Turbidity and Water Level Fluctuations in Graham Lake and the Union River, Results from the 2017 Field Season

By Mark Whiting, Biologist, January 30, 2018

A report for the Downeast Salmon Federation

Title Page: Turbidity in the Union River where it enters Leonard Lake on the Shore Rd. Turbidity at this site was 48 NTU on Nov. 21, 2017.

Introduction:

In January of 2017, I distributed a paper in which I discussed previous turbidity studies of Graham Lake and the Union River (Whiting 2017). Also presented were new data that had been collected almost daily in the spring and early summer of 2016 based on two monitoring sites. One site was on the Union River at the Route 1A bridge in Ellsworth. River turbidity there originates in Graham Lake and was related to high lake water elevations (around 104 feet above sea level (asl)) in the spring and to wind driven waves and erosion. The second monitoring site was at Reeds Brook, a tributary to Graham Lake. Local turbidity problems, such as those recorded in Reeds Brook at the Route 180 bridge, occurred throughout the ice-free season and were also associated with wind storms. Models from the American Fisheries Society were used to extrapolate biological impacts based on the intensity (Suspended Sediments (SS) measured in mg/L) and duration (measured in weeks and months). Major losses in productivity and mortality of fish, macroinvertebrates and aquatic plants were expected based on measured turbidities from 2016. Additional turbidity in the fall was not monitored because access was blocked by road construction.

In 2017, a second field season followed. This time, an attempt was made to tie the observed turbidity in the river to water level fluctuations in Graham Lake and to tie water drawdowns to other environmental impacts in the lake and lower river. Water quality and the impacts of lake level drawdowns are among the environmental issues being considered in the FERC and DEP relicensing of the Leonard Lake and Graham Lakes dams. This report is intended to contribute to that review.

Study Plan:

Turbidity monitoring began at the Ellsworth Route 1A bridge on April 7, 2017 when turbidity was first noticed in the river. Graham Lake was still covered with ice. Ice-out occurred on April 17 at the end of a 2-day wind storm. Water elevations in the spring rose rapidly from 95 feet above sea level (asl) to 101 feet in one week. Turbidity was measured by the cell phone app HydroColor (Leeuw 2015) until November 30, at which point I slipped on a rock and lost my cell phone. Subsequent measurements were by a turbidity tube (which measures visibility in cm, visibility, turbidity in NTU and suspended sediments in mg/L are inter-convertible, see Whiting 2014, 2016). Turbidity/visibility was not measured from July 24 through October 9 because the river water appeared to be clear. Regular turbidity measurement resumed on October 10 after muddy water was observed on the lower river. Like last year, the biological impacts were estimated by American Fisheries Society models based on turbidity intensity and duration (Newcombe and Jensen 1996, Newcombe 1997).

The drawdown of Graham Lake in the summer of 2017 was remarkable, probably the lowest the lake has been in the last 10 to 20 years. Low water elevation resulted in substantial losses of littoral species, especially Unionoid mussels. That loss was documented photographically. Graham Lake water level was obtained from the website Waterline (Waterline FlowCast).

Results and Discussion:

In order to understand the impacts of water level management on Graham Lake, refer to Figure 1. This is the water level operations curve for the Graham Lake dam from Black Bear Hydro Partner's 2015 FERC application. The blue line is the ideal "target" and the red line is the average of actual water levels from the 16-year period of record (1999-2014). The dotted lines are the maximum and minimum levels from the same period. The annual low can be as low as 93.4 feet asl. The annual lowest low water is timed in late March to provide room to capture spring runoff. The lake fills quickly in April and is typically full by May. The high-water elevation is normally 104.2 feet (but could go higher to control spring flooding downstream). The hydroelectric facility is located near head-tide at the Leonard's Lake dam. The Graham Lake dam has no generators and is simply used to store water. Water level in Graham Lake falls during the summer as downstream discharge exceeds incoming flow. The second yearly low point occurs in late October or early November. This low is variable, but the 5-year average is around 98 feet. After this, the lake refills with fall runoff. Notice that actual water levels can vary substantially from the ideal, and there is a history of winter drawdowns as low as 95 ft.

