A Turbidity Study for the Union River and a Discussion of Water Level Fluctuations in Graham Lake

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January 9, 2017

Title Page: Photo of the Union River at the Route 1A bridge in Ellsworth, December 7, 2016
HydroColor turbidity was 7 NTU and suspended sediments 7 mg/l

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Introduction

Sediments are an essential feature of lakes and streams. Natural processes generate and move sediments, thereby defining the geomorphology of stream beds and lake basins, and create bottom conditions for aquatic life. However, excess sediments are pollutants and are a common cause of water impairment in the United States. For these reasons, sediments and their movement are critical considerations for biological studies.

Suspended sediments can be measured directly or indirectly by optical properties such as turbidity or water clarity. These terms are related but are not readily interconverted. Conversions are based on assumptions and are thus approximations. Suspended sediments can be measured directly by filtering a water sample and weighing the amount of sediment trapped by the filter. This measure is Total Suspended Solids (TSS) which sometimes appears in older literature as Suspended Sediment Concentration (SSC) (Bash et al. 2001). Turbidity and water clarity are optical properties and are opposites. For instance, water that is "turbid" has poor clarity and low visibility. Turbidity is measured in NTU but may appear in older literature as JTU (the two are roughly equivalent when the sample value is greater than 25 NTU, Bash et al 2001). Visibility is measured in deep water meters by a Secchi disk or in centimeters in shallow water by a turbidity tube.

In a review document the European Inland Fisheries Advisory Commission examined the effects of turbidity on fish and fisheries. EIFAC lumped the effects into four categories: (1) turbidity has direct effects on fish, causing irritation and clogging of gills, and visual impairment that can prevent effective feeding and interference with obstruction avoidance, (2) particles have direct effect effects on reproduction when they adhere to fish eggs and interfere with the development of eggs or larvae by limiting oxygen uptake and waste removal, (3) turbidity modifies behavior and movement, especially feeding, spawning and migration, and (4) reduces food abundance by causing sediment embeddedness and by degrading habitat quality (EIFAC 1965 and cited by EPA 1986). Invertebrate abundances and diversity also respond strongly to turbidity (Bash et al 2001). Turbidity and light penetration are important variables that influence abundance and distribution of aquatic plants (Rhul et al. 2010) including plankton (Cloern 1987, EPA 1986). Eelgrass and other submerged aquatic plants are keystone species in wetted margins and coastal zones. Aquatic plants are extremely sensitive to poor light penetration and to smothering by sediment deposition (Sweitlik 2011). Turbidity is of critical importance because it has impacts at an ecosystem level.

Shallow lakes and reservoirs with extreme water level fluctuations are especially vulnerable to shoreline erosion and redistribution of sediments by wind and waves. Extreme water level fluctuations cause erosion of unstable banks during high water and sediments are redistributed at lower water levels. Independent of turbidity, water level fluctuations are important stressors for water-dependent plants and animals due to dewatering and exposure (DEP website). This report examines both the effects of suspended sediments and of water level fluctuations since both are critical stressors for organisms in Graham Lake and are factors in the relicensing of the Union River dams.

The effects of sediment on biological communities are a function of duration, intensity, frequency of exposure, life stage, sensitivity of the species of interest, particle characteristics such as size and angularity, type of particle (organic or mineral), natural background conditions, availability of refugia, and interaction with co-stressors such as water temperature and toxic substances (Bash et al. 2001). Thus, turbidity alone without a context, or turbidity that is measured only infrequently is impossible to evaluate. EPA recommends that states use models that consider this complexity and situation-specific conditions when establishing regulatory water quality standards (Sweitlik 2011). An approach like that of Newcombe & Jensen (1996) which was developed for fish is recommended. Other dose-response models have been developed for macroinvertebrates and aquatic plants (Newcombe 1997, Woockman 2012).

Historical Studies

Turbidity was an issue for Graham Lake for FERC and Maine DEP during the 1987 licensing of the downstream Leonard Lake hydropower facility. The Graham Lake dam was built in 1922-1924 to hold water for the hydropower station. The shallow reservoir (mean depth 17 feet), is large (c. 10,000-acres), and has always had fluctuating water levels due to hydropower demand (currently allowed to range 11 feet). There is no hydropower production at the Graham Lake dam. Graham Lake is used to store water for the peak power market and all electrical power is produced at Leonard Lake. Both high and low water levels have presented their own challenges for aquatic life and for riparian land owners and were examined in FERC and DEP reviews.

