptible to Namakan Reservoir's larger than natural winter drawdown (Smith and Peterson 1988, 1991). The winter drawdown forced nearly 80% of the beavers to abandon their lodges and food caches by January or February. As a result, beavers spent winter in woodchip nests under the ice outside their lodges and were forced to find alternative food sources. Although widespread mortality did not occur, weight loss was greater among Namakan Reservoir adults ($\bar{x}$ = 2.5 kg, N = 6) than adults from inland ponds and Rainy Lake ($\bar{x}$ = 1.4 kg, N = 7). Kit production was also lower in Namakan Reservoir ($\bar{x}$ = 2.1 kits/lodge, N = 16) than in more stable, inland ponds ($\bar{x}$ = 3.3 kits/lodge, N = 14). They were also more susceptible to predation, particularly in spring. Movement

Table 4. Comparison of mean numbers of three invertebrate taxa for six common sampling dates on Rainy Lake and Namakan Reservoir (Kraft 1988).

Depth (meters)	*Sialis* spp. Rainy Lake	*Sialis* spp. Namakan Reservoir	*Hexagenia* spp. Rainy Lake	*Hexagenia* spp. Namakan Reservoir	Chironomids Rainy Lake	Chironomids Namakan Reservoir
1	2.0	0.7	105.5	6.3	1,660	3,577
2	47.0	4.0	223.5	37.3	1,205	1,863
3	18.0	16.0	200.5	106.0	726	973
4	50.0	28.7	225.0	94.0	418	514
5	38.0	31.7	179.0	139.7	377	518

resulting from lodge abandonment, which was 100% when water was absent from lodge entrances in spring, exposed the animals to predation by gray wolves (*Canis lupus*). About 25% of spring mortality of beaver on the Namakan Reservoir lakes was attributable to wolf predation.

Effects on muskrats in Namakan Reservoir were similar, even though the animals abandoned houses and constructed new ones in deeper water as lake levels fell before freeze-up in October and November (Thurber et al. 1991). Even with this adjustment, the muskrat's primary food sources became inaccessible as water levels continued to fall throughout winter. The continued drawdown may have also led to increased predation by mink (*Mustela vison*). Errington (1939) found that muskrats foraged much more on top of the ice when burrows and houses became dry, increasing their exposure to predators. These limiting factors caused muskrat densities in Namakan Reservoir to be significantly lower than in Rainy Lake (Table 5).

The regulated lake levels affected river otters primarily by making shallow bays inaccessible during winter (Route and Peterson 1988). Summer observations of unmarked family groups and estimated home ranges of radio-tagged family groups indicated shallow, backwater bays were important as rearing areas. As winter drawdown proceeded and the ice collapsed onto the bottom of bays, river otter shifted their home ranges to deeper water. While these shifts occurred on both Rainy Lake and Namakan Reservoir, they seemed to be greater on Namakan Reservoir where winter drawdown was about 3 times larger.

Fish

Although about 50 fish species occur in Rainy Lake and Namakan Reservoir, concern about the effects of regulated lake levels on fish has centered on walleyes and northern pike because of their importance in the fishery. From the 1920's to the 1980's, they, along with lake whitefish (*Coregonus clupeaformis*), were the principal species in the commercial fishery on Rainy and Namakan lakes. Before 1960, the commercial harvest on Rainy Lake was usually greater than 300,000 kg/year (Minnesota Department of Natural Resources and Ontario Ministry of Natural Resources, unpublished data). Since then, harvest has declined to about 100,000 kg/year. The commercial harvest on Namakan Lake from 1947 to 1980 averaged about 32,000 kg/year (Minnesota Department of Natural Resources and Ontario Ministry of Natural Resources, unpublished data). During the 1980's, commercial fishing for walleyes and northern pike was eliminated from the Minnesota portion of Rainy Lake and was reduced substantially in Ontario waters. These two species are the primary species in the recreational fishery, which is a major component of the region's economy.

The principal concern has been the relation between lake levels during the spring spawning season and year-class strength of walleyes and northern pike. Investigations of this relation for walleyes in Rainy Lake have produced contradictory results. Johnson et al. (1966) and Chevalier (1977) found a positive relation between water levels at spawning time for walleyes and subsequent year-class strength in Rainy Lake. Chevalier's (1977) findings

Table 5. Comparisons of muskrat density by population estimates, trapnight success, and house counts for Kabetogama and Rainy lakes, 1985–87 (Thurber et al. 1991).

