The Journey to Automation: A Glen Lake Story

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This is the story of how the Glen Lake Association (GLA) applied modern technology to their management of Glen Lake's water level. The results are more accurate water level control at substantially less cost, while making it safer and easier for our water level committee members. Along the way, they learned facts about the watershed system never known before.

Background

Glen Lake is one of Michigan's finest lakes. Actually a set of five connected lakes (Big Glen, Little Glen, Big Fisher, Little Fisher and Brooks) in northwest lower-Michigan, it covers about 6,000 acres at depths reaching 130 feet. The output of Glen Lake is the source of the Crystal River which meanders five miles before emptying into Lake Michigan; only one mile away. The flow into the Crystal River is controlled by a dam 18 feet wide with two independent swinging gates. Atypical in Michigan, this dam is not controlled by a drain commissioner, but by volunteer members of the GLA, and it has been that way since the dam was built many years ago. So the GLA formed the Water Level Committee (WLC) in 1955 to manage the Glen Lake level and Crystal River flow as much as nature would allow.


Dam on Crystal River

Law suits over the years have resulted in a court ordered set of rules for both the upper/lower bounds of Glen Lake's water level and the Crystal River's water flow minimums. This means that lake-level/river-flow management is not a hobby for the GLA; it's a legal mandate. A court appointed Technical Committee keeps close watch on the lake-level/river-flow operations and reports status to the court annually. To accommodate the legally mandated limits, the Technical Committee has approved a daily target lake level within a narrow tolerance. The days of summer have a relatively high lake level target (good for boating, enjoying the beach and supplying water to the river during drought periods) and winter days have a low lake level target (to mitigate ice damage and minimize beach erosion). The spring and fall days have targets that are a gradual transition between summer highs and winter lows. Regardless of lake level, the river flow must be kept above a certain minimum water flow so as not to adversely affect the ecology of the river.

Chapter 1: Determining Lake Level

The first requirement in lake level/river flow management is to be able to determine the actual elevation of the lake level, and understand how it changes over time due to the various water inputs and outputs. Only after having that information does one have a chance of managing the balance of lake-level and river flow through dam gate settings.

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For determining lake level, a set of three staff gauges were placed at strategic positions around the lakes to determine water levels. These gauges were surveyed so the actual sea level elevation of the water can be calculated. One of the staff gauges is the standard used for determining legal lake level. Another is used as a backup. The third is used to measure the water level at a location just upstream of the dam – where the water level can vary several inches lower than that at the other gauges. Water levels are supposed to be measured and recorded at these points at least twice a week – more often when weather events dictate. It is not always possible to read the gauges, however. Sometimes windy conditions generate waves that make it impossible to take a precise reading of the staff gauge. At other times, ice and snow obscure the markings on the staff gauge, making it equally impossible to determine an exact reading. Often, the times when lake level knowledge is most important are the times when weather conditions are at their worst. Going out to read the gauges during storms (especially in winter) can be a challenging task for the WLC members.

Chapter 2: Automation Begins

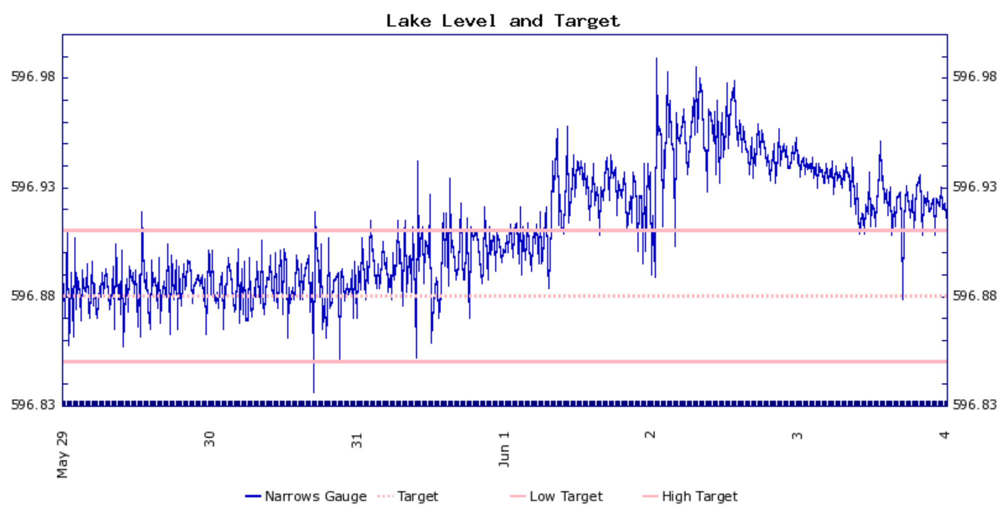
Partly due to the fact that all the WLC members are dedicated volunteers who want precise measurements and partly because many of them are engineers and "tinkerers," it was decided in 2010 to install an automatic lake level sensor. The sensor was installed very close to the staff gauge used to determine the legal lake level elevation, and about three feet below the water's surface. Using a 100-foot underground cable, the sensor was attached to a communication station that contained a data logging device, a cellular modem, a battery and a solar cell. The sensor is an accurate pressure transducer which reads water depth, not elevation. The sensor is compensated for atmospheric pressure changes. Every 15 minutes the data logger records the "depth" of water over the sensor. Every hour the modem is automatically turned on so a remotely located computer server can upload the latest depth readings. The actual elevation of the sensor has been determined through comparison with the staff gauge readings, so this elevation can be added to the depth reading to get the actual lake level.