A summary of turbidity results from historical water quality studies in the Union River watershed is presented in Table 1. In a 1990 study by Northrup Devine & Tarbell (1991), NDT evaluated the effectiveness of the new hydrologic operating curve for the dam (the allowed elevation changes at the Graham Lake dam based on the 1987 permit). The authors mention that there were many complaints about erosion of lake frontage from riparian land owners in the late 1970s. The report also states that "the majority of the shore has been subject to erosion since the establishment of the impoundment" but that observations confirm that the present operating rule was been successful in reducing erosion and the risk to property. However, "minor erosion continues to take place along some sections of shoreline." The water quality summary noted that there was very little variation in water quality measurements among three deep-basin Graham Lake sites, sampled once a month from May-October. The water was turbid (average 3.3 NTU) and highly colored (75.2 PCU). Persistent turbidity and dark water color resulted in low visibility (average Secchi depth 1.7 m) and low algal production (2.3 ug chlorophyll-a/L). Summer water temperatures were warm (19-26.6 °C) but oxygen levels were good (8.3-10.4 mg/L). Macroinvertebrate studies show that diversity was low (29 taxa), but abundance was good (640 individuals) and the assemblage was dominated by a few filter-feeding caddisfly larvae. Fluctuating water levels were found to damage floating peat bogs and marginal wetlands due to erosion during high water and stranding and dewatering during low water. At the time, the authors felt this operating curve was a reasonable compromise to satisfy both the land owners and dam operators. NDT felt that the reduction in allowed high water level would eventually result in shoreline stabilization and reduced erosion and less turbidity.

Table 1. Summary of historical turbidity/water clarity studies on Graham Lake or the Union River. In this case "visibility" refers to Secchi measurements in lakes or turbidity tube measurements in rivers and streams.

Study	Sampling Dates	Sample Interval	Location	Turbidity NTU	TSS mg/L	Visibility m
NDT 1991	1990	monthly	Graham L	1.2 - 18 (?) [1]	<4 - 7 [2]	0.2 - 1.0
E/PRO 2005	2003-2004	bimonthly	Graham L	2 - 7.2		1 - 2
Hussey 2005	2004	bimonthly	Union R			0.3 - >1.2
TRC 2013	2013	bimonthly	Graham L	2.2 - 7.5	2.2 - 4.9	0.7 - 2.9
			Leonard L	1.6 - 7.4		1.5 - 2.5
			Union R			1.7 - 2.6

[1] original text reads values were "low" and ranged "120-180 NTU" an apparent typo

[2] TSS is available only for one date (October)

Turbidity in Graham Lake was revisited in a 2004 study by E/PRO for the relicensing of the Green Lake National Fish Hatchery for a water-discharge permit with DEP. E/PRO reviewed the available data from NDT and used additional data from USFWS and DEP/VLMP (the state Volunteer Lake Monitoring Program). USFWS did some bimonthly sampling from the 2003-2004 field seasons. The report finds that Secchi depth was consistently 1-2 m (lower than the state average of 4 m) due to the influence of moderate summer-time turbidity and dark water color. TP ranged 7.7-22 ug/L with an average around 15 ug/L (moderate - high). Plankton chlorophyll-a was generally 4-5 ppb and did not exceed 6.1 ppb (i.e., "normal" for healthy Maine lakes, those not influenced by algal blooms). The lake is apparently not phosphorus-limited, probably due to light limitation due to water color and persistent turbidity. The turbidity ranged from 2 to 7.2 NTU. Water quality in the lake was found to be "stable and mesotrophic."

In 2003-2004, the Union River Watershed Coalition did some volunteer-based water quality monitoring on the Union River, including Graham Lake, Leonard Lake and the lower river (Hussey 2005). Samples were taken bimonthly during the field season (May – October). Turbidity tubes were used to measure visibility (i.e. water clarity). A turbidity tube is a clear plastic tube with a small Secchi disk on a rubber bung on the bottom. The tube is marked in cm and mm to 120 cm. A turbidity tube is used like a Secchi disk but is designed for wadeable streams. Water is poured into the tube until the black-and-white target is no longer visible. These water clarity measurements are analogous to Secchi readings in lakes and provide roughly equivalent results (Gawley et al. 2014). Visibility in the lower Union River, Graham Lake and downstream, ranged from 27 to > 120 cm (approximately 23 NTU to essentially clear water 0-2 NTU). Low visibility was found only in the lower watershed and was related to urban runoff in Card Brook and to water elevation changes and weather in Graham Lake (Hussey 2005). Wind and strong rain storms were especially important predictors for higher turbidity values in the lower Union River.

In a 2015 report by TRC for Brookfield, water quality in Graham Lake, Leonard Lake and the lower Union River was found to mostly meet state regulatory standards. Turbidity ranged 2-7 NTU and Secchi depth varied 1-2 m. The results of three macroinvertebrate samples from the lower Union River were reported (summarized here in Table 2). Graham Lake is classified as Class B under DEP Water Quality Classification System. In the 2012 Integrated Water Quality Monitoring and Assessment Report, Graham Lake is listed as Class 4c water body, not-attaining its water quality classification due to an "impairment not caused by a pollutant" due to failure to support aquatic life and habitat modifications due to water "drawdown" (DEP 2012). TRC reports that all three marcroinvertebrate samples fail to meet Class B requirements and are thus considered to be impaired communities. Maine's Water Classification Program allows existing hydropower development (i.e. existing prior to June 30, 1992) where the reservoir is classified as a Great Pond and creates an impoundment that is subject to water level fluctuations to have an effect on habitat and aquatic life that is "different from the un-impounded waters and littoral zone," provided that the impoundment continues to support all native fish species and maintains the structure and function of the resident biological community (Maine Revised Statutes, Title 38, Water Classification Program, § 464 9-A). However, downstream reaches must be unimpaired - which is not the case for the lower Union River (Table 2).

