

Regulated Lake Levels and Voyageurs National Park

Editor's Note: The following article, derived from a comprehensive Water Resources Report (WR 86-5), available from the NPS Water Resources Division in Fort Collins, CO, is presented here to show managers and resources staff the merits and application of hydraulic/hydrologic modeling.

By Marshall Flug

Voyageurs National Park, located along the Minnesota-Canadian border, is a complex network of lakes, rivers, portages, and dams that occupy glacier-carved rock basins and extend into bogs, marshes, and beaver ponds. The international boundary, between the United States and Canada, follows the 18th century fur traders route between Lake Superior and Lake of the Woods; Voyageurs NP adjoins a 56-mile stretch of that Voyageurs Highway. Figure 1 provides a flow chart of the hydraulic system with a brief hydrologic description of four major sub-basins given in Table 1. The relative sizes and active depths of Namakan and Rainy Lakes are such that a one-foot change on Rainy Lake is equivalent to a volume of water for a three-foot change on Namakan Lake. These two lakes contribute about two-thirds of the drainage area into the much larger Lake of the Woods.

Although both Namakan and Rainy Lakes existed as natural water bodies, today the reservoirs are larger and regulated to satisfy many specific concerns. Around the lake shores, groups primarily concerned with lake levels include resort owners, tourist outfitters, wild rice harvesters (including native people), pulp and paper companies, municipal water suppliers, commercial and sport fishermen, and commercial and recreation navigators. However, apparent conflicts exist because some interests prefer higher lake levels when others desire lower lake levels, particularly during the spring and summer months. Additional concerns include navigation and pollution abatement, which are dependent on reservoir outflows.

The National Park Service is most interested in restoring "natural conditions" (to comply with the Organic Act) whereas regulated conditions differ in both magnitude and timing from historic natural lake level fluctuations. These physical differences result in alterations of the shoreline habitat and littoral zone, directly affecting the abundance and distribution of the fish, birds, mammals, plants, and invertebrates that use these habitats. Additionally, construction of a dam and powerhouse on the Rainy River paved the way for development of forest product mills, which in turn created communities at International Falls, Minnesota and Fort Frances, Ontario; a transition from fur-trading posts to small urban communities.

Table 1. Hydrologic Subbasins

Subbasins	Active Depth ft	Lake Area mi ²	Drainage Basin Area mi ²
Namakan Lake	11	100	7440
Rainy Lake	4	345	7460
Rainy River			6570
Lake of the Woods	6	1485	5700

hydroelectric Project at International Falls/Fort Frances in 1909 and on Namakan Lake since completion of Kettle Falls and its sister Canadian dams in 1914. The lower lines of Figures 2 and 3 represent the computed natural long-term mean lake levels, respectively, for Namakan and Rainy Lakes (i.e., assuming no dams existed). Of course, there is considerable variability, from year to year and month to month, about these long-term average lines, with variations amounting to as much as seven feet. The point is that naturally occurring lake levels and discharges (i.e., river flows) are variable with time in an uncontrolled system as compared to a highly regulated system. This difference has strong implications for the conservation of scenery, natural objects, and wildlife and preservation in an unimpaired state for future generations.

In 1909 the Boundary Waters Treaty between the United States and Canada was created and established the International Joint Commission (IJC), which is responsible for overseeing reservoir water levels and flow releases. The IJC appoints International Boards of Control, which study and then recommend specific water levels and discharges at different days of the year. Such defined values constitute "rule

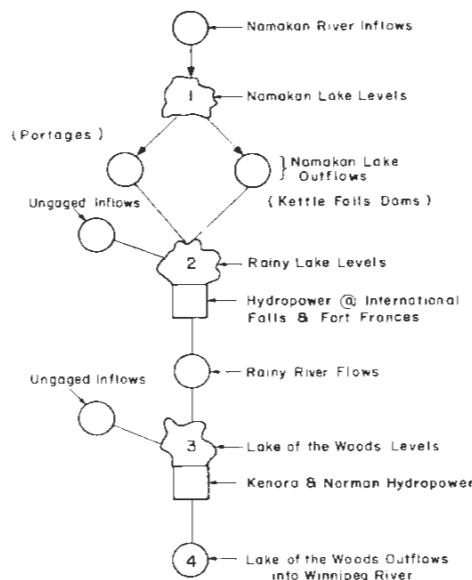


Figure 1. Flow Chart of Water Flows through the Three Reservoir System of Voyageurs National Park

curves" for reservoir operation for securing the most advantageous use of waters. The initial IJC Order of 1949 established specific criteria for flow releases and surface water levels at both Namakan and Rainy Lakes on a monthly basis, with major Amendments added in 1957 and 1970.

