SUPPLEMENTAL ANALYSIS—NHDES DAM #071.03

Oyster River Dam at Mill Pond

Durham, New Hampshire

PREPARED FOR

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JULY 2021

IN PARTNERSHIP WITH

Pare Corporation
Weston & Sampson
Independent Archaeological Consultants
UNH Water Systems Analysis Group
DK Water Resource Consulting LLC
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Executive Summary

The Oyster River Dam, also known as the Mill Pond Dam, is located on the Oyster River as it flows through the Town of Durham prior to its discharge into the Great Bay. Constructed in 1913, the dam is a concrete Ambursen-style dam consisting of a spillway, a set of gated outlets at the right abutment, and a fish ladder at the left abutment. It is approximately 140 feet long, with a maximum structural height of approximately 13 feet. Due to its age, engineering significance, and association with local history, the dam is listed on the NH Register of Historic Places.

The NHDES Dam Bureau has identified several safety deficiencies associated with the current dam, including concerns with its overall structural integrity and stability. The Town was notified of these problems in multiple Letters of Deficiency, most recently in February 2018.

The dam impounds the Oyster River, forming the 9.5-acre "Mill Pond" as well as portions of the Oyster River and Hamel Brook upstream of the Pond. The impoundment is used for numerous recreational activities such as fishing, paddling, birdwatching and ice skating. Over the years, water quality in Mill Pond has declined and portions of the pond have filled with sediment, converting much of the former open water area to emergent wetland habitat.

A detailed Feasibility Study published in November 2020 described several alternatives for addressing the dam safety issues, including detailed discussions of "Alternative 3 (Dam Stabilization)" as well as "Alternative 5 (Dam Removal)."

Following publication of the Feasibility Study, the VHB team was asked to conduct a Supplemental Analysis of Alternative 3 (Dam Stabilization) without Option 1 (Pond Restoration Dredge), as well as to explore additional analysis of the effects of Alternative 5 (Dam Removal). These analyses address questions related to watershed management actions that could improve Mill Pond water quality, the effect of upstream water withdrawals on Mill Pond, and whether Alternative 3 could be modified to improve fish passage and water quality.

Supplemental Water Quality Analysis

Mill Pond has experienced declining water quality conditions for many years, demonstrated by algae and rooted aquatic plant growth, sedimentation, low dissolved oxygen concentrations and increased water temperatures.

One key question posed to the team was whether the water quality impairments within the impoundment can be addressed through watershed management strategies if the Town selects Alternative 3 (Dam Stabilization). To determine how implementation of non-point source watershed management techniques might benefit Mill Pond under this alternative, the team developed a Lake Loading Response Model (LLRM) which predicts how the pond would react to watershed changes. Among the key findings of this analysis:

Most of the impairment issues in Mill Pond are related to over-enrichment of the pond with nutrients, primarily phosphorus.

The external loading of phosphorus would need to be substantially reduced to eliminate most water quality issues and allow Mill Pond to support designated uses. Annual average in-pond total phosphorus concentrations (0.060 mg/L) are more than twice the threshold (0.028 mg/L) for eutrophic ponds in New Hampshire (NHDES 2018b). This means that even modest improvements in Mill Pond water quality would require substantial reductions in the current phosphorus inputs to the pond.

Implementation of the non-point source program outlined in the 2018 Mill Pond Nutrient Control Study would not reduce total phosphorous enough to eliminate the water quality impairments.

The *Mill Pond Nutrient Control Study* (Roseen, Sahl, and Provost, 2018) described a set of 12 stormwater best management practices (BMPs) within the College Brook and Mill Pond Road portions of the Oyster River watershed. Construction of this program was estimated to cost nearly $1.8 million (2018 dollars). While the focus of this program was to reduce nitrogen loading, the BMPs would also treat phosphorous, the limiting nutrient in Mill Pond. The Supplemental Analysis estimated that this program would reduce the estimated total average annual phosphorus load from the targeted portions of the College Brook and Mill Pond sub-watersheds by approximately 52% - a reduction of approximately 109 kg/yr (240 lbs/yr). However, this reduction would benefit the pond only marginally. It would have little overall impact on Mill Pond phosphorus concentrations and Mill Pond would therefore remain in its current eutrophic state. Because College Brook and the Mill Pond Road sub-watershed only represents a small fraction of the total watershed for Mill Pond (about 8%), even complete elimination of the phosphorus load from this subwatershed would have little impact on the phosphorus concentration in Mill Pond.

A meaningful improvement in the water quality within Mill Pond would require a watershed-wide effort, requiring substantial investment from multiple stakeholders.

To reach the NHDES eutrophic threshold criteria of 0.028 mg/L, phosphorus loading across the entire Oyster River watershed nutrient load would need to be reduced by 53% (about 1,218 kg/yr or 2,685 lb/yr). Nutrient reduction on this scale would require a program roughly 10 to 11 times the size of the one discussed in the *Mill Pond Nutrient Control Study*. This would require a very significant investment of land, financial resources, and time to benefit a relatively small waterbody. It seems very unlikely that such a program could be developed and supported by the town of Durham alone. Resources from UNH as well as the towns of Lee and Madbury, would certainly be required, and private landowners and other stakeholders may need to participate to achieve this level of reduction.

Other management techniques may have some benefits, but none appear able to address the cause of the water quality impairment; the amount of improvement from these measures is difficult to predict.

The Supplemental Analysis provided a screening-level assessment of more than 20 lake management measures to improve Mill Pond water quality. Most were found to have low applicability. However, in addition to the non-point source controls discussed above, the following measures were deemed to have medium applicability:

- **Dilution/Flushing** – Due to its small size relative to the watershed, Mill Pond flushes at a very high rate, indicating that increased dilution and flushing would not benefit the pond under normal conditions. However, during very low flows, there is some possibility that water could be released from the upstream Oyster River dam to replace the low oxygen content water with higher oxygen content water which may have some benefit. Increased dilution and flushing would be inexpensive, since it would rely on the existing infrastructure. Water quality in the Oyster Reservoir is roughly equivalent to Mill Pond, at least in terms of nutrient enrichment. So, water from this source is not likely to benefit Mill Pond without substantial upstream non-point source load reduction.
- **Dredging** – As discussed in the November 2020 Feasibility Study, increasing the depth of the pond by means of mechanical or hydraulic dredging would provide temporary improvement to water quality, but at a very high cost. Dredging would be needed on a repeated basis, and therefore extremely difficult or even impossible to permit.
- **Side Stream Aeration** - Side stream aeration is a relatively new pond management technique that withdraws water at low velocity from deep sections of a pond or lake, adds oxygen in a shore-based station, and returns the water at low velocity to the pond. The fact that Mill Pond water temperatures are quite high in the summer would limit the amount of oxygen that can be added. A side stream system may help during low flow periods. However, it is only treating the symptoms of nutrient enrichment (low dissolved oxygen) and not the source. It is unlikely to help

with observed low dissolved oxygen concentrations in the shallow margins of Mill Pond as those areas are isolated to large extent from the "open water" areas by the extensive rooted plant growth and associated lack of water current. Initial design, construction costs, operational and maintenance costs to treat a 2-acre section of a small pond on Cape Cod were $30,000-$50,000 plus operating costs of $7 to $10/day. A similar installation at Mill Pond may result in costs of the same order of magnitude, but it should be noted that there are significant differences between the two systems.

Poor water quality, typified by low dissolved oxygen and high water temperatures, occur throughout the impoundment, not just at the dam site.

Water quality measurements for Mill Pond reported in the 2020 Feasibility Study were collected near the dam, and clearly showed periods of water quality impairment, especially for dissolved oxygen. The question was raised as to whether the data at the dam location is representative of water quality conditions throughout the impoundment. To explore this issue, the team collected and reviewed all available dissolved oxygen data to determine whether water quality varies within the impoundment. These additional sampling locations included the side pools within the downstream portion (Mill Pond proper, between College Brook inflow and the dam) and in the upstream portion (above College Brook and above the confluence between the Oyster River and Hamel Brook). Data included those collected by DK Water Resource Consulting in 2013, and in 2018 and 2019 by the Wollheim lab at UNH (Water Systems Analysis Group). Review of these additional data indicates that low dissolved oxygen levels occur in other areas of the pond and suggest that the dissolved oxygen impairment is not limited to just the lower pond area near the dam.

Hydrological and Hydraulic Analysis

To address questions related to the effect of water supply withdrawals from the Oyster River, the team developed a mass balance hydrological and hydraulic model of the Oyster River Reservoir, located approximately 1.8 river miles upstream of Mill Pond. The model calculates the effect of the withdrawals on Mill Pond and helps to assess whether summertime releases from the reservoir might be able to increase flow rates and reduce residence times (*i.e.,* increase flushing) in the downstream Mill Pond impoundment, thereby improving water quality. The hydraulic analysis previously reported in the November 2020 Feasibility Study was also extended to define the minimum size of the Oyster River and Hamel Brook under typical summertime low-flow and more extreme drought conditions, like those experienced in 2020.

These supplemental hydrological and hydraulic analysis resulted in the following findings:

Drinking water withdrawals from the Oyster River Reservoir have a negligible impact on inflows to Mill Pond during a typical year.

Using data from 2018, the mass balance model indicates that under typical conditions, drinking water withdrawals never decrease the amount of river flow into Mill Pond by more than 0.1 cfs or about 0.5%.

The effect of Oyster River Reservoir drinking water withdrawals is far more pronounced in a drought year like 2020.

In 2020, inflows to Mill Pond in the winter and early spring were above average. Model simulations indicate that in 2020, the effect of drinking water withdrawals on Mill Pond were minimal for much of the year - less than 1%. However, from June through November, monthly inflows were well below average, leading to drought conditions. During the driest months – August, September, and October – elimination of water withdrawals would have increased inflows to Mill Pond significantly, with increases of 72, 367, and 19%, respectively. However, it is important to note that these significant increases in inflow to Mill Pond do not result in equally large reductions in residence time in Mill Pond.

Similarly, residence times in Mill Pond (and therefore water quality conditions), are not significantly affected by Oyster River Reservoir water withdrawals during a typical year but are during a drought year.

Under typical conditions, residence times in Mill Pond are quite short, with the impounded storage volume sometimes being turned over multiple times per day. Residence times are longer during the summer. But even during July 2018, the driest month that year, drinking water withdrawals had a negligible impact, increasing residence time from about 10.3 days to about 10.6 days. However, withdrawals affect residence times in Mill Pond much more significantly during drought years like 2020. For example, in August and September 2020, residence times would have decreased from 123 days to 59 days and 176 days to 54 days, respectively, if withdrawals were eliminated. In both cases, residence times would still be almost two months, so the water quality benefit from curtailment even under drought conditions is unlikely to fully address the water quality impairments in Mill Pond.

Dam removal would substantially reduce the upstream depth and width of the Oyster River and Hamel Brook, especially during low flow conditions.

The November 2020 Feasibility Study reported the results from an extensive hydrological and hydraulic modeling effort which considered "typical flows" such as the median annual flow (34 cfs). For this Supplemental Analysis, the project team extended the modeling effort to include a typical summertime low flow (July 2018, average flow of 7.4 cfs) and more extreme drought conditions (July-September 2020, average flow of 2.5 cfs).

Dam removal would lower the hydraulic control of the river by approximately 9.6 feet. During typical conditions (median annual flow), the upstream surface water would decrease from about 19.7 acres to about 5.4 acres. Under low flow and drought conditions, the river surface area would decrease even more, to about 4.6 acres and 4.4 acres respectively. If the dam were removed, the following changes are predicted to occur at specific reaches:

- Mill Pond: Dam removal would effectively eliminate the pond. Under "normal conditions" typified by the median flow, the pond width would shrink from 514 to about 32 feet. The significance of the predicted changes to all hydraulic characteristics – depth, width, and velocity – grow more significant as river flow decreases. For instance, during the typical summer low flow conditions, the river width would decrease from 449 to 17 feet, and during drought conditions, the river width would decrease from 441 to 9 feet. It is important to remember that removal of the dam would allow tidal flow into the area currently occupied by Mill Pond, so these hydraulic results represent the low tide condition.

- Middle Impoundment, Above Mill Pond: Under median annual flows, average river width in this reach would decrease from about 91 to 41 feet. Again, the proportional change from existing conditions is expected to increase as river flows decrease. For instance, the river width is expected to decrease from 89 to 36 feet under typical summer low flows and from 88 to 34 feet under drought conditions. The removal of the dam will certainly change the hydraulics of the Oyster River in this area, but the scale of the changes in the Middle Impoundment are not as significant as they are predicted to be in Mill Pond, in large part because Middle Impoundment retains a more "riverine" and less "ponded" form in its present state.
- Oyster River Mainstem: Above its confluence with Hamel Brook, the Oyster River Mainstem reach would be relatively less affected than downstream areas. Under a median annual flow condition, the river's top width is expected to decrease from 39 to 37 feet. Even during low flow and drought conditions, the river width would only decrease to about 36 feet.
- Hamel Brook: The impounded portion of Hamel Brook would be significantly affected by dam removal. Under median annual flow conditions, the top width of the impounded portion of Hamel Brook would decrease from about 135 feet to 18 feet. As flows become smaller, the effect of dam removal would be even more pronounced. For instance, under low flow and drought conditions, Hamel Brook width would decrease from about 134 feet to 7 and 4 feet wide, respectively.

Natural Resources

The Supplemental Analysis provides a discussion of how the dam might be adapted under Alternative 3 to accommodate downstream fish passage by installing a low-flow notch in the spillway. And, additional discussion of invasive species is addressed, including a conceptual plan and worst-case cost estimate for management of invasive species.

If the dam is stabilized, a downstream fish passage notch could be installed to prevent fish stranding during low flows such as those experienced during Summer 2020.

The team consulted with NH Department of Fish and Game (NHF&G) personnel who are responsible for operation of the existing fish ladder to develop a concept plan for a downstream fish passage notch. The notch would be located on the right end of the spillway and would consist of three sets of stop logs to control flows and create a series of plunge pools through the height of the spillway. To limit potential for tidal intrusion, the top of the base slab would be set near elevation 6. For safety and operational purposes, a catwalk and railings over the stoplogs would be provided. An easement through the property abutting the south end of the dam may be required to allow for operations. Operation of the notch would be dependent on manual observation of spillway conditions. The additional cost of the notch would be approximately $65,000.

Invasive species management is recommended for either Alternative 3 or Alternative 5.

The risk posed by the potential spread of invasive species is difficult to predict, considering every ecosystem is different, and portions of the pond will be exposed to periodic tidal flow while other areas will continue to retain their freshwater characteristics. However, freshwater areas will likely be the most susceptible to invasive plant establishment. To minimize the threat of invasive species spread, and to aid in the restoration and protection of native plant diversity, it is advisable to develop an Integrated Vegetation Management (IVM) Program to manage the invasive species surround Mill Pond and upstream. This approach entails mechanical, cultural, biological, and chemical methods over a 3- to 5-year period and include actions before and after dam removal. The Supplemental Analysis outlines such an IVM Program and provides a conservative “worst-case” cost for this program at approximately $130,000 over five years. Note that portions of the IVM Program are also recommended if Alternative 3 is selected, in which case the 5-year cost would be just over $90,000.

1

Supplemental Water Quality Analysis

Mill Pond has experienced declining water quality conditions for many years, demonstrated by algae and rooted aquatic plant growth, sedimentation, low dissolved oxygen concentrations and increased water temperatures. To determine how implementation of non-point source watershed management techniques might benefit Mill Pond if the dam is stabilized, our team developed a "Lake Loading Response Model" which predicts how a surface water will react to watershed changes. We also reviewed techniques for in-pond remediation of water quality problems, and considered the available data on how water quality conditions vary within the impoundment.

Lake Loading Response Model

Mill Pond has experienced poor water quality exemplified by algae and rooted aquatic plant growth, sedimentation, low dissolved oxygen concentrations and increased water temperatures. Anthropogenic changes to the pond and the watershed have led to impairment of the designated uses of the pond including aquatic life integrity (based on ammonium, chloride, chlorophyll-*a*, dissolved oxygen saturation, pH and turbidity), fish consumption (based on mercury), potential drinking water supply (based on *E. coli*, fecal coliform and sulfates), primary contact recreation (based on chlorophyll-*a* and *E. coli*) and secondary contact recreation (based on *E. coli*) (NHDES 2018a).

Most of the impairment issues in Mill Pond are related to over-enrichment of the pond with nutrients, primarily phosphorus.[1] The external loading of phosphorus would need to be substantially reduced to eliminate most water quality issues and allow Mill Pond to support designated uses.

Current water and total phosphorus (TP) loading to Mill Pond was assessed using the Lake Loading Response Model (LLRM) methodology (AECOM 2009), which is a land cover export/lake response model developed for use in New England and modified for New Hampshire lakes by incorporating New Hampshire land cover TP export coefficients when available. The original model was calibrated to current conditions using data collected in 2013 (DKWRC 2014).

The direct and indirect nonpoint sources of water and TP to Mill Pond include:

› Atmospheric deposition (direct precipitation to the pond);
› Surface water base flow (dry weather tributary flows, including any groundwater seepage into streams from groundwater);
› Stormwater runoff (runoff from developed areas draining to tributaries or directly to the pond);
› Waterfowl (direct input from resident and migrating birds);
› Internal loading from deep water sediment release and resuspension of nearshore sediments; and
› Direct groundwater seepage including septic system inputs from nearby residences.

The primary conclusion of the DKWRC (2014) water quality report was that the overwhelming source of phosphorus to Mill Pond is from the watershed (>99%). Loading from all other sources including atmospheric, internal and waterfowl is very small in comparison to the watershed load.

Recent discussions regarding the fate of the Oyster River Dam at Mill Pond have prompted questions related to the potential to improve water quality in Mill Pond by reducing nutrient pollution from the watershed. The current LLRM prepared as part of this Supplemental Analysis follows studies targeted at assessing conditions in the pond (DKWRC 2014) and proposed loading reductions from portions of the watershed through the installation of BMPs designed to remove nitrogen but will also remove a portion of the phosphorus load. Specifically, the *Mill Pond Nutrient Control Study* (Roseen, Sahl, and Provost, 2018) identified potential locations for 12 stormwater BMPs within the College Brook portion of the Oyster River watershed to reduced pollutant loads within and downstream of Mill Pond.

Basic characteristics of Mill Pond relevant to this discussion are presented in **Table 1-1**.

Because Mill Pond is a small impoundment on a medium sized river, the flushing rate is extremely high - at times the reservoir flushes several times per day. Phosphorus is likely the controlling nutrient in Mill Pond, as it is in most freshwater lakes and ponds (Wetzel 2001). Based on the analysis presented in DKWRC (2014), annual average in-pond total phosphorus concentrations (0.060 mg/L) are roughly two times higher than the threshold (0.028 mg/L) for eutrophic ponds in NH (NHDES

[1] While nitrogen may play a secondary role in the impairments observed in Mill Pond, excess nitrogen input is more important to Great Bay immediately downstream of Mill Pond (USEPA 2021). Nitrogen impacts within Great Bay were discussed in the November 2020 Feasibility Study (VHB, *et al.*, 2020), which observed that algal and plant biomass growth within Mill Pond can affect the nutrient dynamics and although the impoundment may temporarily retain nitrogen during the summer months, a potentially greater release of dissolved organic nitrogen could occur following plant die-off and the decomposition process.

2018b). This means that to achieve an even modest improvement in pond water quality would require substantial reductions in the current phosphorus inputs to the pond.

The rapid flushing of the pond likely precludes the formation of the most noxious blooms in the open water areas by moving algal cells downstream before they reach bloom concentrations. However, during summers, flushing rates decline considerably, particularly along the margins that have filled in with sediments. Nonetheless, there is sufficient microbial biologic activity in the water column and sediments to result in depression of and near loss of dissolved oxygen (DO) at times, particularly in the summer. This decline in DO is much greater than expected based on warming water temperatures alone. Shallow areas by contrast are isolated from the main flow and are characterized by accumulation of sediment, thick rooted submerged and emergent plant beds, epiphytic (attached) algae, and cyanobacteria.

Table 1-1 Selected Characteristics of Mill Pond, Durham, NH

Parameter	Value
Watershed Area	5,124 ha
Pond Area	3 ha[1]
Watershed Size/Pond Area	1,708
Average Flushing Rate	864 flushings/yr
Annual Phosphorus Load	2,298 kg/yr
Phosphorus load from watershed (includes baseflow and stormwater)	2,294 kg/yr
In-pond Average Phosphorus	0.060 mg/L
Annual Nitrogen Load	23,702 kg/yr
In-pond Average Nitrogen	0.630 mg/L

Source: DK Water Resource Consulting, LLC

1 This area includes the main body of Mill Pond, but does not include the entire impoundment.

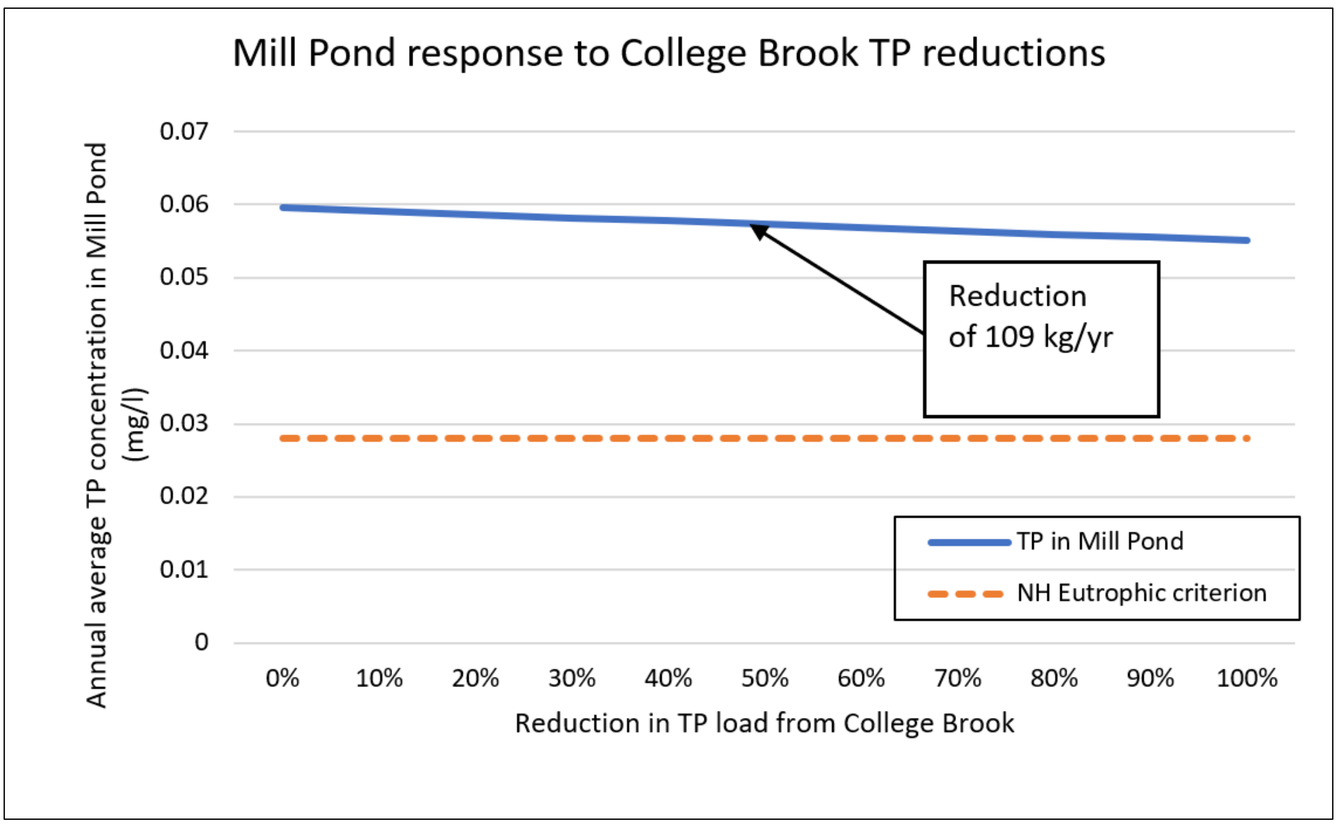
The LLRM model developed and calibrated for the 2013 study (DK 2014) was used to evaluate the influence of potential phosphorus load reductions on Mill Pond. Using projections from the LLRM model (DK 2014), College Brook currently contributes approximately 8% of the annual phosphorus load to Mill Pond.