Table 2. *Macroinvertebrate analysis from the Union River below the Graham Lake dam. Site 1051 is 139 m below the dam, Site 1080 is 855 m below, and Site 1081 is 5,700 m below the dam and only about 267 m above the Route 1A bridge on the Union R. All three samples, from two field seasons, fail to meet Class B standards.*

Site ID	Sample Date	Statutory Class	Attained Class	Final Determination
1051	8/22/2014	B	No	C
1080	8/11/2015	B	No	C
1081	8/11/2015	B	No	C

The Current Study
Methods

In the spring of 2016, I noticed elevated turbidity in the Union River below the Graham Lake dam at the US Route 1A bridge in Ellsworth. This was late March. I have seen this occur every year for the last 15 years that I have been living in Ellsworth. I borrowed a turbidity tube and began monitoring on April 5 (missing the first two weeks and the beginning of the event). The water clarity readings were converted into turbidity (NTU) and suspended sediment load (mg/L) using regressions from DEP publications (Whiting 2009, 2014). Beginning on April 16, I began measuring turbidity directly using a cell phone application developed by the University of Maine Sea Grant Program (Leeuw 2015). This cell phone app is designed to crowd-source turbidity data for studies of Maine estuaries and coastal waters. The method is based on remote-sensing technology developed for satellite monitoring. While this is a direct measurement of turbidity and suspended sediments, it is based on optical properties and is thus an approximation of turbidity expressed as NTU and of TSS expressed in mg/L. The method uses three photographs (Figure 1), first - aphotograph of a neutral gray card to calibrate for the exposure, second - aphotograph of the northern sky to calibrate for available light and color, and third - aphotograph of surface water looking north. The app, called HydroColor, uses regressions to estimate the sediment load and turbidity based on water color in red, blue, and green band widths. The optical measure of suspended sediments is called Suspended Particulate Matter (SPM) expressed as mg/L (the same as grams/cubic meter).