Using automatic sensors to gather lake level data proved to be very accurate and reliable. The sensor is accurate to 1/8-inch and any fluctuations in the lake level due to wind gusts or waves are eliminated by averaging over time. The WLC realized the advantage right away; the technique gave them accurate information on an hourly basis. And with a new website, the information was available to all members without leaving their homes.

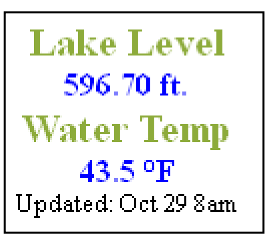
Chapter 3. The Website Begins

Turning "raw data" from both the automatic and manual gauges into "information" that can be used to make decisions was solved by the introduction of the WLC website. Many thousands of lines of code were written to generate graphs and tables that make it easy to know things like:

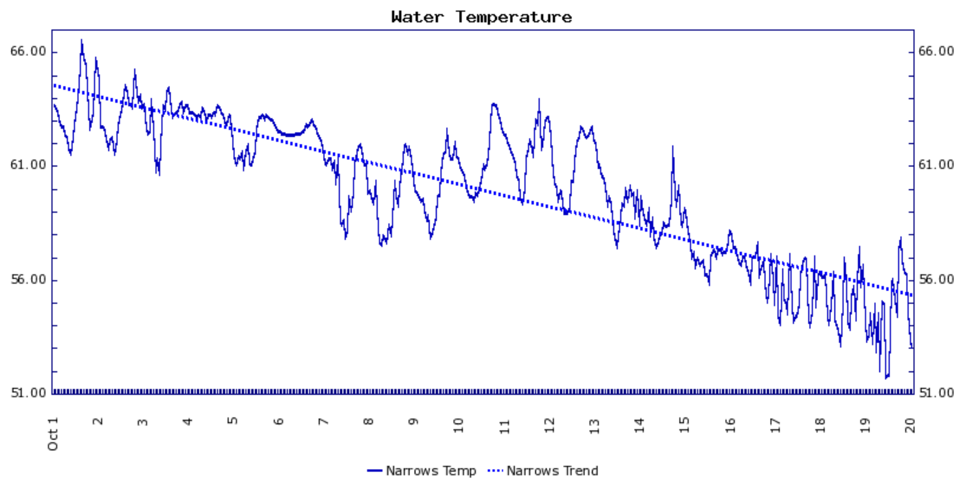
- Is the lake level on target?
- Is the lake level trending in the right direction?
- How long will it take before the lake level is in (or out) of target tolerance?
- How much did it rain last night?