The *Mill Pond Nutrient Control Study* (MPNCS) includes a proposed suite of 12 stormwater treatment BMPs to be installed in the lower part of the College Brook watershed and the Mill Road area that drains directly to Mill Pond. The proposed BMPs were selected to optimize nitrogen removal to address the nitrogen impairment in downstream estuarine waters of the Oyster River and to comply with federal stormwater requirements (i.e., the NPDES MS4 Permit). The proposed BMPs were predicted to result in an estimated annual nitrogen load reduction of 1,091 kg/yr (2,400 lbs/yr) by treating runoff from 257 acres of impervious cover. The estimated cost to implement these BMPs was $1,762,000 (Roseen, Sahl, and Provost, 2018). The estimated nitrogen load reduction represents approximately 50% of the total nitrogen load from the 257-acre study area and approximately 5% of total annual N load from the entire Mill Pond watershed (see Table 1-1).

Although the MPNCS BMPs were designed primarily to remove nitrogen, they would also remove a portion of the phosphorus from the contributing drainage area as well. Applying the phosphorus load export rates included in the Attachment 2 of Appendix F of the 2017 NH MS4 Permit to the various land use areas included in the MPNCS study area results in an estimated total average annual phosphorus load of approximately 208 kg/yr (460 lbs/yr) from the same 257-acre drainage area evaluated in the MPNCS study, which includes the lower portions of the College Brook watershed. The BMPs proposed in the MPNCS would potentially remove approximately 109 kg/yr (240 lbs/yr) or 52% of the estimated phosphorus load from the MPNPS study area if sized to handle a 0.5-inch storm, based on the EPA BMP performance data included in Appendix F of the MS4 Permit. Similar to nitrogen, this potential phosphorus load reduction represents approximately 5% of the estimated total average phosphorus load of 2,298 kg/yr from the Mill Pond watershed (see Table 1-1).

The LLRM model was then used to predict what affect a range of potential load reductions in the College Brook portion of the Mill Pond watershed would have on average annual phosphorus concentration in Mill Pond. Results are presented in **Figure 1-1** and **Table 1-2**. As illustrated in **Figure 1-1**, because the potential load reduction resulting from implementation of the MPNCS BMPs represents a small fraction of the overall watershed load, there would be minimal change in the Mill Pond phosphorus concentrations and Mill Pond would remain in its current eutrophic state. Even complete elimination of the phosphorus load from College Brook would likely have little impact on the phosphorus concentration in Mill Pond because the College Brook watershed only represents a small fraction of the total watershed for Mill Pond.

Figure 1-1 Annual Average Phosphorus Concentrations in Mill Pond as predicted by LLRM, College Brook Subwatershed

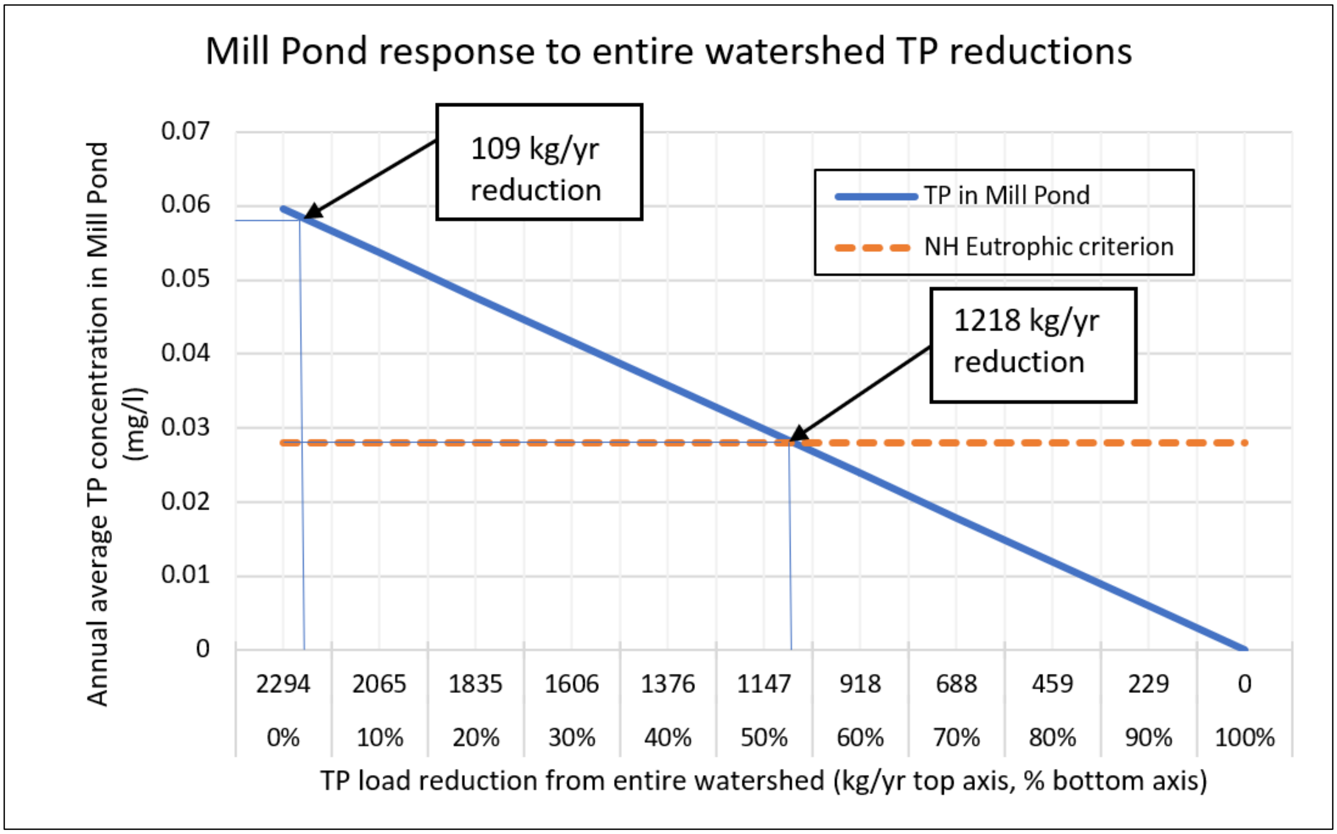


Note: 109 kg/yr reduction estimate is based on the BMP program described in Roseen, Sahl, and Provost (2018).

The model was then used to assess what level of potential phosphorus reduction would be needed in the entire Mill Pond watershed to cause a meaningful effect on Mill Pond phosphorus concentrations

(**Figure 1-2**). To reach the NHDES (2018) eutrophic threshold criteria of 28 µg/l (0.028 mg/L), phosphorus loading *across the entire Oyster River watershed would need to be reduced by 53% or by 1,218 kg/yr (2,685 lb/yr)*. In other words, to improve the trophic status of Mill Pond would likely require a load reduction that is more than 10 times greater than that predicted to occur with the proposed BMPs included in the MPNCS study.

Figure 1-2 Annual Average Phosphorus Concentrations in Mill Pond as predicted by LLRM, Oyster River Watershed



Note: The 109 kg/yr total phosphorous reduction estimate is based on the BMP program described in Roseen, Sahl, and Provost (2018). The LLRM predicts that a phosphorous reduction of 1,218 kg/yr is needed to eliminate Mill Pond's eutrophic condition.

Nutrient reduction on this scale would require a much more significant BMP program than the one discussed in the *Mill Pond Nutrient Control Study,* which by itself is estimated to cost nearly $1.8 million. As demonstrated by the LLRM, the amount of stormwater treatment in the watershed would need to be 10 to 11 times greater than that outlined in the MPNCS to improve the trophic status of Mill Pond. This would require a very significant investment of land and financial resources to benefit a relatively small waterbody. It seems unlikely that such program could be developed and supported by the town of Durham alone, and would certainly require participation and commitments from private landowners and other stakeholders in adjacent watershed communities to fully implement the range and extent of treatment measures likely needed to achieve this magnitude of load reduction.

The *Oyster River Integrated Watershed Management Plan* developed for the Town in 2014 presented a wide range of nonpoint source control measures including increased fertilizer use education and restrictions, improved manure management associated with agriculture operations, enhanced septic

Table 1-2 Projected Changes in Mill Pond with Reductions from Mill Pond Nutrient Control Study BMP program

		Mill Pond Current Conditions	10% TP load reduction College Brook	20% TP load reduction College Brook	30% TP load reduction College Brook	40% TP load reduction College Brook	50% TP load reduction College Brook	60% TP load reduction College Brook	70% TP load reduction College Brook	80% TP load reduction College Brook	90% TP load reduction College Brook	100% TP load reduction College Brook
% TP Reduction from College Brook		0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
College Brook TP Load (kg/yr)		175	157.23	139.76	122.29	104.82	87.35	69.88	52.41	34.94	17.47	0
Total TP Load (kg/yr)		2298	2281	2263	2246	2228.2	2211	2193	2176	2158	2141	2123
Mill Pond Response	Predicted TP (mg/L)	0.05959	0.05913	0.05868	0.05822	0.05777	0.05732	0.05686	0.05641	0.05596	0.05551	0.05505
	Predicted Chlorophyll a (mg/L)	0.0303	0.03	0.0297	0.0294	0.0291	0.0288	0.0285	0.0282	0.0279	0.0276	0.0273
	Predicted Probability of Algal Bloom > 0.010 mg/L	97.50%	97.40%	97.30%	97.20%	97.00%	96.90%	96.70%	96.60%	96.40%	96.30%	96.10%

Source: DKWRC

system technologies and stormwater treatment focusing on reducing nitrogen loads in the watershed. This study generally had similar findings in that the feasible upper limits for potential nitrogen load reductions represented approximately 5 to 10% of the estimated total watershed load as a result of the various measures proposed, and had estimated overall 20-year life-cycle cost to the Town of approximately $500,000/year (2014 dollars). The Program would require participation and commitments from various partners including various aspects of UNH facility operations, private landowners and assistance from non-profit organizations such as the Piscataqua Region Estuaries Program to conduct a public education campaign.

Because these BMPs would reduce both phosphorous and nitrogen, such reductions would benefit not only Mill Pond, but also Great Bay, which is likely to generate interest and support from state and federal agencies. Even with broad support, however, the project development process, including funding, land acquisition, design and permitting, and construction would take many years or even decades before any measurable benefits would be realized.

Additional In-Pond Measures

This section discusses a screening level alternatives analysis for in-pond management of water quality in Mill Pond. The analysis describes each reasonable alternative, discusses its applicability to Mill Pond, and provided generalized costs. Feasibility is not assessed, and the benefits and impacts are discussed in qualitative terms.

This review was prepared to screen in-pond management alternatives for suitability to address water quality issues in Mill Pond caused primarily by phosphorous loading and sedimentation. The factors that control primary productivity (plants and algae) or the symptoms of excess primary productivity (physical loss of use (aquatic plants), low dissolved oxygen) form the basis for many of the techniques. Others change the physical environment. Light and nutrients are the critical needs for primary productivity. Management techniques such as dyes, artificial circulation and selective plantings seek to establish light limitation, while methods such as oxygenation, dilution and flushing, drawdown, dredging, phosphorus inactivation, and selective withdrawal are used to reduce nutrient availability and/or increase oxygen content.

Table 1-3 provides a listing of the management techniques to control primary productivity in current use in ponds and lakes. The table provides an assessment of which techniques are applicable for use in Mill Pond. The second column provide qualitative rankings of cost from low to high. It is possible that techniques with high applicability may not be appropriate because of high cost. More detail on each of these measures is reported in **Appendix A,** which contains an update of the screening reported in DKWRC (2014), but includes techniques that have been developed and refined since that evaluation and takes into consideration new water quality data and developments in lake management over the last several years.

Appendix A lists other key considerations for the various techniques evaluated for possible use to enhance Mill Pond. Preference is given to those techniques that address phosphorus loading rather than the symptoms of nutrient enrichment, but the list includes a range of options that may achieve either source control or treat the symptoms of nutrient enrichment in Mill Pond. These techniques take advantage of algal or plant ecology and supplement or counteract the forces involved in algal and plant losses or growth, respectively. The techniques with medium or high applicability are described in more detail below and more cost information is provided.

Table 1-3 Summary of Lake Management Measures to Improve Mill Pond Water Quality

Management Option	Applicability	Cost
1. Nutrient input reduction		
1a. Point source control	n/a – no point sources	n/a
1b. Non-point source controls	high	high
1c. Pollutant Trapping (Stormwater BMPs)	medium[1]	very high
2. Circulation and destratification	low - pond is not consistently stratified and flushes rapidly	medium
3. Dilution/Flushing	medium	low
4. Drawdown	n/a – except in context of dredging	low
5. Dredging		
5a. Dry Dredging	high	high
5b. "Wet" excavation	low	high
5c. Hydraulic dredging	medium	high
6. Light blocking/limitation		
6a. Light blocking dyes	n/a - flushing rate too high, migration of dye downstream	low
6b. Surface covers	n/a - cover would eliminate recreation opportunities and much aquatic life	medium
7. Plant Harvesting	low – frequent maintenance	low
8. Selective Withdrawal	n/a – stratification has not been documented	medium
9. Sonication	low – high flushing rate would limit effectiveness	medium
10. Aeration and oxygenation		
10a. Hypolimnetic aeration/oxygenation	low – no stratification	high
10b. Side stream oxygenation	medium	medium
11. Herbicides		
11a. Copper herbicides	low – aquatic toxicity, high flushing rate	low
11b. Peroxides	low – costly, high flushing rate	high
11c. Synthetic herbicides	low – aquatic toxicity, high flushing rate	medium
12. Phosphorus inactivation	low – no documented internal loading	medium

13. Sediment oxidation	low – no documented internal loading	medium
14. Settling agents	low – frequent maintenance	medium
15. Selective nutrient addition	n/a – targets cyanobacteria	low
16. Biomanipulation		
16a. Herbivorous fish	low – requires introduction of non-native species	low
16b. Enhanced grazing	low – difficult to establish target species in open system	low
17. Bottom feeding fish removal	n/a – no documented occurrence	medium
18. Microbial competition	low – favorable results for P control not documented	medium
19. Pathogens	low – experimental algae treatment	medium
20. Competition and allelopathy by plants		
20a. Plantings for nutrient control	n/a – dense vegetation already present	low
20b Plantings for light control	n/a – dense vegetation already present	low
20c. Addition of barley straw	low – experimental algae treatment	low

Source: DK Water Resources Consulting, LLC. Additional detail, including a brief definition of each Management Option, presented in **Appendix A**.

1 See analysis of stormwater BMP effectiveness in LLRM discussion.

The following sections discuss the specific measures which may be somewhat helpful to mitigate water quality concerns in Mill Pond. It should be noted that none of the in-pond techniques is expected to address all the impairments in Mill Pond and all will perform better with a reduction in the nutrient supply to the pond. Several of the alternatives (dredging, side stream oxygenation and dilution/flushing) primarily address the symptoms of nutrient enrichment. Non-point source controls address the cause of many of the pond impairments.

Dredging

A conceptual plan for Mill Pond dredging was evaluated in detail in the November 2020 Feasibility Study, and will not be fully described here. Dredging will increase the volume of Mill Pond, will remove nutrients from the sediments, that are often a source of phosphorous to the water column, and create additional open water habitat. However, the controlling nutrient dynamics of the pond will not change appreciably since based on the LLRM model, the overwhelming majority of the nutrients in Mill Pond (99.85%) come from the watershed, not from internal loading from the pond sediments (DKWRC 2014). Dredged areas will exhibit less aquatic plant growth for a time after dredging. However, because the nutrient supply will remain largely unchanged, there may be additional free floating and attached algal growth. In the context of current nutrient and sediment loading, dredging should be considered a maintenance activity rather than a restoration activity. Without substantial nutrient and sediment loading reduction from the watershed, the pond will refill with sediments. The cost for a 2.4-acre Pond Restoration Dredge was presented in the Feasibility Study to be approximately $3.15 million, assuming hydraulic dredging. However, given concerns regarding the sustainability of the pond dredge, obtaining regulatory approvals for this component of the project would be extremely difficult or perhaps even impossible.

Increased Dilution and Flushing – Oyster Reservoir Management

Dilution and flushing were given an applicability score of medium after a more thorough analysis. According to the water quality modeling, phosphorus concentrations in the Oyster River portion of the watershed are roughly equivalent to those observed in Mill Pond. Therefore, water from this source is not likely to benefit Mill Pond without substantial non-point source load reduction upstream. It is worth noting that Mill Pond already flushes on average 3 times per day. There is some possibility that water could be released from the upstream Oyster River dam during periods of low river flow and low dissolved oxygen in Mill Pond to replace the low oxygen content water with higher oxygen content water. While this may be somewhat helpful in the short term as the minimum amount of water available is sufficient to replace about 60% of the Mill Pond water, it should be recognized that lower flows entering Mill Pond will prevail as the Oyster River impoundment refills after a flushing event. In addition, the low dissolved oxygen water from Mill Pond would be flushed into the estuary downstream and may result in localized oxygen issues there, however release of water over the dam will result in some reaeration between the pond and the estuary. Reducing municipal water withdrawals from the Oyster River is expected to have a very minor effect as these withdrawals are very small relative to the river flow.[2] Furthermore, this alternative should be viewed as treating the symptom of nutrient enrichment only and not the cause. The initial capital costs for this option are expected to be minimal as existing infrastructure would be used.

Side Stream Aeration

Side stream oxygenation is a relatively new pond management technique (Gerling *et al*., 2014) that withdraws water at low velocity from deep sections of a pond or lake (typically isolated lower layers), adds oxygen in a shore-based station and returns the water at low velocity to the pond. This technique does not cause substantial mixing of the water column. This technique was given a medium applicability score for Mill Pond due to the fact that Mill Pond rarely thermally stratifies and the flushing rate is high most of the year which may call for a relatively large system unless treatment were only targeted to the summer period. The fact that Mill Pond water temperatures are quite high in the summer and warm water holds less oxygen than cold water is a limit on the amount of oxygen that can be added. A side stream system may help during low flow periods; however, it is only treating the symptoms of nutrient enrichment (low dissolved oxygen) and not the source. It is unlikely to help with observed dissolved oxygen in the shallow margins of Mill Pond as those areas are isolated to large extent from the "open water" areas by the extensive rooted plant growth and associated lack of water current. Initial design, construction costs, operational and maintenance costs to treat a 2-acre section of a small pond on Cape Cod were $30,000-$50,000 plus operating costs of $7 to $10/day. A similar installation at Mill Pond may result in costs of the same order of magnitude. Because there are significant differences between the two systems (a small stratified

[2] Chapter 2 of this report discusses a mass balance model of the Oyster River Reservoir, and provide some information on the likely effects of managing flows from the reservoir.

pond vs a rapidly flushed unstratified impoundment) specific costs cannot be estimated without additional feasibility analysis.

Mill Pond Water Quality Spatial Variation

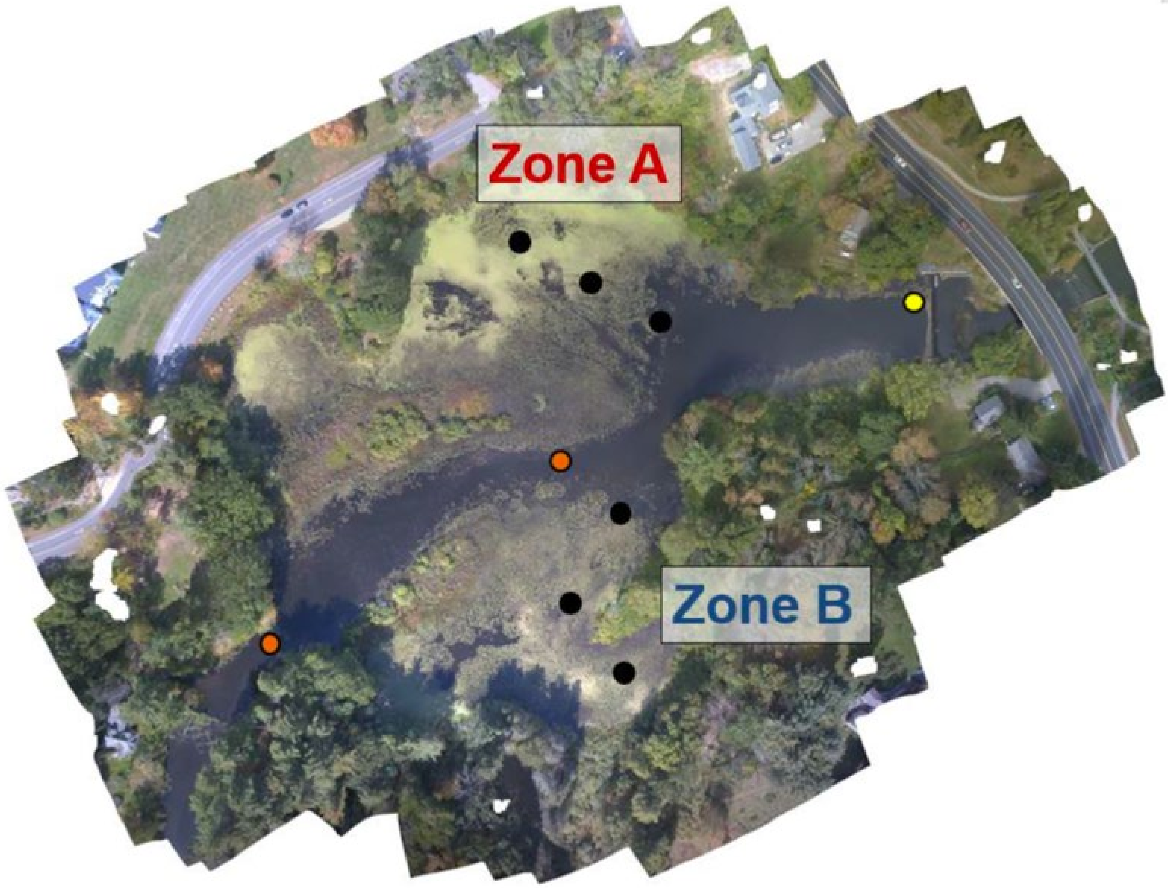
Most of the water quality measurements in Mill Pond have been collected near the dam, which clearly show periods of water quality impairment, especially for dissolved oxygen. The question has arisen as to whether data at this location is representative of water quality conditions in the pond as a whole. To explore this issue, all available data within the pond were collected and reviewed to determine water quality variability within the reservoir, including in the side pools within the downstream portion (Mill Pond proper, between College Brook inflow and the dam) and in the upstream portion (above College Brook and above the confluence between the Oyster River and Hamel Brook). This includes data collected using handheld meters during summers by DK Water Resource Consulting in 2013, and in 2018 and 2019 by the Wollheim lab at UNH (Water Systems Analysis Group). This analysis focuses on Dissolved Oxygen (DO) and Water Temperature (Temp) as the most relevant water quality variables.

Within Mill Pond proper, DO levels in the shallower margins, which consist of most of the surface area of Mill Pond (Zones A and B in **Figure 1-3**) tend to be much lower than at the dam (OMPD) most of the time (**Figure 1-4a**, DO < 100% saturation), but there were periods with supersaturation (**Figure 1-4a**, DO > 100% saturation). DO greater than 100% saturation indicates DO inputs via photosynthesis, which may occur during algal blooms. All these data were collected during the day, so DO would likely tend to be lower at night when photosynthesis is not occurring, while respiration by algae and bacteria continues. Further, DO is lower at the edges of the pond than in the main channel, based on transects through Zone A and Zone B in **Figure 1-3** (Balch 2020). Temperature also tended to be several degrees warmer in the side pools, but this effect seemed small compared to the seasonal effects (**Figure 1-4b**).