Variable	Kabetogama Lake		Rainy Lake	
	Mean	SE	Mean	SE
Population estimates[a]				
Fall 1985	0.25	0.05	0.93	0.14
Fall 1986	0.59	0.27	1.45	0.29
Trapnight success[b]				
Fall 1985	0.22	0.06	0.26	0.08
Fall 1986[c]	0.14	0.03	0.35	0.04
House counts[d]				
Winter 1985–86[c]	0.05	0.02	0.14	0.03
Winter 1986–87[c]	0.21	0.05	0.33	0.06

[a] Muskrats per hectare of emergent vegetation.
[b] Trapnight success = total captures ÷ total trapnights.
[c] Differences between Kabetogama and Rainy lakes were significant at $P < 0.05$.
[d] Muskrat houses per hectare of emergent vegetation.

were based on walleye year-class strength as determined from commercial gillnet catches of walleyes from the Minnesota and Ontario portions of the lake from 1948 to 1969. Osborn et al. (1981), however, found no significant relation between spring water levels and year-class strength of walleyes from commercial gillnet catches from the Minnesota portion of the lake from 1949 to 1980.

Osborn et al. (1981) also found no significant relation between spring water levels and year-class strength of walleyes from experimental gillnet catches in Kabetogama, Namakan, and Sand Point lakes. However, they did find a significant relation between the average rise in water levels during the spawning season and the subsequent abundance of 4-year-old northern pike in Kabetogama and Sand Point lakes.

These inconclusive results prompted the National Park Service to reassess the relation between spring water levels and year-class strength of walleyes and yellow perch in Rainy, Kabetogama, Namakan, and Sand Point lakes (Kallemeyn 1987a). Significant positive relations were found between spawning season lake levels and abundance of age-0 walleyes in all of the lakes except Namakan. Relations between lake levels and abundance of age-0 yellow perch were significant only in Sand Point Lake.

A positive relation was also observed between northern pike reproductive success and spring water levels in Kabetogama Lake (Kallemeyn 1987b). Reproductive success was higher when water levels reached emergent vegetation, which is preferred spawning habitat of northern pike (Fabricius and Gustafson 1958; Franklin and Smith 1963), in the 3-week period following ice-out. For emergent vegetation in Kabetogama Lake to be flooded during this period, however, water levels had to exceed the maximum levels called for under the 1970 rule curve.

Kallemeyn (1987a, 1987b) suggested a combination of an earlier spring rise in water levels and a summer drawdown would expand the area of wave-washed gravel and emergent vegetation at lower elevations and would enhance spawning success of walleyes, yellow perch, and northern pike. At present, these preferred spawning habitats occur at relatively high elevations because of the high, stable lake levels that are maintained throughout the summer and early fall on Rainy Lake and Namakan Reservoir. As a result, a substantial rise in lake levels, particularly on Namakan Reservoir, is required each spring to make these areas available for spawning. A summer drawdown, by providing spawning habitat at lower elevations, would reduce the amount of spring rise required to provide satisfactory spawning conditions. Such a change should be particularly beneficial in years when runoff is limited.

Cohen and Radomski (1993) found water level regulation has affected both the amplitudes and frequencies of annual water level fluctuations (YMXR). Dominating amplitudes in YMXR were evident at periods of 3 and 13 years (Fig. 4). At these two frequencies, greater than normal portions of the littoral area are exposed and then reinundated. For most frequencies, the power of the Rainy Lake YMXR time series was within the 95% C.I. of unregulated Lac La Croix's spectrum, while Namakan Reservoir's was largely outside. Since these lakes are in the same drainage, one would expect them to be synchronized or have similar spectra. This indicates the effect of water level regulation on YMXR is greater on Namakan Reservoir.

Significant coherencies were found between annual water level fluctuations (YMXR) and commercial fish catches on Rainy Lake and Namakan Lake (Cohen and Radomski 1993). On Rainy Lake, catches of lake whitefish and walleye were synchronized with YMXR at frequencies of 3–4 years (Fig. 5a). On Namakan Lake, lake whitefish catches were synchronized with YMXR at a frequency of 4 years (Fig. 5b). Cohen and Radomski (1993) also found that water level regulation, through its effects on YMXR, changed inter-specific interactions of fish in Rainy and Namakan lakes. Their results suggested that the fishery was more disturbed on Namakan Lake than on Rainy Lake, and that this was caused in part by water level regulation.

