Turtle Lake ups and downs: 2008-2018

*Turtle Lake's Surface Stays Well **Above** the concrete Dam, Except During an Extreme Drought. Why?*

By George M. Lawrence, PhD, With much help. Version of 2/19/2020.

(*This report is about* Turtle Lake (*141 acres*) *in Walworth County, WI. We measured lake levels because we had lost the use of a concrete dam ¼ mile South of the lake—so there were concerns that the lake level would drop. I try to tell most of the story on pages 2-5.*) (*The hyperlinks are alive.*)

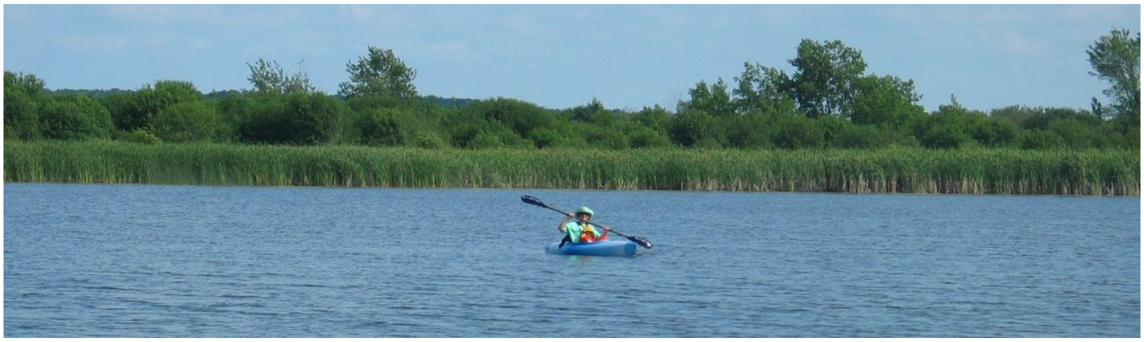

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Fig. 1. Outflow from the Turtle Lake: The marsh, the natural dam, and the creek.

This is a Google Earth photo from 3/16/18, green-enhanced better to show the trees. The water flows out of the lake through the marsh, then ¼ mile southward down Turtle Creek, dropping as much as 5.3 ft to get under Turtle Lake Road through culverts. The marsh is the darker region arcing just south of the lake.

When water leaves the lake, it has to get through the marsh and then over a **high point** (natural dam) **in the creek**. The **purple square** shows the **officially** mapped position of WDNR dam #1533, "Dam Turtle Lake". This natural dam defines the levels of Turtle Lake. From 1936 to 2002, the WDNR's definition of Turtle Lake's dam changed twice from a 1930s 20-ft wide concrete dam **South of Turtle Creek Road**; to the 9-ft wide 1942 concrete dam just north of the road; to the natural dam near the lake. This earthen natural dam was "always" there, but not always recognized and it became the **only** dam when the breach in the creek occurred. Natural dam #1533 **saves** Turtle Lake from draining through the much lower culverts at the road. **Protect our natural dam!**

In late summers, denser marsh and creek vegetation also resists the outflow, raising the lake further. In winters, ice resists the outflow. Note the bush near the lower right corner of the purple square. The bush indicates high ground and we see it in aerial photos at least back to 2005 (Fig. 12, pg. 12).

The red arrow just above the road shows the infamous breach in the creek which diverted the flow to very low culverts and dried the concrete dam. The breach has caused much anguish.

The 1942 historic concrete dam at the road hides (mostly) dry in the red circle. Later we argue that this dam's elevation is near 899.1 feet above sea level—on a scale consistent with our elevation reference. A 1965 official survey of the concrete dam allowed a 2" stoplog atop the dam. However, a 1979 inspection by the WDNR caught a 7" stoplog there—a No-No because it floods farmland and the road.

The blue triangle locates the official survey marker (center of section 14) closest to the concrete dam. It locates local property and section lines—and is an elevation standard.

The lake goes up and down. We measured elevations of Turtle Lake starting June 2008

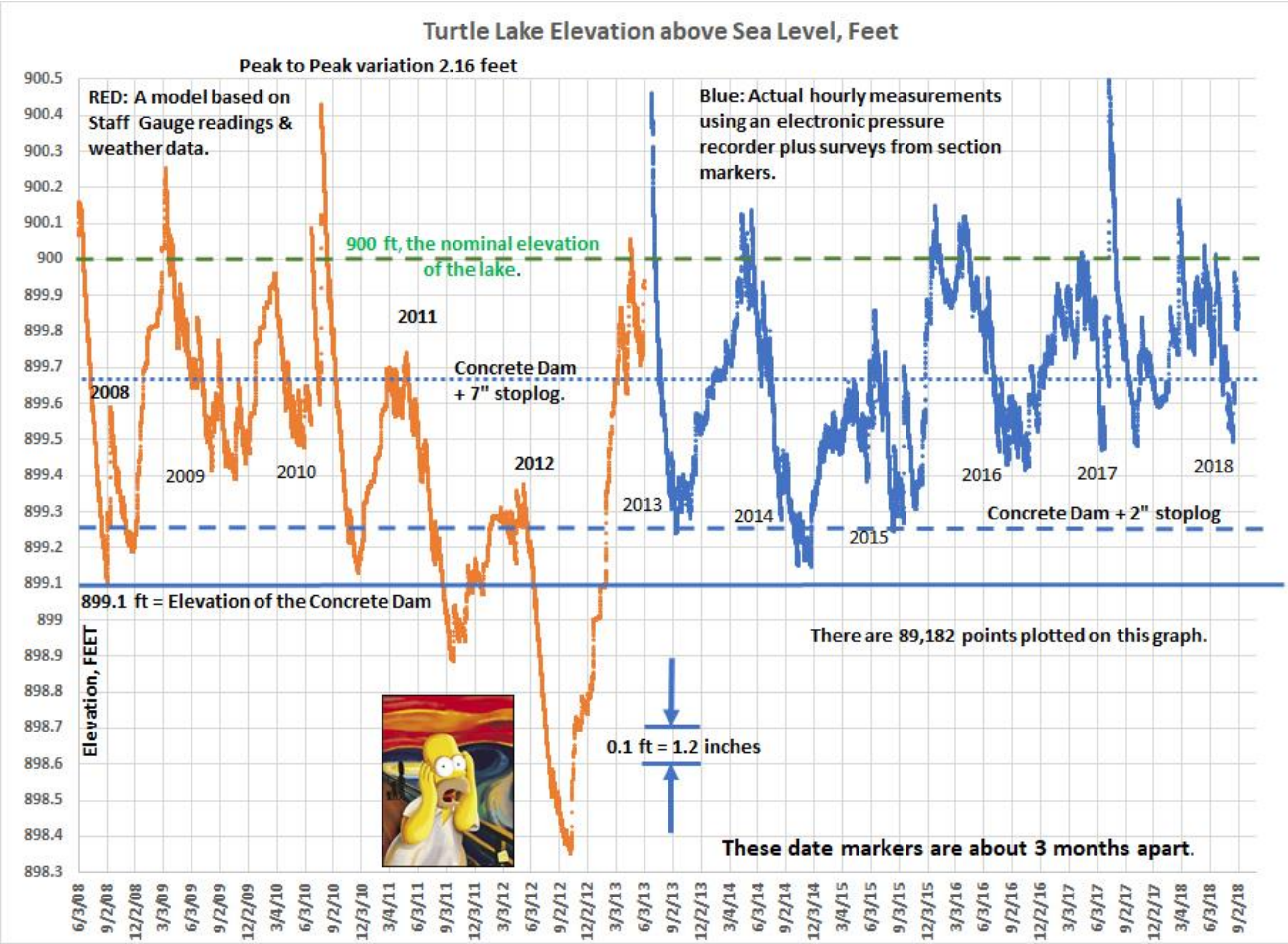

Fig. 2. 89,182 Hourly Elevations June 2008 to September 2018.