In the section of Mill Pond between the Hamel and College Brook Confluences (Station OHC), DO levels were generally similar to that observed at the upstream Oyster River station (ORR) and higher than at the dam (**Figure 1-5**). Similar results were observed in 2013 (**Figure 1-7**). However, in 2019, there were at least three instances early in the summer where DO levels in the OHC section were lower than at the OMPD (**Figure 1-5**). Water temperatures were generally similar in this section of Mill Pond compared to that observed at the OMPD (data not shown). Finally, in the Hamel Brook section of the impoundment, two limited transects conducted in July 2018 showed similar DO levels in the impounded section of Hamel Brook near the Oyster River confluence that were higher than that at OMPD. But at a site upstream of the impounded section (**Figure 1-6b**, site M), the DO levels were much lower and near 0% saturation. These levels were lower than at OMPD (**Figure 1-6**). This might suggest a potential source of oxygen demand related to decay of organic matter. Flow from the upstream wetland in the Long Marsh area might also contribute to these low dissolved oxygen levels.

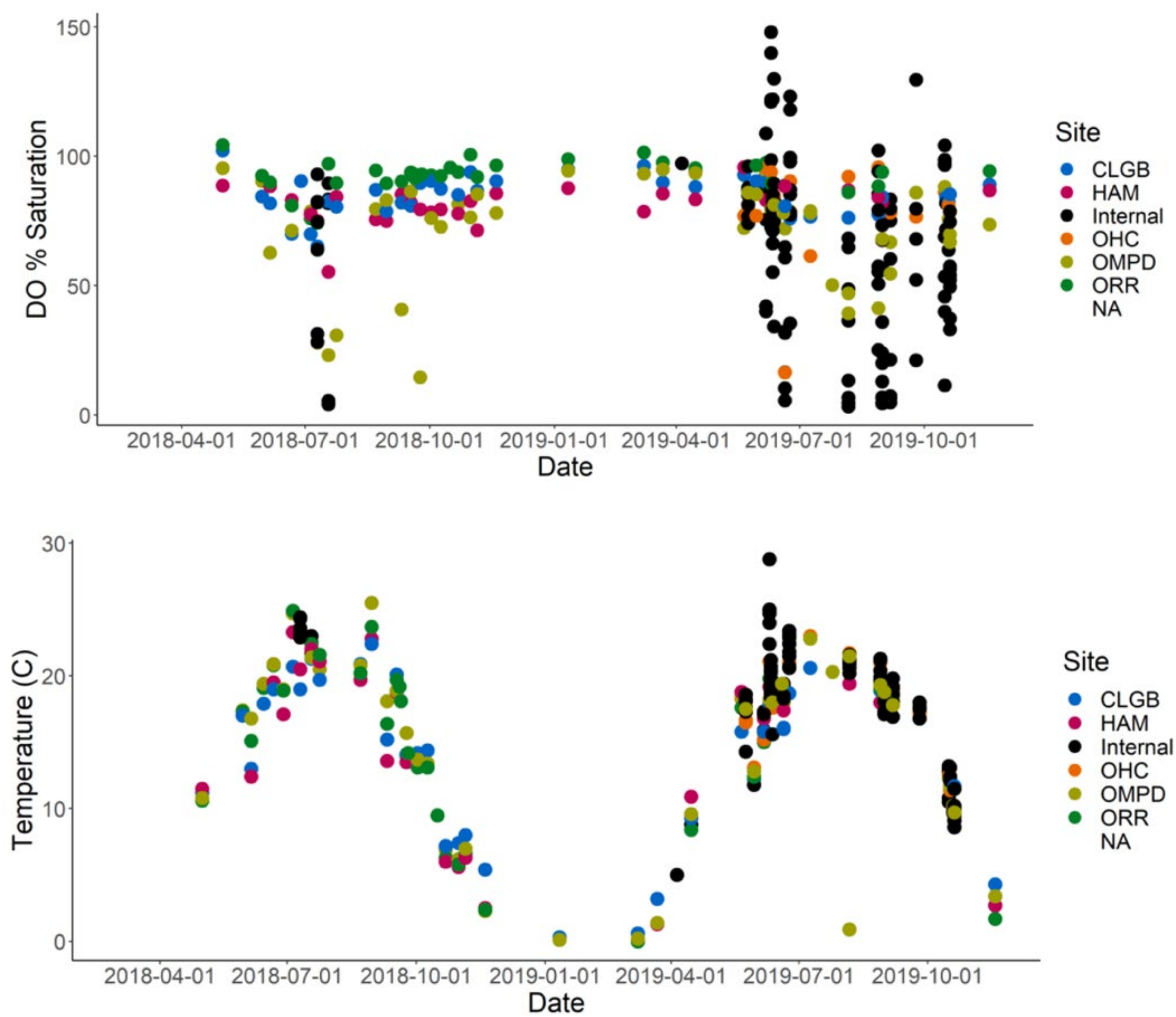
Review of this additional data indicates that low dissolved oxygen levels occur in other areas of the pond and suggest that the dissolved oxygen impairment is not limited to just the lower pond area near the dam.

Figure 1-3 Mill Pond from the Dam to College Brook Confluence



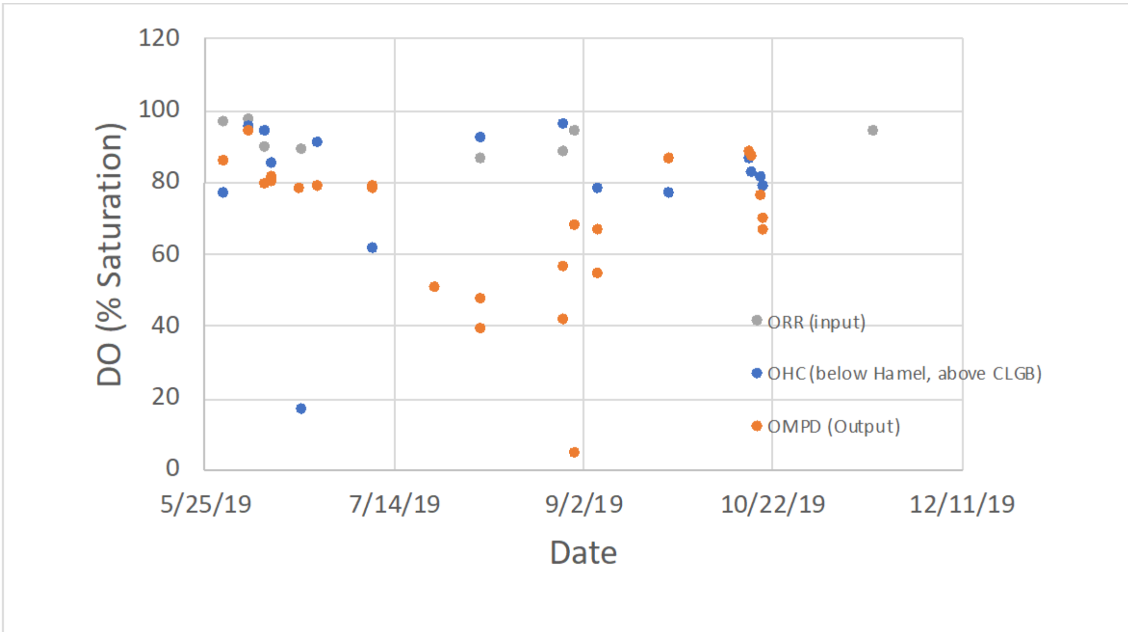
Notes: Zone A and Zone B are shallow sections where sediments have accumulated. Black dots represent sample locations in Zone A and B, while other dots represent sample locations in the deeper sections of the reservoir.

Figure 1-4 Dissolved Oxygen and Temperature Variation within Mill Pond Impoundment



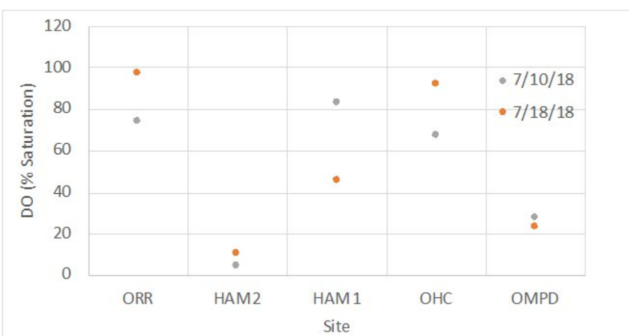
Notes: a) Top - Dissolved oxygen percent saturation and b) Bottom - Water temperature at the inputs, outputs and within Mill Pond. CLGB = College Br. (free flowing), HAM = Hamel Br. (free flowing, ORR = Oyster River at River Rd (free flowing), OMPD = Oyster River at the Mill Pond Dam (ponded outflow), OHC = Oyster at Hamel Chapel (between Hamel/Oyster confluence and College Br.

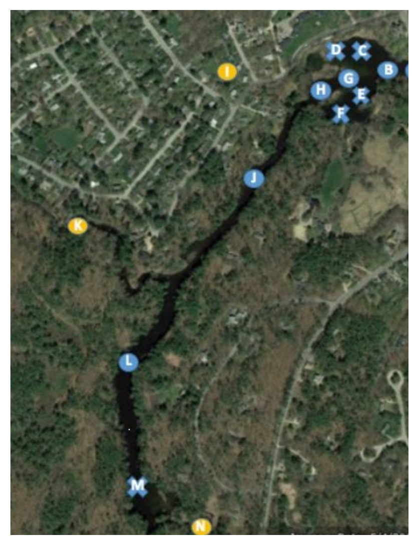
Figure 1-5 Dissolved Oxygen at Mill Pond Impoundment Upstream Stations, 2019



Notes: DO % saturation during the 2019 growing season at the outflow (OMPD), in the channelized inflow (ORR), and at OHC (near Hamel Chapel, between Hamel/Oyster confluence and College Br. confluence).

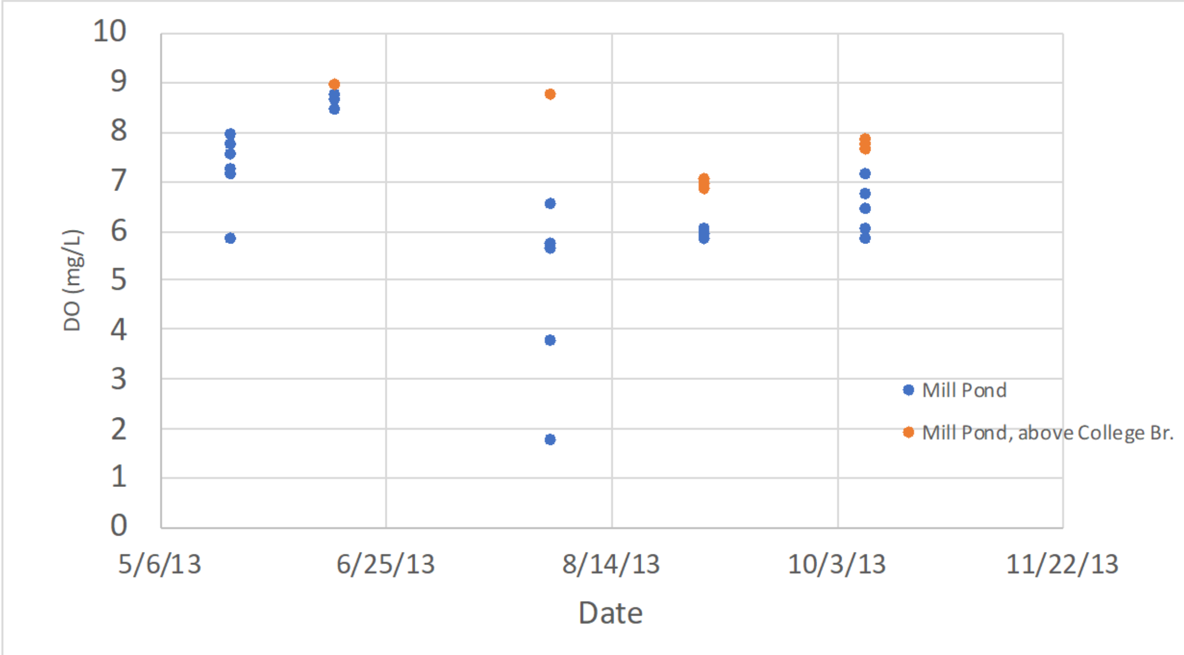
Figure 1-6 Dissolved Oxygen at Mill Pond Impoundment Upstream Stations, 2018





Notes: a) (left) DO % saturation at several locations distributed throughout the Mill Pond reservoir during two different days in July 2018. b) (right) Map of Mill Pond with sample locations. ORR is the Oyster River at River Rd (free flowing), OMPD = Site A (outflow just above dam), OHC = Site J (near Hamel Chapel), HAM1 = Site L, HAM2 = Site M.

Figure 1-7 Dissolved Oxygen in Mill Pond Thalweg, 2013



Notes: DO concentrations in the deep part of Mill Pond near the dam and upstream of the College Br. confluence (roughly corresponding with site "J" in Figure 1-6b) in 2013 (Source: DKWRC). Multiple points on a given day indicate different concentrations at different depths at the location.

2

Supplemental Hydrological & Hydraulic Analysis

To address questions related to the effect of water supply withdrawals from the upstream Oyster Reservoir, our team developed a mass balance hydrological model of that impoundment. We used the model to evaluate the effect of the withdrawals on Mill Pond, and to understand whether summertime releases from the reservoir might be able to increase flow rates and reduce residence times (i.e., increase flushing) in the downstream Mill Pond impoundment, thereby improving water quality. We also extended the hydraulic analysis we previously reported in our November 2020 Feasibility Study to define the minimum size of the Oyster River and Hamel Brook under low-flow and drought conditions, like those experienced in 2020.

Oyster Reservoir Mass Balance Model

The project team developed a mass balance model of the Oyster River Reservoir ("the Reservoir") to answer the following questions:

› How does the Oyster River Reservoir Dam impact downstream flows in the lowest reaches of the Oyster River, including Mill Pond?
› How do the drinking water withdrawals from the Reservoir impact those downstream flows? and

- What are the average inflows and residence times in Mill Pond during both typical years and dry years?

Answering these questions will help to determine whether the water quality impairments within Mill Pond can be addressed through a series of watershed management strategies.

Model Development

The project team developed a mass balance model of the Oyster River Reservoir, computing reservoir storage and water level on a daily basis, based on several fluxes both in and out of the reservoir. A mass balance model of a reservoir is effectively summarized by the following equation:

$V_t = V_{t-1} + Q_{in} - Q_{out} + P - E - W + G$, where

V_t = reservoir storage volume on day t;
Q_{in} = the streamflow entering the reservoir;
Q_{out} = the streamflow exiting the reservoir, in this case, flow over the spillway;
P = precipitation on the reservoir surface;
E = evaporation from the reservoir surface;
W = drinking water withdrawals; and
G = net groundwater inflow (can be negative indicating a net loss to groundwater).

The model was initially developed and calibrated, to check its reliability, by focusing on the period 2015-2019, for which daily drinking water withdrawal and reservoir level data are available. Based on those datasets and on high quality streamflow data record at the USGS gage upstream, the project team was able to estimate average groundwater inflows/outflows from the reservoir on a monthly basis. Based on those monthly average groundwater contributions and the high quality, long-term USGS streamflow dataset, the model was used to simulate daily changes in reservoir level for the period 1970-2020. The results of such long-term model simulations informed the project team's understanding of the typical impacts of the Oyster River Reservoir and drinking water withdrawals on inflows to Mill Pond. Each model parameter is discussed in more detail below.

The following sub-sections discuss the various fluxes in and out of the Reservoir that were incorporated into the model. Later sections discuss the calibration effort and model findings.

Stage-Storage

Inflow and outflow datasets tend to be represented as flow rates or volumes, but changes in the reservoir are generally more conveniently expressed in terms of reservoir level (or stage). Therefore, it is useful to develop a "stage-storage" curve that relates a reservoir's level with its storage volume. In the case of the Oyster River Reservoir, stage-storage data pairs below the normal water line near the spillway elevation, were provided by the Town.[3] Stage-storage data above the normal water line were estimated by applying the equation for the storage volume of a trapezoidal prism to the reservoir's surface area at 1-ft. contour intervals, based on the latest LiDAR available from GRANIT.[4] Based on the stage-storage curve developed in this manner, the reservoir's total storage ranges from 0.0

3 Based on a bathymetric map and calculations developed by Keith McKane in December 1984.

4 State of New Hampshire: LIDAR for the North East – ARRA and LiDAR for the North East Part II (2011).

million gallons at the bottom of the reservoir, El. 32.6, to 14.7 million gallons when the reservoir is just starting to spill water, El. 49.0, to 29.8 million gallons when the reservoir is full to the dam crest, El. 53.0.

Streamflow

The primary source of water into the Reservoir is streamflow carried by the Oyster River. The drainage area of the Oyster River at the Oyster River Reservoir Dam is approximately 16.0 sq mi. A long-term USGS gage, #01073000, which is located further upstream on the Oyster River, has a drainage area of approximately 12.1 sq mi. Using an area-weighting methodology, USGS gage streamflow data was multiplied by a factor of 1.33 to estimate streamflow entering the Reservoir.

Precipitation

In some reservoir models, it is important to differentiate rainfall that occurs on the reservoir surface itself – and is therefore immediately "available" to the reservoir – from rainfall that occurs upstream and is converted first to runoff and then streamflow before entering the reservoir sometime later. This distinction is particularly important for systems where the reservoir represents a significant portion of its watershed. In this case, however, as the Reservoir is a small fraction (~0.06%) of the size of its watershed, that distinction is unnecessary. In other cases, it may be useful to distinguish between streamflow into a reservoir and rainfall on its surface if the source of streamflow data, such as a USGS gage, is a relatively long distance upstream, and there is a significant lag between when runoff events are recorded at the gage and when they reach a reservoir. That is not the case here; the Reservoir is roughly four miles downstream of the USGS Oyster River gage. Any lag in flow changes would be expected to be on the order of six hours or less. Based on the hydrology of the Oyster River and the availability of high quality, long-term streamflow data recorded a short distance upstream, precipitation landing directly on the Reservoir's surface was assumed to be sufficiently represented by the area-weighted streamflow inflow dataset.

Evaporation

Evaporation occurs from standing water of all kinds (e.g., ponds, wetlands, puddles, raindrops caught on tree leaves, etc.), and transpiration occurs via plants and trees throughout an entire watershed. On a watershed scale, precipitation, evaporation, and transpiration are largely reflected in the streamflow exiting the watershed. Because direct evaporation rates from large open waterbodies, like reservoirs, are relatively large, on a per area basis, when compared to evaporation and transpiration (ET) rates across a whole watershed, the additional ET losses from the reservoir may not be adequately reflected in area-weighted streamflow data. However, in this case, because the Reservoir's surface area is a small fraction of the larger drainage area and because the Reservoir is relatively long, thin, and partially covered by overhanging trees during the warm months, those additional evaporation losses are negligible and can, in fact, be assumed to be sufficiently represented in area-weighted streamflow inflow dataset.

Spillway Discharge

Streamflow out of the reservoir consists primarily of flow discharged over the spillway, which is a function of reservoir level and can be estimated with an equation for a generic weir:

$Q = C_d \times L \times H^{3/2}$, where

Q = discharge rate (cfs);
C_d = is a coefficient of discharge based on the design of the spillway;
L = the length of the spillway (feet); and
H = head or depth of flow across the spillway (feet).

In this case, the length of the spillway, 97 feet, was determined from the design drawings of the dam.[5] The head or depth of flow across the spillway is calculated by subtracting the reservoir water surface elevation from the elevation of the top of the 2-foot-tall flashboards that are installed on the spillway, El. 49.0.[6] During the model calibration process, head over the spillway was calculated from daily reservoir levels reported by Water Treatment Facility staff between 2015 and 2019.[7] (In early 2020, daily reservoir levels were no longer taken.) The coefficient of discharge was iteratively changed during the calibration process until a value was identified that maximized agreement between simulated and historically observed reservoir levels.

Drinking Water Withdrawals

In addition to discharge over the spillway, water in the reservoir is also "lost" to drinking water withdrawals. The magnitude and frequency of withdrawals from the Oyster River Reservoir changed considerably when the Spruce Hole groundwater source went online in September 2015. Typical monthly withdrawal rates over the January 2016 – December 2020 period, are summarized in **Table 2-1**, based on data included in Monthly Treatment Reports submitted by the Town to the New Hampshire Department of Environmental Services.[8] For context, monthly withdrawal rates are compared to average monthly streamflow entering the reservoir.

Groundwater

In most cases, rivers and streams are constantly sharing water back and forth with the underlying aquifer. Sometimes there is a net inflow from groundwater to surface water, in which case the stream is a "gaining" stream, and sometimes there is a net outflow from the surface water to the aquifer, in which case the stream is a "losing" stream. In many cases, the same river or stream will be gaining for part of the year and losing for other parts. In general, reservoirs tend to be "losing" more often than free-flowing reaches upstream and/or downstream because the pond level is artificially high compared to the natural groundwater table. Regardless, groundwater inflows and outflows from a reservoir are notoriously difficult to estimate, even with significant, long-term field data gathered specifically for that purpose. In the case of the Oyster River Reservoir, there are no such datasets available. Instead, average groundwater losses from the reservoir (or gains to the reservoir) were estimated based on a comparison of the historically observed changes in reservoir level and the changes in reservoir level that would have been expected based on all the other fluxes into and out of the reservoir, for which high quality data does exist for the calibration period, 2015-2019.

5 Water Supply System from Oyster River – General Plan of Dam and Filtration Plant, October 1934.

6 Elevations identified in this report indicate a height, in feet, above mean sea level as referenced to the National Geodetic Vertical Datum of 1929 (NGVD29) unless otherwise noted.

7 Monthly Treatment Report – UNH-Durham Water Supply, January 2015 – December 2020.

8 Monthly Treatment Report – UNH-Durham Water Supply, January 2015 – December 2020.

Table 2-1 Average Drinking Water Withdrawals and Streamflow by Month

Month	Days with Withdrawal	Average Withdrawal (gallons per day)	Average Streamflow (gallons per day)
January	0	0	3,686,507,530
February	2	944	3,629,811,808
March	13	24,692	4,492,375,290
April	24	9,771	5,816,269,674
May	37	44,357	2,667,904,394
June	32	35,598	1,150,490,327
July	9	4,611	667,286,789
August	80	69,503	698,313,019
September	92	115,917	475,455,551
October	64	86,125	1,098,182,845
November	2	1,966	2,896,915,684
December	1	1,842	3,666,794,731

There is also considerable variability in drinking water withdrawals from year-to-year as shown in **Table 2-2.**

Table 2-2 Average Drinking Water Withdrawals by Year

Month*	Days with Withdrawal	Total Withdrawals (gallons)
2015	89	51,791,400
2016	63	5,956,360
2017	47	7,273,888
2018	15	2,947,535
2019	133	23,502,071
2020	98	23,767,112

Note: Data from 2015 includes withdrawal records before September 2015, when the Spruce Hole groundwater source went online.

Model Calibration

By iteratively modifying the spillway's effective discharge coefficient and by iteratively estimating monthly average groundwater net losses (or gains), the project team calibrated the model to refine agreement with historically observed reservoir levels over the January 2015 – December 2019 period. As shown in **Table 2-3**, the agreement between simulated reservoir levels and historically observed values are quite close, with average monthly deviations ranging from the model underpredicting reservoir levels by an average of 0.02 feet in September and overpredicting reservoir levels by up to 0.05 feet in April and May.