The 1970 rule curves (rule band) are shown in Figures 2 and 3, respectively, for Namakan and Rainy Lakes. The maximum lake level rule curve is

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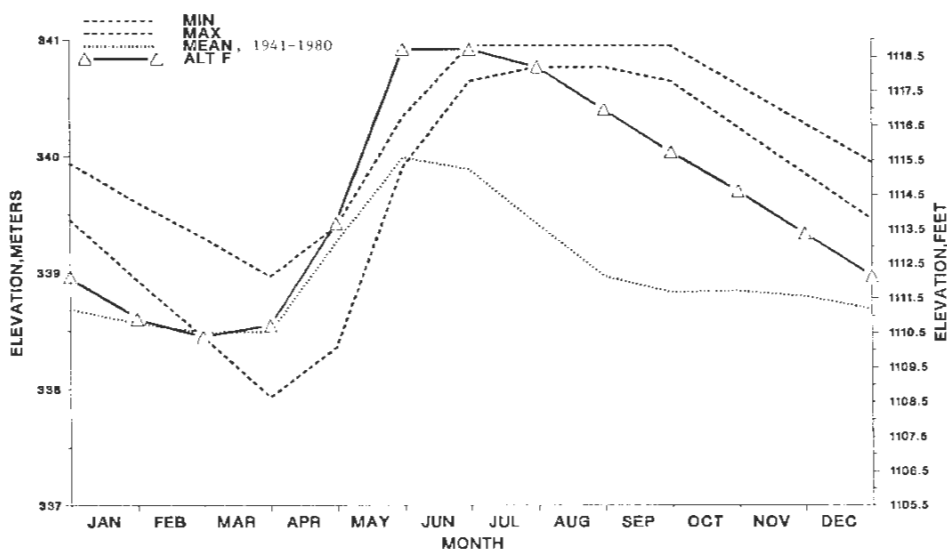


Figure 2. Namakan Lake Levels

Historical Lake Levels and Regulation

Artificially regulated levels have existed on Rainy Lake since completion of the International Falls Hy-

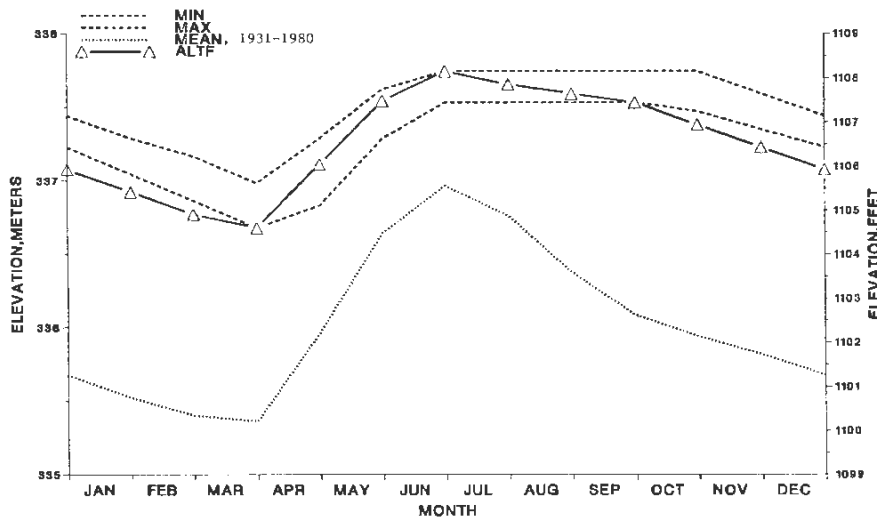


Figure 3. Rainy Lake Levels

Voyageurs NP

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identified by the MAX curve on Figures 2 and 3; the minimum levels of the IJC order correspond to the curves labeled MIN. In brief, the 1957 and 1970 Amendments modified the timing at which full reservoir levels were achieved, adjusted the low level in April to improve fish spawning, replaced the rule curve with a maximum and minimum rule band, redefined "emergency conditions," provided greater flood reserve capacity, and established minimum discharges for downstream pollution abatement.