Cohen and Radomski (1993) concluded, as had Wilcox and Meeker (1991) in regard to aquatic vegetation, that the water management system should allow for variability in water levels. For assuring adequate fish habitat, they recommended that frequencies and amplitudes in the regulated lakes be allowed to correspond to those of Lac La Croix, the native dynamic.

In summary, most species and biological communities investigated in Rainy Lake and Namakan Reservoir have been affected by the alteration of the annual cycle in water levels as well as the reduction in year-to-year variability. The greatest effects were associated with the larger than natural water level fluctuations on the Namakan Reservoir lakes. The plants and animals have not been able to adjust to the changes in the magnitude and timing of lake

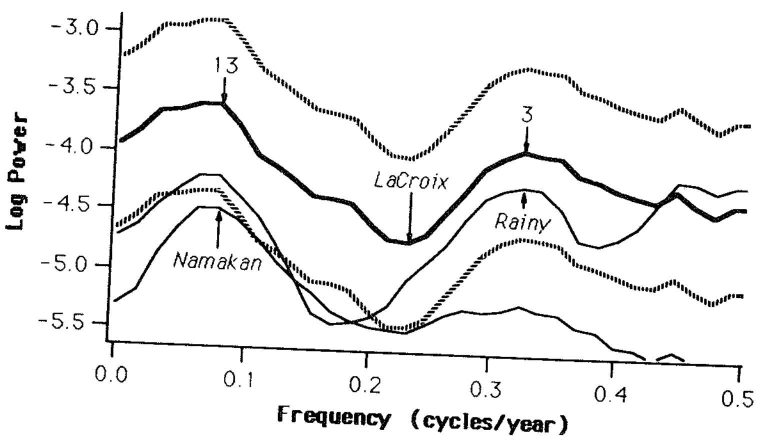

Fig. 4. Log power spectra for YMXR from Rainy Lake, Namakan Reservoir, and Lac La Croix. *Broken lines* indicate 95% C.I. *Numbered vertical arrows* indicate dominating periods (years per cycle; Cohen and Radomski 1993).

level fluctuations since the dams were constructed, and in particular to the water management program used since 1970.

Alternative Rule Curve Development and Assessment

We believe the best means of overcoming these biological problems is implementation of a water management program that more closely approximates the magnitude and timing of natural fluctuations in lake levels with which the affected species evolved. From the biological perspective, alternative regulatory programs should match the projected natural or predam fluctuations, albeit at the higher lake level stages associated with the dams. Year-to-year variability should be included in the hydrologic system. Simulation of natural hydrologic cycles is commonly used in wetlands management to benefit plants and animals and produce more typical marsh communities (Weller 1978; Ball 1985).

Our proposals probably should be considered goals because their complete implementation would likely result in conflicts with other water users. Limitations imposed by the continued presence of the dams and the necessity of meeting the needs of various users will likely restrict our efforts to rehabilitation rather than restoration of the ecosystem (Magnuson et al. 1980). Even with these limitations, however, it should be feasible to develop a water regulatory program that is more ecologically sound.

Embracing this philosophy, the National Park Service in 1990 developed 13 alternative regulatory programs, each consisting of a pair of rule curves—one for Rainy Lake and one for Namakan Reservoir (Kallemeyn and Cole 1990). Each alternative was analyzed with Flug's (1986) hydrology model to determine if the reservoir system could accommodate it under normal hydrologic conditions as well as under extreme high- and low-flow conditions. The model also provided projections of hydropower production.

An impact assessment matrix was used to relate the results of the environmental studies and the hydrology model analysis to potential effects of various alternatives. Ranking factors were developed for various biological attributes along with hydropower production, navigation, flood control, archeological resources, public beaches, and boat dock usability and susceptibility to ice damage, all of which would be affected by changes in rule curves. The ranking factors were then used to evaluate effects of alternatives on these attributes, with the results being entered into the matrix. The matrix integrated the information and facilitated discussions among the public and resource agencies.