Table 2-3 Model Calibration Results

Month	Average Deviation* (feet)
January	0.02
February	0.04
March	0.05
April	0.05
May	0.02
June	0.01
July	0.01
August	0.01
September	-0.02
October	0.01
November	-0.01
December	0.02

Notes:

1 Average Deviation of Simulated Reservoir Level from Historical Observations by Month, 2015-2019

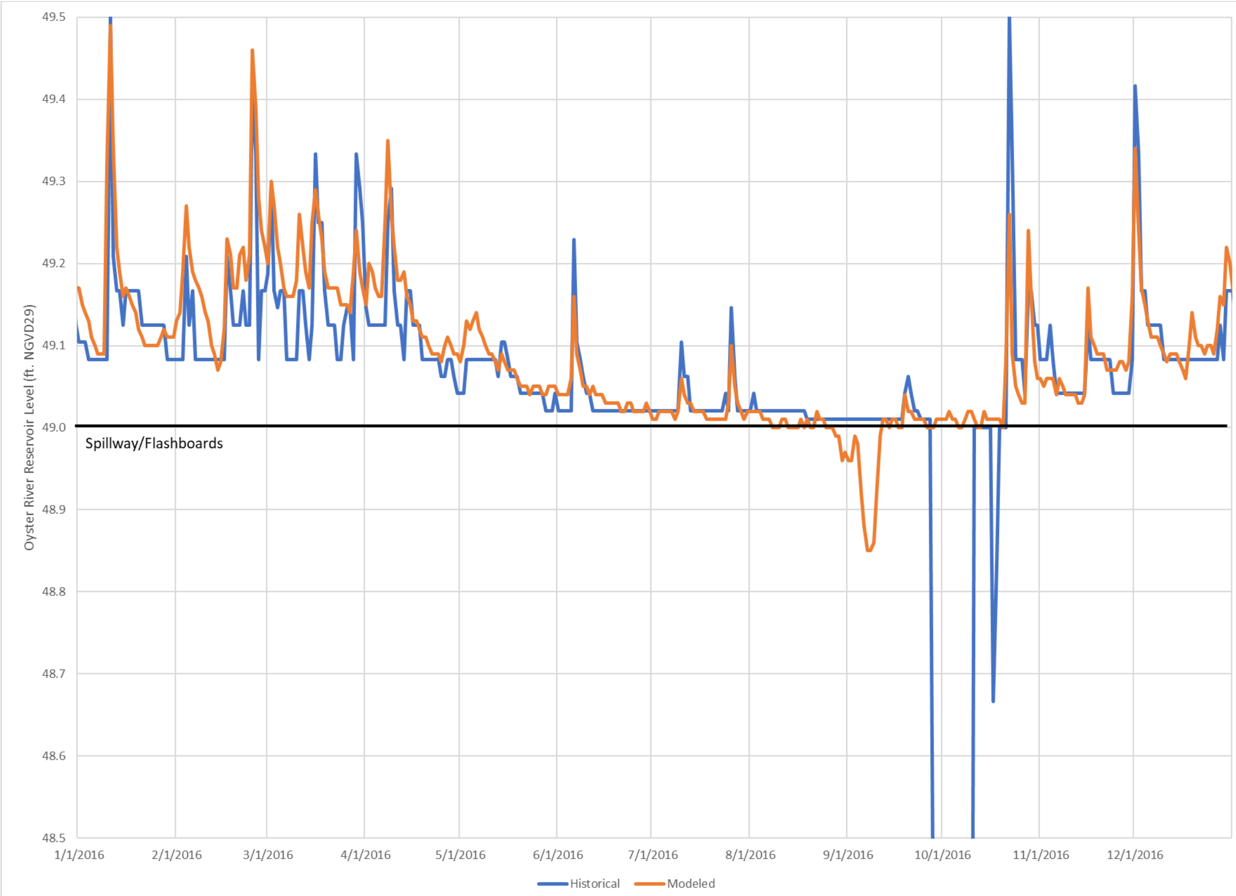
2 Positive values indicate the model simulates a higher reservoir level than were historically observed.

Figure 2-1 illustrates the ability of the mass balance model to recreate historically observed reservoir levels and some of its seasonal nuances. Overall, the simulated reservoir level (orange line) and historical levels (blue line) track very well, and the model recreates general seasonal trends as well as the reservoir's response to individual storm events and periods of drought. Given the goals of this supplemental analysis, it's worth noting that the model does a good job during the low water conditions that were observed from mid-May through mid-October in 2016. Simulated water levels over that period are generally within 0.02 feet of observed levels, and the model quite accurately recreates the reservoir's response to four significant rain events that occurred in June (1), July (2), and August (1).

There are two deviations worth noting, however. The first is that the model predicts that the reservoir should have dropped below its spillway flashboards, indicating no direct discharge into the downstream channel, although groundwater baseflow would likely have continued to feed the Oyster River, albeit to a lesser degree. Historically, no such drop below the flashboards was recorded. However, the treatment plant operators did indicate a reservoir level of "0 inches over the spillway," which is exceedingly rare in the Monthly Treatment Report dataset. It is possible, perhaps likely, that the reservoir did truly drop below the flashboards, but the depth below the dam crest was not entirely captured in the historical records.

The second deviation worth mentioning is the significant two week drawdown that occurred at the end of September and into the first half of October 2016. This drawdown was conducted to allow for maintenance and inspection of the dam and intake structure. A similar drawdown occurred in September-October 2018 as well. No attempt was made to recreate the operation of the dam's low-level outlet that created those drawdowns; the deviation present in **Figure 2-1** is the natural result.

Figure 2-1 Calibration Results – Simulated vs. Historically Observed Reservoir Levels in 2016



Downstream Flows

The majority of inflows to Mill Pond discharge through the Oyster River Reservoir Dam. In fact, approximately 16.0 sq mi or 82% of the Mill Pond's 19.7-sq mi watershed is upstream of the Oyster River Reservoir Dam, and the calibrated mass balance model described above can be used to understand streamflow entering Mill Pond from the Oyster River. The remaining inflows to Mill Pond come from Hamel Brook (1.8 sq mi or 9%), College Brook (1.0 sq mi or 5%) and direct drainage on the impoundment surface and immediate surroundings (0.8 sq mi or 4%).

Stage data was collected by automated pressure transducers in College Brook by UNH staff and students for large parts of 2013 through 2020. Streamflow was manually measured in the brook dozens of times over that same period. By comparing those streamflow measurements to concurrent automated stage data, a best-fit line or "rating curve" was developed to convert stage data to estimates of streamflow. While the stage data and therefore estimates of streamflow in College Brook were collected for large parts of the period of interest, January 2015 through December 2019, for various reasons there were gaps in the dataset. To produce a continuous streamflow dataset for the brook, the project team compared the significant but incomplete streamflow estimates that were developed for the brook against streamflow data gathered by the USGS gage in the Oyster River. The ratio of College Brook flow to Oyster River flow varies by season due to the nature of the two drainage areas. Those ratios are shown on a monthly basis in **Table 2-4**.

The College Brook drainage area is approximately 8% of the drainage area upstream of the USGS gage on the Oyster River. In a perfectly analogous setting, one would expect to see ratios around 8% as well. However, given the "flashiness" of smaller basins, the relatively high impervious cover of the College Brook basin, and its relative lack of wetlands that capture or attenuate runoff, these ratios are appropriate. The fact that the monthly ratios peak during the dry summer and early fall months is consistent with those same hydrologic differences. Therefore, these ratios were used to convert USGS gage data from the Oyster River into a long-term, daily dataset of College Brook discharge into Mill Pond.

Table 2-4 Estimated Ratio of College Brook Flow to Oyster River USGS Gage Flow by Month

Month	Ratio
January	10.2%
February	6.9%
March	6.2%
April	7.5%
May	7.7%
June	12.8%
July	17.7%
August	17.0%
September	22.7%
October	20.4%
November	9.4%
December	6.9%

A similar effort was made to develop monthly ratios of Hamel Brook discharge to USGS gage data from the Oyster River. However, field data was only collected in Hamel Brook for intermittent periods during 2018 and 2019. The rating curve developed from that limited data was of relatively low accuracy and produced monthly ratios that were not reasonable. For instance, the inaccurate ratios estimated for two of 12 months indicated that Hamel Brook had greater streamflow than the Oyster River despite the Oyster being several times its size. Unlike College Brook, Hamel Brook's drainage area is far more similar to that of the Oyster River in its composition (e.g., largely forested, low impervious cover, significant wetland presence, etc.). Given the lack of alternatives and the hydrologic similarities, daily streamflow in Hamel Brook was estimated from USGS gage data in the Oyster using a straight area-weighting methodology.

Direct runoff from land areas immediately surrounding the Mill Pond impoundment was estimated from USGS gage data from the Oyster River using an area-weighted methodology as well.

Mill Pond Inflow

The Oyster River Reservoir mass balance model, combined with the estimated College Brook and Hamel Brook streamflow and the direct runoff datasets described in the previous section, were used to develop estimates of historical inflow to Mill Pond on a daily basis from January 2015 through December 2020. The mass balance model was then modified to evaluate how inflows to Mill Pond may have been different over that timeframe if 1) no drinking water withdrawals were made from the Oyster River Reservoir, and 2) the Reservoir did not exist at all. Simulated inflows to Mill Pond and the increase in inflows to Mill Pond as a result of the two hypothetical scenarios are shown on a yearly basis in the figures provided in **Appendix B**. Those potential benefits are also summarized in **Table 2-5**, for "typical conditions," typified by simulation results for 2018, which, of the years in the 2015-2020 analysis period, experienced summer flows most like long-term averages in the watershed.

Based on the mass balance model simulations, the elimination of all drinking water withdrawals from the Oyster River Reservoir had a negligible impact on inflows to Mill Pond during a typical year such as 2018, never more than a 0.10 cfs or 0.5% increase. The benefits of removing the Oyster River Reservoir altogether were larger, although still small. Those benefits were experienced throughout the year, approaching 0.5 cfs in the late winter and early spring. The greatest relative increases over historical conditions occurred in the late spring and early summer with the greatest relative increases occurring in May (1.5%), June (2.2%), and July (2.7%). None of the other months of the year experienced an increase of more than 1% over historical conditions in 2018.

Table 2-5 Mill Pond Inflow by Month – Typical Conditions (2018)

Month	Estimated Historical	No Drinking Water Withdrawals		No Oyster River Reservoirs	
	Inflow (cfs)	Inflow (cfs)	Δ Inflow (cfs)	Inflow (cfs)	Δ Inflow (cfs)
January	44.64	44.64	0.00	44.89	0.25
February	61.31	61.31	0.01	61.70	0.40
March	56.12	56.12	0.00	56.58	0.46
April	80.29	80.30	0.01	80.79	0.50
May	21.69	21.79	0.10	22.02	0.33
June	8.15	8.15	0.00	8.32	0.18
July	7.35	7.38	0.03	7.56	0.20
August	24.04	24.04	0.00	24.16	0.11
September	19.43	19.43	0.00	19.40	-0.03[1]
October	29.50	29.50	0.00	29.65	0.14
November	121.10	121.10	0.00	121.13	0.02
December	62.35	62.35	0.00	62.56	0.20

Note:
1 A negative value, indicating that removing the Oyster River Reservoir will actually reduce inflows to Mill Pond, is unreasonable and due to modeling "white noise."

As expected, the benefits to Mill Pond inflow as a result of the elimination of drinking water withdrawals or the removal of the Oyster River Reservoir are substantially more pronounced during particularly dry summers than during typical conditions. As is visible in **Appendix B**, the longest sustained dry period occurred in 2020, so the change in inflows to Mill Pond for that year are summarized in **Table 2-6**.

Table 2-6 Mill Pond Inflow by Month – Dry Year (2020)

Month	Estimated Historical	No Drinking Water Withdrawals		No Oyster River Reservoirs	
	Inflow (cfs)	Inflow (cfs)	Δ Inflow (cfs)	Inflow (cfs)	Δ Inflow (cfs)
January	44.46	44.46	0.00	44.71	0.25
February	40.94	40.94	0.00	41.34	0.40
March	46.14	46.33	0.19	46.78	0.65
April	58.94	58.94	0.00	59.42	0.48
May	24.49	24.49	0.00	24.73	0.23
June	3.69	3.74	0.05	3.93	0.24
July	5.03	5.03	0.00	5.19	0.16
August	0.32	0.55	0.23	0.66	0.34
September	0.12	0.56	0.44	0.53	0.41
October	1.39	1.66	0.27	1.80	0.40
November	4.72	4.72	0.00	4.73	0.01
December	38.73	38.73	0.00	38.95	0.22

During the 2020 simulations, historical inflows to Mill Pond in the winter and early spring were actually higher than average. However, from June through November, average monthly inflows were well below the 2015-2020 averages (and longer-term averages). Model simulations indicate that in 2020 the benefits of eliminating drinking water withdrawals from the Oyster River Reservoir would likely have been minimal for much of the year, less than 1%, but that during the driest months – August, September, October – inflows to Mill Pond would have increased significantly over historical conditions, with increases of 72, 367, and 19%, respectively. As with 2018, a typical year, the benefits of removing the Oyster River Reservoir altogether were experienced fairly evenly throughout 2018 in absolute terms, with increases to inflow reaching as high as 0.65 cfs in March. The relative benefits are rather small for much of the year, generally less than 1.5%, but large relative increases were simulated to occur in August (106%), September (342%), and October (29%).

Mill Pond Residence Times

To put these benefits into perspective, however, it is important to consider how they compare to the size of the Mill Pond Dam impoundment, as an increase of 0.5 cfs is far more impactful to the water quality and ecology of a small pond than it is to a large lake. To provide this context, average monthly flows were converted to residence time, which is the length of time it would take to replace the entire stored volume of a pond. The volume of the Mill Pond impoundment varies by water level of course, but as the dam is a run-of-river structure, the water level is generally close to the spillway invert, El. 10.85. At that elevation, the impoundment has a stored volume of approximately 3,073,000 cubic feet (22.98 million gallons, 70.54 acre-feet). Residence times in Mill Pond during 2018 are summarized by month in **Table 2-7**.

Table 2-7 Mill Pond Average Residence Time by Month – Typical Conditions (2018)

Month	Estimated Historical	No Drinking Water Withdrawals		No Oyster River Reservoir	
	Res. Time (days)	Res. Time (days)	Δ Res. Time (days)	Res. Time (days)	Δ Res. Time (days)
January	1.88	1.88	0.00	1.84	-0.04
February	0.81	0.81	0.00	0.80	-0.01
March	0.70	0.70	0.00	0.69	-0.01
April	0.61	0.61	0.00	0.60	-0.01
May	1.94	1.94	-0.01	1.91	-0.03
June	7.36	7.36	0.00	7.03	-0.33
July	10.57	10.34	-0.23	9.61	-0.96
August	2.16	2.16	0.00	2.15	-0.02
September	3.52	3.52	0.00	3.54	0.02[1]
October	1.54	1.54	0.00	1.53	-0.01
November	0.40	0.40	0.00	0.40	0.00
December	0.72	0.72	0.00	0.72	0.00

Note:

1 A positive value, indicating that eliminating the Oyster River Reservoir withdrawals will actually increase residence times in Mill Pond, is unreasonable and due to modeling precision.

Historically, during a typical year, like 2018, residence times in Mill Pond are quite short, with the impounded storage volume being turned around in one to three days or less, depending on the month. Residence times are a bit longer during the summer, but even during July 2018, the driest month that year, the average residence time was less than 11 days. The elimination of drinking water withdrawals had a negligible impact on residence times in Mill Pond. Even in July 2018, residence times were reduced by 0.23 days (2.2%). The relative benefit of all other months was no greater than 0.3%. The removal of the Oyster River Reservoir altogether would have only a modest benefit to residence times in Mill Pond, with residence times being reduced by less than an hour for all months except June and July, which would experience reductions in residence time of 0.33 (4.5%) and 0.96 (9.1%), respectively.

The benefits to residence times in Mill Pond are more significant during very dry years like 2020. As shown in **Table 2-8**, residence times are generally longer than in 2018 because average monthly inflows to the pond are lower. Residence times were considerably higher, historically, during the summer and early fall in particular. Whereas the single highest monthly average residence time in 2018 was just over 10 days, six of 12 months had residence times near or well beyond ten days in 2020. In fact, August and September had residence times of 123 and 176 days, respectively. A residence time of 176 days indicates that due to very low runoff from all corners of the watershed, the water in Mill Pond was being turned over on the order of every 4-6 months during the peak of the dry season in 2020.

Table 2-8 Mill Pond Average Residence Time by Month – Drought Conditions (2020)

Month	Estimated Historical	No Drinking Water Withdrawals		No Oyster River Reservoirs	
	Res. Time (days)	Res. Time (days)	Δ Res. Time (days)	Res. Time (days)	Δ Res. Time (days)
January	0.82	0.82	0.00	0.81	0.00
February	1.00	1.00	0.00	0.99	-0.01
March	0.70	0.70	0.00	0.69	-0.01
April	0.60	0.60	0.00	0.59	-0.01
May	1.89	1.89	0.00	1.86	-0.03
June	11.29	10.86	-0.43	10.22	-1.08
July	9.44	9.44	0.00	8.93	-0.50
August	123.29	58.93	-64.36	48.10	-75.19
September	175.99	53.50	-122.49	57.03	-118.96
October	83.92	34.48	-49.44	29.32	-54.60
November	12.17	12.17	0.00	12.21	0.04[1]
December	1.12	1.12	0.00	1.11	-0.01

Note:

1 A positive value, indicating that removing the Oyster River Reservoir will increase residence times in Mill Pond, is unreasonable and due to modeling "white noise."

If no drinking water withdrawals had occurred in 2020, residence times would not have improved substantially over estimated historical conditions. However, during the peak of the 2020 drought – August and September – Mill Pond water would still have taken nearly two months to turn over. Removal of the Oyster River Reservoir altogether would have produced further reductions to Mill Pond residence times, but for nearly three months in the heart of the 2020 drought, Mill Pond water would have been replaced once every 1.5-2 months.

Low Flow Hydraulic Analysis

The November 2020 Feasibility Study reported the results from an extensive hydrological and hydraulic modeling effort. This included a HEC-RAS hydraulic model, which was previously used to understand how the Oyster River-Hamel Brook system functions and looks under "typical flows" such as the median annual flow and under several flood conditions, as well as to understand fish passage conditions.

For this Supplemental Analysis, the project team has extended this modeling effort to include low flow and drought conditions as well. Two additional low flow regimes were considered:

› The average flow in July 2018 (7.4 cfs), which is quite close to the long-term average flow during the driest month of the year, and is referred to below as a "typical summer low flow" and

› The average flow in July-September 2020 (2.5 cfs), which is likely the lowest or close to the lowest three-month average flow experienced at Mill Pond over the past two decades and is referred to below as a "very low flow" or "drought conditions." These flows were estimated based on the mass balance model analyses discussed above.

As with the initial Feasibility Study, the project team has evaluated both general changes to the hydraulics of the Mill Pond impoundment as well as more detailed changes to specific reaches within the Oyster River-Hamel Brook system. This comparison was made for Alternative 1 – No Action, Alternative 3 – Dam Stabilization, and Alternative 5 – Dam Removal. Note that the current hydraulic modeling effort refined the Alternative 3 geometry in two ways relative to the Alternative 3 geometry evaluated in the initial Feasibility Study: 1) the dredging of Mill Pond described as "Option 1 – Pond Restoration Dredge" in the November 2020 Feasibility Study was eliminated from the model; and 2) a small notch in the dam's spillway was added to the Alternative 3 model.[9]

General Hydraulic Model Findings

Tables 2-9 and **2-10** summarize the predicted changes in the impoundment volume and surface area, respectively, under Dam Stabilization and Dam Removal Alternatives, while **Table 2-11** summarizes the predicted change in average river depth within the impoundment. Additionally, the HEC-RAS graphs provided in **Appendix C** show the profile view of water elevations in the Oyster River under typical summer low flow and very low flow conditions. The figures in **Appendix D** show the aerial extent of inundation for Alternatives 3 and 5 under the median annual flows, typical summer low flows and drought conditions. The major conclusions that can be drawn from this analysis are discussed below.

› Under all flow conditions, there would be only a negligible change in the impoundment's surface area, storage volume, and average depth under Alternative 3 – Stabilization. Unless dredging occurs, this alternative would not significantly change the hydraulic characteristics of the dam or its operation.

› For normal flows, there would be a substantial decrease in the impoundment under Alternative 5 – Dam Removal. The removal of Oyster River Dam would replace the existing hydraulic control of the riverine impoundment (i.e., the crest of the dam's spillway at El. 10.85 ft) with a reconstructed river channel with its thalweg or lowest point at approximately El. 1.25 near the location of the existing dam. This 9.6-foot drop in the hydraulic control of the Oyster River would be accompanied by a substantial reduction in the impounded volume. As shown in **Tables 2-9** and **2-10**, during the median annual and low flow conditions, the impounded volume would be expected to decrease by 88 to 94%. Dam removal would reduce the impoundment's surface area by 73 to 77% as well and its average depth by 61 to 71%.

9 This notch is discussed in greater detail in Chapter 3 of this report, but for the purposes of understanding its likely impact on river and pond hydraulics during low flow conditions, it was assumed that one 6-inch stop log was removed from the notch to maintain at least 4.5 inches of flow during all low flow conditions evaluated here.

Table 2-9 Impoundment Surface Area, by Alternative and Flow Condition

Flow Condition	River Flow (cfs)	Alt 1 Existing Condition (ac)	Alt 3 Dam Stabilization[1] (ac)	Alt 5 Dam Removal (ac)	Percent Change Relative to Existing Condition	
					Alt 3 (%)	Alt 5 (%)
Median Annual	34.2	19.7	19.5	5.4	-1%	-73%
July 2018 (Typical Summer Low)	7.4	18.6	18.5	4.6	0%	-75%
July-Sept 2020 (Very Low Flow)	2.5	18.5	18.2	4.4	-1%	-77%

Note:
1 Alternative 3 results assume a notch is installed and open by 6 inches, with no dredging.

Table 2-10 Impoundment Volume, by Alternative and Flow Condition

Flow Condition	River Flow (cfs)	Alt 1 Existing Condition (ac-ft)	Alt 3 Dam Stabilization[1] (ac-ft)	Alt 5 Dam Removal (ac-ft)	Percent Change Relative to Existing Condition	
					Alt 3 (%)	Alt 5 (%)
Median Annual	34.2	77.0	76.5	9.5	-1%	-88%
July 2018 (Typical Summer Low)	7.4	73.8	73.3	7.3	-1%	-91%
July-Sept 2020 (Very Low Flow)	2.5	73.0	71.0	6.6	-3%	-94%

Note:
1 Alternative 3 results assume a notch is installed and open by 6 inches, with no dredging.

Table 2-11 Average Depths, by Alternative and Flow Condition

Flow Condition	River Flow (cfs)	Alt 1 Existing Condition (ft)	Alt 3 Dam Stabilization[1] (ft)	Alt 5 Dam Removal (ft)	Percent Change Relative to Existing Condition	
					Alt 3 (%)	Alt 5 (%)
Median Annual	34.2	3.2	3.2	1.2	0%	-61%
July 2018 (Typical Summer Low)	7.4	3.2	3.2	1.0	0%	-68%
July-Sept 2020 (Very Low Flow)	2.5	3.2	3.1	1.0	-2%	-71%

Note:
1 Alternative 3 results assume a notch is installed and open by 6 inches, with no dredging.

Predicted Changes at Specific Reaches

Like many run-of-river dams on shallowly sloped coastal rivers, the Oyster River Dam impounds the Oyster River-Hamel Brook system and its tributaries for several miles upstream. The removal or modification of Oyster River Dam has the potential to impact water levels, velocities, and other characteristics for the full length of the impoundment. The project team utilized the HEC-RAS hydraulic model of the Oyster River-Hamel Brook system to predict what, where, and when those impacts may occur.

The hydraulic impacts of dam removal or dam modification are predicted to be greatest immediately upstream of the dam and diminish moving away from the dam. However, different reaches of the Oyster River-Hamel Brook system will experience these changes differently. The hydraulic model results indicate that the type and magnitude of changes in the hydraulic characteristics of the Oyster River Dam impoundment divide the Oyster River-Hamel Brook system into five distinct sections, including:

- Oyster River, Tidal (downstream of Oyster River Dam);
- Oyster River, Mill Pond;
- Oyster River, Middle Impoundment (Mill Pond to Hamel Brook confluence);
- Oyster River, Mainstem (Oyster River Reservoir Dam to Hamel Brook confluence); and
- Hamel Brook.