FIGURE 2
HISTORIC OPERATING CURVE, GRAHAM LAKE

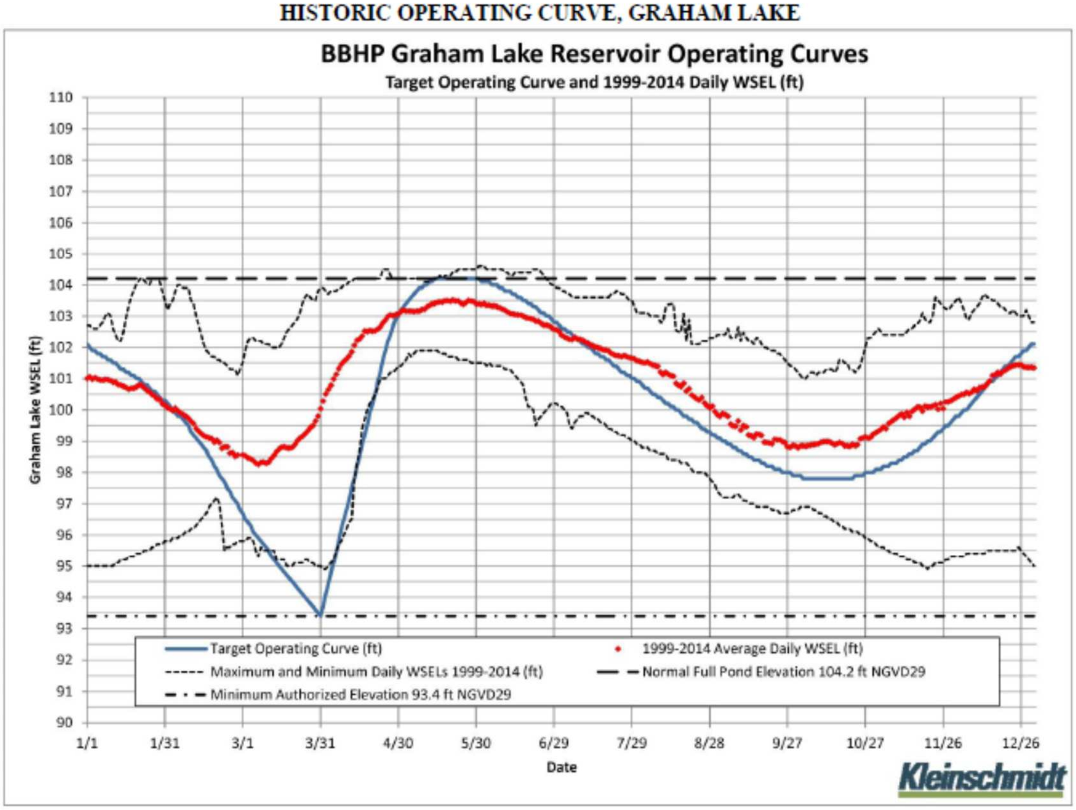

Figure 1. The Black Bear Hydro Power operations curve for Graham Lake. The blue line is the ideal. The red line represents the average of actual water levels, and the dotted lines on either

side show the maxima and minima for 16 years of record (1990-2014). The allowed water elevations range from a low of 93.4 feet to a normal high of 104.2 feet.

This year's field season had relatively mild turbidity in the spring with strong turbidity in the fall (Figure 2). Although 2016 was a bad year for the Union River, the 2017 field season was worse. While 28 NTU was the observed turbidity high for the 2016 field season, in 2017 the October-December average was 25 NTU with a high value of 74 NTU. Summer values, especially from July 24 through September were very low, essentially zero.