This graph plots ten years of elevations above sea level. Elevations in feet are plotted vs. calendar date. We'll explain on pg. 7 how we measured these elevations. Note the drought in 2011 & 2012. Note the heavy horizontal lines drawn for elevation references. Lowest is the concrete dam shown at 899.1 ft. The next (dashed) line is a legal 2" stoplog atop the concrete dam and it still lies (most of the time) below the natural water levels. The dam plus illegal 7" stoplog (dotted) hits the levels about in the middle, and 900 feet is shown because that is the standard elevation shown on maps. There were only three times in these 10 years that the elevation rose very briefly **above** 900.4 ft. The level then comes down quickly because 900.4 ft is high enough to find paths around the natural dam #1533. That is, it has lots of wetland area to flow over. Above 900.4 ft, some lakefront properties begin to show shore-line flooding—but not for long. (A recent exception is the summer of 2019—it rained a **lot**.)

Elevations? Levels?

I revealed the main conclusion in the subtitle. The lake surface naturally lies **most times** above the 1942 concrete dam—this concrete dam itself would do almost no good in raising the lake. However, an illegal 7-inch stoplog atop the concrete dam **would** do **some** good—and some harm. Significantly raising the lake would require a dam at least 7 inches higher than the concrete dam.

Ironically, even though the drought in 2012 caused the lake to go 9 inches below the concrete dam, the dam would not have helped because the creek dried up. No water in the creek, no water over the concrete dam. There was no outflow from the lake—only evaporation in the hot, dry air. Note that it took 3 months to drop to the lowest point—during three months of the "extreme drought of 2012". During an extreme drought, the level will drop below **any** working dam.

Fig. 3. Pick an elevation for a new dam: How often would that elevation raise the lake?

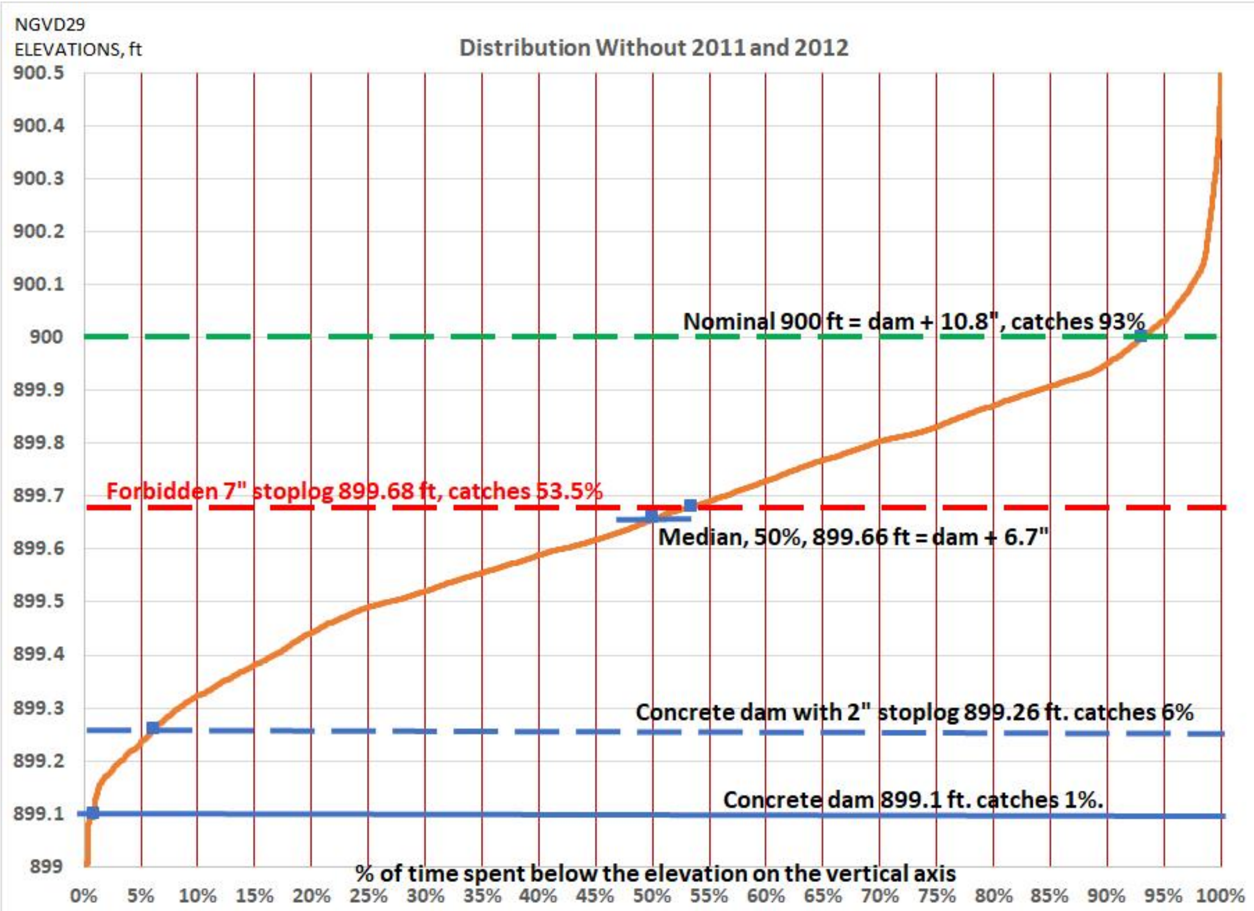

Fig. 3. ***Distribution of non-drought Elevations.*** *The horizontal axis is the % of time that the lake spent below the elevation shown on the vertical-axis. The horizontal lines show various elevations of possible dams vs. the % of time they would help raise the level. This distribution curve was calculated from the elevation data of Fig. 2—less the years 2011 and 2012. If we gamble that the lake will be high enough on a random day, this graph gives the odds.*

Note: Elevations **over** 900.4 ft. flood yards, **under** 899.3 ft. make some shores shallow and muddy. The lake behaves fairly well, except for drought years. Non-drought, minimum to maximum is 1.5 ft, and 90% of the time it spreads only 1 ft. Let's read the graph where the horizontal elevation lines cross the red-orange distribution curve: The concrete dam alone would only raise the lake 1% of the time. The dam plus the 2" stoplog helps 6% of the time. A dam at 899.66 ft would raise the lake 50% of the time, and using the illegal 7" stoplog at the road would help 53.5% of the time. A dam at 900 ft elevation (10.8" higher than the concrete dam) is the elevation of Turtle Lake on maps and would raise the lake 93.1% of the time.

One foot of variation still affects fish and vegetation populations. Drought years are frustrating.