Results of the hydraulic model for each of these reaches is provided in **Tables 2-12** through **2-16**. Each is discussed in more detail below.

Oyster River: Tidal

The Oyster River is tidally influenced for a length of approximately 2.9 miles from the downstream face of Oyster River Dam down to its discharge into Little Bay. Most of this reach is characterized by a broad, shallowly sloped channel with very fine sediments and extensive salt marshes in its low-lying floodplains. The current in this reach is completely controlled by the tides. On the banks of this reach of the Oyster River are the Durham Wastewater Treatment Facility; Jackson's Landing with its public boat launch and UNH Boathouse; and the scenic park at Durham Landing. One length of the tidally influenced Oyster River that is markedly different from the rest is the approximately 110-foot length of river between the dam and the NH 108 bridge crossing just downstream. This short section is characterized by a steep rocky channel with high banks, generally 5-10 feet tall, often lined with dry set or mortared stone, which limit the river's access to its floodplain under some flow conditions.

Alternative 3 – Stabilization, would have no impact on the hydraulics of the Oyster River's tidal reach. In contrast, Alternative 5 – Dam Removal is expected to have only modest impacts to the river's hydraulics in the short 110-foot reach upstream of NH 108 during most flow and tide conditions, but those changes are not expected to propagate any further downstream. Changes in this area under Alternative 5 are relatively larger during low tide when the reach is free flowing and amplified further during low flow conditions. These modest changes are the result of proposed changes to the river channel and floodplain in this area that would accompany the removal of the dam. These changes would be necessary to create a stable river channel that approximates natural conditions.

The reach of the Oyster River between Oyster River Dam and the NH 108 bridge crossing is typified by the area immediately upstream of the bridge. As shown in **Table 2-12**, the top width of the river, the average depth of water in the channel, and the average velocity change very little as a result of dam removal during the median annual flow with changes of no more than +/-10% anticipated. The maximum depth, however, is expected to increase from 0.3 to 0.9 feet, a change that is attributed to the channel modifications that would accompany a dam removal.

During low flow conditions, however, this reach of the Oyster River is expected to change significantly under Alternative 5, as indicated in **Table 2-12**. For instance, the top width of the river is expected to narrow from 30 to 10 feet during typical summer low flows and from 29 to 7 feet during very low flow conditions. Depths and velocities will increase, however. The average depth will increase from 0.1 feet to 0.2-0.3 feet; and the maximum depth in the deepest part of the channel will increase from 0.1 to 0.3-0.5 feet. Average velocities will change as well, increasing from 2.0 to 2.9 feet per second (fps) during typical summer flows and from 1.5 to 2.3 fps during very low flows.

In summary, the hydraulic changes in the tidally influenced reach of the Oyster River are expected to be noteworthy under Alternative 5 only when low tide and low flows occur simultaneously, and essentially absent under Alternative 3 - Dam Stabilization. No changes are expected downstream of the NH 108 crossing under any alternative or flow condition.

Oyster River, Mill Pond

In sharp contrast to the short rocky channel downstream of Oyster River Dam, the reach of the Oyster River immediately upstream of the dam, Mill Pond, is predicted to experience substantial changes in both river depths and velocities if the dam were removed. Mill Pond is the widest part of the impoundment, and although it contains the deepest point, sediment has been deposited in the pond over the many decades since the dam’s construction. This influx of sediment has created a mound of sediment immediately upstream of the dam such that the channel bottom rises as it approaches the dam. A significant amount of sediment has also been deposited along both sides of the pond. This reach of the impounded Oyster River, known as Mill Pond, is wide and shallow relative to other reaches of the impoundment upstream.

As shown in **Table 2-13**, Alternative 3 – Dam Stabilization, with the construction of a notch but without dredging, would have only very minor effects on the depths, widths and velocities in the pond, and even then only if a stoplog were removed from the notch.

Alternative 5 – Dam Removal would effectively eliminate the pond. Under “normal conditions” typified by the median flow, the average depth of the pond reach is expected to decrease from 2.2 to 0.5 feet, and the top width is expected to shrink from 514 to 32 feet. Naturally, with the removal of the dam which impounds the pond, velocities will increase accordingly, from less than 0.1 to 2.3 fps under median flow conditions. The significance of the predicted changes to all three hydraulic characteristics – depth, width, and velocity – grow modestly more significant as river flow decreases. For instance, during the typical summer low flow conditions, the maximum river depth is expected to decrease from 5.9 to 0.5 feet while the width decreases from 449 to 17 feet and velocities increase from less than 0.1 to 1.8 fps. During very low flows, the maximum river depth is expected to decrease from 5.9 to 0.3 feet while the width decreases from 441 to 9 feet and velocities increase from less than 0.1 to 2.1 fps. It is important to remember that removal of the dam would allow tidal flow into the area currently occupied by Mill Pond; these hydraulic results represent the low tide condition.

Oyster River, Middle Impoundment

The "Middle Impoundment," extends from the upstream end of Mill Pond to the confluence of the Oyster River and Hamel Brook, running parallel with Mill Pond Road. This reach of river is very consistent in its width and depth, and it is, on average, the deepest portion of the impoundment.

Alternative 5 is expected to have a substantial impact on the river's average depth, its width, and its velocities in this area under all flow conditions. As shown in **Table 2-14**, under a median annual flow condition, for instance, the river's average depth is expected to decrease from 4.0 to 1.4 feet, while the maximum depth would decrease from 7.1 feet to 2.1 feet. Its width will decrease accordingly, from 91 to 41 feet across. The significant reduction in both height and width indicates a decrease in cross-sectional flow area, and, therefore, a significant increase in average velocity, from 0.1 to 0.6 fps. Again, the proportional change from existing conditions is expected to increase as river flows decrease. For instance, the river depth is expected to decrease from 6.9 to 1.6 feet under typical summer low flows and to 1.3 feet under very low flow conditions. Similarly, the river's top width is expected to decrease to 34 feet.

The removal of the dam will certainly change the hydraulics of the Oyster River in this area, but the scale of the changes in the Middle Impoundment are not as significant as they are predicted to be in Mill Pond, in large part because Middle Impoundment retains a more "riverine" and less "ponded" form in its present state. As the following sections will discuss, this pattern continues upstream on the Oyster River mainstem. The further upstream from Oyster River Dam, the smaller its hydraulic influence is, and the more "riverine" the current character of the river channel and floodplain would remain. Therefore, the scale of the hydraulic changes related to dam removal generally decrease, approaching zero at the limits of the dam's current impoundment.

Oyster River, Mainstem

The Mainstem of the Oyster River flows from north to south upstream from the confluence of Hamel Brook. The limit of the Oyster River Dam impoundment is located approximately 1,500 feet upstream of the confluence, very close to the municipal pump station located near the intersection of Oyster River Road and Thompson Lane. This portion of the impoundment is noticeably narrower and shallower than Middle Impoundment, and, as Figure 3.2-3 shows, the channel is steeper.

Hydraulically, Alternative 3 is expected to have a negligible impact on the Mainstem reach of the Oyster River. In contrast, Alternative 5 is expected to impact the river's average depth, width, and velocity in this area to varying degrees. Although, as expected, those impacts, highlighted in **Table 2-15**, are progressively smaller than those expected for Mill Pond or the Middle Impoundment reaches

For instance, under a median annual flow condition, the river's average depth is expected to decrease from 1.4 to 0.3 feet and its velocity is expected to increase accordingly, from 0.5 to 2.9 fps. During lower flow conditions, the relative impact of dam removal on the river's depth is more significant. For instance, the river's average depth would decrease from 1.3 to 0.1 feet during typical summer low flows and to less than 0.1 feet during very low flow conditions. However, as the channel in this reach is better defined, its width would only be expected to decrease from 39 to 36 feet under both low flow conditions. Average velocities would increase from 0.1 fps or less to 1.9 and 1.2 fps for typical summer low flows and very low flows, respectively. Upstream of the limit of the impoundment, near Oyster River Road and Thompson Lane, the HEC-RAS hydraulic model confirms that dam removal would have no discernable impact on the hydraulics of the Oyster River.

Hamel Brook

Hamel Brook is unusually complex. The brook's headwaters drain an area consisting predominantly of farmland and forest bordered roughly by NH 108, Palmer Drive, Willey Road, and Cutts Road. Through its tributaries, Longmarsh Brook and Bedford Brook, it also drains an area of forest and wetland along the east side of NH 108, extending upstream roughly to 181 Newmarket Road. At least two culverts beneath NH 108 connect Hamel Brook and its tributaries to tributaries of the Lamprey River on the west side of the highway.

Upstream of NH 108, Hamel Brook is quite flat and impounded by Longmarsh Road, a former Class VI road that now acts effectively as a dam, and other smaller, natural restrictions. Crossing under NH 108, a clear channel emerges, roughly 10 feet across and 2 feet deep. This channel is noticeably steeper than upstream tributaries and runs approximately 800 feet before reaching the limit of the Oyster River Dam impoundment. The channel bottom continues to drop steadily in elevation for another 800 feet or so into the impoundment before flattening out between El. 5 and 6 feet (NAVD88). In total, Hamel Brook is impounded by Oyster River Dam for approximately 2,400 feet above its confluence with the Oyster River.

One other noteworthy aspect of the Hamel Brook reach is the presence of an overflow channel to the left of the main channel, approximately 180 feet downstream of where the brook crosses under NH 108. While dry under normal and low flow conditions and during small storm events, when water levels in the steep section of Hamel Brook reach approximately 1.5 feet in height, the river jumps its left bank and discharges down a rock-lined secondary channel, roughly 15 feet wide at its base. The downstream end of the secondary or overflow channel discharges into the far southern limit of the Oyster River Dam impoundment. The hydraulic model results presented in **Table 2-16** focus on the impounded portion of Hamel Brook.

Hydraulically, Alternative 3 would have a negligible impact on Hamel Brook. In contrast, Alternative 5 is expected to significantly impact the brook's average depth, width, and velocity. For instance, under "normal conditions" typified by the median annual flow, the top width of the impounded portion of Hamel Brook is reduced from 135 to 18 feet as a result of the dam removal. The average depth decreases from 3.3 feet to 0.2 feet. The significant reduction in flow area and the elimination of the backwater effect from Oyster River Dam results in an increase in average velocity from negligible under existing conditions to 0.7 fps.

As flows become smaller, the significance of dam removal on the brook's hydraulic character is increased. For instance, dam removal is expected to reduce the brook's average depth from 3.2 feet to 0.1 feet under typical summer low flows and from 3.1 feet to less than 0.1 feet under very low flow conditions. Brook width will also be decreased significantly, from 134 feet to 7 and 4 feet, respectively. Average velocities will increase, however, from negligible in its current impounded state to approximately 1.0 fps with the dam removed, during low flow conditions.

Table 2-12 Supplemental Hydraulic Model Results - Oyster River: Tidal

River Flow	Existing Condition				Alternative 3 - Dam Stabilization				Alternative 5 - Dam Removal			
	Max. Depth (ft)	Avg. Depth (ft)	Top Width (ft)	Avg. Velocity (ft/s)	Max. Depth (ft)	Avg. Depth (ft)	Top Width (ft)	Avg. Velocity (ft)	Max. Depth (ft)	Avg. Depth (ft)	Top Width (ft)	Avg. Velocity (ft)
Median Annual	0.3	0.3	34	3.2	0.3	0.3	34	3.2	0.9	0.3	31	3.4
July 2018 (Typical Summer Low)	0.1	0.1	30	2.0	0.1	0.1	30	2.0	0.5	0.3	10	2.9
July-Sept 2020 (Very Low)	0.1	0.1	29	1.5	0.1	0.1	29	1.5	0.3	0.2	7	2.3

Note: Data represents model cross-section RS 6701.054, immediately upstream of NH 108. Alternative 3 results assume a notch is installed and open by 6 inches, with no dredging.

Table 2-13 Supplemental Hydraulic Model Results - Oyster River: Mill Pond

River Flow	Existing Condition				Alternative 3 - Dam Stabilization				Alternative 5 - Dam Removal			
	Max. Depth (ft)	Avg. Depth (ft)	Top Width (ft)	Avg. Velocity (ft/s)	Max. Depth (ft)	Avg. Depth (ft)	Top Width (ft)	Avg. Velocity (ft)	Max. Depth (ft)	Avg. Depth (ft)	Top Width (ft)	Avg. Velocity (ft)
Median Annual	6.1	2.2	514	0.0	6.1	2.3	509	0.0	0.9	0.5	32	2.3
July 2018 (Typical Summer Low)	5.9	2.3	449	0.0	5.9	2.3	444	0.0	0.5	0.2	17	1.8
July-Sept 2020 (Very Low)	5.9	2.3	441	0.0	5.8	2.1	423	0.0	0.3	0.1	9	2.1

Note: Data represents model cross-section RS 7305.741, which cuts through the areas of heaviest sediment deposition in the pond. Alternative 3 results assume a notch is installed and open by 6 inches, with no dredging.

Table 2-14 Supplemental Hydraulic Model Results - Oyster River: Middle Impoundment

River Flow	Existing Condition				Alternative 3 - Dam Stabilization				Alternative 5 - Dam Removal			
	Max. Depth (ft)	Avg. Depth (ft)	Top Width (ft)	Avg. Velocity (ft/s)	Max. Depth (ft)	Avg. Depth (ft)	Top Width (ft)	Avg. Velocity (ft)	Max. Depth (ft)	Avg. Depth (ft)	Top Width (ft)	Avg. Velocity (ft)
Median Annual	7.1	4.0	91	0.1	7.1	4.0	91	0.1	2.1	1.4	41	0.6
July 2018 (Typical Summer Low)	6.9	3.9	89	0.0	6.9	3.9	89	0.0	1.6	1.0	36	0.2
July-Sept 2020 (Very Low)	6.9	3.9	88	0.0	6.8	3.9	87	0.0	1.3	0.8	34	0.1

Source: Data represents model cross-section RS 8220.75, which is currently well within the impoundment. Alternative 3 results assume a notch is installed and open by 6 inches, with no dredging.

Table 2-15 Supplemental Hydraulic Model Results - Oyster River: Mainstem

River Flow	Existing Condition				Alternative 3 - Dam Stabilization				Alternative 5 - Dam Removal			
	Max. Depth (ft)	Avg. Depth (ft)	Top Width (ft)	Avg. Velocity (ft/s)	Max. Depth (ft)	Avg. Depth (ft)	Top Width (ft)	Avg. Velocity (ft)	Max. Depth (ft)	Avg. Depth (ft)	Top Width (ft)	Avg. Velocity (ft)
Median Annual	1.4	1.4	39	0.5	1.4	1.4	39	0.5	0.3	0.3	37	2.9
July 2018 (Typical Summer Low)	1.3	1.3	39	0.1	1.3	1.2	39	0.1	0.1	0.1	36	1.9
July-Sept 2020 (Very Low)	1.3	1.2	39	0.0	1.2	1.1	38	0.0	0.0	0.0	36	1.2

Note: Data represents model cross-section RS 10532.03 near the upper limit, but within the impoundment. Alternative 3 results assume a notch is installed and open by 6 inches, with no dredging.

Table 2-16 Supplemental Hydraulic Model Results – Hamel Brook

River Flow	Existing Condition				Alternative 3 - Dam Stabilization				Alternative 5 - Dam Removal			
	Max. Depth (ft)	Avg. Depth (ft)	Top Width (ft)	Avg. Velocity (ft/s)	Max. Depth (ft)	Avg. Depth (ft)	Top Width (ft)	Avg. Velocity (ft)	Max. Depth (ft)	Avg. Depth (ft)	Top Width (ft)	Avg. Velocity (ft)
Median Annual	5.1	3.3	135	0.0	5.1	3.3	135	0.0	0.5	0.2	18	0.7
July 2018 (Typical Summer Low)	5.0	3.2	134	0.0	5.0	3.1	134	0.0	0.2	0.1	7	1.0
July-Sept 2020 (Very Low)	4.9	3.1	134	0.0	4.9	3.0	133	0.0	0.1	0.1	4	1.1

Note: Data is from model cross-section RS 1558.227, representative of a portion of Hamel Brook that is currently impounded. Alternative 3 results assume a notch is installed and open by 6 inches, with no dredging.

3

Natural Resources

This chapter provides additional discussion of a few key natural resource issues related to the Oyster River Dam at Mill Pond to supplement the discussion of natural resource impacts and benefit contained in the Feasibility Study. Specifically, we provide a discussion of how the dam might be adapted to accommodate downstream fish passage by installing a low-flow notch in the spillway. And, we provide some additional discussion regarding the management of invasive species within and adjacent to the impoundment.

Downstream Fish Passage

The project team developed a conceptual design for a fish migration structure to promote downstream fish migration past the dam structure during periods of low flow. As observed during periods of low flow such as occurred in 2020, out-migrating fish including adults and juveniles are unable to navigate over the spillway due to shallow flow depths. This condition results in fish mortality due to stranding on the concrete spillway surfaces or increased predation. The conceptual outmigration structure could also be utilized to support pond level and flow adjustments being considered as part of water quality improvements efforts, as discussed in Chapters 1 and 2.

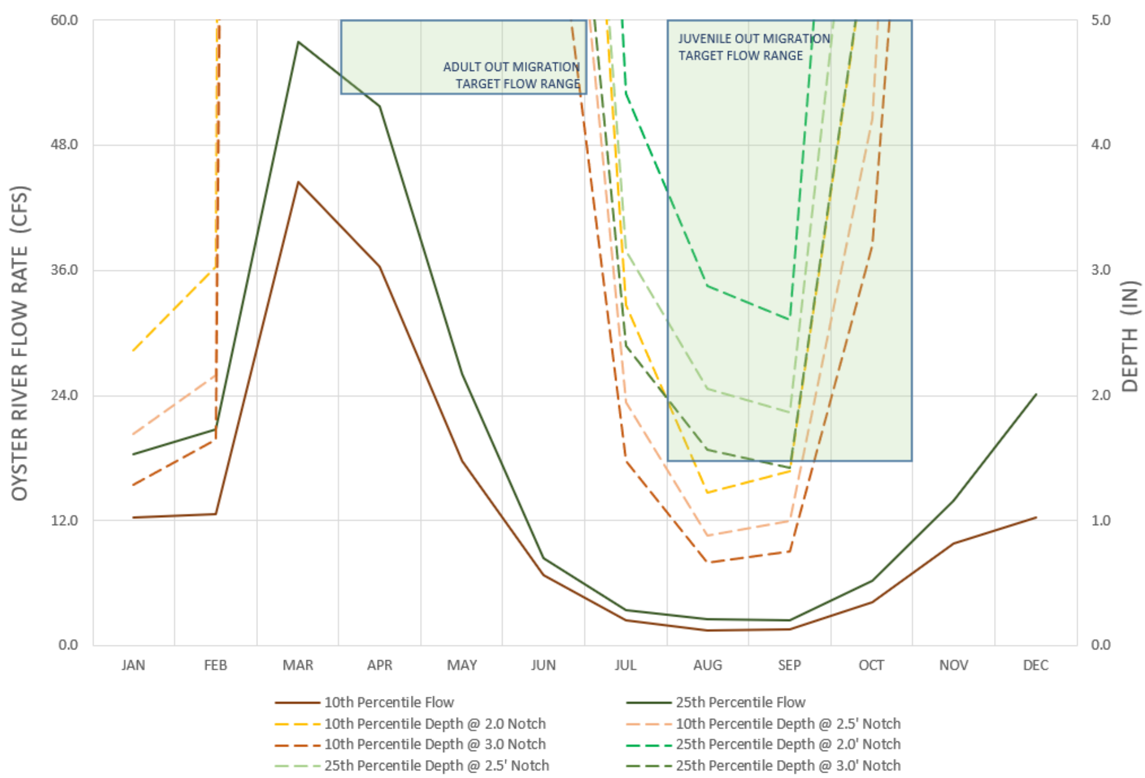
As part of the concept development, the team consulted with NH Department of Fish and Game (NHF&G) personnel who are responsible for operation of the existing fish ladder. NHF&G reported that current fish counts suggest that species which currently use the fish ladder include about 40% alewives and 60% blueback herrings; while the alewife population accounts for a significant percentage of use, NHDES suggests that the alewife population has remained consistent; relative percentage has increased due to decreasing population of blueback herring. As such, migration improvements are recommended to focus on blueback herring populations.

Photo 1: A fish migration notch at Wiswall Dam

Fish passage design guidance provided by NHF&G suggests that the blueback herring adults generally out-migrate shortly after spawning, typically between April and June. Juvenile outmigration occurs later in the summer/early Fall, typically between August and September. For outmigration facilities, design flow depths are generally 1.5 times the fish height; adult herring are generally 3-inches tall and juveniles are generally 1-inch tall.

To determine required notch dimensions, monthly flows developed as part of this study were considered; 25th percentiles flows were selected as a study point with a check completed for 10th percentile flow. Based upon flow depth calculations, it was determined that for juvenile outmigration, a 2.5-foot-wide notch will provide a flow depth of greater than 1.9 inches for 25th percentile flow; 10th percentiles flows result in flow depths decreasing to nearer 1 inch. During adult outmigration, low flow statistics suggest that adequate flow is available to provide required out migration flow depth during the months of April and May as well as meet fish ladder flow requirements. During June, 25th percentile flows are adequate to support both fish ladder and outmigration flow requirements; however, flows below this percentile may result in less than minimum flow depths at the outmigration notch to support fish ladder flow. Monthly flow rates for the 25th and 10th percentiles flows along with resulting notch flow depths are graphically presented in **Figure 3-1**. A conceptual design for the notch is provided in **Appendix E**.

Figure 3-1 Notch Flow Depth Assessment



Source: Pare Corporation

The notch is proposed to be located on the right end of the spillway; siting of the notch considered the south end of the spillway. However, outmigration notches in the vicinity of fish ladders may confuse fish attempting to navigate the system due to varied flow conditions. The notch would consist of three sets of stop logs to control flows and create a series of plunge pools through the height of the spillway. To construct the notch, full depth demolition of the spillway would be completed at the right end of spillway adjacent to the right training wall. A reinforced concrete base slab would be constructed as an independently stable section to support to proposed training walls, stoplog, and plunge pool geometries; to limit potential for saltwater intrusion, the top of the base slab would be set near El. 6.

For safety and operational purposes, the notch would be provided with a catwalk and railings over the stoplogs. An easement through the property abutting the south end of the dam may be required to allow for operations.

Before the outmigration of both the adults and juveniles, the notch should be inspected to ensure the operability of the stop logs. During adult and juvenile outmigration, the notch should be monitored daily to verify the proper depth of flow over the notch. If the flow depth is not sufficient, the stop logs should be adjusted to attain the proper flow depth. The required depth should be verified at each of the sets of stop logs.

The fish migration notch is assumed to be constructed as part of other remediation work at the dam. The following provides a magnitude of cost for the incorporation of the fish migration notch within Alternative 3 - Dam Stabilization. Costs will be considerably higher if undertaken as an independent installation. Cost may be lower if a similar notch is incorporated within a complete replacement project.

Table 3-1 Fish Migration Notch Magnitude of Cost

Construction Components	OPC
Additional Demolition & Removal	$ 1,000
Structural Slab and Training Walls	$12,000
Stop Logs & Equipment	$20,000
Gratings & Railings	$11,000
Subtotal	$43,000
Contingency (25%)	$11,000
Additional Design & Permitting	$12,000
Total Magnitude of Cost	**$65,000**

Invasive Species

An invasive plant species is one that is not native to the region and is likely to cause harm to the environment, economy, or human health. Invasive plants have several traits that allow them to spread quickly and become widespread: lack of natural predators in their new environment, high production of fruits or seeds, rapid growth rates, and tolerance of a range of conditions. Invasive plants can change how natural systems look and function, suppress native plant regeneration, change availability of insects for nesting songbirds, harbor higher densities of ticks that transmit Lyme disease, and choke freshwater wetlands, affecting habitat for wildlife and other aquatic organisms.