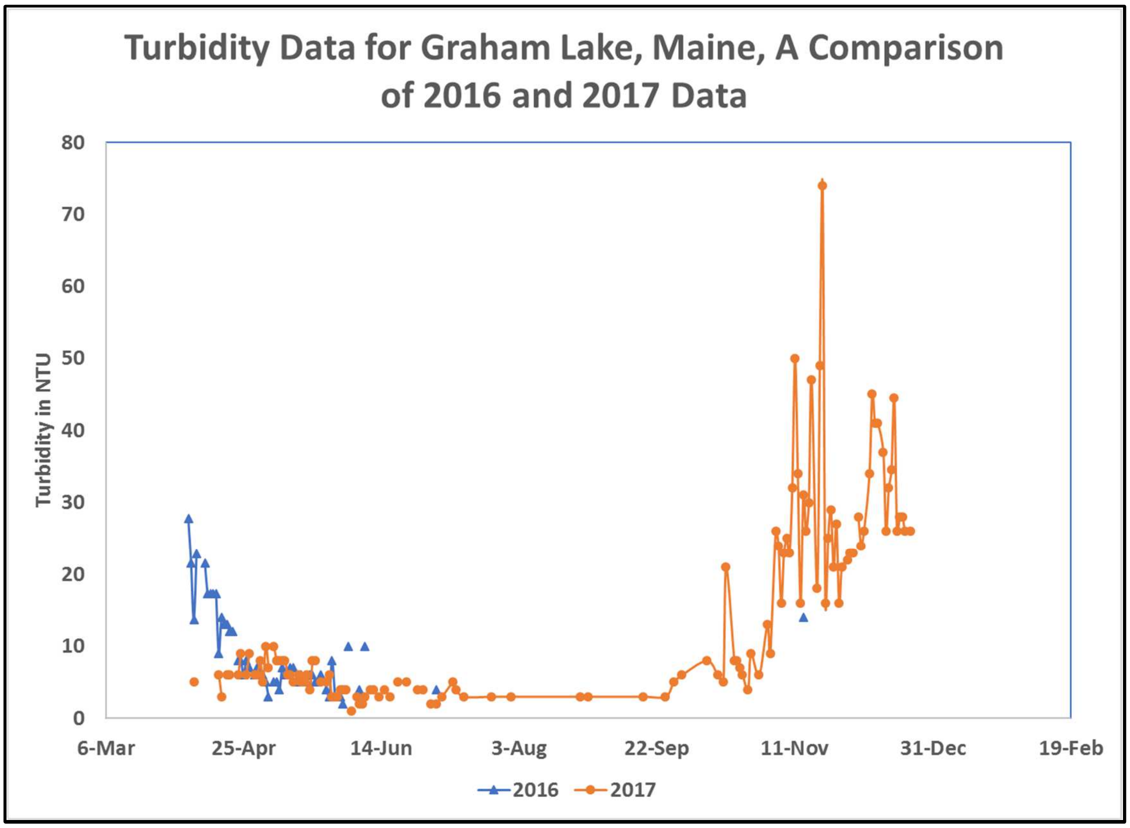

Figure 2. Turbidity measured in the Union River below the Route 1A bridge in Ellsworth, a comparison of the 2016 and 2017 field seasons. In 2016, turbidity monitoring mostly ceased after MDOT occupied the access point for a staging area during the reconstruction of Route 1A/Oak Street. Measurement of summer (August-September) 2017 turbidity was spotty, reflecting the mostly clear water during that period (so data gaps here are essentially zero).