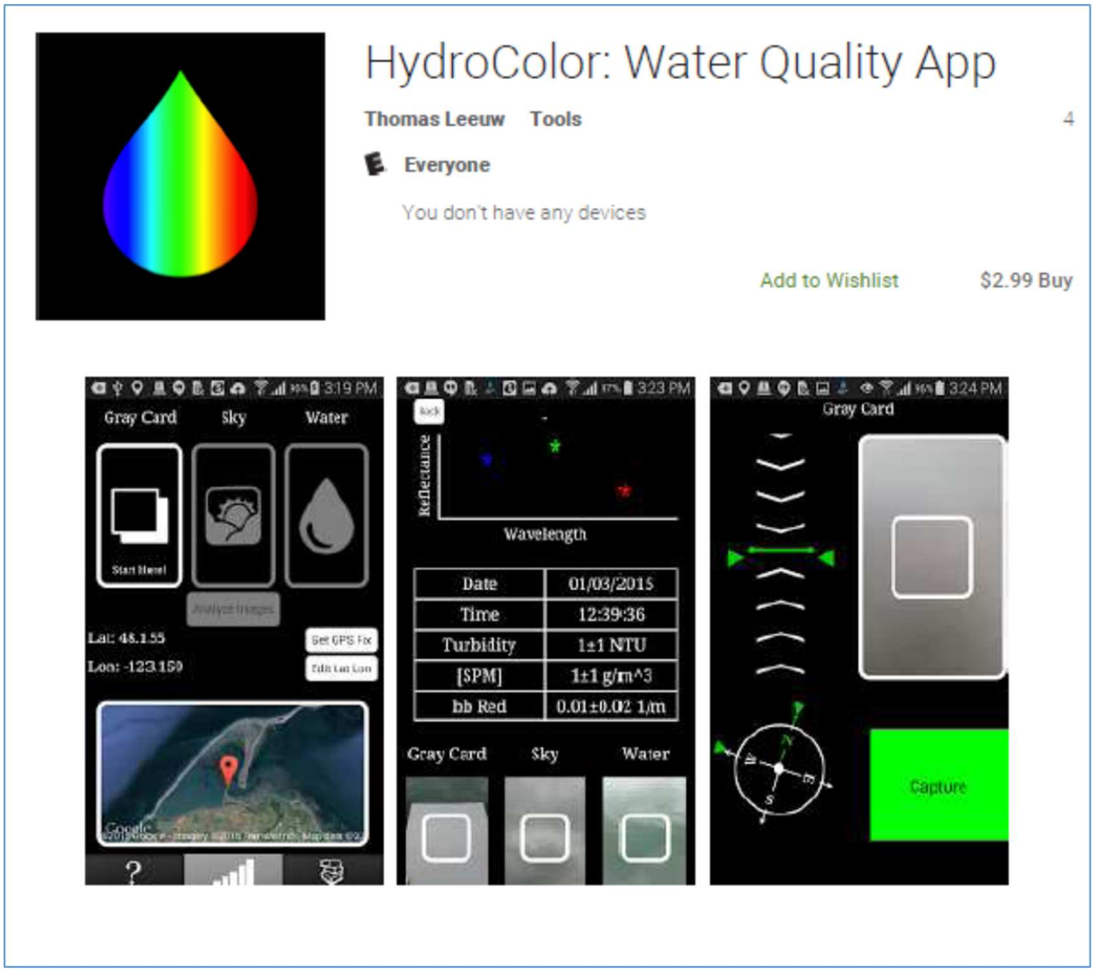

Figure 1. This is a reproduction of a web page that explains the cell phone app HydroColor. The app uses GPS to locate the sample site and orient the photographer. A compass is used to orient the photographer to the north and an inclinometer is used to get the correct angle for the photographs. The first photo uses a photographic gray card to calibrate the exposure. A second photo is taken of the northern sky to determine the color temperature of the available light. The third photo is of the turbid water. Regressions are used to convert red, green and blue reflectance to turbidity in NTU and Suspended Particulate Matter (SPM) in mg/L. The underlying technology is the same as that used by environmental satellites for oceanographic studies.

In early June, Maine Department of Transportation began reconstruction of US Route 1A in Ellsworth from the Route 1A bridge to the triangle at Oak and State St. The parking area near the Union R bridge became part of the staging area and was no longer accessible. I moved my routine monitoring to Graham Lake on the east side of the Route 180 bridge on Reeds Brook, a tributary (at the entrance to the Green Lake National Fish Hatchery). The cove at the mouth of Reed Brook is one of the erosion sites on the lake and is an obvious source of suspended sediments. Reeds Brook was monitored in June, July and through the first half of August, at which point the lake level became too low to continue.

The impact of turbidity on aquatic life is a function of intensity and duration. For this paper, I primarily used two publications. For fish, I used Newcombe and Jenson (1996). In this report, there are different models for different species. Adult salmonids are the most tolerant. So, the models that are most relevant for my study are for the less tolerant species and life stages (refer to Figure 4 "Eggs and Larvae of Salmonids and Non-salmonids," Figure 5 "Adult Estuarine Non-salmonids," and Figure 6 "Adult Freshwater Non-salmonids"). Exposure duration in hours, days, weeks and months is found on the X axis. The concentration of suspended sediments (SS) in mg/L is on the Y axis. The numbers in the tables are impacts called "Scale of Severity of Ill Effects" and are explained in Table 1. Similar tabular models can be found for macroinvertebrates and plants in a different publication by Newcombe (1997) (Figure 8 B "Aquatic Invertebrates and Flora" and Table 3b for impact severity for invertebrates and Table 3c for plants).

The Present Study
Results and Discussion

Turbidity tube measurements began on April 5. The measurement of turbidity and suspended sediments using HydroColor began on April 16. The measurement of water clarity with the turbidity tube continued through May 15, so that the two methods overlapped for one month. A regression of the turbidity tube inferred TSS data with HydroColor SPM is given in Figure 2. Both methods are approximations of measured TSS and are good approximations of each other. The r^2 is 0.7183 with HydroColor yielding a slightly higher number. To reduce the amount of time in the field, HydroColor was used almost exclusively after May 15.