The concrete dam is at least 7 inches too low. The 7" stoplog at the concrete dam really raises the lake ½ of the time, but: We cannot, may not, should not, use a **7" stoplog** at the concrete dam because:

A. There is a major breach in the creek, usually keeping the dam dry.
B. 7 inches would eventually destroy any fix that had been made to the breach.
C. 7 inches is forbidden by the WDNR so as to protect the road and adjacent property.
D. 7 inches would threaten the road with flooding.
E. 7 inches floods private land whenever water is flowing over such a "dam with 7 inch stoplog" and especially during the spring runoff because the level might rise ½ foot above the spillway for this 9 ft wide dam.

Conclusions

Questions definitely answered by this study.

1. If we repaired the creek breach, would it raise the lake? (**Only *1 to 6% of the time*: *Not worth it*.**)
2. What is the ideal location for a new dam? (***At WDNR natural dam #1533.***)
3. How high must any new dam be? (***7 to 11" higher than the concrete dam.***)
4. Would a higher dam help during extreme drought years? (***No, the lake will drop below any dam.***)
5. Why does the creek dry up during droughts? (***The lake drops below WDNR dam #1533*)**
6. Why have lake levels been OK, except for the drought years 2011-2012? (***WDNR dam #1533*)**
7. Why have the low culverts at the road not lowered the lake? (***WDNR dam #1533 is much higher than the culverts.*)**

History and Main Points.

A. Sometime before 1979 someone found a way to actually raise the lake—the forbidden 7" stoplog on the concrete dam. This 7" stoplog caused serious problems because the dam is at the road and the terrain slopes to the west. It may have caused the breach.
B. Except for an extreme drought, the lake level—with natural dam #1533—behaves fairly well, at maximum varying 1.5 ft. and within a range of 0.9 feet for 90% of the time.
C. The lake levels in 2008-2018 behaved very similarly to the historical USGS measurements of 1951-1979. The high to low range was the same and there was a drought or two in both eras.
D. In a decade, the lake rises briefly to about 900.5 ft a few times after large storms. Since this is higher than the road, a high dam at the road risks flooding the road, and breaching the creek bank.
E. Every decade or so, there is a risk of an extreme drought during which the lake level drops well below natural dam #1533 and the creek dries up.
F. The lake surface naturally sits higher than the concrete dam (899.1 ft.) at Turtle Lake Road—except during a drought—because of WDNR dam #1533. Any new dam or weir should be at least at 899.7 NGVD29 feet elevation to raise the lake about 50% of the time. (Fig. 3). Better would be 900 feet which is the natural elevation of the nearby wetlands. It should **not** be near the road. Better to raise natural dam #1533. The ideal elevation range for a dam **near the lake is**: 899.7 to 900 feet (to the datum NGVD29).
G. It has been known at least since 1965 that the natural restriction in Turtle Creek, now called dam #1533, raises the lake higher than the 1942 dam.
H. If we are content with the elevations in non-drought years, then we should do nothing except protect and encourage natural dam #1533. Can we find an approved way to raise our natural dam? Fill in the creek channel? (The creek was dredged and widened when the duck pond was built.)
I. **I do not know** how to hold the elevation during an extreme drought. Ideas anyone? Note that all the U.S. farmers who lost their crops in 2012 did not find a solution. When is the next drought?

The natural dam is real.

The natural dam #1533:

A) was postulated in 1965 by Sr. Engineer R. E. Purucker, seeing the lake higher than the dam,
B) was seen visually by Beth Auer and myself about 2007 on a rowboat trip down Turtle Creek,
C) was hydrodynamically inferred by AECOM in 2014 at least at an **effective** 899.4 ft elevation,
D) is recognized and mapped by the WDNR as "Dam Turtle Lake", Dam Key Seq No 1533,
E) keeps the lake mostly above the old concrete dam and always above the much lower culverts,
F) is not a hard, level surface like a concrete wall, but continues slow flow below its effective level,
G) becomes more resistant to outflow as summer progresses because of marsh growth,
H) might be building each decade because of marsh growth and decay, and
I) probably has existed for centuries.

Glossary:

AECOM: An international engineering firm with an office in Middleton, Wisconsin that contracted with the town of Richmond to answer whether repairing the breach at Turtle Lake Road would stabilize lake levels. Their answer was "minimal effect". (The conclusion **here** is that it helps only 1% to 6% of the time.) You should read their draft report of 9/14/14, especially the conclusion section 4.0 and the history in section 1.2. Our report agrees with AECOM, but also describes the actual lake ups and downs over 10 years.

Channel: A groove in the land that carries water downhill. The bed of a creek.

DATUM: Here, a defined standard for vertical position. NGVD29 or NAVD88.

WDNR: The Wisconsin Department of Natural Resources. Called the Public Service Commission (PSC) before 1967.

Drought: An abnormally long period without rain.

Elevation: Feet above sea level. Here, with respect to NDVD29 because that is used by markers.

Median: The 50% point of a distribution: ½ above and ½ below.

NAVD88: 1988 elevation reference, about 0.15 feet lower than NGVD29; for GPS instruments.

NGVD29: 1929 elevation reference, about 0.15 feet higher than NAVD88. Our survey markers use this datum.

Outflow: Water leaving Turtle Lake and entering Turtle Creek.

Section: Part of the U.S. land survey system. A rectangular area containing 1 square mile = 640 acres. They typically have permanent markers at the corners and centers—with official elevations.

SEWRPC: Southeastern Wisconsin Regional Planning Commission. Seven counties.

Stoplog: Some extra height adjuster at a weir or dam. Often rectangular metal plates or boards.

USGS: U.S. Geological Survey.

Wisconsin GIS: The online data source for property lines, elevations, maps, tax info, etc.

George M. Lawrence very short bio

BA high honors, 1959 Physics, University of Utah.

PhD, 1963 Physics, Caltech. Post Doc Princeton, Sr. Research Associate, University of Colorado, retired 2003. I married a Turtle Lake property owner in 1985.

My career was in laboratory physics and space science and my strong points are science, measurements, mathematical models, and engineering physics. I understand the physical world quite well—politics maybe not so well. Email: **George.Lawrence@comcast.net**

Acknowledgements

Many thanks to all who helped with this project, including:

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A dam can either control floods **or** set surface level, but not both.

Dams are built to store water against a drought, or to control floods, **or** to control level. For example, a dam across the river in a river valley forms a constant level lake behind the dam. Especially in the west, dams form reservoirs to store snow melt for use in the summer. For flood control, a dam should be empty in late winter and then fill in the spring; for storage, it should be full. To control level, it should be full—and thus not controlling floods. Thus, if you control the level at the road, the dam is full and the road will get flooded during a heavy rain storm or the spring thaw.

We measure elevations above sea level with markers, rulers, and surveying.

In 2007, we were told that personal perceptions of a lowered lake would not do; that we needed actual measurements. We started measuring. The initial plan was to put rulers into the lake and read them each summer. We then use standard surveying techniques to determine the sea-level elevation of the rulers, based on nearby official markers.