The difference in the two years appears to be related to water elevation variations in Graham Lake and the way the Graham Lake dam is operated. For instance, the strongest spring turbidity in 2016 occurred when the Graham Lake water level was very high, around 104 feet, the maximum allowed under the current FERC license. To put this in perspective, a water elevation of 104 feet is above bank-full on Reeds Brook at the Green Lake National Fish Hatchery. Values from 103-104 ft cause lake water to invade beyond the tree line. The trees are alive, so this functions as seasonal flood plain. In other areas, high water around 104 feet in 2016 lapped at the base of cliffs and caused wave action to undercut banks along the lake shore. Bank failures led to complaints from property owners. In 2017, the maximum water level was 103 feet and lasted through late May and early June. There was less shore erosion and fewer complaints from property owners. Graham Lake appears to have been the primary turbidity source for the Union River below Graham Lake, Leonard's Lake, and the Union River estuary. Turbidity in the early spring and late fall was substantial even though the lake was frozen over. This appears to be from sediments stored in the river itself. Substantial sediment embeddedness in the river has been photographically documented by the author.

As mentioned earlier, the Graham Lake dam is managed so that water is stored in the spring and used in the summer to generate electricity. In a dry summer, the lake can be drawn down quickly. This was the case in 2016 and 2017. The summer low water typically exposes vast mudflats. In the fall, the lake water level recovers. In a dry year, the recovery may be slow. As the lake water level rises, it overtops the old river channel and floodplain and then extends back over the mudflats. If water levels rise slowly, then there are long periods where shallow water is lapping on muddy unconsolidated sediment. In strong winds, there is substantial resuspension of lake mud. Thus, fall tends to be the other muddy season for Graham Lake (see Figure 3). This was observed but not monitored in 2016. Fall turbidity in 2017 was especially severe. The highest values were apparently related to water level and wind storm turbulence. The worst turbidity occurred at 95.5 feet, but high turbidity continued up to 98.5 feet. The fall of 2017 was thought by many observers to be "the worst ever" for river turbidity. The lake and river froze over on December 16. Lake turbidity cleared within 24 hours after the formation of ice cover. However, strong river turbidity was observed daily and continued as late as January 24, 2018 (but was not measured due to unsafe shore access). This winter turbidity appears to be due to the reworking of sediments already in the river (since the most energy in the system at this time of year is in the river). Winter turbidity in January (the 13th and 23rd) was associated with large rain-on-snow events. The highest observed water level was 106.53 feet on January 24, 2018 (the 100-year flood event for Graham Lake is 106.8 feet, Maine Floodplain Management Program). The lowest low water level was 93.8 feet observed October 25, 2017. So, this field season includes historic highs as well as lows.