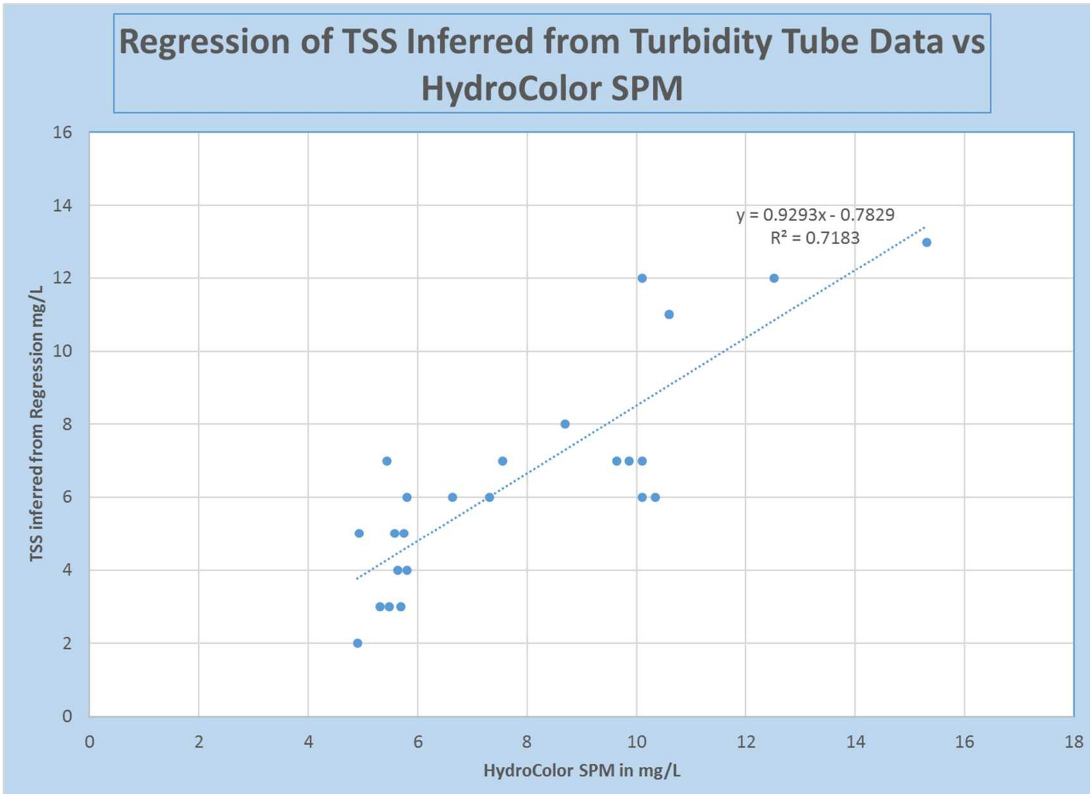

Figure 2. Regression analysis of total suspended sediments inferred from turbidity tube measurements and as inferred from HydroColor measurements. The comparison is good ($r^2 = 0.7183$) with HydroColor giving a slightly higher estimate.

Maine DEP has no numerical criteria for turbidity or suspended sediments. However, Maine does have narrative criteria that water quality be adequate support all intended uses including fishing and recreation, support all indigenous species, and aquatic communities should be "unimpaired" (MRS Title 38 § 465, 3. Class B waters).

In the first two weeks of the study inferred-TSS varied from 10-27 mg/L, then in a one-week period suspended particulate matter gradually dropped to 6-7 mg/L, and then hovered between 5-8 mg/L through May (Figure 3). Some very low values in late May and early June (2-3 mg/L) are essentially clear water. This compares well with historic data, i.e. E/PRO reported that summer time conditions in Graham Lake ranged 2-7 NTU. Referring to Newcombe & Jensen's (1996) Figure 4 "Eggs and Larvae of Salmonids and Non-salmonids" moderate amounts of suspended sediments (7 mg/L) for more than 7 weeks is a "12" on the scale of severity (from Table 1). This represents a "lethal and paralethal" condition that includes "reduced growth rate, delayed hatching and reduced fish densities" with "habitat degradation" and an estimated 40-60% mortality. It is a little worse than the impact from first two weeks alone at higher levels 10-27 mg/L (the average was 17 mg/L) approximately an 11 effect (20-40% mortality). The estimated impact on Adult Estuarine Non-salmonids (alewife, shad, etc.) is much greater, where large mortalities (effect 14, 80-100% mortality) are expected in a matter of days (Figure 5). Since this was measured in the river not in the lake, the impact is presumably to river spawners (the eggs and fry of blueback herring, shad, tomcod, and sea-run rainbow smelt). To have a more complete turbidity study, we still need some data from Graham and Leonard Lakes to estimate the impacts to alewife eggs and fry. Adult Freshwater Non-salmonids (bass, pickerel, perch, and minnows) fare better with an impact of 10 (Figure 6) which is "0-20% mortality, increased predation, with moderate to severe habitat degradation" (Table 1).