←**Fig. 4.** ***Inch foot-ruler compared to a surveyor's ruler in tenths of feet.*** *Note that 6 inches matches 0.5 feet, 3 inches matches 0.25 feet, 12 inches matches 1 foot, and so on.*

←**Fig. 5.** ***Ruler in the lake (Staff gauge) reading 2.22 feet.*** *We then add the elevation of the zero point of the gauge to get sea level elevations.*

↑**Fig. 6.** ***Marker at the end of Garden Terrace Road.*** *It reads: "WALWORTH COUNTY WITNESS MARKER 3/27/85 Penalty for Disturbing this Marker." The cross in the center marks the east west line between sections 11 and 14 and the north-south center line of both. The 4" metal disk is set into a concrete block. Officially, its elevation is 919.902 ft to the NGVD29 datum.*

Beth Auer and I in **2007** ordered staff gauges (official rulers) to put into the lake to measure its elevation—getting first measurements in June 2008. Beth makes measurements each summer, having coffee at her boat, and removes the gauge each winter to save it from damage by ice. The entire Baas family, led by Brad, also measured near their dock starting in 2010. It is important to record the time of measurement, because the lake level can change from AM to PM. We survey the elevations of the staff gauges starting at the nearest marker and using a surveyor's rod and an auto-balancing optical level on a tripod. (No matter where we make measurements in the lake, we should get the same answer—because the lake is a water level. The Auer and Baas readings agree fairly well, with a few exceptions.) After a few years of surveying elevations, we realized that the larger dock posts are very stable and started using them as supports for the staff gauges. We bolt the Auer gauge to an Auer dock post, and periodically re-survey the elevations of the staff gauges. These summer staff gauge measurements can be seen as small circles in Figs. 7 and 8 below. We estimate the fluctuation in these readings to be ± 0.05 feet. A few measurements, made during windy conditions, are more uncertain. The average is probably good to ± 0.02 ft (± ¼ inch). See Figs. 7 & 8 below.

Fig. 7: The first five years: staff gauges and a weather-based model.

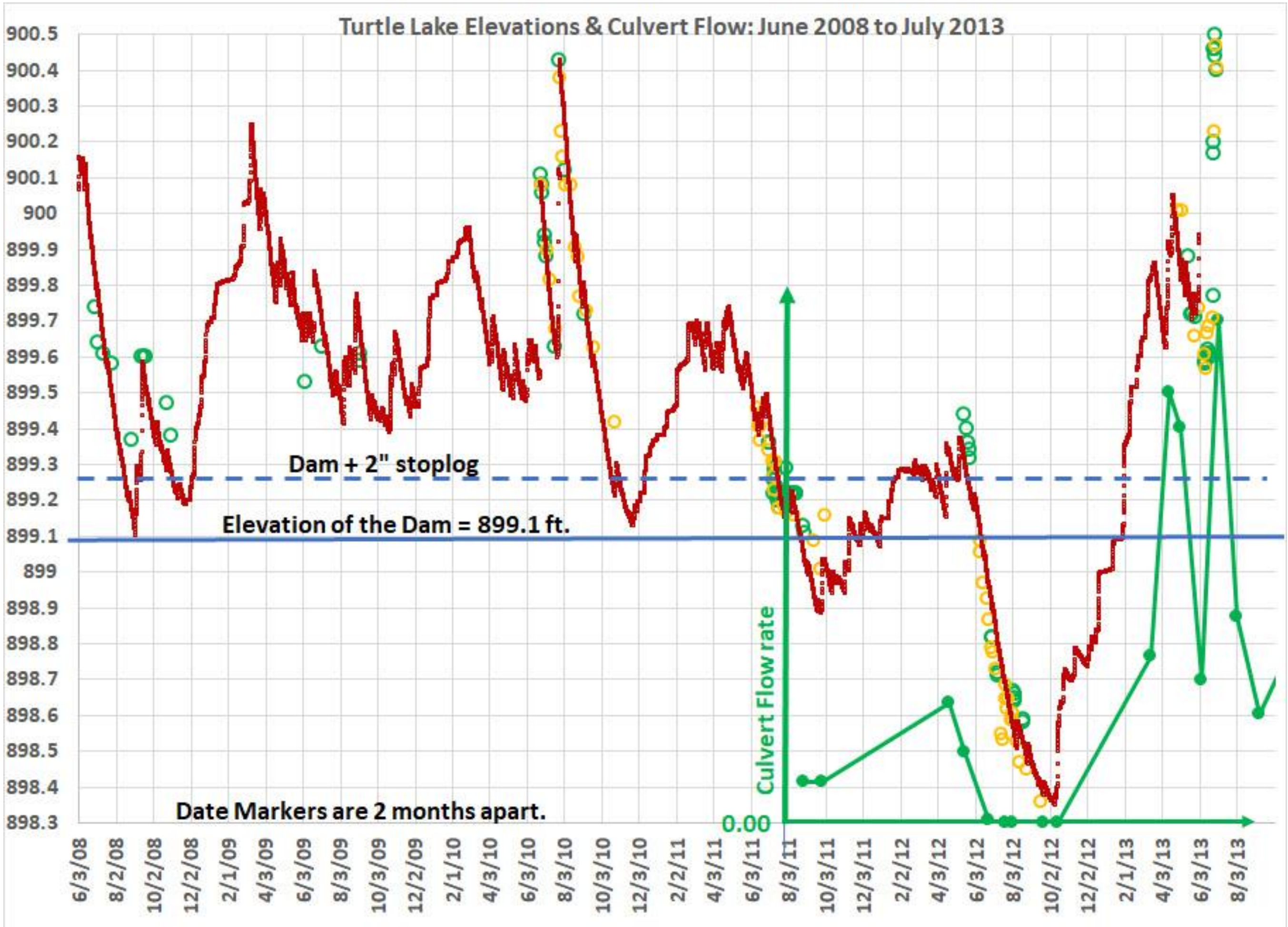


Fig. 7. ***Lake Elevations & Culvert flow: June 28, 2008 to June 26, 2013—1st five years.*** *Green circles are* ***Auer staff gauge*** *measurements; gold-orange circles are* ***Baas measurements****. Vertical grid lines (showing time) are about 2 months apart; the horizontal grid lines (showing elevation) are 0.1 feet apart. The red curve is an hourly mathematical model based on regional weather data. It fits the staff gauge data as best it can. The green inset shows culvert flow. This figure and Fig. 8 plot a total of 741 staff gauge measurements.*

When you study the elevation vs. time plots (Figs. 2, 7, 8, and 13) be aware of the vertical scale and the horizontal scale. How far apart are the grid lines as labeled? What is the range of the horizontal and vertical axes? Do the ups and downs correspond with your experience of the lake? What causes the very high and very low excursions?

The Fig. 7 (red) **model** is more uncertain than the Fig. 8 (blue) **measurements**, especially in winter. In Fig. 7, you will again notice the painful drought that started in 2011 and became severe in 2012. The drought in both years caught our attention and motivated lots more staff gauge measurements. We then quit measuring for the winter and found the elevations restored by early summer 2013. Note that the lake lies **above** the concrete dam (except for drought years) because the natural dam is higher. The **allowed** 2" stoplog would help only a tiny bit.

Turtle Creek dries up during an extreme drought.

In Fig. 7, the green inset graph at bottom right shows the relative flow through the culverts at the road, as measured by Pat Carroll. The lake dropped well below dam #1533 and the creek and culverts dried up completely (zero flow) in the summer of 2012. The lake continued to go down because of evaporation—and/or ground leakage. With a dry creek, a dam cannot help raise the lake.

Fig. 8. Automated 24/7 hourly measurement of elevations.