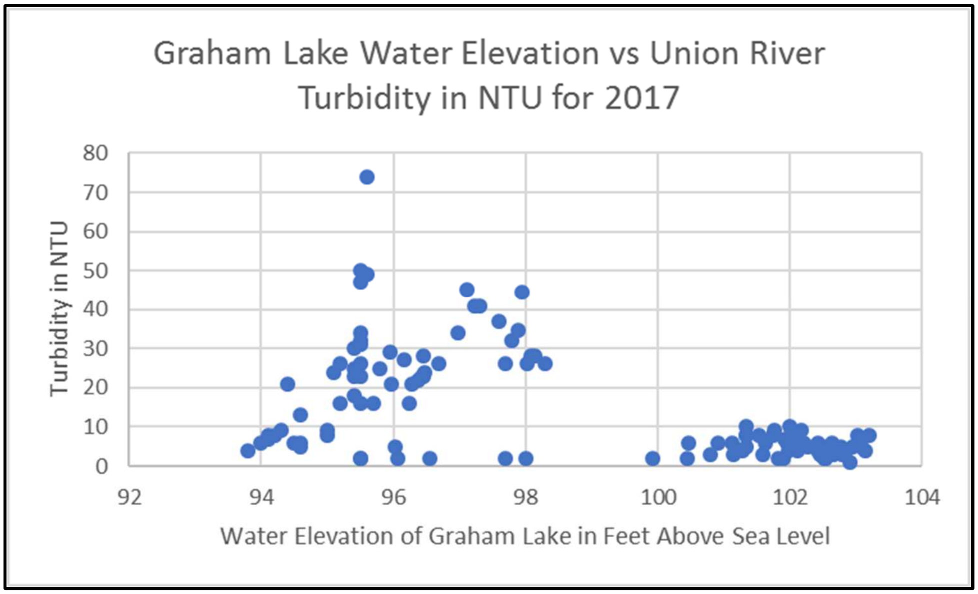

Figure 3. Water elevation in Graham Lake in feet above sea level and measured turbidity in the Union River at the Route 1A bridge in Ellsworth. The worst turbidities were observed when lake water levels extended over the vast mudflats in the fall and early winter. Water elevations in Graham Lake are available online at http://www.h2oline.com.

The average turbidity from October 10 through December 21 was 25 NTU, with a range of 4-74 NTU for almost 11 weeks. A turbidity value of 25 NTU is roughly equivalent to 25 mg/L suspended sediment (SS). Referring to Newcombe & Jensen (1996) Figure 4, the effect on "Eggs and Larvae of Salmonids and Non-salmonids", the impact of at least 20 SS for 7 weeks is a level 13 effect. Referring to Table 1, "Scale of Severity (SEV) of Ill Effects Associated with Excess Suspended Sediments," a 13 effect is 60 - 80% mortality. Even higher mortality is expected for adult estuarine fish species. Referring to Newcombe (1997) for impacts to "Aquatic Invertebrates and Aquatic Flora" Figure 7-B suspended sediments at least 20 SS for 7 weeks is an 11 effect. Table 3-c interprets this as "number of taxa reduced," with 20 - 40% mortality, and distribution reduced by a similar amount. This is essentially the same finding as last year because of the large increments in the tables. The next step in severity requires an average of SS 50 mg/L or exposure that lasts for 4 months.

In addition to turbidity, there are effects due to fluctuating water levels and dewatering of habitat. Last year's report noted that the operations curve for the Graham Lake dam allow the dewatering of the entire littoral zone of the lake. While turbidity alone causes large losses of species diversity, reduced abundances and reduced distributions of plants and macroinvertebrates, the dewatering of the littoral zone results in 100% losses for most organisms (Figure 4). Some plants like brown-fruited rush (*Juncus pelocarpus*) and creeping spearwort (*Ranunculus repens*) thrive on the higher elevations of Graham Lake's mudflats. However, species that are intolerant of exposure are eliminated and most of the mudflats are bare of any plant cover. In late October, large losses of freshwater mussels and other invertebrates were documented by Ed Damm, Brett Ciccotelli and the author (Figure 5).

Figure 4. Aerial photo of Graham Lake in the summer of 2017 looking north. This shows the confluence with the East Branch and the extent of the exposed mudflats during low water level. This photo was taken by a drone on October 26, 2017 when the water elevation was 94 feet. The 94-foot elevation floods the original river channel and floodplain but exposes land that had been forested upland before the construction of the dam. Numerous depressions, seen here, can strand fish during water level drawdowns, a problem mentioned by Maine DIFW. Photo provided by Brett Ciccotelli.