As the National Park Service program proceeded in 1990, concerns continued to be expressed about the present water management program, particularly effects on navigation, flood control, power generation, and water access. Proponents for those uses, despite having influenced the alternatives analyzed by the National Park Service, felt the National Park Service preferred alternative did not adequately address their concerns and that it placed too much emphasis on ecosystem integrity. In 1991, a steering committee consisting of U.S. and Canadian representatives from private industry (the dam owner), the public, and the government formed to develop a consensus on how the waters of Rainy Lake and Namakan Reservoir should be managed. The committee's three objectives are to

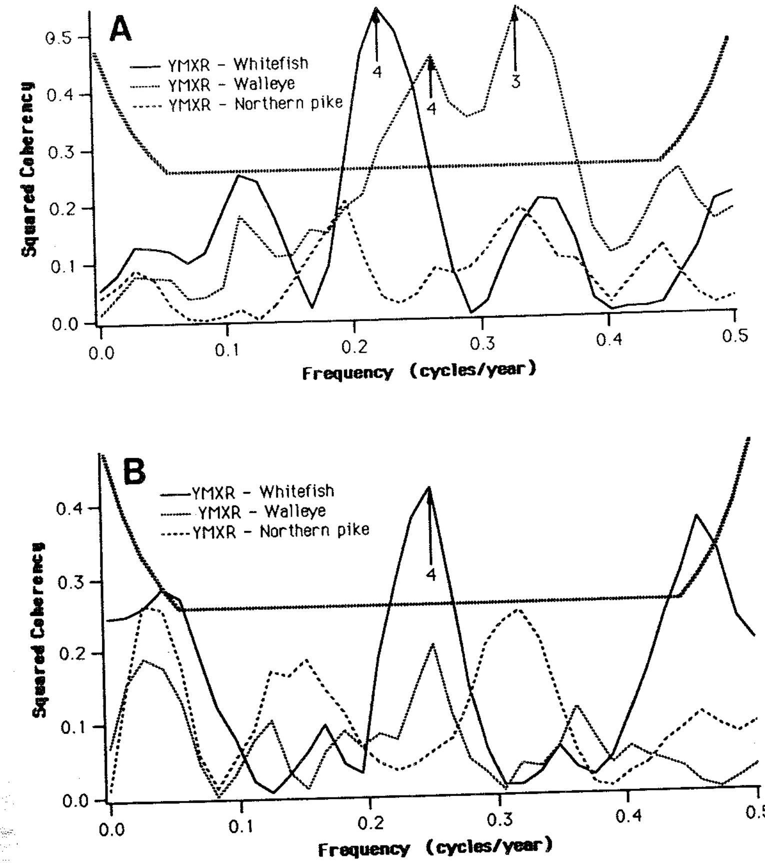

Fig. 5. Squared coherency between the residuals of the YMXR and species' series of commercial catches (kilograms) for the Minnesota portion of the South Arm, Rainy Lake(A), and for Namakan Lake(B). *Vertical arrows* indicate dominating periods (years per cycle). Values above the *broken line* indicate $P \leq 0.05$ significance (Cohen and Radomski 1993).

(1) provide a process for public involvement in discussions, (2) consider proposals for change, and (3) if in the public interest, submit a proposal for change in water level management to the International Joint Commission. Before any proposal is submitted to the International Joint Commission, it must undergo a public review process.

Conceivably, any plan submitted by the committee to the International Joint Commission could also be used by the dam owner to fulfill requirements of their Federal Energy Regulatory Commission license for the U.S. portion of the International Falls dam. The National Park Service and the Minnesota Department of Natural Resources, which are on the steering committee, are two of the three government agencies that the licensee is required to consult with in developing a management plan for Rainy Lake; the other is the U.S. Fish and Wildlife Service.

From 1991 to February 1993, the steering committee attempted to obtain consensus by addressing each representative's interests. The representatives, recognizing that some uses would conflict, agreed to use principled negotiation, which is a method for incorporating environmental policy into resource use conflicts (Fisher and Ury 1981). An integral component of this approach is identification of objective criteria for resolving conflicts. Historically, when environmental interests interacted with interests that used narrowly focused monetary costs as objective criteria, environmental concerns were devalued because of their inability to quantify costs, benefits, or losses. However, in the Rainy Lake–Namakan Reservoir negotiations, environmental interests were accepted because of the results of the research on those waters. Objective criteria that the committee used to develop and negotiate alternative water management programs included scientific judgment, monetary costs, and equal treatment of interests.