In 2011, I tried to make automatic lake measurements, hourly, 24/7, winter and summer, but I failed because a thief stole one of the automatic sensors to get an anchor. In 2012 I failed because I had programmed the sensors incorrectly (a cockpit error). Finally, 2013-2018 we got 5 years of blue results shown in Figs. 2 & 8. I wanted automatic measurements because: A). In science, more measurements are better. B). More points will allow precise determinations of the outflow rates and maybe flow from springs. This extra analysis continues and may allow a second report. The automatic measurements are made by a pair of Keller-Druck DCX-18 ECO **pressure** loggers, made in Switzerland. One sensor measures water plus air pressure (sitting on a submerged concrete block), the other only air pressure. We then subtract the two to get only the water pressure—and hence the height of water above the submerged sensor. Then we add the best number to match the sea-level staff gauge elevations.

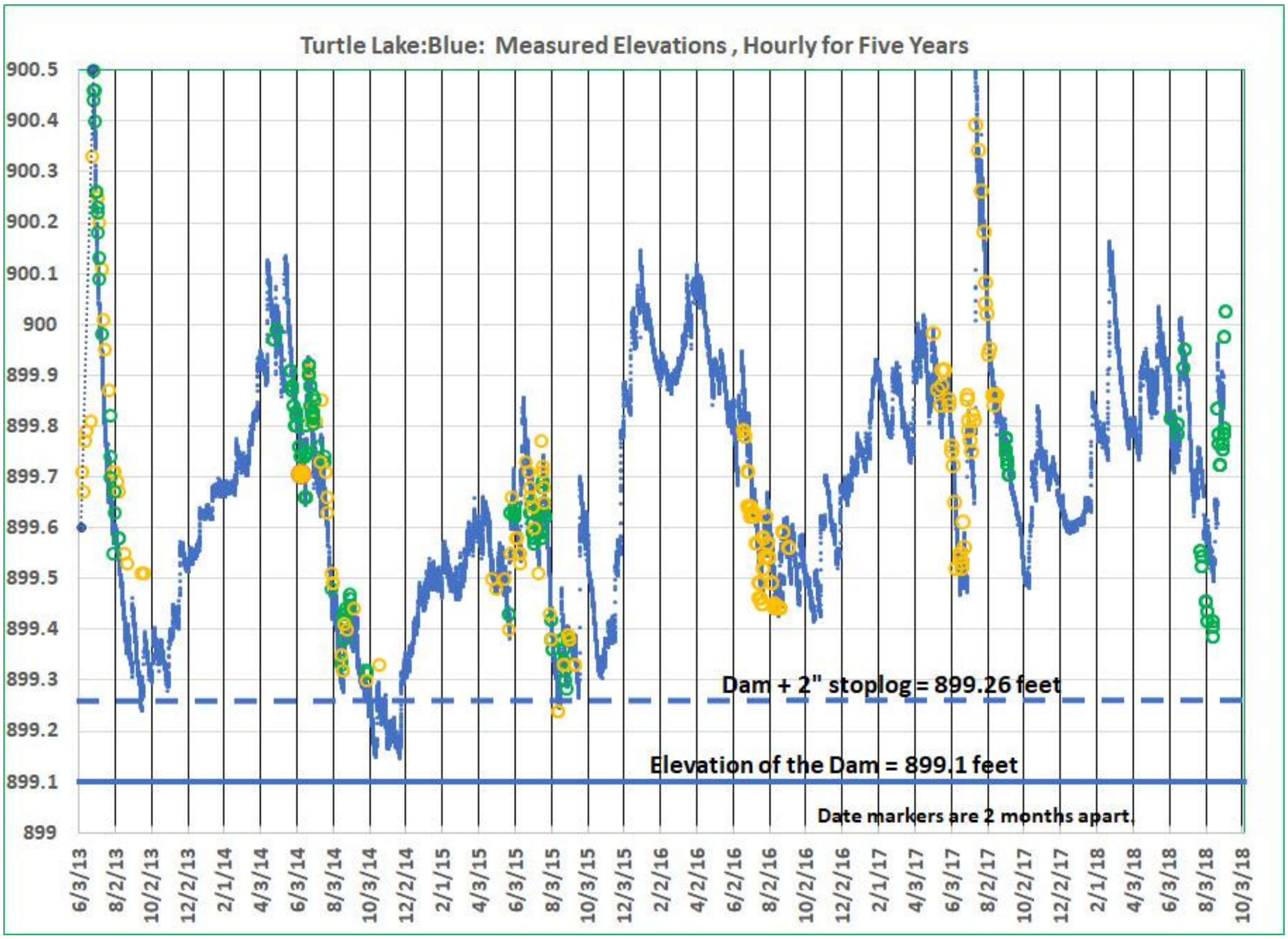


Fig. 8. ***Automatic measurements of the lake elevations from 6/7/13 to 9/4/18—next five years.*** *The vertical range is less than in drought years (see Fig. 7). Mostly, the levels are between 899.2 and 900.1 ft, a range of 0.9 ft.*

Again, the green and yellow-orange circles are the staff gauge readings. The vertical grid lines are here 2 months apart. The blue dots—which merge into a continuous line most places—are the actual measurements every hour, 24/7, winter and summer. In winter the pressure loggers include the weight of the ice and snow so are water-equivalents because a kilogram of ice is the same weight as a kilogram of water. The solid gold dot ● at 6/10/14 and 899.705 feet is the AECOM measurement on that day corrected to Our Scale. See Fig. 13 for a closeup of the gold dot region. Notice that in the entire 5-year period the lake level stays entirely above the concrete dam. (There was no drought.) Note that the elevation jumps up whenever there is a heavy storm.

Each summer, I pull the sensors out of the lake and download the year's data into a laptop. I then clean, recharge, and re-program the sensors; and put them back into the lake for another year. Now that this has been done five times, we lose about 6 hours (six data points) during the pull out, download, re-charge, and re-install. The sensors also measure their own temperatures which is useful for sensing when the lake has frozen over. The air sensor, in a bottom-sealed pipe pushed deep into the lake bottom, shows a very slow and gradual temperature change. Neither sensor ever freezes because the lake does not freeze to the bottom—except very close to the shore.

Head, the extra height above a spillway:

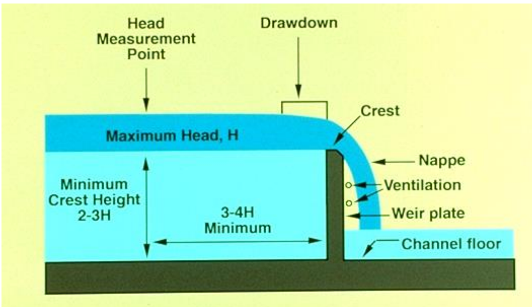


Fig. 9. ***Flow pattern over a dam***, *showing the extra height, called head*.

Note that if a lot of water flows over the dam, the lake level is higher than the spillway. The extra height, called "head", is required to speed up the flow to get the required cubic feet per second over the spillway. The higher the flow, the higher the head. The wider the dam, the lower the head. For the 9 ft. wide concrete dam at the road, the spring runoff can easily make ½ ft. of head. The spillway height cuts off flow if the lake level falls below the dam. Thick vegetation at the natural dam also raises the head because it takes extra energy to flow through it. From aerial maps, we see that the vegetation has gotten much thicker since 2005 (Fig. 12). Given the flow rate, we could calculate the head for the concrete dam, but we don't know the shape of natural dam #1533, so we can't calculate the head for it.