The economic and environmental impacts of invasive plants are so great that many states, including New Hampshire, maintain a list of "prohibited' plant species that are "illegal to collect, transport, sell, distribute, propagate or transplant."[10] The New Hampshire Department of Agriculture, Markets and Food oversees the State's efforts to monitor, manage, and control invasive plants. Doug Cygan, NH Invasive Species Coordinator, is active in educating the general public, conservation commissions, municipal and state highway departments, and others about invasive plants.

Town of Durham Invasive Plant Efforts

For several years, the Town of Durham has worked on invasive plant control on several conservation areas, including Doe Farm, Milne Nature Sanctuary, Mill Pond Park, Oyster River Forest, Thompson Forest, and Wagon Hill Farm North (Snyder, 2020). These efforts have been implemented with the help of Town staff, volunteers, interns, contractors, and local, state and federal partners. The goal for much of this work is to reduce the density of invasive plants and recover a healthier native plant community.

In 2019, the Town of Durham initiated a pilot project with Doug Cygan, NH Invasive Species Coordinator, to treat invasive Japanese knotweed behind the Town Hall and along Mill Pond Road, as

[10] NH Department of Agriculture, Markets, and Food Invasive Plant Program, NH List of Prohibited Invasive Plants

well as other invasive plants in the focus area, including glossy buckthorn, Asiatic bittersweet, burning bush, multiflora rose, bush honeysuckle, Autumn olive, privet, and Japanese barberry.

This first year of treatment included cutting the knotweed to the ground in June, which was completed by Durham's Land Stewardship Coordinator and two UNH summer interns. Although time-intensive, this resulted in less vegetative growth that needed follow-up herbicide treatment in the Fall (after the flowering period). In September 2019, Doug Cygan used a low volume foliar spray herbicide application on invasive plants covering about one acre along the northern limits of Mill Pond roughly between Town Hall and Milne Nature Sanctuary.

The same methods were replicated in 2020. Given the effective treatments in 2019, the density of knotweed was considerably less and thus much less effort and herbicide were needed in 2020. In both years, a selection of other invasive shrubs along the north shore of Mill Pond were also treated. A similar effort is planned for 2021. The goal is not to treat everything in one year, to lessen the visual impact of many dead stems and to allow for a slow transition to more native vegetation (such as arrowwood viburnum, silky dogwood, speckled alder, red maple, red oak, and other species that grow here).

The Town of Durham also owns and manages the one-acre Milne Nature Sanctuary, which borders Mill Pond and College Brook. The Milnes donated this land to the town as a wildlife sanctuary and the Trustees have recommended that no herbicides be used on this parcel. Beginning in 2017, a small committee was formed to guide stewardship of this parcel, including management of invasive plants. The Milne Trust funded the removal of several dozen invasive Norway maple trees by Orion Tree Service. The Land Stewardship Coordinator has organized volunteers, students, and interns each year to hand lop, pull, and dig invasive plants. This was augmented with the planting of native shrubs and herbaceous plants to restore a native plant community to the sanctuary.

In 2018, the Town received the donation of the 5-acre on south side of Mill Pond, called The Meadows. No management has occurred yet, but this offers an opportunity to manage invasive plants more effectively on the south side of Mill Pond.

Mill Pond Dam and Invasive Plants

The studies and discussions around the Mill Pond Dam offer an opportunity to continue and expand on the invasive plant control efforts that the Town has initiated along the north shore of Mill Pond and along College Brook. Whether the dam is removed or renovated, this invasive plant effort has valuable ecological benefits. Control of invasive plants is one step toward restoring a native plant community around this ecologically significant waterway in the heart of Durham.

In May 2021, Peter Walker (VHB), Dr. Tom Lee (UNH Emeritus Professor), Doug Cygan (NH Dept of Agriculture, Markets, and Food), and Ellen Snyder (Ibis Wildlife Consulting), met at Mill Pond Park to discuss the options for invasive plant control as part of the Mill Pond decision-making, as well as the potential for invasive plants to spread into areas that were previously inundated if the dam is removed.

Invasive glossy buckthorn is abundant around Mill Pond, on islands within the Pond and upstream, and along the shores of the Oyster River and Hamel Brook. Buckthorn is aggressive in colonizing canopy openings, does well under a white pine canopy and along the fringes of water bodies; it is less productive under a dense canopy of hardwood trees. Buckthorn spreads solely by seed dispersal, not vegetatively (Goodwin, 1943).

Given the presence of buckthorn along the banks, there is a high likelihood that there is a concentration of seeds in the sediment of the river, brook, and pond bottom. These seeds can move downstream as water flow moves sediment; however, they are not salt tolerant and therefore would not present a risk to existing downstream tidal areas, nor brackish habitats that are expected to form under Alternative 5. Seeds in upland soils can survive in a dormant state for at least three years until conditions are right for germination (Goodwin, 1943). It is not known how long seeds can survive in sediment under water, where lack of oxygen may limit survival.

It may be useful to determine the viability of buckthorn seeds in the existing sediment. There are at least two methods to investigate this issue. One is to take substrate samples and simulate post dam removal conditions to determine germination potentials. The second approach is to drop the existing surface water elevation of the pond to expose a fringe that could then be studied/monitored for germination potential. The latter approach would yield a more representative result, but could have other impacts and issues.

Under Alternative 5, the removal of the dam and subsequent water drawdown could lead to the spread of buckthorn (and other invasive plants). As much as 6.5 acres of fertile, moist former pond and stream bed would offer habitat for buckthorn seeds that drop from parent plants along the shore. Additionally, if dormant seeds in the sediment are still viable, then they could germinate following drawdown. Buckthorn seeds will continue to be dispersed by birds and mammals, whether the dam is removed or not.

The risk posed by the potential spread of invasive species is difficult to predict, considering every ecosystem is different, and portions of the pond will be exposed to periodic tidal flow while other areas will continue to retain their freshwater characteristics. However, freshwater areas will likely be the most susceptible to invasive plant establishment.

Pre-emptive steps can be taken to start to control the existing seed sources along the shorelines. This will decrease the amount of new seed added to the environment each year. After drawdown, the fate of new buckthorn seedlings may depend on what other plant species establish on the newly exposed substrate. If there are few other plants, buckthorn could proliferate. But if native herbaceous plants establish quickly and form dense vegetation, buckthorn and other invasive plant species may be inhibited.

To minimize the threat of invasive species spread, and to aid in the restoration and protection of native plant diversity, it is advisable to develop an Integrated Vegetation Management (IVM) Program to manage the invasive species surround Mill Pond and upstream. This approach entails mechanical,[11] cultural, biological and chemical methods over a 3- to 5-year period and include actions before and after dam removal. This time span allows a transition period from invasive-dominated to native-dominated plant communities. The primary target is glossy buckthorn; however, other invasive species should be treated as well, including Japanese knotweed, Asiatic bittersweet, burning bush, multiflora rose, bush honeysuckle, Autumn olive, privet, and Japanese barberry.

[11] Mechanical control of invasive species has recently been discussed by Snyder (2021).

Complete eradication of invasive plants is not feasible. The goal in an IVM Program is to reduce the existing seed sources, limit the survival of new sprouts from the seed bank, and encourage the establishment of native grasses, sedges, wildflowers, shrubs, and trees.

Components of an IVM Program

Prior to Dam Removal or Dam Stabilization

› Map the extent (and species) of invasive plants in the focus area, using EDDMapS or some other mapping tool. To be most effective, this effort should involve requesting landowner permission to conduct field visits on private property around the impoundment.

› Conduct study of seed viability in pond and stream sediments, using either or both of following methods: (1) draw down water level a few inches to expose sediment and observe germination in multiple locations around pond; (2) collect sediment samples from same locations. Place sediments in containers in the open covered with a fine mesh screen, keep well-watered and observe germination

› Continue pilot project of knotweed and other invasive plant control along Mill Pond Road

› Empower Durham Land Stewardship Coordinator to engage volunteers and interns in hand pulling or digging small seedlings where feasible in the focus area

› Engage private landowners in the focus area to assist in reducing seed sources

› Target a reduction of the large seed-producing plants using mechanical methods and herbicide. This will reduce the quantity of plants that disperse seeds onto the pond as the water is drawn down

Post Dam Removal (Years 1-5)

› During the first year, monitor for flush of invasive plant seedlings in the newly exposed sediments; hand pull as feasible. This will likely require visits once a month from April to September (6 visits).

› Continue to monitor for flush of invasive plant seedlings in years 2-5 and hand pull as feasible. This will likely require three visits (April/May, June/July, August/September)

› Spread wetland seed mix on newly exposed sediment to suppress invasive plant growth

› Develop and implement a 5-year plan to control invasive plants in and around Mill Pond and upstream using a combination of techniques to reduce the density of invasive plants

- Shrubby invasive plants killed the previous year along the shoreline should be removed by mechanically clipping and removing the dead plant material to allow native vegetation to recolonize the space
- Where feasible, continue to hand pull or dig invasive plant seedlings
- Apply cut-stem or low volume foliar spray herbicide to invasive plants in target areas; the Plan should include a map of the target areas in each of the five years
- A recent study by UNH provides guidance on percent solution of Glyphosate and Garlon that results in mortality of glossy buckthorn after one treatment using cut-stem (Glyphosate 5% solution) and surface application to the lower 1.5 feet of bark stem (Garlon 5% solution) (Lee, 2020).

Project Phasing and Focus Areas

The IVM Program can be divided into three focus areas:

- Focus Area 1 (Recommended for either Alternative 3 or Alternative 5): Upland invasive species treatment around the Mill Pond impoundment (focusing on glossy buckthorn and Japanese knotweed). This area is approximately 3.5 acres, including portions of both the north and south sides of the existing Mill Pond.
- Focus Area 2 (Alternative 5): If the dam is removed, monitoring for the establishment of invasive species within the dewatered area (focusing on glossy buckthorn, Japanese knotweed, and Phragmites) and hand pull these species. No or limited herbicide treatment would be recommended in the dewatered wetland area. This area is about 6.5 acres.
- Focus Area 3 (Recommended for either Alternative 3 or Alternative 5): Upland invasive species treatment around the Middle Reach and Hamel Brook impoundment areas, focusing on glossy buckthorn and Japanese knotweed. Conservatively assuming this focus area extends about 100 feet from the existing impoundment on either side, this would be approximately 18 acres.

Invasive Species Management Costs

The cost of invasive species management can vary widely depending on numerous factors such as the species being targeted, site accessibility, and density of the target population. Furthermore, in the case of the Mill Pond Dam, it is not clear whether the habitat to be created if the dam were to be removed would be appropriate for the spread of knotweed or buckthorn, the two species of most concern. Relatively minor invasive species impacts have been observed for similar dam management projects in the northeast. However, the presence of non-native populations directly adjacent to the pond suggests that an appropriate monitoring and control plan be in place and funded to ensure that invasive species are properly managed.

Anecdotal, project bid databases, and gray literature reflect the wide range of costs for invasive species control. Based on these sources, per acre costs for invasive species range can range from a low of $10/acre for mechanical or chemical treatments of low-density shrubs, to as high as $8,000-$10,000 per acre for complete removal of high density populations. A review of recent NHDOT bid results suggests that control of invasive species as part of highway construction projects can range as high as $22,990 per acre for non-woody species to $24,490 for woody species, although these costs reflect a scope of work exceeding the efforts required for this project.[12] **Table 3-2** provides data from based on a recent study in the mid-Atlantic region that developed a regional (city-wide) invasive species control plan.

Based on the available information regarding typical costs for invasive species control, and considering the conceptual IVM plan outlined in this section, the team developed a planning-level opinion of cost for a comprehensive 5-year IVM. These costs are presented in **Table 3-3**.

[12] NHDOT Specifications require contractors to provide a bid price to manage invasive species on a square yard cost basis. See Items 201.881 and 201.882 in the NHDOT Standard Specifications, or at the online bid database here: https://www.nh.gov/dot/org/administration/finance/bids/bidresults/index.htm

Table 3-2 Cost to Control Invasive Shrub Species, per acre, by Treatment Type

Invasive Species % Cover	Basal Bark	Foliar Treatment (Backpack)	Foliar Treatment (ATV)	Cut/Treat	Grub
Extremely Dense (81-100%)	$2,600	$1,445	$607	$5,200	$10,400
Very Dense (61-80%)	$2,022	$1,011	$462	$4,045	$8,089
Dominant (41-60%)	$1,445	$722	$347	$2,889	$5,778
Present, Near Dominant (21-40%)	$867	$433	$202	$1,733	$3,467
Present, Sub-Dominant (1-20%)	$295	$150	$64	$584	$1,161

Source: Modified from Biohabitats (2013). Costs per acre have been averaged and escalated for inflation to adjust from 2013 dollar to 2021 dollars.

Table 3-3 Preliminary Opinion of Probable Cost, 5-Year Invasive Species IVM

Item	Quantity	Unit	Cost/Unit	Total Item
Year 1				**$39,625**
Planning, Coordination, Administration	1	ea	$6,000	$6,000
Initial Mapping	28	ac	$500	$14,000
Invasive Control - Focus Area 1	3.5	ac	$1,750	$6,125
Invasive Control - Focus Area 3	18	ac	$750	$13,500
Year 2				**$29,450**
Coordination/Administration	1	ea	$4,000	$4,000
Monitoring[1]	6.5	ac	$500	$3,250
Invasive Control - Focus Area 1	3.5	ac	$1,400	$4,900
Invasive Control - Focus Area 2[1]	6.5	ac	$1,000	$6,500
Invasive Control - Focus Area 3	18	ac	$600	$10,800
Year 3				**$24,010**
Coordination/Administration	1	ea	$3,000	$3,000
Monitoring	6.5	ac	$500	$3,250
Invasive Control - Focus Area 1	3.5	ac	$1,120	$3,920
Invasive Control - Focus Area 2	6.5	ac	$800	$5,200
Invasive Control - Focus Area 3	18	ac	$480	$8,640
Year 4				**$19,830**
Coordination/Administration	1	ea	$3,000	$3,000
Monitoring	6.5	ac	$500	$3,250
Invasive Control - Focus Area 1	3.5	ac	$840	$2,940
Invasive Control - Focus Area 2	6.5	ac	$640	$4,160
Invasive Control - Focus Area 3	18	ac	$360	$6,480
Year 5				**$16,435**
Coordination/Administration	1	ea	$3,000	$3,000
Monitoring	6.5	ac	$500	$3,250

Invasive Control - Focus Area 1	3.5	ac	$630	$2,205
Invasive Control - Focus Area 2	6.5	ac	$480	$3,120
Invasive Control - Focus Area 3	18	ac	$270	$4,860
TOTAL (Alternative 5)				**$129,350**
TOTAL (Alternative 3)				**$91,370**

Notes:

1 Items related to Focus Area 2, as well as annual monitoring, could be eliminated if Alternative 3 -Dam Stabilization is selected. Additionally, annual coordination and administration would be reduced under and IVM adopted for Alternative 3.

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Appendix A - Mill Pond Management Options Review

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Appendix A.

Table A-1. Mill Pond management options review (Adapted from Wagner 2004, DK 2014)

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO MILL POND
1) Management for nutrient input reduction	♦ Includes wide range of watershed and pond edge activities intended to eliminate nutrient sources or reduce delivery to pond ♦ Essential component of algal and plant control strategy where internal recycling is not the dominant nutrient source, and desired even where internal recycling is important	♦ Acts against the original source of algal and plant nutrition ♦ Creates sustainable limitation on algal growth and may help control plant growth. ♦ May control delivery of other unwanted pollutants to pond ♦ Facilitates ecosystem management approach which considers more than just control of vegetation. ♦ Will benefit downstream resources	♦ May involve considerable lag time before improvement observed ♦ May not be sufficient to achieve goals without some form of in-pond management ♦ Reduction of overall system fertility may impact fisheries ♦ May cause shift in nutrient ratios which favor less desirable algae.	♦ Applicable (see below for evaluation of input management alternatives)
1a) Point source controls	♦ More stringent discharge requirements	♦ Often provides major input reduction	♦ May be very expensive in terms	♦ Not applicable – no point sources

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO MILL POND
	♦ May involve diversion ♦ May involve technological or operational adjustments ♦ May involve pollution prevention plans	♦ Highly efficient approach in most cases ♦ Success easily monitored ♦	of capital and operational costs ♦ May transfer problems to another watershed ♦ Variability in results may be high in some cases	
1b) Nonpoint source controls	♦ Reduction of sources of nutrients ♦ May involve elimination of land uses or activities that release nutrients ♦ May involve alternative product use, such as no phosphate or organic fertilizer. ♦ Includes limitations on waterfowl feeding. ♦ Includes public education and outreach	♦ Removes the source of nutrients. ♦ Limited ongoing costs	♦ May require purchase of land or remedial action on private property. ♦ May be viewed as limitation of use of property. ♦ Usually requires education and gradual implementation	♦ High applicability ♦ Essential to control external sources to reduce probability of algal blooms and excessive plant growth. ♦ Control of external sources may increase the effectiveness or longevity of any in-pond remedial activities. ♦ Watershed-based plans detail source reduction options
1c) Nonpoint source pollutant trapping	♦ Capture of pollutants between source and pond ♦ May involve drainage system alteration ♦ Often involves wetland treatments (det./infiltration)	♦ Minimizes interference with land uses and activities ♦ Allows diffuse and phased implementation throughout watershed	♦ Does not address actual sources ♦ May be expensive on necessary scale ♦ May require substantial maintenance ♦	♦ Somewhat applicable ♦ Few locations where there is sufficient land to enhance trapping between sources and the pond due to dense development and size of inflow streams.

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO MILL POND
	♦ May involve stormwater collection and treatment as with point sources	♦ Highly flexible approach ♦ Tends to address wide range of pollutant loads		
3) Circulation and destratification	♦ Use of water or air to keep water in motion. ♦ Intended to prevent or break stratification. ♦ Generally driven by mechanical or pneumatic force.	♦ Reduces surface build-up of algal scums. ♦ May disrupt growth of cyanobacteria. ♦ Counteraction of anoxia improves habitat for fish/invertebrates. ♦ Can eliminate localized problems without obvious impact on whole pond.	♦ May spread localized impacts by mixing poor quality water throughout the pond. ♦ May lower oxygen levels in shallow water. ♦ May promote downstream impacts. ♦ May circulate nutrients up into the photic zone.	♦ Not applicable as pond is not consistently stratified and flushes rapidly.
4) Dilution and flushing	♦ Addition of water of better quality can dilute nutrients. ♦ Addition of water of similar or poorer quality flushes system to minimize algal build-up. ♦ May have continuous or periodic additions of water.	♦ Dilution reduces nutrient concentrations without altering load. ♦ Flushing minimizes detention; response to pollutants may be reduced. ♦ May displace low oxygen water.	♦ Diverts water from other uses. ♦ Flushing may wash desirable zooplankton from pond. ♦ Use of poorer quality water increases loads. ♦ Possible downstream impacts from low oxygen water.	♦ Limited applicability ♦ No large source of high quality dilution water available. ♦ Pond is already rapidly flushed much of the year. ♦ Possible application during summer low flow periods if sufficient water is available however, only

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO MILL POND
				flushing rate would be increased. ♦ Nutrient concentration of water in pond would not be improved. ♦ May move low oxygen water downstream.
5) Drawdown	♦ Lowering of water over autumn period allows oxidation, desiccation and compaction of sediments. ♦ Duration of exposure and degree of dewatering of exposed areas are important. ♦ Algae are affected mainly by reduction in available nutrients.	♦ May reduce available nutrients or nutrient ratios, affecting algal biomass and composition. ♦ Opportunity for shoreline clean-up/structure repair ♦ Flood control utility. ♦ May provide rooted plant control.	♦ Possible impacts on non-target resources. ♦ Alteration of downstream flows and winter water level. ♦ May result in greater nutrient availability if flushing is inadequate. ♦ Possible effects on overwintering reptiles and amphibians.	♦ Not generally applicable except in context of dredging. ♦ Will not address loading issue.
6) Dredging	♦ Sediment is physically removed by wet or dry excavation, with deposition in a containment area for dewatering. ♦ Dredging can be applied on a limited basis, but is most often a major	♦ Can control algae if internal recycling is main nutrient source. ♦ Increases water depth. ♦ Can reduce pollutant reserves. ♦ Can reduce sediment oxygen demand.	♦ Temporarily reduces benthic invertebrate populations. ♦ May create turbidity. ♦ May eliminate fish community (complete dry dredging only).	♦ Somewhat applicable ♦ (See below for evaluation of specific dredging methods)

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO MILL POND
	restructuring of a severely impacted system. ♦ Nutrient reserves are removed and algal growth can be limited by nutrient availability if external supply is reduced.	♦ Can improve spawning habitat for many fish species. ♦ Allows complete renovation of aquatic ecosystem. ♦ Can remove rooted aquatic plants.	♦ Possible impacts from containment area discharge. ♦ Possible impacts from dredged material disposal. ♦ Interference with recreation or other uses during dredging.	
6a) “Dry” excavation	♦ Pond drained or lowered to maximum extent practical. ♦ Target material dried to maximum extent possible. ♦ Conventional excavation equipment used to remove sediments.	♦ Tends to facilitate a very thorough effort. ♦ May allow drying of sediments prior to removal. ♦ Allows use of less specialized equipment.	♦ Eliminates most aquatic biota unless a portion left undrained. ♦ Eliminates pond use during dredging. ♦ Expensive.	♦ Likely applicable. ♦ Pond cannot be drained completely due to river flow. ♦ Disposal may be expensive. ♦ Benefits would be temporary unless nutrient and sediment sources from watershed are reduced substantially.
6b) “Wet” excavation	♦ Pond level may be lowered, but sediments not substantially exposed. ♦ Draglines, bucket dredges, or long-reach backhoes used to remove sediment.	♦ Requires least preparation time or effort, tends to be least cost dredging approach. ♦ May allow use of easily acquired equipment.	♦ Usually creates extreme turbidity. ♦ Normally requires intermediate containment area to dry sediments prior to hauling. ♦ May disrupt ecological function.	♦ Not applicable. ♦ Pond is too large to manage with shore-based equipment. ♦ No large staging area near shore.

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO MILL POND
		♦ May preserve aquatic biota.	♦ Use disruption.	
6c) Hydraulic removal	♦ Pond level not reduced. ♦ Suction or cutterhead dredges create slurry which is hydraulically pumped to containment area. ♦ Slurry is dewatered; sediment retained, water discharged.	♦ Creates minimal turbidity and impact on biota. ♦ Can allow some pond uses during dredging. ♦ Allows removal with limited access or shoreline disturbance.	♦ Often leaves some sediment behind. ♦ Cannot handle coarse or debris-laden materials. ♦ Requires sophisticated and more expensive containment area.	♦ Somewhat applicable. ♦ Would require use of adjacent town property. ♦ Regulatory approvals difficult to impossible. ♦ Pumping hydraulically dredged sediments uphill to a potential staging area would be a challenge. ♦ Would be expensive.
7) Light-limiting dyes and surface covers	♦ Creates light limitation.	♦ Creates light limit on algal growth without high turbidity or great depth. ♦ May achieve some control of rooted plants as well.	♦ May cause thermal stratification in shallow ponds. ♦ May facilitate anoxia at sediment interface with water.	♦ Not applicable. ♦ Flushing rate too high, migration of dye downstream.
7a) Dyes	♦ Water-soluble dye is mixed with pond water, thereby limiting light penetration and inhibiting algal and plant growth. ♦ Dyes remain in solution until washed out of system.	♦ Color appealing to some. ♦ Creates illusion of greater depth.	♦ May not control surface bloom-forming species. ♦ May not control growth of shallow water algal mats. ♦ Altered thermal regime.	♦ Not applicable. ♦ Flushing rate too high ♦ Artificial color objectionable to some.