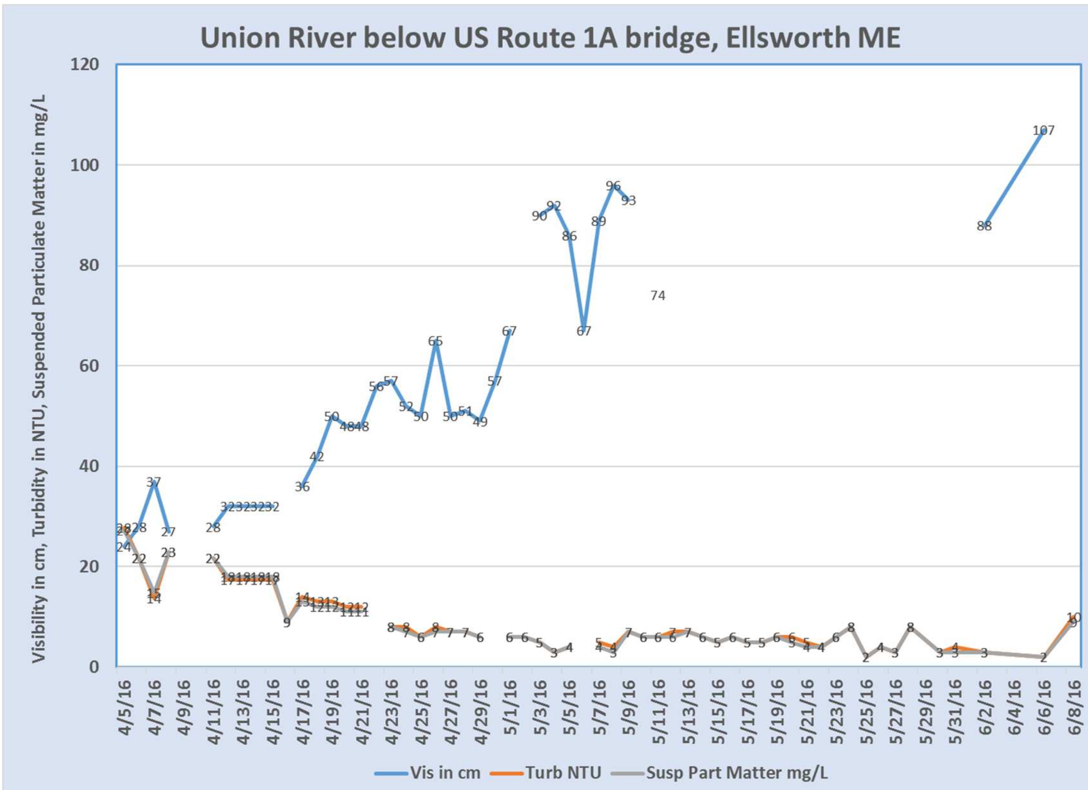

Figure 3. A comparison of visibility, turbidity and suspended sediments in the Union River below the Route 1A bridge. Visibility is based on turbidity tube measurements. After April 16, Turbidity in NTU and suspended particulate matter in mg/L are from HydroColor cell phone app, while turbidity and suspended sediments prior to April 16 are from regressions with turbidity tube measurements. The predicted impacts of moderate turbidity for long periods is severe habitat degradation and variable mortality (0-60%) depending on the species and life stages being modeled.

For aquatic invertebrates and aquatic plants refer to a later publication by Newcombe (1997). Here two months of moderate suspended sediment (7 mg/L) exposure is an 11 effect for macroinvertebrates (Figure 8B) "more than 20-40% mortality" with similar reductions in densities (Table 3b). There is less data available for aquatic plants but the limited model available (Figure 9) with an exposure of 55 mg/L SS for 2 days predicts the effect is 10, "reduced diversity and reduced survival" mortality 0-20%, and standing crop reduced by 0-20% (Table 3c).

While Maine's Water Classification Program allows for water level fluctuations from hydropower development and allows for changes in natural biological communities, the law also states unequivocally that "all surface waters of the state shall be free of settled substances which alter the physical or chemical nature of bottom material and of floating substances, except as naturally occur which impair the characteristics and designated uses ascribed to their class" (Title 38, § 464, 4B). Clearly this turbidity, habitat embeddedness, predicted losses of fish and invertebrates, with reduced plant diversity and standing crop in the lake and river are impairments that are specifically not allowed.

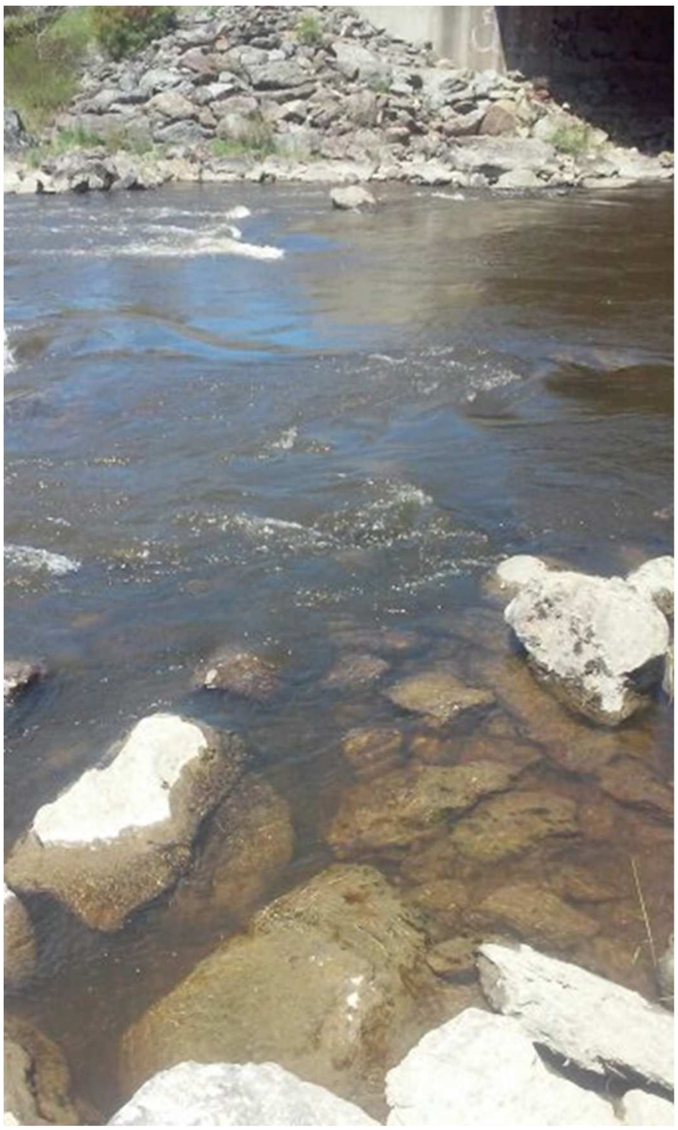

Figure 4. Photo of Union River bottom conditions below the Route 1A bridge (Ellsworth Falls area) on July 4, 2016. Note the coating of mud on every surface below the spring waterline. Even those rocks above the current water line have a coating of mud from high flow conditions. Note that the gravel bottom is embedded with silt. The Ellsworth Falls rapids are a high velocity stream section, but there is clearly a deposition of fine sediments along the stream margins. This fine sediment alone could explain poor macroinvertebrate results below the Graham Lake dam and is one of the predicted results (i.e., "severe habitat degradation") of the Newcombe & Jensen sedimentation models.