History

Farmers South of what is now Turtle Lake Road petitioned on 11/1/1908 to dig an 11 mile ditch, draining the 3,188 acres of wetlands **south of the road** for farming—making Turtle Creek a straight and deep canal south of the road. Sometime after 1909 the town and lake volunteers built a concrete and wood, not-approved, dam **south of the road** because they perceived that the lake had gone down 2 ft sometime after the drainage ditch was built. They added plywood to raise the dam, thus creating a cultural ethic: "raise the dam". By 1938 or 1939 culverts were installed under the road to eliminate the stream flowing across the road and they removed the wooden bridge that travelers had used to cross the stream.

The Concrete Dam at Turtle Lake Road. The concrete dam was mandated in 1941 and completed by spring 1942. It was surveyed on 7/16/**1965** by R. E. Purucker of the Public Service Commission (PSC) and the results reported in a letter to Dan Schroeder. Purucker found the height of the dam was 2 inches (0.16 feet) lower than the **allowable limit**. Therefore, the town was **allowed** to place a **2-inch stoplog** on top of the spillway. Mr. Purucker **also** found that day that the water was not flowing over the dam—but was about ½ a foot below the spillway. The main lake itself was 7 inches higher than the water at the dam. He concluded that **"the channel [**Turtle Creek upstream**] apparently affected control of the water levels in the lake."** He also said that any proposal to raise the dam higher than 2 inches would flood the [creek] area which "probably would drain through **existing culverts in the town road**." He ended by saying that before applying to raise the dam to a higher level, one should hire a competent engineer "to determine if the **lake** should be diked adjacent to the outlet—and if the stream (**creek**) should be ditched and diked to confine the water in the land and stream." By outlet I believe he meant near the lake. By ditched and diked he meant the creek near the concrete dam. Note that, **in 1965**, he identified the dominant restriction in lake outflow (the natural dam near the lake), and he foresaw a breach if the concrete dam were raised higher than 2". Both raising the dam higher than 2" and the breach actually happened. He also tells us that the culvert immediately at the concrete dam was not the only one at the road in 1965.

An international engineering company, AECOM, calculated in 2014 that Turtle Creek bed probably rose to at least an **effective** 899.4 feet (NGVD29) near the lake—above the dam's elevation by 3.6 inches. AECOM concluded that "repairing the breach and restoring Turtle Creek flow to the spillway may have **minimal effect** on the elevation of the lake…due to the natural constriction" …near the lake. Further, they noted that during the drought of 2012, there was no water flowing in the creek. The lake had fallen below the natural dam #1533. There was no way for the dam to raise the lake. I encourage everyone to read this detailed report. AECOM also reports that in 1979 a WDNR inspection discovered a 7" forbidden stoplog on top of the dam. We've now seen that the extra 7 inches **did** raise the lake, which would have rewarded people for illegally slipping it in. The cultural memory is that to raise the lake, you raise the concrete dam at Turtle Lake Road. The WDNR says **NO** to the 7" stoplog near the road—since 1965 and before.

Fig. 10. USGS elevation changes in Turtle Lake for 28 years (1951-1979).

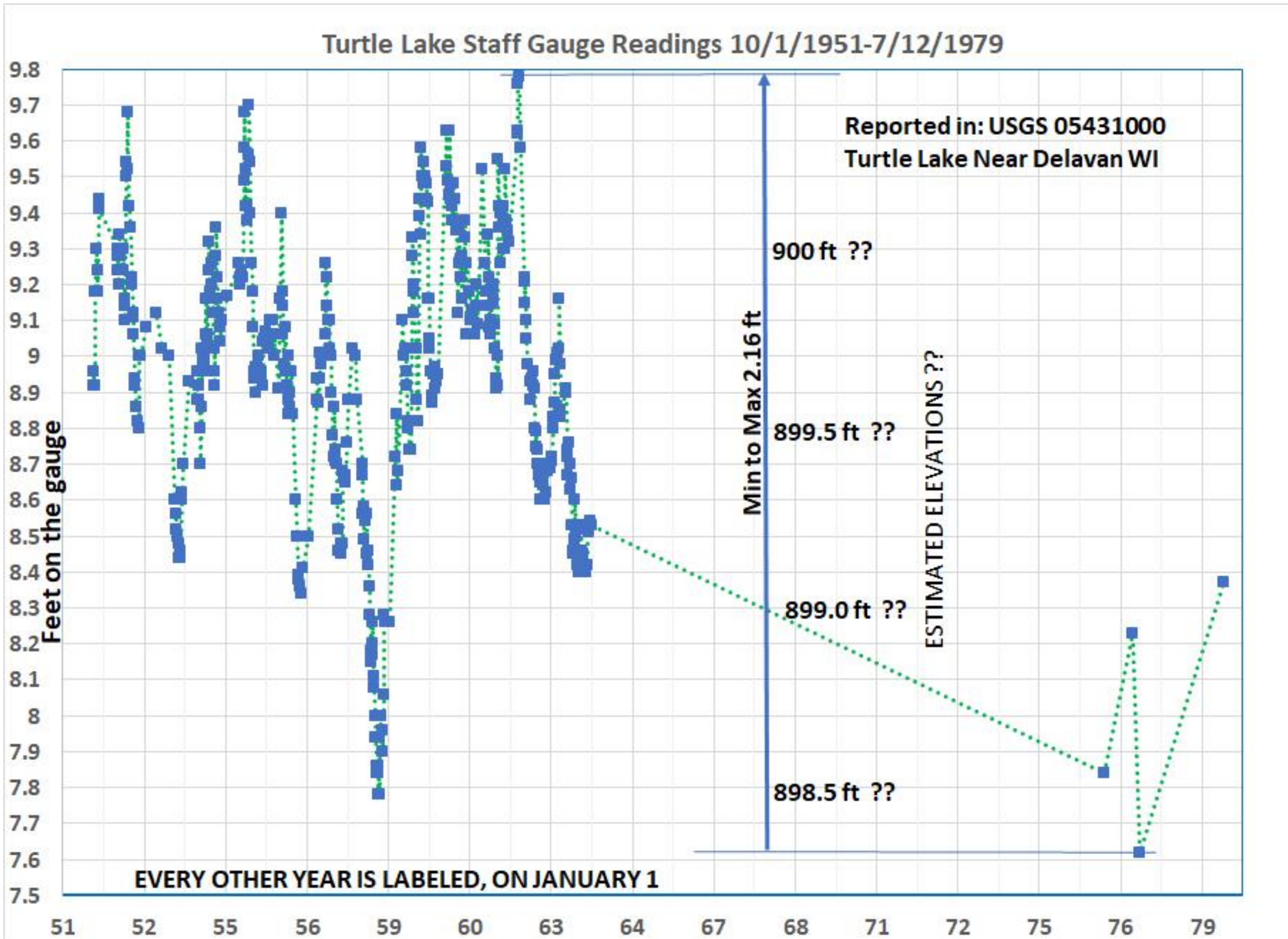
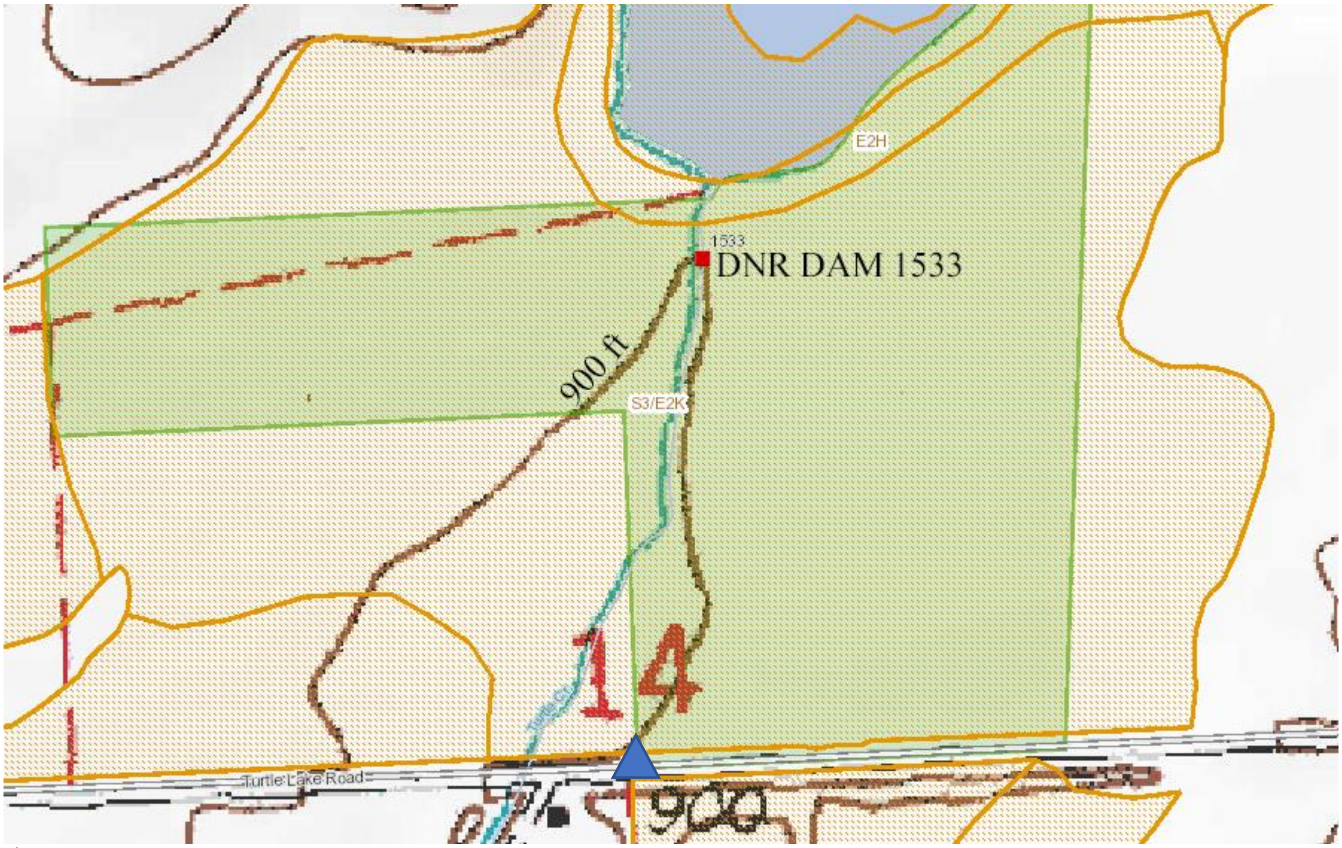


