Author's Commentary: The Great Lakes Problem

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The Problem

The teams that tackled the Great Lakes Problem discovered that the water-level control of the Great Lakes is a formidable and complex challenge. As advertised in the problem statement and description, the problem is wicked, with many divergent perspectives, varying multiple scales, interdependencies, conflicting interests of stakeholders, and several nuanced elements difficult to understand and even more demanding to model. Modeling of multifarious issues such as the stakeholders' needs were major hurdles to setting the environment for the optimal water-level goals and the effects on the water-control mechanisms. The Great Lakes are not only overwhelming in size and diversity but also quite fragile, in that there are only two human control mechanisms to affect the water levels and manage the complex ecosystem.

The International Joint Commission (IJC), with representatives from both the United States and Canada, regulates outflows in an effort to provide balance among stakeholder interests. The IJC control algorithms are based on a vast amount of data on the Lakes' input and output flows. The IJC looks to set dam outflows to keep the lake levels within a specific range, near their long-term averages.

In addition to the two control dams, teams noticed that there are other human-controlled factors, e.g., reservoirs in the drainage basin and the mechanisms to handle ice jams and snowpack melt. The rates of rain, evaporation, erosion, ice jams, and river flow are beyond human manipulation. The Great Lakes have a regular annual pattern, but a variance from normal of 2–3 ft of water level can dramatically affect some of the stakeholders, especially shoreline property owners and businesses.

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Team Modeling Approaches

Most teams started by searching the literature. They realized that despite seasonal variations, nature has provided for considerable stability in water levels that help with the goals to protect residents, industries, and transportation systems, and maintain environmental health of the huge drainage basin region. However, as the literature also shows, there can be grave consequences when these goals are not fulfilled.

The next step for many teams was to understand the impact of the data provided and to look for other sources of needed or helpful information. As I read the submissions as a judge, I was immediately impressed at how well nearly every team accomplished these initial steps in their problem-solving plan. Much of this initial work was interdisciplinary, in that many of the skills were more from social science, engineering, data science, and cultural geography than from basic mathematics or science disciplines. I clearly saw that many teams were able to normalize and clean the existing data; and some were able to find additional data to help with some of the more nuanced elements of the problem, such as the impacts of the Ottawa River on the protections and vulnerabilities of the city of Montreal.

I enjoyed reading well-written reports and seeing that so many teams were well prepared as modelers—their assumptions were usually reasonable and well justified. Their overall network-flow models were usually accurate and contained the information that the team would need as it continued its model development. Some teams spent considerable time analyzing the stakeholder needs, realizing the seasonal differences and even differences between the residents and other stakeholders on different lakes. Most teams used a suitable decision algorithm to assign weights to the various elements. Then they could use those measures to help with the optimization of the water levels at various times of the year. Most teams used some form of discretization (e.g., month, season) in their multi-objective optimization. Some teams spent considerable time and effort in the optimization and explained their solution algorithm very well. Teams performed sensitivity analysis, but sometimes this work seemed like an afterthought and was not used to benefit or improve the model.

Several methods were used for the control of the dam gates for the two water-level controls, Compensating Works and Moses-Saunders Dam. Perhaps the most popular method was Proportional-Integral-Derivative (PID), where the model reduces the difference between the desired or optimal level and the current level. Proportionality tries to track current adjustment needs, integration tracks recent past adjustments, and differentiation considers known or anticipated future trends. People who have a cruise control on a car are familiar with this kind of mechanism, but it is asking a lot from a simple dam-gate adjuster to manage 20% of the world's freshwater.

Since I am a long-time resident of the shores of Lake Ontario, and several other judges for the problem live on the other Great Lakes, we took great interest in the insights provided in the reports that were developed through the teams' modeling and the creativity and innovation that they used in developing algorithms for water flow and control.

Many teams recognized the significant danger of high water to the city of Montreal, which has a metropolitan population of over four million people, with several hundred thousand living on the island in the middle of the St. Lawrence River. Unfortunately, the last control dam (Moses-Saunders) on the system is before the entrance of a potentially sizable and varying inflow from the Ottawa River into the St. Lawrence. Therefore, protection from flooding Montreal is limited and indirect—part of the fragility of the system.

Teams recognized very quickly that nature—in the form of precipitation, evaporation, ice jams, and snowpack in the huge drainage basin—is the dominant force in the water-level control struggle. Climate change adds even more demands to any system that uses just two human-operated control mechanisms.

The south shore of Lake Ontario holds mixed populations of urban, suburban, and rural residents of New York State. The main urban center is Rochester, with smaller cities of Oswego and Watertown also on or near the lake. However, for the most part, the residents on or near the Lake live in rather small seasonal tourist villages that swell up in the summer and shrink in population in the cooler weather. The lakefront land owners are vulnerable to larger-than-normal water-level deviation. In addition to suffering loss of boating access from destruction of their docks and facilities, they have also suffered loss of sand and rock beaches, dirt or stone banks, steel or concrete breakwalls, and land directly from the erosion forces of too high of water (especially during the summers of 2017 and 2019, and in stormy winter weather). In some cases, such as my own and that of my neighbors on a small bay, the sand bars and narrow barrier bars between Lake Ontario and the protected bays were breached and destroyed by high-water wave action. The result was that the properties that were previously protected from the lake's waves and storms were now subject to those new dangers with devastating results.

The bottom line is that I was more than impressed by the modeling and the sophistication of the algorithms that were developed. Many of the teams tried to solve and analyze the optional considerations or issues mentioned in the problem, although for the most part these were just natural steps on building the model to control water level. Also, most teams gave some extra effort on the issues associated with the stakeholders and factors influencing Lake Ontario, and most teams tried to show how much better their model handled the flooding on Lake Ontario and St. Lawrence River in 2017 and 2019.

About the Author

Chris Arney is an Emeritus Professor at the US Military Academy. His Ph.D. is in mathematics from Rensselaer Polytechnic Institute. He served as a dean and acting Vice President for Academic Affairs at the College of Saint Rose in Albany and had tenures as division chief and program manager at the Army Research Office in Research Triangle Park, NC, where he performed and supported research in cooperative systems, information networks, and artificial intelligence. Chris was the founding Director of the ICM. Particularly relevant to the Great Lakes Problem, he owned a marina on Lake Ontario and lives on its south shore.