At Reeds Brook the 32-sample average for almost two months was 10 mg SPM/L with a range of 4-28 mg/L (Figure 4). As for the Union R samples, low levels for a long time were worse than a few peaks that lasted only for a day. Impacts ranged from 10 to 12 for different species and life stages of fish, an 11 for invertebrates and a 10 for freshwater plants. Large losses of productivity and biomass, and the degradation of habitat would qualify as an "impaired" habitat and thus not allowed by state law. Loss of species is predicted. The loss of indigenous species of fish (Atlantic salmon, shad, blueback herring) would be not allowed by law even for a hydropower development.

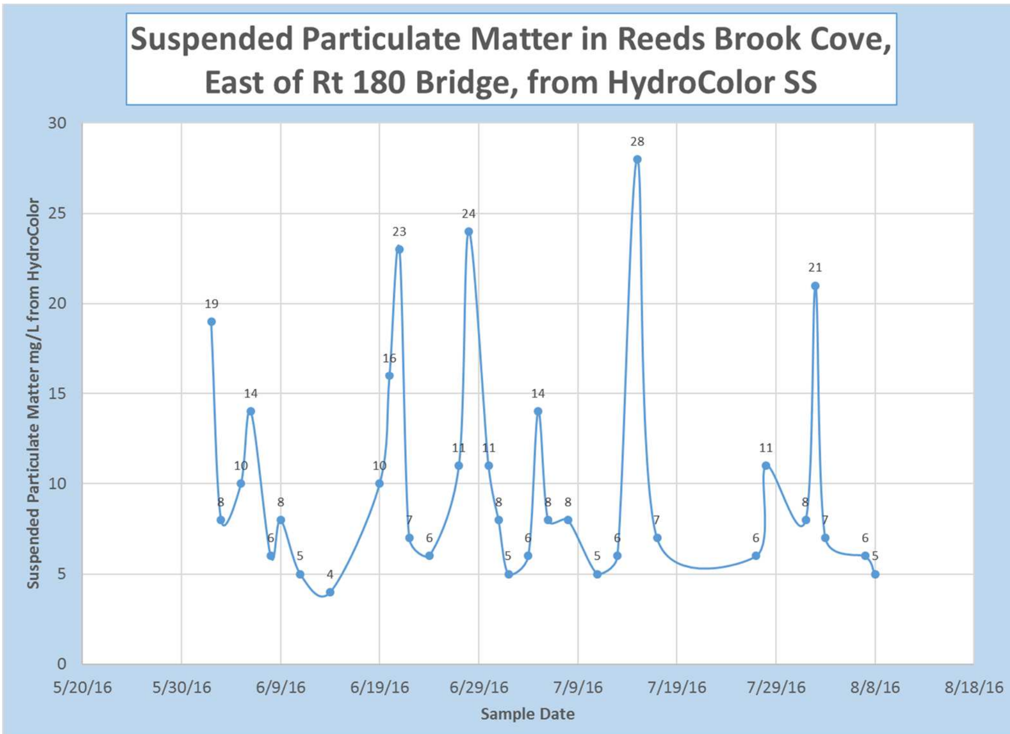

Figure 5. Suspended particulate matter measured by HydroColor in Reeds Brook cove. Reeds Brook is a tributary to Graham Lake. The cove has sandy bluffs which are a source of bank failure and erosion, and are an episodic source of turbidity in Graham Lake. High water results in wave-cut losses of banks. Seasonal low water redistributes sediments stored from earlier erosion events. In addition to water level, wind intensity, wind direction, and fetch are also important.

Suspended sediments at Reeds Brook are higher than that reported for limnological studies of Graham Lake. Earlier studies focused on the three deep basins forming the old river channel. The summer mean for the lake was 4 NTU while the summer mean for Reeds Brook was 10 NTU. The emphasis on the deep basins was appropriate for a limnological study but it missed spatial diversity along the shore. Also, these limnological studies were measuring water quality monthly or twice a month, while turbidity needs to be measured at least daily. Because of the temporal variability USGS recommends that turbidity be measured continuously by automated sondes (Anderson 2005). Because of the spatial heterogeneity, it would take many sondes (one for each major erosional site) or else daily overflights by airplane or drone to characterize conditions in the lake and watershed. So, the definitive turbidity study for the watershed is yet to be done.

An issue that is related to turbidity is the fluctuation in water level and the ever-changing shoreline. These fluctuations prevent the lake from establishing a stable shoreline. Therefore, turbidity becomes a chronic problem in the lower watershed. Water fluctuations are a problem for wildlife and plants, and for riparian property owners. Erosion causes loss of property and the receding shoreline is a problem for water access (Figures 6-8).

Figure 6. Eroding bluff on the SW side of Graham Lake along the Mariaville Road (State Route 180) taken during high water. Note vegetation that has fallen into the water and caused local turbidity. Photo taken by Eddie Damm April 28, 2016.

Figure 7. Photo of Graham Lake from North Street (State Route 179) in Ellsworth during low water (elevation 95.45 feet). The distance from the shore to the waterline here is about 300 feet. Photo by Eddie Damm, November 11, 2016.