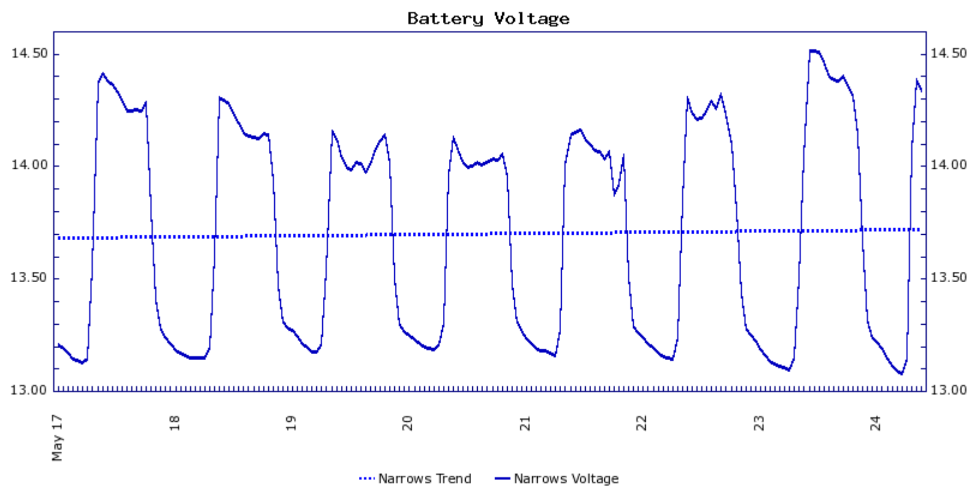
The WLC soon developed a wide set of charts and graphs on the website that answered these questions quickly and accurately. What's more, the information led to the discovery of facts about the lake never known before. For example, the WLC discovered a resonance between Big and Little Glen – water sloshes back-and-forth under the Narrows Bridge about every 40 minutes.



Besides water level, the sensor also records water temperature. Soon we were updating the GLA public website every hour with a posting that reflected current conditions.



The sensor also records battery voltage in the station. If the voltage goes below 12v. the website automatically alerts the WLC with an email warning. Most of the time this means someone has to brush the snow off of the solar cell.



Chapter 4: Determining River Flow

A fourth staff gauge (called a "stream gauge") was installed years ago in the Crystal River just downstream from the dam. This gauge was used in conjunction with a U. S. Geological Survey (USGS)-provided rating table to estimate Crystal River water flow. This is a very common method for calculating river flow; the principle being that the higher the water level in the river, the higher the water flow. One reads the stream gauge in the river and refers to the rating table, which then yields an estimated river flow. But as nature would have it, the conditions of the river are always changing, and changes degrade the accuracy of this method. Small effects can be due to natural changes in the river bed and growth of vegetation on the banks of the river. Larger effects can be due to trees and branches falling into the river (downstream or upstream), ice/snow in the river, and canoes banging in to the stream gauge. One of the most common reasons for inaccurate river flow estimations was found to occur after a large rain event or snow melt. Water flows into the river from various places below the dam which swells the river and causes this method to overestimate the flow over the dam by as much as 20%.

Because conditions continually change, regular re-calibration of the adjustment factor applied to the stream gauge readings was required. With a flow device, the USGS manually measured water flow in the river at a cross section just below the dam, taking measurements every foot at various depths. These measurements were summed to produce an accurate river flow for that point in time. Comparing that actual flow to the estimated flow from the rating table produced an adjustment or "shift" value for the WLC to use. After a calibration, the WLC members could get an accurate river flow measurement at the dam by reading the stream gauge, adding or subtracting the "shift" and then applying that value to the rating table. Since the WLC wanted to be very precise on measuring water flow – especially at low flows when we were close to the court mandated minimum – calibrations were done five times a year at a cost of $3,000 every year to the Glen Lake Association

Unfortunately, the accuracy of the re-calibration proved to be short-lived. As soon as the re-calibration was completed, the river would change. When the WLC would get a new shift, especially one that was a significant change from the previous shift, they knew that they had been recording imprecise river flows for some unknown time and amount. Besides that, no amount of calibration could result in accurate river flow measurements after a precipitation event mentioned above. In addition, reading the stream gauge in wintertime was a chore at best and a safety hazard at worst. WLC volunteers had to walk a distance through unfavorable terrain, stand on a sometimes ice-covered bank to read the stream gauge 10-feet out in the river. The WLC started thinking about a better way to do business.

Chapter 5: Making Dam Gate Adjustments

The Crystal River dam was first built in the early 1900's and was originally adjusted by adding or removing boards across the dam. The dam was remodeled in 2002 to allow for easier and finer adjustments. Two 7 ½-foot wide gates were added side by side, hinged at the bottom and adjusted by winching them up or down. The gates travel just under 24" from fully open to fully closed.