Fig. 10. *Someone at the lake, directed by the USGS, installed an official ruler (staff gauge) and read the* ***changes*** *in lake level* [*from 1951 to 1979 (28 years).*] *The graph shows the readings from the staff gauge as blue squares, connected by a green dotted line to aid the eye.* The local USGS office still has the file for these measurements. The reader(s) measured about once a week then quit after 1963 but came back to it when the lake again painfully dropped again in 1975. **The range high to low was 2.16 feet**, the same as our data in the last 10 years. The lake and the weather seem similar in different decades: A few very-highs and a few very lows. The official markers with sea level elevations were not installed until 1965, 6 years after they quit.

I added a guess for the sea level elevation scale—with double question marks. What sea level elevations would **you** put there? Why did I guess that particular elevation scale? How **uncertain** do you think my guess is—0.1 ft, 0.2 ft, 0.3 ft?

Fig. 11 The Detail sheet for Dam #1533 and official map.

The WDNR detail sheet (report) for Dam #1533 can be found online by searching in the WDNR Dam Safety site. You then enter 1533 in the Dam sequence number box, and click "search". Then click the "view dam" box, and then click on the report tab to read the report. (I can email the report on request. You will find that not all items are up to date.)



↑Fig. 11 *WDNR Map locating WDNR dam #1533 (As of June 2019).*

Green shading shows public (WDNR) land; orange shows mapped wetlands. (The survey marker in the road [blue triangle] locates one edge of the WDNR land.) The official dam (red square) lies on the **900 ft contour** & the mapped creek (thin blue line). It is just south of the westerly bend in the creek and south of the permanent marsh (E2H). The breach is not yet shown in this map. You can exercise the **layers** of this map online.

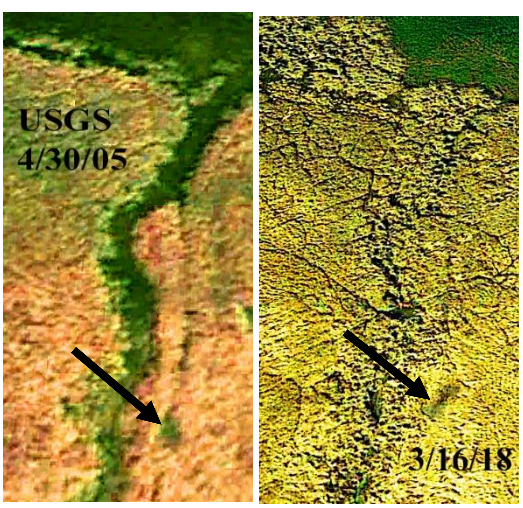


Fig. 12. 2005 & 2018 Closeups: note bush &the arrow crossing the creek.

Dam #1533 may be at the arrow crossing. Note the growth of vegetation in the channel and shore since 2005. The channel is again filling in. Aerial photos from 2005 and 2018 show a "permanent" bush or tree within about 30 feet of this dam, indicating high ground. After about 2011, it became impossible to take a boat to dam #1533 because of increased vegetation in the channel. Perhaps walking in from east or west keeping south of the permanent marsh would be possible, especially in winter or very early spring.

The Elevation of the dry concrete Dam is near 899.1 feet NGVD29.

An official standard for sea level is called a vertical "datum". Two important **vertical** datums are the National Geodetic Vertical Datum of 1929 (NGVD29) and the North American Vertical Datum of 1988 (NAVD88)—idealized reference surfaces at sea level. Near our markers, NGVD29 elevations are **theoretically** 0.206 feet higher than NAVD88 elevations. Some official marker tie sheets from 2004 list 0.14 or 0.15 ft higher. Any given elevation must specify the datum. We use the NGVD29 datum, because that is what the official markers use—though a few official tie sheets list elevations to both datums.

In Figs. 2, 3, 7, & 8, the elevation of the concrete dam is shown as 899.1 feet—to be compared with the lake levels. Let's make sure we know the elevation of the concrete dam—on the same datum as our measurements—so we can determine what would really happen if we were to fix the breach in the creek. We have the AECOM NAVD88 measurement of the elevation of the dam and one other GPS NAVD88 measurement, shown in Table 2. However, we have three AECOM measurements that can be directly compared to get an empirical offset, discussed in Table 1. At stake here is about 0.05 foot of uncertainty in the elevation of the concrete dam.