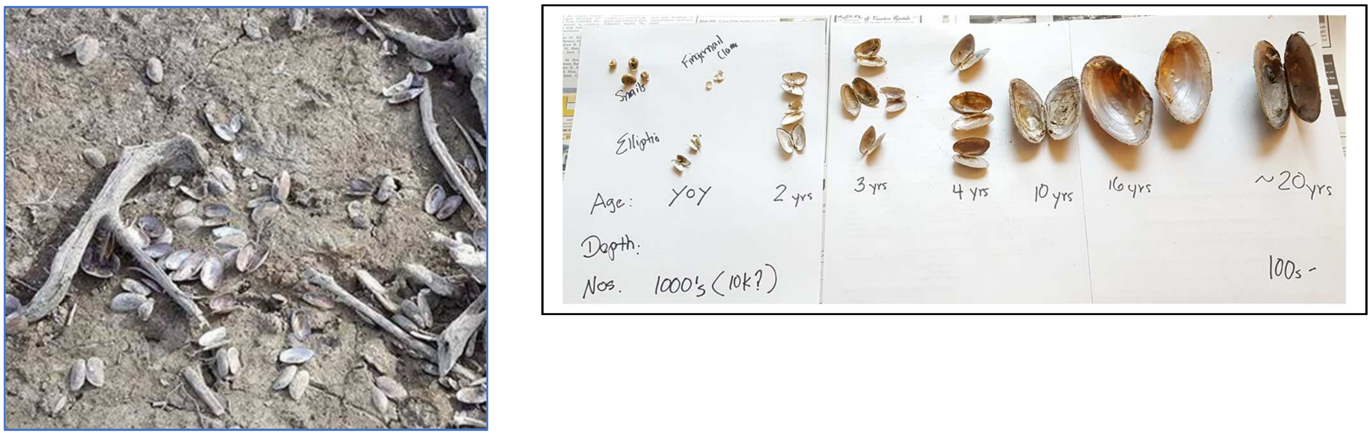

Figure 5a &b. (a) Photograph of Graham Lake exposed mud in October of 2017 showing mortality of freshwater mussels, and (b) a photograph of selected invertebrate remains from the same area sorted by type and age. On the left are some snails and fingernail clams. Snails were rare, but dead fingernail clams were abundant. Most of the larger clams were common Elliptio (Elliptio complanata). However, the 10- and 16-year old clams are alewife floaters (Anodonta implicata) and are recognized by their more triangular shape. There were many thousands of the smaller shells and a few hundred of the larger ones. The smaller shells include young-of-the-year or "YOY." The larger shells are in the range of 10-20 years old. The lake elevation at the time was around 94 feet. Neither of these mussels are listed as Endangered or Threatened by state or federal conservation programs. Photos provided by Ed Damm.

The oldest clams (15- to 20-years old) were at the lowest elevations 94-95 feet, and the greatest number of clams were found within the 94 to 96-foot elevations. The water level at the time was 94 feet. This elevation is lower than the Black Bear Hydro operations curve for this time of year and apparently the lowest the lake has been in 10-20 years (based on the age of the dead clams).

Based on this year's turbidity data, elevations below 98.5 feet generate a lot of lake turbidity from wave action on the exposed mudflats. The elevations 99 to 103 feet are better for turbidity by providing deeper water over the mudflats. If the mudflats were maintained to support a littoral zone, they could support plant and animal life that could help stabilize sediments (rooted plants) or reduce turbidity by filter feeding (clams) (Science News 2017, Blevins et al. 2018). Mussels are important prey species for river otter but must be protected from dewatering. Freshwater mussels are endangered throughout their native range due mainly to habitat loss (Blevins et al 2018).

Maine Dept. of Inland Fisheries and Wildlife recommended that Graham Lake elevations be kept above 97 feet to protect fish fry and eggs, prevent adult fish from being stranded and killed in depressions during drawdowns, and allow for the development of a vegetated littoral zone. However, this elevation is problematic for turbidity. The worst turbidity occurs at elevations between 95.5 and 97 feet. A better minimum elevation would be around 98.5 feet.

Summary:

The management of the lower Union River, including Leonard and Graham Lakes for hydropower production causes several biological impairments. These impairments appear to not be allowed by state law. These include:

- The annual drawdowns on Graham Lake cause the lake to be listed as an impaired water body in DEP's Integrated Biological Assessment report to EPA and Congress. Specifically, it is listed under category 4c "not attaining" due to failure to support "aquatic life" and "habitat modification" due to hydropower modifications. Maine's water quality law MRS Title 38, Chapter 4, § 464, 4H allows biological changes in hydropower reservoirs provided that the habitat and aquatic life criteria of those water's classification are met. The minimum criteria are Class C. Chapter 3 § 465 specifies that Class C waters must be able to support "all indigenous fish species" and maintain "the structure and function of biological communities." A lack of certain species such as Atlantic salmon, shad, tom cod, and probably some mussel species are not now maintained. Many other species occur only at very low levels (e.g. blueback herring). Turbidity in the lake and downstream river reaches impairs all fish, macroinvertebrate and plant species, causing loss of species, reductions in diversity and productivity, and reductions in distributions of remaining species. And finally, drawdowns in the lake currently exposes the entire littoral zone, eliminating the structure and biological functions of this important habitat.
- The lack of adequate fish passage for upstream and downstream migration endangers indigenous fish species and impairs the structure and function of communities. Passage is currently failing for salmon, American eel, river herring (3 species), and tom cod. This is not allowed under state or federal law.
- The hydropower exemptions do not allow reservoirs to cause downstream receiving waters to not meet their water quality criteria. The lower Union River is Class B and is impaired by water level fluctuations, turbidity, and sediment embeddedness. It fails to meet Class B criteria according to 3 macroinvertebrate samples collected by Black Bear Hydro and assessed by Maine DEP (Whiting 2017).
- DEP has no numerical criteria for turbidity but does have narrative criteria. Title 38 requires downstream waters to be unimpaired. Models published by the American Fisheries Society show that fish eggs and fry, and to a lesser extent adult fishes are greatly impaired by present turbidity. Similar models show large losses of macroinvertebrates and plants.
- MRS Title 38, Chapter 3, Subchapter 1, Article 4-A, § 464, 4B requires that "All surface waters of the state shall be free of settled substances which alter the physical or chemical state of bottom material" and should not impair any "designated uses" such as aquatic life, wildlife, habitat, recreation, and fishing ascribed to that water classification. Not specifically mentioned is loss of property value and loss of access to water due to recession of the water line. Apparently, turbidity is not allowed at all, and especially if it is severe enough to harm designated uses.

So, what is the best way forward? Removal of the dams would be the best option for the biological integrity of the river and lakes. It would also be the best option for the property owners along the shores of Graham Lake (although a replacement structure would be needed to stabilize water levels around 101-102 feet). Hydropower generation probably could be continued provided there are some changes in operation of the dams. First, there must be fish passage at the dams and migrating fish must be excluded from turbine intakes. Second, Graham Lake water levels are currently too extreme. Experience shows that turbidity can be managed by better attention to water level in Graham Lake. The highest allowed water level of 104 feet is too high, as this causes erosion, turbidity, and property loss. An elevation of 103 appears to be a workable solution. The low water levels are too low. Erodible flats are exposed, fish are stranded in depressions, and aquatic plants are killed. Maine DIFW says that water levels above 97 feet will protect fish, establish a functional littoral zone, and will protect freshwater mussels. However, 97 feet is demonstrably a bad elevation for turbidity and erosion. Based on Figure 3, a better minimum elevation would be 98.5 feet. Historically, the elevations between 97 and 103 feet are where Bangor Hydro and Black Bear Hydro made most of their electricity (Figure 1). The ideal line (in blue) stays mostly above 98 feet. The establishment of a predictable waterline would allow for the establishment of rooted vegetation and would substantially reduce turbidity. A higher minimum water level would allow freshwater mussels to live in shallow waters that are now seasonally drained. Mussels filter water and a robust population can mitigate turbidity. For instance, an experiment in the Bronx River with a 20 by 20-foot raft colonized ribbed mussels, the mussels filtered 3 million gallons/day and removed 350 pounds of sediment from the water column (Science News 2017). Because of the long history of turbidity in the lower Union River watershed, the re-working of sediments stored in the river causes some uncertainty about where sediments are coming from at any one point in time. This is problematic when trying to choose a minimum summer water level for Graham Lake. So initially, it is preferable to have a conservative figure (like 98.5 feet) that designed to mitigate the most harm.

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