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO MILL POND
7b) Surface covers	♦ Opaque sheet material applied to water surface.	♦ Minimizes atmospheric and wildlife pollutant inputs.	♦ Minimizes atmospheric gas exchange. ♦ Limits recreation. ♦ Limits aquatic life.	♦ Not applicable ♦ Cover would eliminate recreation opportunities and much aquatic life.
8) Mechanical removal of algae or rooted plants.	♦ Filtering of pumped water for water supply purposes to remove algae. ♦ Collection of floating scums or mats with booms, nets, or other devices. ♦ Cutting and gathering of rooted plants. ♦ Continuous or multiple applications per year usually needed.	♦ Algae, plants and associated nutrients can be removed from system. ♦ Surface collection can be applied as needed. ♦ May remove floating debris. ♦ Collected algae/ macrophytes dry to smaller volume and weight	♦ Filtration of algae from water requires high backwash and sludge handling capability. ♦ Labor and/or capital intensive to remove plants. ♦ Need a staging area. ♦ Possible impacts on non-target aquatic life. ♦ Would need to continue indefinitely.	♦ Not applicable ♦ Would not decrease nutrient levels because or rapid resupply from the watershed. ♦ Mechanical harvesting of plants would be required every few weeks to a month. ♦ Large staging area needed to harvest macrophytes. ♦ Shallow water would make navigation by harvesting boat nearly impossible.
9) Selective withdrawal	♦ Discharge of bottom water which may contain (or be susceptible to) low oxygen and higher nutrient levels. ♦ May be pumped or utilize passive head differential.	♦ Removes targeted water from pond efficiently. ♦ May prevent anoxia and phosphorus build up in bottom water. ♦ May remove initial phase of algal blooms which start in deep water.	♦ Possible downstream impacts of poor water quality. ♦ May promote mixing of remaining poor quality bottom water with surface water.	♦ Not applicable as stratification has not been documented. ♦ May move oxygen problems to estuary downstream.

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO MILL POND
			♦ May cause unintended drawdown if inflows do not match withdrawal.	
10) Sonication	♦ Sound waves disrupt algal cells.	♦ Supposedly affects only algae (new technique). ♦ Applicable in localized areas.	♦ Unknown effects on non-target organisms. ♦ May release cellular toxins or other undesirable contents into water column.	♦ Not applicable. ♦ Flushing rate is faster than technique takes to kill algae. ♦ Very localized effect
11)Aeration or oxygenation	♦ Addition of air or oxygen provides oxic conditions. ♦ Can also withdraw water, oxygenate, then replace.	♦ Oxic conditions reduce phosphorus availability. ♦ Oxygen improves habitat. ♦ Oxygen reduces build-up of reduced compounds.	♦ May disrupt thermal layers important to fish community. ♦ Theoretically promotes supersaturation with gases harmful to fish.	♦ Possibly applicable ♦ If sized properly would reduce volume of anoxic water. ♦ Would require continuous operation during low oxygen period. ♦ Has shore power and infrastructure needs
a) Traditional hypolimnetic	♦ Add oxygen or air to lower layers without changing stratification.	♦ Can eliminate anoxia at depth. ♦ Can reduce anoxic release of nutrients, particularly phosphorus.	♦ May result in destratification or increased transport of nutrients from sediments by inducing currents.	♦ Not applicable, no reliable stratification. ♦ May “pump” nutrients up from sediments.

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO MILL POND
			♦ Does not change nutrient loading.	
b) Side-stream oxygenation	♦ Remove water from low oxygen areas with a shore based pump, add oxygen and return water to pond.	♦ Does not destratify pond or lake because of low velocities. ♦ Relatively low energy costs. ♦ Small outbuilding.	♦ Does not deal with source of nutrients. ♦ May result in supersaturation if not monitored. ♦ Will not work without power.	♦ Possibly applicable ♦ Would likely be needed for much of summer/fall to keep oxygen concentrations high. ♦ Will not change nutrient loading or plant/algae growth.
12) Herbicides	♦ Liquid or pelletized algaecides/herbicides applied to target area. ♦ Algae or plants killed by direct toxicity or metabolic interference. ♦ Typically requires application at least once/yr, often more frequently.	♦ Rapid elimination of algae or plants from water column , normally with increased water clarity. ♦ May result in net movement of nutrients to bottom of pond.	♦ Possible toxicity to non-target species. ♦ Restrictions on water use for varying time after treatment. ♦ Increased oxygen demand and possible toxicity. ♦ Possible recycling of nutrients.	♦ Somewhat applicable ♦ (see below for discussion of specific algaecides).
a) Forms of copper	♦ Cellular toxicant, disruption of membrane transport.	♦ Effective and rapid control of many algae species.	♦ Possible toxicity to aquatic fauna.	♦ Not applicable ♦ Won't change nutrient conditions that caused

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO MILL POND
	♦ Applied as wide variety of liquid or granular formulations.	♦ Approved for use in most water supplies.	♦ Accumulation of copper in system. ♦ Resistance by certain green and blue-green nuisance species. ♦ Lysing of cells releases nutrients and toxins. ♦ Will migrate downstream in rapidly flushed system.	bloom so bloom conditions may re-occur in same season. ♦ Will migrate downstream in highly flushed system. ♦ Application to cyanobacteria in macrophyte beds would be difficult. ♦ Will require application permit.
b) Peroxides	♦ Disrupts most algal cellular functions, tends to attack membranes. ♦ Applied as a liquid or solid. ♦ Typically requires application at least once/yr, often more frequently.	♦ Rapid action. ♦ Oxidizes cell contents, may limit oxygen demand and toxicity.	♦ Much more expensive than copper. ♦ Limited track record. ♦ Possible recycling of nutrients. ♦	♦ Not applicable. ♦ May work to reduce or eliminate an existing bloom but at high cost. ♦ Won't appreciably change conditions that caused bloom so bloom conditions may re-occur in same season. ♦ May require an application permit.
12c) Synthetic organic algaecides and herbicides	♦ Absorbed or membrane-active chemicals which disrupt metabolism. ♦ Causes structural deterioration.	♦ Used where copper is ineffective. ♦ Both systemic and contact products available. ♦ Limited toxicity to fish at recommended dosages.	♦ Non-selective in treated area. ♦ Toxic to aquatic fauna (varying degrees by formulation). ♦ Time delays on water use .	♦ Somewhat applicable ♦ Will reduce or eliminate an existing bloom. ♦ Won't appreciably change conditions that caused bloom so bloom conditions may

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO MILL POND
		♦ Rapid action.	♦ Decay of plants may release additional nutrients.	re-occur in same season. ♦ Will migrate downstream in highly flushed system. ♦ Will require permit. ♦ May have waterbody use restrictions.
13) Phosphorus inactivation	♦ Typically salts of aluminum, iron or calcium are added to the pond, as liquid or powder. ♦ Phosphorus in the treated water column is complexed and settled to the bottom of the pond. ♦ Phosphorus in upper sediment layer is complexed, reducing release from sediment. ♦ Permanence of binding varies by binder in relation to redox potential and pH.	♦ Can provide rapid, major decrease in phosphorus concentration in water column. ♦ Can minimize release of phosphorus from sediment. ♦ May remove other nutrients and contaminants as well as phosphorus. ♦ Flexible with regard to depth of application and speed of improvement.	♦ Possible toxicity to fish and invertebrates, especially by aluminum at low pH. ♦ Possible release of phosphorus under anoxia or extreme pH. ♦ May cause fluctuations in water chemistry, especially pH, during treatment. ♦ Possible resuspension of floc in shallow areas. ♦ Adds to bottom sediment, but typically an insignificant amount.	♦ Not Applicable. ♦ Significant internal loading of phosphorus not documented by data collected to date. ♦ Watershed loading and large size of watershed suggest that treatment lifespan would be very short.

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO MILL POND
14) Sediment oxidation	♦ Addition of oxidants, binders and pH adjustors to oxidize sediment. ♦ Binding of phosphorus is enhanced. ♦ Denitrification is stimulated.	♦ Can reduce phosphorus supply to algae. ♦ Can alter nitrogen to phosphorus ratios in water column. ♦ May decrease sediment oxygen demand.	♦ Possible impacts on benthic biota. ♦ Longevity of effects not well known. ♦ Possible source of nitrogen for cyanobacteria.	♦ Not applicable. ♦ Sediments are not a major source of nutrients. ♦ Effects are not well understood and there are insufficient case studies to predict effectiveness with any degree of confidence.
15) Settling agents	♦ Closely aligned with phosphorus inactivation, but can be used to reduce algae directly too. ♦ Lime, alum or polymers applied, usually as a liquid or slurry to inlet or pond. ♦ Creates a floc with algae and other suspended particles. ♦ Floc settles to bottom of pond. ♦ Re-application typically necessary at least once/yr .	♦ Removes algae and increases water clarity without lysing most cells. ♦ Reduces nutrient recycling if floc sufficient. ♦ Removes non-algal particles as well as algae. ♦ May reduce dissolved phosphorus levels at the same time.	♦ Possible impacts on aquatic fauna. ♦ Possible fluctuations in water chemistry during treatment. ♦ Resuspension of floc possible in shallow, well-mixed waters. ♦ Promotes increased sediment accumulation.	♦ Likely not applicable. ♦ Would require frequent retreatment if used in pond. ♦ May be applicable for injection into tributaries but no documented example of implementation in NH to date. ♦ May increase sediment accumulation in pond.
16) Selective nutrient addition	♦ Ratio of nutrients changed by additions of selected nutrients. ♦ Addition of non-limiting nutrients can	♦ Can reduce algal levels where control of limiting nutrient is not feasible.	♦ May result in greater algal abundance through uncertain biological response.	♦ Not applicable. ♦ Likely would involve adding nitrogen to favor species other than cyanobacteria.

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO MILL POND
	change composition of algal community. ♦ Processes such as settling and grazing can then reduce algal biomass.	♦ Can promote non-nuisance forms of algae. ♦ Can improve productivity of system without increased standing crop of algae.	♦ May require frequent application to maintain desired ratios. ♦ Possible downstream effects.	♦ Contrary to principles of watershed management, particularly with respect to nitrogen limited estuarine resources downstream of Mill Pond. ♦ Nitrogen addition may result in additional algal growth of non-cyanobacteria species
17) Biomanipulation	♦ Manipulation of biological components of system to achieve grazing control over algae. ♦ Typically involves alteration of fish community to promote growth of grazing zooplankton.	♦ May increase water clarity by changes in algal biomass or cell size without reduction of nutrient levels. ♦ Can convert unwanted algae into fish. ♦ Harnesses natural processes.	♦ May involve introduction of exotic species. ♦ Effects may not be controllable or lasting. ♦ May foster shifts in algal composition to even less desirable forms.	♦ See below. (pond is too small and an open system, would be very difficult to control)
17a) Herbivorous fish	♦ Stocking of fish that eat algae.	♦ Converts algae and plant biomass directly into potentially harvestable fish. ♦ Grazing pressure can be adjusted through stocking rate.	♦ Typically requires introduction of non-native species. ♦ Difficult to control over long term. ♦ Smaller algal forms may be benefited and bloom.	♦ Not applicable. ♦ Not permitted in NH.

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO MILL POND
17b) Enhanced grazing through food chain interactions	♦ Reduction in planktivorous fish to promote grazing pressure by zooplankton. ♦ May involve stocking piscivores or removing planktivores. ♦ May also involve stocking zooplankton or establishing refugia.	♦ May increase water clarity by changes in algal biomass or cell size without reduction of nutrient levels. ♦ Converts algae indirectly into harvestable fish. ♦ Zooplankton response to increasing algae can be rapid. ♦ May be accomplished without introduction of non-native species. ♦ Generally compatible with most fishery management goals.	♦ May involve introduction of exotic species. ♦ Effects may not be controllable or lasting. ♦ May foster shifts in algal composition to even less desirable forms. ♦ Highly variable response expected; temporal and spatial variability may be high. ♦ Requires careful monitoring and management action on 1-5 yr basis. ♦ Larger or toxic algal forms may be benefitted and bloom.	♦ Not applicable. ♦ A balanced and stable fish and invertebrate community is generally supportive of good water quality. ♦ Nuisance cyanobacterial species are generally not preferred by grazers. ♦ Difficult to achieve target community in a small open system like Mill Pond.
18) Bottom-feeding fish removal	♦ Removes fish that browse among bottom deposits, releasing nutrients to the water column by physical agitation and excretion.	♦ Reduces turbidity and nutrient additions from this source. ♦ May restructure fish community in more desirable manner.	♦ Targeted fish species are difficult to control. ♦ Reduction in fish populations valued by some pond users (human/non-human).	♦ Not applicable. ♦ No documented occurrence of such fish in Mill Pond.

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO MILL POND
19) Microbial competition	♦ Addition of microbes, often with oxygenation, can tie up nutrients and limit algal growth. ♦ Tends to control nitrogen more than phosphorus.	♦ Shifts nutrient use to organisms that do not form scums or impair uses to same extent as algae. ♦ Harnesses natural processes. ♦ May decrease sediment.	♦ Minimal scientific evaluation. ♦ Nitrogen control may still favor cyanobacteria. ♦ May need aeration system to get acceptable results.	♦ Not applicable. ♦ Favorable results for phosphorus control have not been documented.
20) Pathogens	♦ Addition of inoculum to initiate attack on algal cells. ♦ May involve fungi, bacteria or viruses.	♦ May create pondwide "epidemic" and reduction of algal biomass. ♦ May provide sustained control through cycles. ♦ Can be highly specific to algal group or genera.	♦ Largely experimental approach at this time. ♦ May promote resistant nuisance forms. ♦ May cause high oxygen demand or release of toxins by lysed algal cells. ♦ Effects on non-target organisms uncertain.	♦ Not applicable. ♦ Experimental.
21) Competition and allelopathy by plants	♦ Plants may tie up sufficient nutrients to limit algal growth. ♦ Plants may create a light limitation on algal growth. ♦ Chemical inhibition of algae may occur through substances	♦ Harnesses power of natural biological interactions. ♦ May provide responsive and prolonged control.	♦ Some algal forms appear resistant. ♦ Use of plants may lead to problems with vascular plants. ♦ Use of plant material may cause	♦ Not applicable (see below for discussion of alternatives).

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO MILL POND
	released by other organisms.		depression of oxygen levels.	
21a) Plantings for nutrient control	♦ Plant growths of sufficient density may limit algal access to nutrients. ♦ Plants can exude allelopathic substances which inhibit algal growth. ♦ Portable plant “pods” , floating islands, or other structures can be installed.	♦ Productivity and associated habitat value can remain high without algal blooms. ♦ Can be managed to limit interference with recreation and provide habitat. ♦ Wetland cells in or adjacent to the pond can minimize nutrient inputs.	♦ Vascular plants may achieve nuisance densities. ♦ Vascular plant senescence may release nutrients and cause algal blooms. ♦ The switch from algae to vascular plant domination of a pond may cause unexpected or undesirable changes .	♦ Not applicable. ♦ Mill Pond already supports an overly large community of vascular plants.
21b) Plantings for light control	♦ Plant species with floating leaves can shade out many algal growths at elevated densities.	♦ Vascular plants can be more easily harvested than most algae. ♦ Many floating species provide waterfowl food.	♦ Floating plants can be a recreational nuisance. ♦ Low surface mixing and atmospheric contact promote anoxia.	♦ Not applicable. ♦ Plants would interfere with recreational activities.

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO MILL POND
21c) Addition of barley straw	♦ Input of barley straw can set off a series of chemical reactions which limit algal growth. ♦ Release of allelopathic chemicals can kill algae. ♦ Release of humic substances can bind phosphorus.	♦ Materials and application are relatively inexpensive. ♦ Decline in algal abundance is more gradual than with algaecides, limiting oxygen demand and the release of cell contents.	♦ Success appears linked to uncertain and potentially uncontrollable water chemistry factors. ♦ Depression of oxygen levels may result. ♦ Water chemistry may be altered in other ways unsuitable for non-target organisms.	♦ Not applicable. ♦ Experimental technique with unpredictable results.

Appendix B – Oyster Reservoir Hydrological Mass Balance Model Results

Appendix C – Supplemental Hydraulic Model Results

Appendix D – Low Flow Inundation Maps

Appendix E – Conceptual Dam Stabilization Plan with Notch

Appendix A - Mill Pond Management Options Review

Appendix A.

Table A-1. Mill Pond management options review (Adapted from Wagner 2004, DK 2014)

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO MILL POND
1) Management for nutrient input reduction	♦ Includes wide range of watershed and pond edge activities intended to eliminate nutrient sources or reduce delivery to pond ♦ Essential component of algal and plant control strategy where internal recycling is not the dominant nutrient source, and desired even where internal recycling is important	♦ Acts against the original source of algal and plant nutrition ♦ Creates sustainable limitation on algal growth and may help control plant growth. ♦ May control delivery of other unwanted pollutants to pond ♦ Facilitates ecosystem management approach which considers more than just control of vegetation. ♦ Will benefit downstream resources	♦ May involve considerable lag time before improvement observed ♦ May not be sufficient to achieve goals without some form of in-pond management ♦ Reduction of overall system fertility may impact fisheries ♦ May cause shift in nutrient ratios which favor less desirable algae.	♦ Applicable (see below for evaluation of input management alternatives)
1a) Point source controls	♦ More stringent discharge requirements	♦ Often provides major input reduction	♦ May be very expensive in terms	♦ Not applicable – no point sources

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO MILL POND
	♦ May involve diversion ♦ May involve technological or operational adjustments ♦ May involve pollution prevention plans	♦ Highly efficient approach in most cases ♦ Success easily monitored ♦	of capital and operational costs ♦ May transfer problems to another watershed ♦ Variability in results may be high in some cases	
1b) Nonpoint source controls	♦ Reduction of sources of nutrients ♦ May involve elimination of land uses or activities that release nutrients ♦ May involve alternative product use, such as no phosphate or organic fertilizer. ♦ Includes limitations on waterfowl feeding. ♦ Includes public education and outreach	♦ Removes the source of nutrients. ♦ Limited ongoing costs	♦ May require purchase of land or remedial action on private property. ♦ May be viewed as limitation of use of property. ♦ Usually requires education and gradual implementation	♦ High applicability ♦ Essential to control external sources to reduce probability of algal blooms and excessive plant growth. ♦ Control of external sources may increase the effectiveness or longevity of any in-pond remedial activities. ♦ Watershed-based plans detail source reduction options
1c) Nonpoint source pollutant trapping	♦ Capture of pollutants between source and pond ♦ May involve drainage system alteration ♦ Often involves wetland treatments (det./infiltration)	♦ Minimizes interference with land uses and activities ♦ Allows diffuse and phased implementation throughout watershed	♦ Does not address actual sources ♦ May be expensive on necessary scale ♦ May require substantial maintenance ♦	♦ Somewhat applicable ♦ Few locations where there is sufficient land to enhance trapping between sources and the pond due to dense development and size of inflow streams.

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO MILL POND
	♦ May involve stormwater collection and treatment as with point sources	♦ Highly flexible approach ♦ Tends to address wide range of pollutant loads		
3) Circulation and destratification	♦ Use of water or air to keep water in motion. ♦ Intended to prevent or break stratification. ♦ Generally driven by mechanical or pneumatic force.	♦ Reduces surface build-up of algal scums. ♦ May disrupt growth of cyanobacteria. ♦ Counteraction of anoxia improves habitat for fish/invertebrates. ♦ Can eliminate localized problems without obvious impact on whole pond.	♦ May spread localized impacts by mixing poor quality water throughout the pond. ♦ May lower oxygen levels in shallow water. ♦ May promote downstream impacts. ♦ May circulate nutrients up into the photic zone.	♦ Not applicable as pond is not consistently stratified and flushes rapidly.
4) Dilution and flushing	♦ Addition of water of better quality can dilute nutrients. ♦ Addition of water of similar or poorer quality flushes system to minimize algal build-up. ♦ May have continuous or periodic additions of water.	♦ Dilution reduces nutrient concentrations without altering load. ♦ Flushing minimizes detention; response to pollutants may be reduced. ♦ May displace low oxygen water.	♦ Diverts water from other uses. ♦ Flushing may wash desirable zooplankton from pond. ♦ Use of poorer quality water increases loads. ♦ Possible downstream impacts from low oxygen water.	♦ Limited applicability ♦ No large source of high quality dilution water available. ♦ Pond is already rapidly flushed much of the year. ♦ Possible application during summer low flow periods if sufficient water is available however, only

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO MILL POND
				flushing rate would be increased. ♦ Nutrient concentration of water in pond would not be improved. ♦ May move low oxygen water downstream.
5) Drawdown	♦ Lowering of water over autumn period allows oxidation, desiccation and compaction of sediments. ♦ Duration of exposure and degree of dewatering of exposed areas are important. ♦ Algae are affected mainly by reduction in available nutrients.	♦ May reduce available nutrients or nutrient ratios, affecting algal biomass and composition. ♦ Opportunity for shoreline clean-up/structure repair ♦ Flood control utility. ♦ May provide rooted plant control.	♦ Possible impacts on non-target resources. ♦ Alteration of downstream flows and winter water level. ♦ May result in greater nutrient availability if flushing is inadequate. ♦ Possible effects on overwintering reptiles and amphibians.	♦ Not generally applicable except in context of dredging. ♦ Will not address loading issue.
6) Dredging	♦ Sediment is physically removed by wet or dry excavation, with deposition in a containment area for dewatering. ♦ Dredging can be applied on a limited basis, but is most often a major	♦ Can control algae if internal recycling is main nutrient source. ♦ Increases water depth. ♦ Can reduce pollutant reserves. ♦ Can reduce sediment oxygen demand.	♦ Temporarily reduces benthic invertebrate populations. ♦ May create turbidity. ♦ May eliminate fish community (complete dry dredging only).	♦ Somewhat applicable ♦ (See below for evaluation of specific dredging methods)

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO MILL POND
	restructuring of a severely impacted system. ♦ Nutrient reserves are removed and algal growth can be limited by nutrient availability if external supply is reduced.	♦ Can improve spawning habitat for many fish species. ♦ Allows complete renovation of aquatic ecosystem. ♦ Can remove rooted aquatic plants.	♦ Possible impacts from containment area discharge. ♦ Possible impacts from dredged material disposal. ♦ Interference with recreation or other uses during dredging.	
6a) "Dry" excavation	♦ Pond drained or lowered to maximum extent practical. ♦ Target material dried to maximum extent possible. ♦ Conventional excavation equipment used to remove sediments.	♦ Tends to facilitate a very thorough effort. ♦ May allow drying of sediments prior to removal. ♦ Allows use of less specialized equipment.	♦ Eliminates most aquatic biota unless a portion left undrained. ♦ Eliminates pond use during dredging. ♦ Expensive.	♦ Likely applicable. ♦ Pond cannot be drained completely due to river flow. ♦ Disposal may be expensive. ♦ Benefits would be temporary unless nutrient and sediment sources from watershed are reduced substantially.
6b) "Wet" excavation	♦ Pond level may be lowered, but sediments not substantially exposed. ♦ Draglines, bucket dredges, or long-reach backhoes used to remove sediment.	♦ Requires least preparation time or effort, tends to be least cost dredging approach. ♦ May allow use of easily acquired equipment.	♦ Usually creates extreme turbidity. ♦ Normally requires intermediate containment area to dry sediments prior to hauling. ♦ May disrupt ecological function.	♦ Not applicable. ♦ Pond is too large to manage with shore-based equipment. ♦ No large staging area near shore.

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO MILL POND
		♦ May preserve aquatic biota.	♦ Use disruption.	
6c) Hydraulic removal	♦ Pond level not reduced. ♦ Suction or cutterhead dredges create slurry which is hydraulically pumped to containment area. ♦ Slurry is dewatered; sediment retained, water discharged.	♦ Creates minimal turbidity and impact on biota. ♦ Can allow some pond uses during dredging. ♦ Allows removal with limited access or shoreline disturbance.	♦ Often leaves some sediment behind. ♦ Cannot handle coarse or debris-laden materials. ♦ Requires sophisticated and more expensive containment area.	♦ Somewhat applicable. ♦ Would require use of adjacent town property. ♦ Regulatory approvals difficult to impossible. ♦ Pumping hydraulically dredged sediments uphill to a potential staging area would be a challenge. ♦ Would be expensive.
7) Light-limiting dyes and surface covers	♦ Creates light limitation.	♦ Creates light limit on algal growth without high turbidity or great depth. ♦ May achieve some control of rooted plants as well.	♦ May cause thermal stratification in shallow ponds. ♦ May facilitate anoxia at sediment interface with water.	♦ Not applicable. ♦ Flushing rate too high, migration of dye downstream.
7a) Dyes	♦ Water-soluble dye is mixed with pond water, thereby limiting light penetration and inhibiting algal and plant growth. ♦ Dyes remain in solution until washed out of system.	♦ Color appealing to some. ♦ Creates illusion of greater depth.	♦ May not control surface bloom-forming species. ♦ May not control growth of shallow water algal mats. ♦ Altered thermal regime.	♦ Not applicable. ♦ Flushing rate too high ♦ Artificial color objectionable to some.