To make a dam adjustment, one WLC member cranks the winch wheel while another WLC member measures the vertical distance between the gate and a reference point on the side of the dam. A specially calibrated "yard stick", complete with a leveling bubble, is used to make sure the measurements are accurate. Eight rotations of the winch wheel results in about one inch of vertical movement of the gates, which affects the dam flow anywhere from three to 10 cubic feet per second (CFS). After making an adjustment, the river needs some time to settle into its new level. So after waiting 20 minutes to allow for this settling, another reading is taken of the stream gauge, another calculation of the dam flow is made from the rating table, and additional adjustments are made as needed. All of these measurements and adjustments are recorded and the data kept for years.

Chapter 6: Automation Continues

Enthused with the results of the automatic sensor installed the year before, the WLC decided to take the much bigger step of fixing the problems related to calculating dam flow. There were four parts to this solution:

1. Install another automatic sensor 25 feet in front of the dam,
2. Develop a weir equation that calculates dam flow given the gate setting, water level and dam geometry, and
3. Regularly compare river flows (using several manual methods) to the weir equation spanning a year and over a wide range of flows to "tune" the equation, and
4. Report process and findings to the Technical Committee regularly.

Given the physical characteristics of the Crystal River dam, the standard rectangular weir equation was applied:

$$Q = C_E \bullet W \bullet H^{1.5}$$

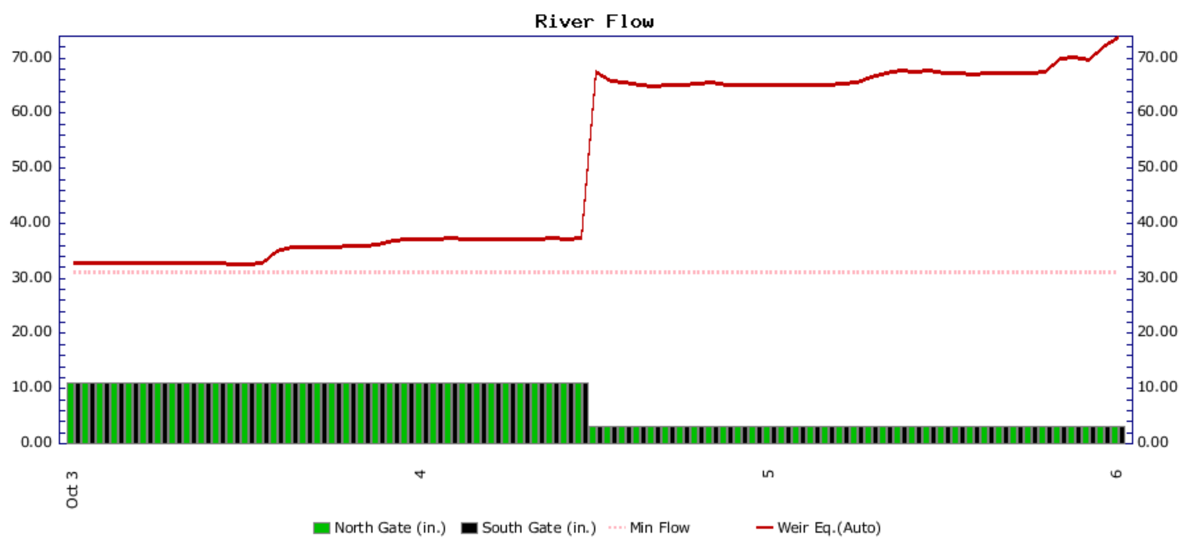
Where:

"C_E" is a constant (around 3.3) which was empirically determined by comparing manually determined water flow to calculated results.

"W" is the width of the dam gate. Since the dam has two gates, the weir equation needed to be used twice, once for each gate. The values are summed for the total river flow. In this way, the gates can be set at far different elevations and the flow is calculated correctly.

"H" is the "head," or difference in elevation between the water level above the dam and gate setting. Note that calculating the head requires a modeling of gate setting to gate elevation.

In the fall of 2011, this automatic sensor was installed and calibration of the weir equation started. Over the next year, using many manual river flow measurements from the USGS and the WLC at a broad range of flows, the weir equation was calibrated and found to be far more accurate than the stream gauge estimating method.