Figure 8. Access to the water is a problem for riparian land owners in the late summer and fall during low water. Photo by Eddie Damm September 29, 2016. Recreation is one of the protected uses under DEP water quality regulations.

Seasonal low water is not just a problem for landowners. The littoral zone for a lake is defined as approximately 2-3 times the Secchi depth, with the lower values applicable for estuaries and reservoirs and the higher values for naturally clear lakes (Cloern 1987). In Graham Lake, this would be 2 X 1.7 m = 3.4 m (about 11 feet). Since the annual allowed drawdown is 11 feet, this allows the dewatering of the entire littoral zone. The littoral zone is supposed to be a "hot spot" for local production and biodiversity (Kaufman et al. 2014). Referring to Figure 7 notice that the local productivity and biodiversity for the littoral zone is essentially zero due to lake drawdown and habitat dewatering. While turbidity has important negative impacts for plants and animals, dewatering is worse. Macroinvertebrates and aquatic plants are the most affected because they cannot move fast enough to keep up with the receding water line. Fish are more mobile, but they could be stranded in isolated pools as water recedes. Fish are indirectly affected because of the loss of habitat and productivity at the bottom of the food chain.

Summary

As seen in the cover page photo, the lower Union River looks different than any other river in Maine. In 2016, the river experienced mild to moderate turbidity from late March through December (nine months). Although this study only followed turbidity through the summer low water period, turbidity continued through the summer and increased in the fall. So, this is not the definitive turbidity study for the river. This is the study that showed that turbidity causes the river to not meet state water quality standards and that more attention needs to be paid to this issue. Future studies need to provide more spatial coverage, higher temporal resolution (hourly?), better equipment (e.g. data sondes), and must cover the entire ice-free season.

Moderate or even mild suspended sediment loads for long periods kill fish and other aquatic life. Turbidity is regulated in Maine as a "discharge" to state waters. Observed turbidity and suspended sediment levels in Graham Lake and the Union River are sufficient to cause significant mortality of fish eggs and young, mortality and loss of productivity in invertebrate communities, with loss of species diversity and productivity in plants. Looking back on the available data for 2016 the days with relatively good water quality (see Figure 4 from July 4 with turbidity 2 NTU) were rare, and moderate turbidity (see title page photo from December 7 with turbidity 7 NTU) was more usual. Problems began soon after ice-out and lasted through December. Ice cover in Graham Lake formed in late November, so turbidity observed in December was due to sediments stored in the river channel. The bottom line is that mud kills fish and other aquatic life. The effects predicted by models were only for the first part of the summer and missed additional turbidity in the later summer and fall. Nine months of exposure is worse than the two months documented in this study. For instance, for "Eggs and larvae of salmonids and non-salmonids" nine months is between 4 and 11 months on the model, but is closer to 11 months. For 11 months of exposure to 7 mg/L of suspended sediments the effect is 14 (the highest value, at least 80-100% mortality). 2016 was an especially bad year for the lower Union River.

The species probably most impacted are alewife, shad, blueback herring, tomcod, rainbow smelt, stripers, native minnows, freshwater mussels and smaller invertebrates in the river and along lake margins, and native plants in the littoral zone and along the shore. Freshwater mussels that are typical of streams and rivers do not tolerate even the “slightest amount” of siltation (Swartz & Nadeau 2007). The loss of mussels from streams can be a significant loss of ecological function, since mussel biomass typically dominates benthic infauna and can be greater that total fish biomass (Swartz & Nadeau 2007). Loons do not tolerate fluctuations in water levels and can survive in Graham Lake only by nesting on floating bogs. Dabbling ducks are likely to be impacted by large losses of invertebrates and vegetation in the littoral zone. Otter, mink, muskrat and beaver are impacted by the large retreat in shorelines from nest sites.

Graham Lake is a significant wildlife resource. It has one of the most valuable alewife runs in Maine. But there are problems that greatly reduce the value of the lower Union River to human and wildlife communities. Fish passage is a huge issue not addressed in this study, but turbidity and water level fluctuations result in huge additional losses of fish, invertebrates and littoral vegetation. Where the littoral zone should be a hot-spot of local biodiversity (Kaufman et al. 2014), in Graham Lake this opportunity is lost due to the way the lake is managed for peak power production. Local land values and recreation are also affected. Turbidity makes the Union River less desirable for swimming and boating and is a danger to swimmers in trouble. EPA recommends that states develop turbidity standards for recreational uses exactly because of the public safety issue (Sweitlik 2011). Turbidity and river embeddedness are huge impacts to habitat in the lower Union and are part of the explanation of why invertebrate communities are poor. In contrast, the Union River above Graham lake is listed as a “focus area of statewide ecological significance” due to the high habitat quality and the support given to several rare species (DIFW website). The contrast between the upper Union and the greatly modified lower river is stark.

If Graham Lake had a more stable water level, it would be more productive with better species diversity and would have cleaner water. Silver Lake in Bucksport is also a large shallow reservoir that is managed as a drinking water supply. With less water level changes, the lake has a stable shoreline and a well-vegetated littoral zone. Even though it is shallow and has lots of wind and fetch exposure, the lake water quality is better than Graham Lake. Silver Lake might be a good model for what Graham Lake could be.

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