Model Description

The NPS became interested in evaluating alternative rules for reservoir operation to complement their involvement in studies of littoral biota, vegetation and benthic organisms, fish communities of walleye and northern pike, shore and marsh nesting birds, beaver, and muskrat. These biologic studies are directed at answering questions related to management policies and their effect on preservation of the natural environment. A mathematical simulation model of the multi-lake watershed is a valuable tool to permit management to evaluate whether slight modification of the regulated operation rules can reduce adverse effects on Park aquatic and riparian life without conflicting with other authorized uses of water.

A conceptual schematic, which identifies the major components of the modeling approach, is given in Figure 4. In brief, the hydrologic/hydraulic system of concern is isolated and the flow path of water through the rivers and lakes identified.

Figure 1 portrays the hydrologic/hydraulic system of the drainage basin in a flow chart format. The network system begins at the upstream end of the watershed with inflows to the Namakan Lake chain and proceeds through the lake with outflows via Kettle Falls Dams and portages. These outflows then enter Rainy Lake along with other unmeasured inflows. Flows out of Rainy Lake are all through the dam at International Falls Fort Frances and generate hydropower up to a maximum turbine discharge and based on a turbine efficiency. These Rainy River flows then become input to Lake of the Woods along with other ungaged inflows. Discharges from Lake of the Woods are through the hydropower facilities at Norman and Kenora.

The drainage basin network shown in Figure 1 is interpreted as a series of *nodes* and *links* that operate by defined mathematical relationships. A mass balance model simulates the lake system by maintaining continuity between reservoirs in the system such that:

$$\text{Inflow} = \text{Outflows} + \text{Change in Storage}$$

where, Inflows serve as the input data (i.e. the independent variable); Outflows are computed at each node (i.e., dam outlet); and the Change in Storage is computed for each reservoir.

In addition to continuity, various constraints are included in the model, representing physical or legal limitations of the reservoir system. These constraints include maximum outflows through existing outlet works, minimum flow requirements for water pollution, both maximum and minimum lake levels, and others as appropriate. The resulting mathematical equations are then solved for the input data given (i.e., hydrologic inflows).