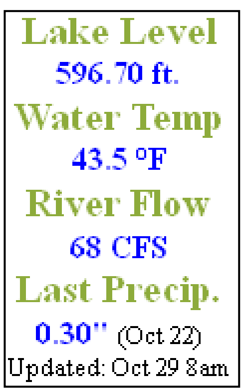
In the summer of 2013 the Technical Committee was convinced of the accuracy of the weir equation. With their support, the court recognized the advancement and gave the WLC permission to use the weir equation for making dam setting decisions.

Chapter 7: The Website Expands

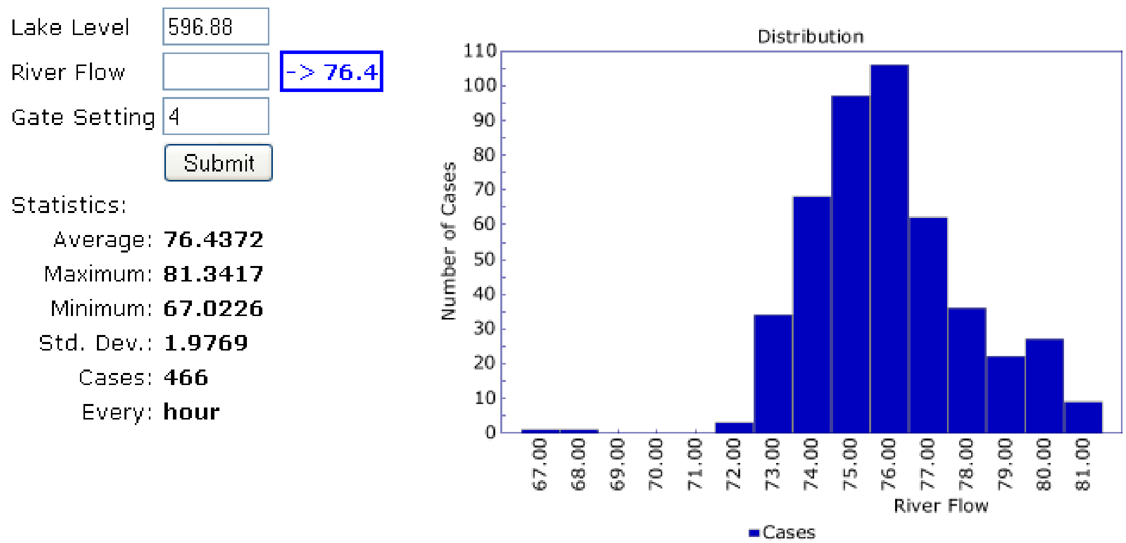
The backbone to the WLC operations and automation is the website and the programming behind it. There are several parts to the website:

1. Graphs
    a. Lake levels, trends and targets
    b. River flow trends and limits
    c. Water temperature
    d. Battery voltage
    e. Precipitation events
    f. Calibration comparisons
2. Charts
    a. Raw data storage and retrieval
    b. Current conditions at-a-glance
    c. Monthly reports
3. Manual Input
    a. Staff gauge readings
    b. Dam settings
    c. Comments about current conditions
4. Calculators
    a. River flow : Lake level : Dam setting
    b. Dam setting recommendations
5. Team Membership
    a. Contact information
    b. Schedule of assignments
6. Photos
7. Documents

Besides the website, there are programs on the computer server that run automatically to update data, check for certain conditions, and send email alerts. With these advancements in the website programming we updated the posting on the GLA public website to include river flow and precipitation events.



Now that the website has been running for several years capturing data every 15 minutes, enough data exists to do some statistical analysis. One of the calculators on the website allows the user to enter two of three values (river flow, lake level, dam setting) and it will produce the statistical plot of the third value.



Chapter 8: Results

With the fine efforts of many WLC members, lake level management has been made easier, safer and more accurate. It also pays for itself. Since the flow estimating method is no longer used, there is no need for the USGS to make river flow re-calibrations. By canceling that contract the WLC recaptured the expense of an automation station in a single year. But there is more to be learned. Now that data exists to be "mined," the WLC can learn things like:

- amount of groundwater in and out of the lake system
- evaporation values
- daily lake level targets to maximize water level and minimize shore erosion
- methods to minimize flooding of Crystal River
- etc.

And with the capability of adding additional sensors to the system, the WLC can learn even more about water quality and the effects of different weather events. We highly recommend using these methods for other lakes.