Table 1. ***What is the empirical offset between AECOM GPS measurements and our scale?***

	AECOM measurement And **markers** we used.	Used by	NGVD29 Tie sheet	**AECOM** GPS	Add to AECOM for our scale	Average Offset
1	South end of Garden Terrace Rd. Marker at SW ¼ of T3N R15E S11	Auer	**919.902**	919.8	0.102	0.081 round to 0.1
2	At Baas shoreline. On the west side of the lake, Sections 11 & 12.	Baas	**901.08**	900.96	0.087	
3	Lake elevation at boat ramp, midday 6/10/14. Fig. 13	Our measure	**899.705**	899.65	0.055	

Empirically, the AECOM NAVD88 measurements of the markers and the lake elevation are near 0.1 ft lower than the GIS NGVD29 standards, rather than the tie sheet value near 0.15 ft. How to resolve this 0.05 ft difference? I choose the empirical difference rather than the theoretical, retaining our scale.

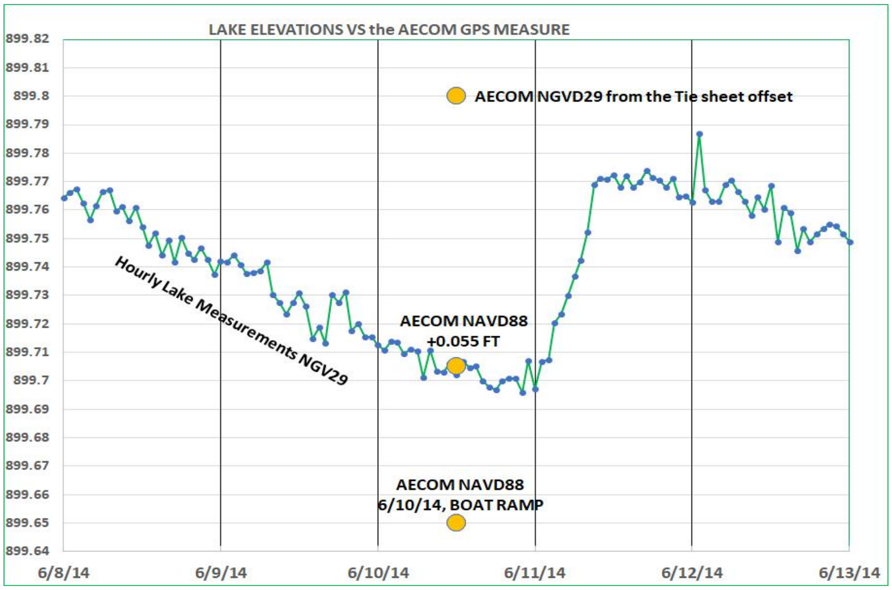
The GPS elevation measurements use two satellite receivers, with one making the measurement, and one as reference at a "known" elevation. AECOM says "The survey data was referenced to established benchmarks and control points near the site… using a Trimble R8 with ±2 centimeter [±0.066 ft] accuracy in good conditions." That is, they used the official markers in the ground. By good conditions, they mean no trees overhead. However, all three places in Table 1 are surrounded by trees and the GPS **basic** relative accuracy is larger than the 0.05 ft discrepancy.

I thought it would be wise to get a non-GPS determination of the elevation of the dam against the "triangle" marker shown in Figs. 1 and 11. However, I soon found that this marker—in the road—had recently lost a battle with a snow plow. Rob Merry, Chief Surveyor for SEWPRC, assured me that they would fix it "right away" and let me know the new elevation. They quickly repaired it by 6/4/19 and its new official elevation is 899.569 ft NGVD29 (Rob Merry email). We **could** now make one more (optical) survey of the dam. The **argument not to make another measurement** is that it is only of **historical** interest to know the elevation of an (almost) permanently dry dam more accurately than 0.05 foot (about 5/8 inch).

Table 2. *Direct measurements of the elevation of the top center of the concrete dam. The next to last column corrects the GPS by adding 0.081 ft as determined in Table 1.*

Who	When	How	*GPS*	GPS + 0.081 ft	Round up
Fluid Clarity	1/7/05	GPS + reference	*899.006*	899.087	899.1 ft
AECOM	6/10/14	GPS + reference	898.99	899.070	899.1 ft
			converted	Survey result	Rounded

So, on Figures 2, 7, & 8, the elevation of the concrete dam is shown as 899.1 ft. This elevation is uncertain by at about 0.05 ft (0.6 inch)—plus or minus half a vertical division on Figs. 2, 3, 7, & 8.



The AECOM measurement of the lake level on 6/10/14.

←Fig. 13. *The correction applied to the 6/10/14 AECOM NAVD88 measurement to match our lake levels is + 0.055 ft. (Vertical steps are 0.01 ft. We've zoomed in 365 times horizontally, and 10 times vertically.)*

This correction is used above to help establish the elevation of the concrete dam to our datum. Gold dots show the AECOM measurements—and with 2 different corrections.

Notes: **A)** When measuring lake levels, always record the time of day. **B)** The random fluctuations in the automatic lake level readings are usually less than ± 0.02 ft.
C) There is a lot of information in the automatic elevation measurements.
D) It rained more than an inch from midnight 6/11/14 to 9 AM.

How Extreme was the Drought of 2012?

Weather is everything. If it quickly rains 6", the lake level rises ½ foot—maybe eventually more—because of runoff from higher ground. Longer term weather, called climate, determines the ground water—whether springs fill the lake or the lake leaks out through the ground. In 2011-2012 there was a national drought, reaching southern Wisconsin as officially "extreme" in summer 2012. It was very painful because the lake went down more than a foot from normal levels and 1 ft vertically translates into several feet recession of the shoreline. In contrast, the ups and downs in normal, non-drought, years are plus and minus about half a foot (± 0.5 ft). Let's look at annual precipitation:
Table 3 ***Annual precipitation each year,*** derived from regional weather stations.
I emphasize the **"extreme drought of 2012"** in bold.

YEAR	2008	2009	2010	2011	**2012**	2013	2014
Inches precipitation/year	45	49.8	36.3	34.6	**25.7**	39.2	40.7
Inches Evaporation/year	-7	-7	-8.4	-9.5	**-13.8**		
Net precipitation to Lake	38	42.8	27.9	25.1	**11.9**		

Notice that the drought began in 2010 so we perhaps also lost some flow of groundwater (springs) by 2012. Note that the evaporation almost doubled in 2012 because the air was so dry and hot. I personally remember that there were no mosquitoes. 2012 had only 28% of the net precipitation of 2009. A 2 ½ minute slide show from the drought monitor demonstrates that the 2012 extreme drought was a national disaster that migrated northward to southern Wisconsin.

Appendix: Get the Turtle Lake Weather Station on your smart phone or desktop.

Turtle Lake has a 24/7 weather station since October 2015, run by Frank Primozich. In your app store, search for "Davis Weatherlink" and install it. Sign in with your email and an un-forgettable password. Take the free version, not the pro version. To add new weather stations, tap the plus sign within a circle at upper left. Start typing: "Turtle Lake Walworth County, WI" and add it and save it by tapping the rectangle with a notch in the bottom. Add Delavan and Janesville, also…