A comparison of two alternative rule curves provides an example of this process (Fig. 6). On the basis of the accepted criteria, the natural rule curve would rank high biologically because it approximates natural hydrologic conditions and addresses

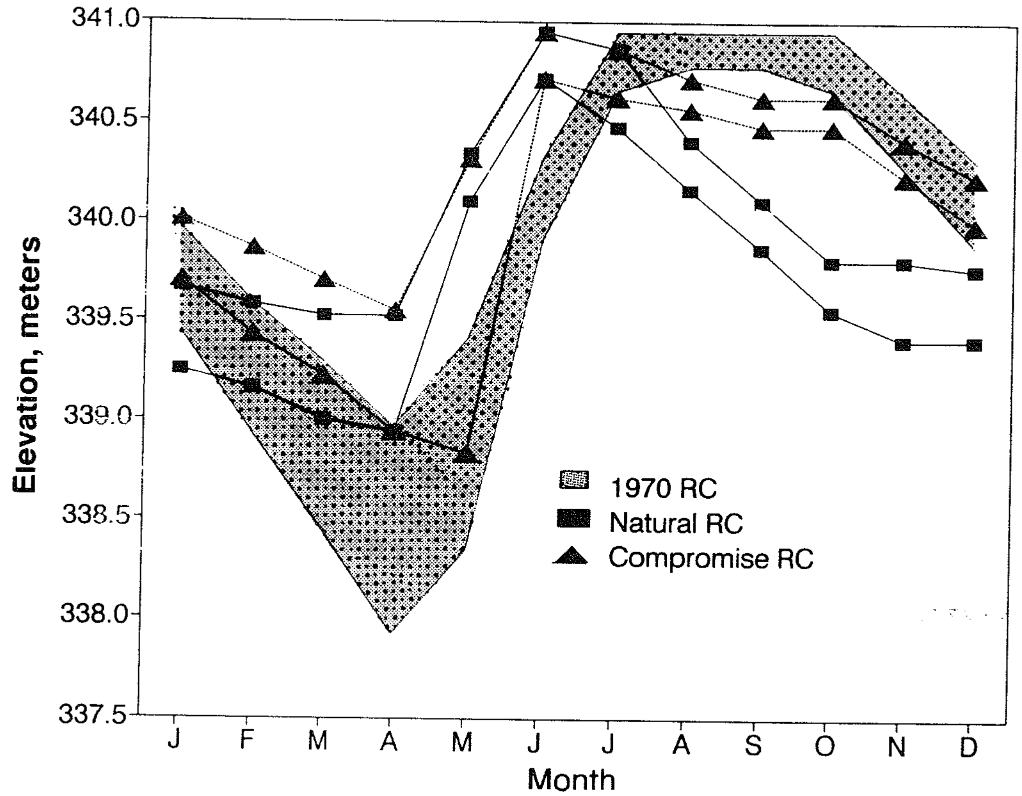

Fig. 6. Comparison of alternative rule curves with the 1970 rule curve for Namakan Reservoir.

many of the fish and wildlife concerns. However, because of the summer drawdown, it would rank low for navigation, dock usability, and hydropower production. The compromise rule curve, with its reduced summer drawdown, improves conditions for those attributes while still providing some improvement in biological conditions. Neither of these alternatives, however, addresses restoration of more extreme periodic fluctuations in lake levels.

Compromises will be necessary to balance competing needs of environmental and socio-economic interests. Implementation of environmentally sensitive rule curves will require shifts in priorities because historically, socio-economic uses were given precedence even though there was no legal mandate for such action. Incorporating some of the annual and long-term variability in water levels that is an integral component of an unregulated system will be particularly difficult. To incorporate that variability may require development of a forecasting system that will enable users that require a consistent source of water to adjust to changes in runoff and lake levels.

Any alternative water management plan submitted to the International Joint Commission should provide for postimplementation monitoring and research. Information from such programs is needed to determine if rule curve modifications can reduce negative effects on the aquatic ecosystem without seriously conflicting with other uses. Should that not be the case, the study results could serve as the basis for further modifications.

An alternative plan should also provide for the continued involvement of the many affected constituencies. Cooperation among various users seems to be the best means of convincing the International Joint Commission to develop and implement a water management program that protects the aquatic ecosystem and meets the needs of human users.

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