Operating Rules

The "operating rules" provide attributes by which

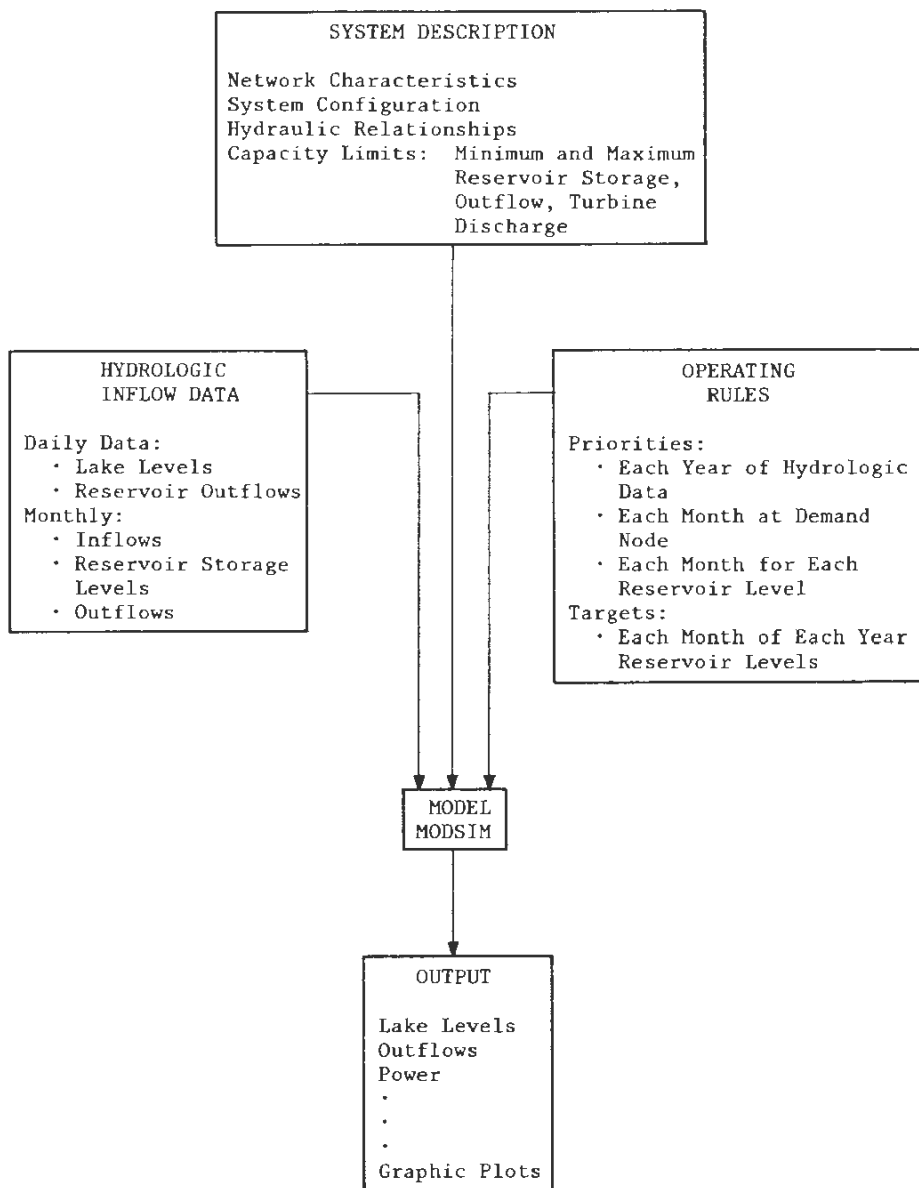


Figure 4. Model Overview

the model is instructed to allocate and route water through the system. To simulate management options for reservoir operation requires a set of alternative operating rules for Namakan and Rainy Lakes. The target lake levels, labeled ALT F in Figures 2 and 3 are only one example of an alternative set of operating rules. Specific values associated with ALT F in Figures 2 and 3 for each month are selected by attempting to follow the pattern and aspects of the naturally occurring lake levels. The natural levels are shown as the mean in these figures. Adjustments were made to these naturally occurring flows to accommodate the higher lake levels created by the dams at Kettle Falls and at International Falls-Fort Frances.

After simulating the operation of this system for the hydrologic input data and subject to the hydraulic constraints, the resulting lake levels, reservoir outflows, and hydropower generated each month of the simulation are output. Specific management options are analyzed by comparing the results from simulations (with alternative target operating rules) to historic reservoir regulation rules. Numerous graphic and tabular options are used to compare results from one simulation to another.

Summary

Aquatic and riparian habitats within Voyageurs NP are influenced by dams constructed in the early 1900s, regulated for the primary purpose of hydropower generation. Reservoir operating rules, which primarily specify desired lake elevations but also define limited discharge constraints, evolved over the years. Changes were periodically implemented in response to various lake shore interests and due to difficulties in operating the physical system in adherence to the existing rules of regulation. Interest groups continue to voice their concerns for more natural lake level fluctuations, different timing of peak and low lake elevations, increased flood storage reserve, navigation, and improved water levels for fish, wild rice, nesting birds, and other aquatic and riparian life, as well as individuals and resort owners with vested lake shore interests.

Of late, the NPS (circa 1975) was given the responsibility to conserve natural objects and wildlife, and to leave them unimpaired for future generations. This is a formidable task for a system that was regulated for over half a century.

The Park Service is interested in management options for regulating lake levels and reservoir outflows to accommodate all beneficial uses of these waters. An optimizing simulation model is used to help assess the impact of alternate reservoir operating rules on various lake shore interests. An analysis of impacts on specific beneficial uses of these waters is quantifiable by simulation modeling. Such an effort supplies sound information for evaluating management options.

As new data become available, from ongoing aquatic and riparian studies, alternative reservoir target elevations can be modeled. The results provide information for discussions and negotiations between Federal, State, international, and private interests, and can lead to mutually agreeable solutions for continued beneficial use of these waters. Use of a simulation model and the associated output provides concrete indications as to what changes are possible and goes a step beyond idle rhetoric of what are and are not realistic management options.

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