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO MILL POND
7b) Surface covers	♦ Opaque sheet material applied to water surface.	♦ Minimizes atmospheric and wildlife pollutant inputs.	♦ Minimizes atmospheric gas exchange. ♦ Limits recreation. ♦ Limits aquatic life.	♦ Not applicable ♦ Cover would eliminate recreation opportunities and much aquatic life.
8) Mechanical removal of algae or rooted plants.	♦ Filtering of pumped water for water supply purposes to remove algae. ♦ Collection of floating scums or mats with booms, nets, or other devices. ♦ Cutting and gathering of rooted plants. ♦ Continuous or multiple applications per year usually needed.	♦ Algae, plants and associated nutrients can be removed from system. ♦ Surface collection can be applied as needed. ♦ May remove floating debris. ♦ Collected algae/ macrophytes dry to smaller volume and weight	♦ Filtration of algae from water requires high backwash and sludge handling capability. ♦ Labor and/or capital intensive to remove plants. ♦ Need a staging area. ♦ Possible impacts on non-target aquatic life. ♦ Would need to continue indefinitely.	♦ Not applicable ♦ Would not decrease nutrient levels because or rapid resupply from the watershed. ♦ Mechanical harvesting of plants would be required every few weeks to a month. ♦ Large staging area needed to harvest macrophytes. ♦ Shallow water would make navigation by harvesting boat nearly impossible.
9) Selective withdrawal	♦ Discharge of bottom water which may contain (or be susceptible to) low oxygen and higher nutrient levels. ♦ May be pumped or utilize passive head differential.	♦ Removes targeted water from pond efficiently. ♦ May prevent anoxia and phosphorus build up in bottom water. ♦ May remove initial phase of algal blooms which start in deep water.	♦ Possible downstream impacts of poor water quality. ♦ May promote mixing of remaining poor quality bottom water with surface water.	♦ Not applicable as stratification has not been documented. ♦ May move oxygen problems to estuary downstream.

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO MILL POND
			♦ May cause unintended drawdown if inflows do not match withdrawal.	
10) Sonication	♦ Sound waves disrupt algal cells.	♦ Supposedly affects only algae (new technique). ♦ Applicable in localized areas.	♦ Unknown effects on non-target organisms. ♦ May release cellular toxins or other undesirable contents into water column.	♦ Not applicable. ♦ Flushing rate is faster than technique takes to kill algae. ♦ Very localized effect
11)Aeration or oxygenation	♦ Addition of air or oxygen provides oxic conditions. ♦ Can also withdraw water, oxygenate, then replace.	♦ Oxic conditions reduce phosphorus availability. ♦ Oxygen improves habitat. ♦ Oxygen reduces build-up of reduced compounds.	♦ May disrupt thermal layers important to fish community. ♦ Theoretically promotes supersaturation with gases harmful to fish.	♦ Possibly applicable ♦ If sized properly would reduce volume of anoxic water. ♦ Would require continuous operation during low oxygen period. ♦ Has shore power and infrastructure needs
a) Traditional hypolimnetic	♦ Add oxygen or air to lower layers without changing stratification.	♦ Can eliminate anoxia at depth. ♦ Can reduce anoxic release of nutrients, particularly phosphorus.	♦ May result in destratification or increased transport of nutrients from sediments by inducing currents.	♦ Not applicable, no reliable stratification. ♦ May “pump” nutrients up from sediments.

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO MILL POND
			♦ Does not change nutrient loading.	
b) Side-stream oxygenation	♦ Remove water from low oxygen areas with a shore based pump, add oxygen and return water to pond.	♦ Does not destratify pond or lake because of low velocities. ♦ Relatively low energy costs. ♦ Small outbuilding.	♦ Does not deal with source of nutrients. ♦ May result in supersaturation if not monitored. ♦ Will not work without power.	♦ Possibly applicable ♦ Would likely be needed for much of summer/fall to keep oxygen concentrations high. ♦ Will not change nutrient loading or plant/algae growth.
12) Herbicides	♦ Liquid or pelletized algaecides/herbicides applied to target area. ♦ Algae or plants killed by direct toxicity or metabolic interference. ♦ Typically requires application at least once/yr, often more frequently.	♦ Rapid elimination of algae or plants from water column , normally with increased water clarity. ♦ May result in net movement of nutrients to bottom of pond.	♦ Possible toxicity to non-target species. ♦ Restrictions on water use for varying time after treatment. ♦ Increased oxygen demand and possible toxicity. ♦ Possible recycling of nutrients.	♦ Somewhat applicable ♦ (see below for discussion of specific algaecides).
a) Forms of copper	♦ Cellular toxicant, disruption of membrane transport.	♦ Effective and rapid control of many algae species.	♦ Possible toxicity to aquatic fauna.	♦ Not applicable ♦ Won’t change nutrient conditions that caused

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO MILL POND
	♦ Applied as wide variety of liquid or granular formulations.	♦ Approved for use in most water supplies.	♦ Accumulation of copper in system. ♦ Resistance by certain green and blue-green nuisance species. ♦ Lysing of cells releases nutrients and toxins. ♦ Will migrate downstream in rapidly flushed system.	bloom so bloom conditions may re-occur in same season. ♦ Will migrate downstream in highly flushed system. ♦ Application to cyanobacteria in macrophyte beds would be difficult. ♦ Will require application permit.
b) Peroxides	♦ Disrupts most algal cellular functions, tends to attack membranes. ♦ Applied as a liquid or solid. ♦ Typically requires application at least once/yr, often more frequently.	♦ Rapid action. ♦ Oxidizes cell contents, may limit oxygen demand and toxicity.	♦ Much more expensive than copper. ♦ Limited track record. ♦ Possible recycling of nutrients. ♦	♦ Not applicable. ♦ May work to reduce or eliminate an existing bloom but at high cost. ♦ Won’t appreciably change conditions that caused bloom so bloom conditions may re-occur in same season. ♦ May require an application permit.
12c) Synthetic organic algaecides and herbicides	♦ Absorbed or membrane-active chemicals which disrupt metabolism. ♦ Causes structural deterioration.	♦ Used where copper is ineffective. ♦ Both systemic and contact products available. ♦ Limited toxicity to fish at recommended dosages.	♦ Non-selective in treated area. ♦ Toxic to aquatic fauna (varying degrees by formulation). ♦ Time delays on water use .	♦ Somewhat applicable ♦ Will reduce or eliminate an existing bloom. ♦ Won’t appreciably change conditions that caused bloom so bloom conditions may

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO MILL POND
		♦ Rapid action.	♦ Decay of plants may release additional nutrients.	re-occur in same season. ♦ Will migrate downstream in highly flushed system. ♦ Will require permit. ♦ May have waterbody use restrictions.
13) Phosphorus inactivation	♦ Typically salts of aluminum, iron or calcium are added to the pond, as liquid or powder. ♦ Phosphorus in the treated water column is complexed and settled to the bottom of the pond. ♦ Phosphorus in upper sediment layer is complexed, reducing release from sediment. ♦ Permanence of binding varies by binder in relation to redox potential and pH.	♦ Can provide rapid, major decrease in phosphorus concentration in water column. ♦ Can minimize release of phosphorus from sediment. ♦ May remove other nutrients and contaminants as well as phosphorus. ♦ Flexible with regard to depth of application and speed of improvement.	♦ Possible toxicity to fish and invertebrates, especially by aluminum at low pH. ♦ Possible release of phosphorus under anoxia or extreme pH. ♦ May cause fluctuations in water chemistry, especially pH, during treatment. ♦ Possible resuspension of floc in shallow areas. ♦ Adds to bottom sediment, but typically an insignificant amount.	♦ Not Applicable. ♦ Significant internal loading of phosphorus not documented by data collected to date. ♦ Watershed loading and large size of watershed suggest that treatment lifespan would be very short.

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO MILL POND
14) Sediment oxidation	♦ Addition of oxidants, binders and pH adjustors to oxidize sediment. ♦ Binding of phosphorus is enhanced. ♦ Denitrification is stimulated.	♦ Can reduce phosphorus supply to algae. ♦ Can alter nitrogen to phosphorus ratios in water column. ♦ May decrease sediment oxygen demand.	♦ Possible impacts on benthic biota. ♦ Longevity of effects not well known. ♦ Possible source of nitrogen for cyanobacteria.	♦ Not applicable. ♦ Sediments are not a major source of nutrients. ♦ Effects are not well understood and there are insufficient case studies to predict effectiveness with any degree of confidence.
15) Settling agents	♦ Closely aligned with phosphorus inactivation, but can be used to reduce algae directly too. ♦ Lime, alum or polymers applied, usually as a liquid or slurry to inlet or pond. ♦ Creates a floc with algae and other suspended particles. ♦ Floc settles to bottom of pond. ♦ Re-application typically necessary at least once/yr .	♦ Removes algae and increases water clarity without lysing most cells. ♦ Reduces nutrient recycling if floc sufficient. ♦ Removes non-algal particles as well as algae. ♦ May reduce dissolved phosphorus levels at the same time.	♦ Possible impacts on aquatic fauna. ♦ Possible fluctuations in water chemistry during treatment. ♦ Resuspension of floc possible in shallow, well-mixed waters. ♦ Promotes increased sediment accumulation.	♦ Likely not applicable. ♦ Would require frequent retreatment if used in pond. ♦ May be applicable for injection into tributaries but no documented example of implementation in NH to date. ♦ May increase sediment accumulation in pond.
16) Selective nutrient addition	♦ Ratio of nutrients changed by additions of selected nutrients. ♦ Addition of non-limiting nutrients can	♦ Can reduce algal levels where control of limiting nutrient is not feasible.	♦ May result in greater algal abundance through uncertain biological response.	♦ Not applicable. ♦ Likely would involve adding nitrogen to favor species other than cyanobacteria.

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO MILL POND
	change composition of algal community. ♦ Processes such as settling and grazing can then reduce algal biomass.	♦ Can promote non-nuisance forms of algae. ♦ Can improve productivity of system without increased standing crop of algae.	♦ May require frequent application to maintain desired ratios. ♦ Possible downstream effects.	♦ Contrary to principles of watershed management, particularly with respect to nitrogen limited estuarine resources downstream of Mill Pond. ♦ Nitrogen addition may result in additional algal growth of non-cyanobacteria species
17) Biomanipulation	♦ Manipulation of biological components of system to achieve grazing control over algae. ♦ Typically involves alteration of fish community to promote growth of grazing zooplankton.	♦ May increase water clarity by changes in algal biomass or cell size without reduction of nutrient levels. ♦ Can convert unwanted algae into fish. ♦ Harnesses natural processes.	♦ May involve introduction of exotic species. ♦ Effects may not be controllable or lasting. ♦ May foster shifts in algal composition to even less desirable forms.	♦ See below. (pond is too small and an open system, would be very difficult to control)
17a) Herbivorous fish	♦ Stocking of fish that eat algae.	♦ Converts algae and plant biomass directly into potentially harvestable fish. ♦ Grazing pressure can be adjusted through stocking rate.	♦ Typically requires introduction of non-native species. ♦ Difficult to control over long term. ♦ Smaller algal forms may be benefited and bloom.	♦ Not applicable. ♦ Not permitted in NH.

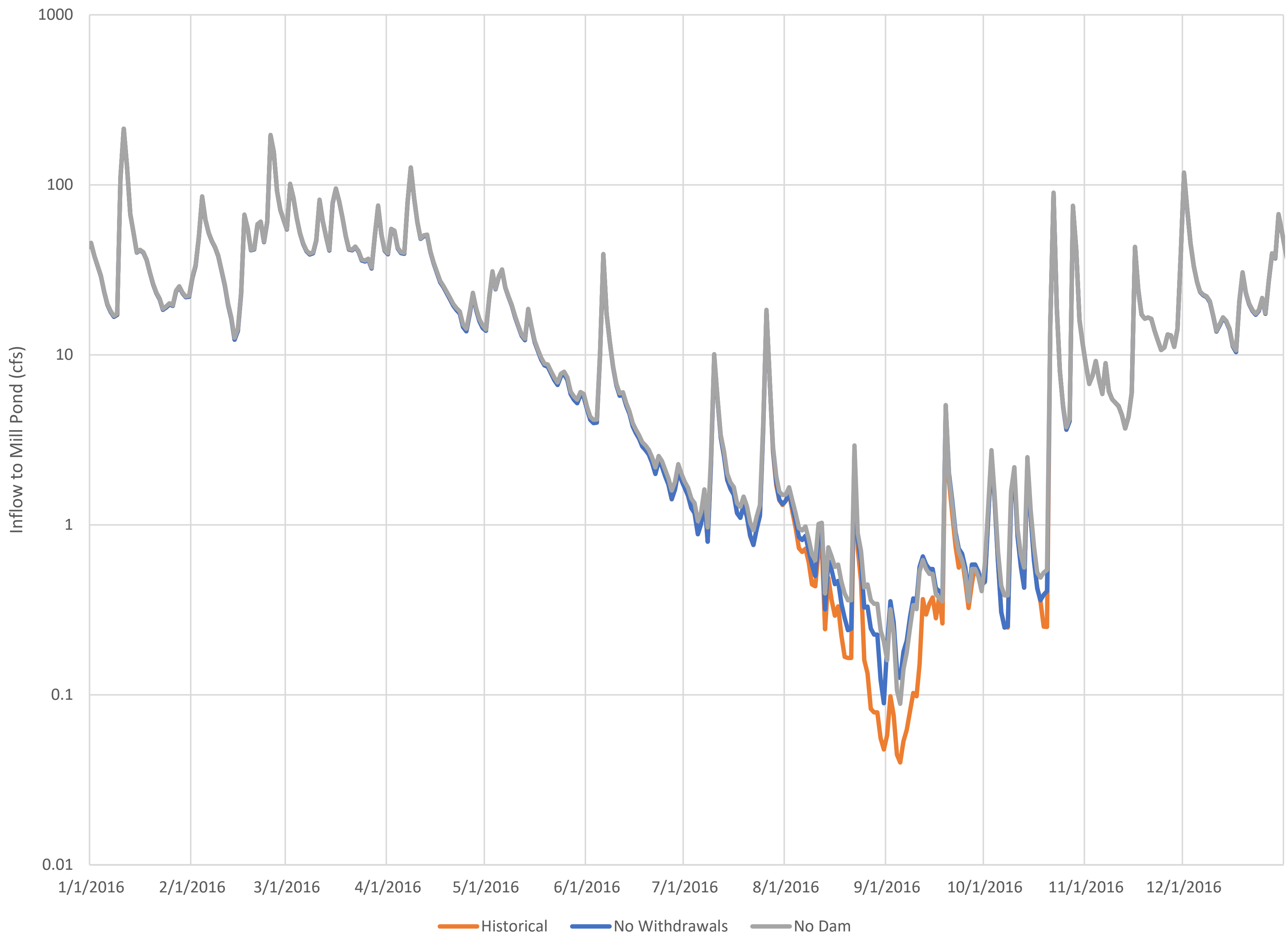
OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO MILL POND
17b) Enhanced grazing through food chain interactions	♦ Reduction in planktivorous fish to promote grazing pressure by zooplankton. ♦ May involve stocking piscivores or removing planktivores. ♦ May also involve stocking zooplankton or establishing refugia.	♦ May increase water clarity by changes in algal biomass or cell size without reduction of nutrient levels. ♦ Converts algae indirectly into harvestable fish. ♦ Zooplankton response to increasing algae can be rapid. ♦ May be accomplished without introduction of non-native species. ♦ Generally compatible with most fishery management goals.	♦ May involve introduction of exotic species. ♦ Effects may not be controllable or lasting. ♦ May foster shifts in algal composition to even less desirable forms. ♦ Highly variable response expected; temporal and spatial variability may be high. ♦ Requires careful monitoring and management action on 1-5 yr basis. ♦ Larger or toxic algal forms may be benefitted and bloom.	♦ Not applicable. ♦ A balanced and stable fish and invertebrate community is generally supportive of good water quality. ♦ Nuisance cyanobacterial species are generally not preferred by grazers. ♦ Difficult to achieve target community in a small open system like Mill Pond.
18) Bottom-feeding fish removal	♦ Removes fish that browse among bottom deposits, releasing nutrients to the water column by physical agitation and excretion.	♦ Reduces turbidity and nutrient additions from this source. ♦ May restructure fish community in more desirable manner.	♦ Targeted fish species are difficult to control. ♦ Reduction in fish populations valued by some pond users (human/non-human).	♦ Not applicable. ♦ No documented occurrence of such fish in Mill Pond.

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO MILL POND
19) Microbial competition	♦ Addition of microbes, often with oxygenation, can tie up nutrients and limit algal growth. ♦ Tends to control nitrogen more than phosphorus.	♦ Shifts nutrient use to organisms that do not form scums or impair uses to same extent as algae. ♦ Harnesses natural processes. ♦ May decrease sediment.	♦ Minimal scientific evaluation. ♦ Nitrogen control may still favor cyanobacteria. ♦ May need aeration system to get acceptable results.	♦ Not applicable. ♦ Favorable results for phosphorus control have not been documented.
20) Pathogens	♦ Addition of inoculum to initiate attack on algal cells. ♦ May involve fungi, bacteria or viruses.	♦ May create pondwide "epidemic" and reduction of algal biomass. ♦ May provide sustained control through cycles. ♦ Can be highly specific to algal group or genera.	♦ Largely experimental approach at this time. ♦ May promote resistant nuisance forms. ♦ May cause high oxygen demand or release of toxins by lysed algal cells. ♦ Effects on non-target organisms uncertain.	♦ Not applicable. ♦ Experimental.
21) Competition and allelopathy by plants	♦ Plants may tie up sufficient nutrients to limit algal growth. ♦ Plants may create a light limitation on algal growth. ♦ Chemical inhibition of algae may occur through substances	♦ Harnesses power of natural biological interactions. ♦ May provide responsive and prolonged control.	♦ Some algal forms appear resistant. ♦ Use of plants may lead to problems with vascular plants. ♦ Use of plant material may cause	♦ Not applicable (see below for discussion of alternatives).

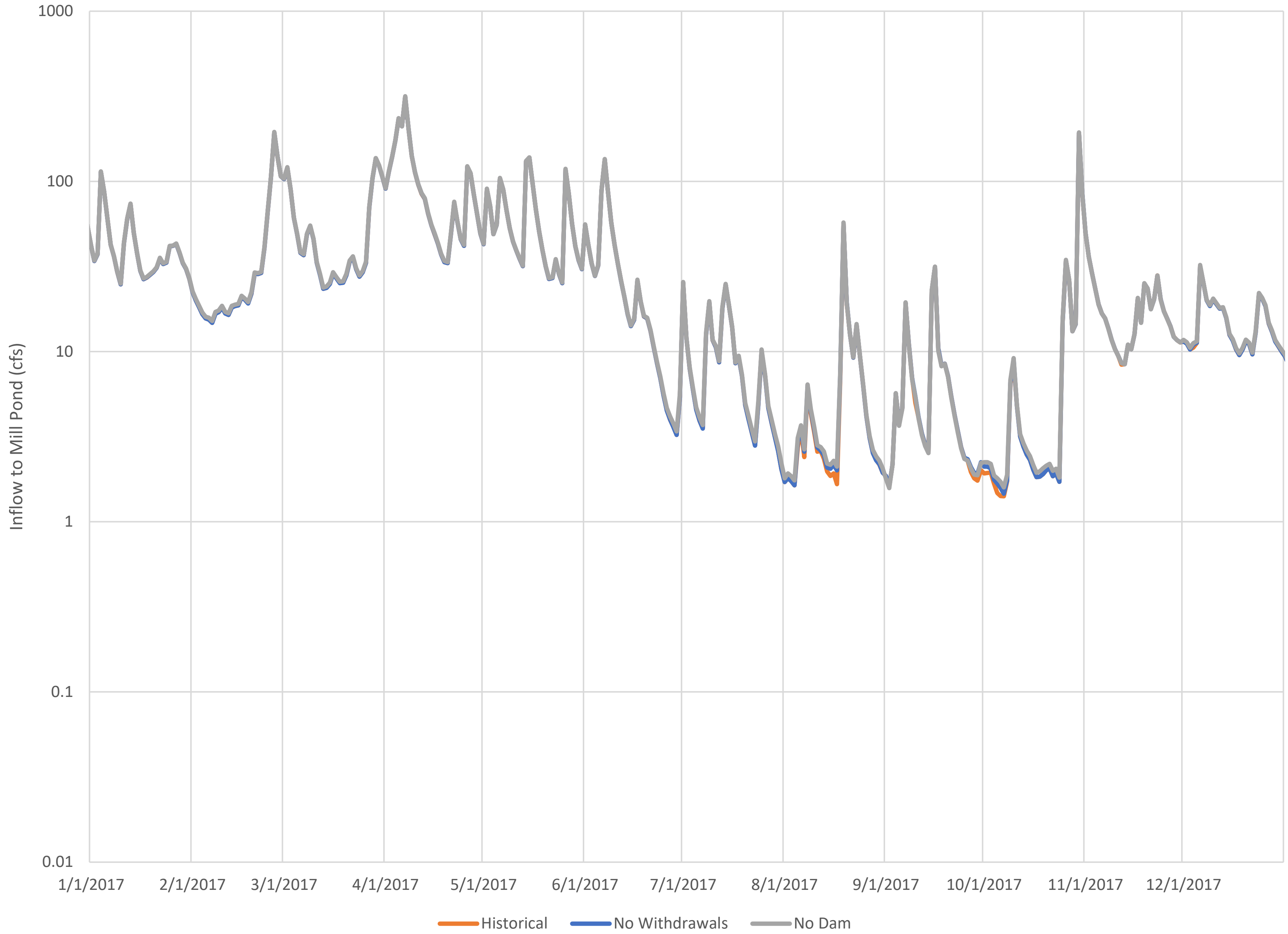
OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO MILL POND
	released by other organisms.		depression of oxygen levels.	
21a) Plantings for nutrient control	♦ Plant growths of sufficient density may limit algal access to nutrients. ♦ Plants can exude allelopathic substances which inhibit algal growth. ♦ Portable plant “pods” , floating islands, or other structures can be installed.	♦ Productivity and associated habitat value can remain high without algal blooms. ♦ Can be managed to limit interference with recreation and provide habitat. ♦ Wetland cells in or adjacent to the pond can minimize nutrient inputs.	♦ Vascular plants may achieve nuisance densities. ♦ Vascular plant senescence may release nutrients and cause algal blooms. ♦ The switch from algae to vascular plant domination of a pond may cause unexpected or undesirable changes .	♦ Not applicable. ♦ Mill Pond already supports an overly large community of vascular plants.
21b) Plantings for light control	♦ Plant species with floating leaves can shade out many algal growths at elevated densities.	♦ Vascular plants can be more easily harvested than most algae. ♦ Many floating species provide waterfowl food.	♦ Floating plants can be a recreational nuisance. ♦ Low surface mixing and atmospheric contact promote anoxia.	♦ Not applicable. ♦ Plants would interfere with recreational activities.

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO MILL POND
21c) Addition of barley straw	♦ Input of barley straw can set off a series of chemical reactions which limit algal growth. ♦ Release of allelopathic chemicals can kill algae. ♦ Release of humic substances can bind phosphorus.	♦ Materials and application are relatively inexpensive. ♦ Decline in algal abundance is more gradual than with algaecides, limiting oxygen demand and the release of cell contents.	♦ Success appears linked to uncertain and potentially uncontrollable water chemistry factors. ♦ Depression of oxygen levels may result. ♦ Water chemistry may be altered in other ways unsuitable for non-target organisms.	♦ Not applicable. ♦ Experimental technique with unpredictable results.

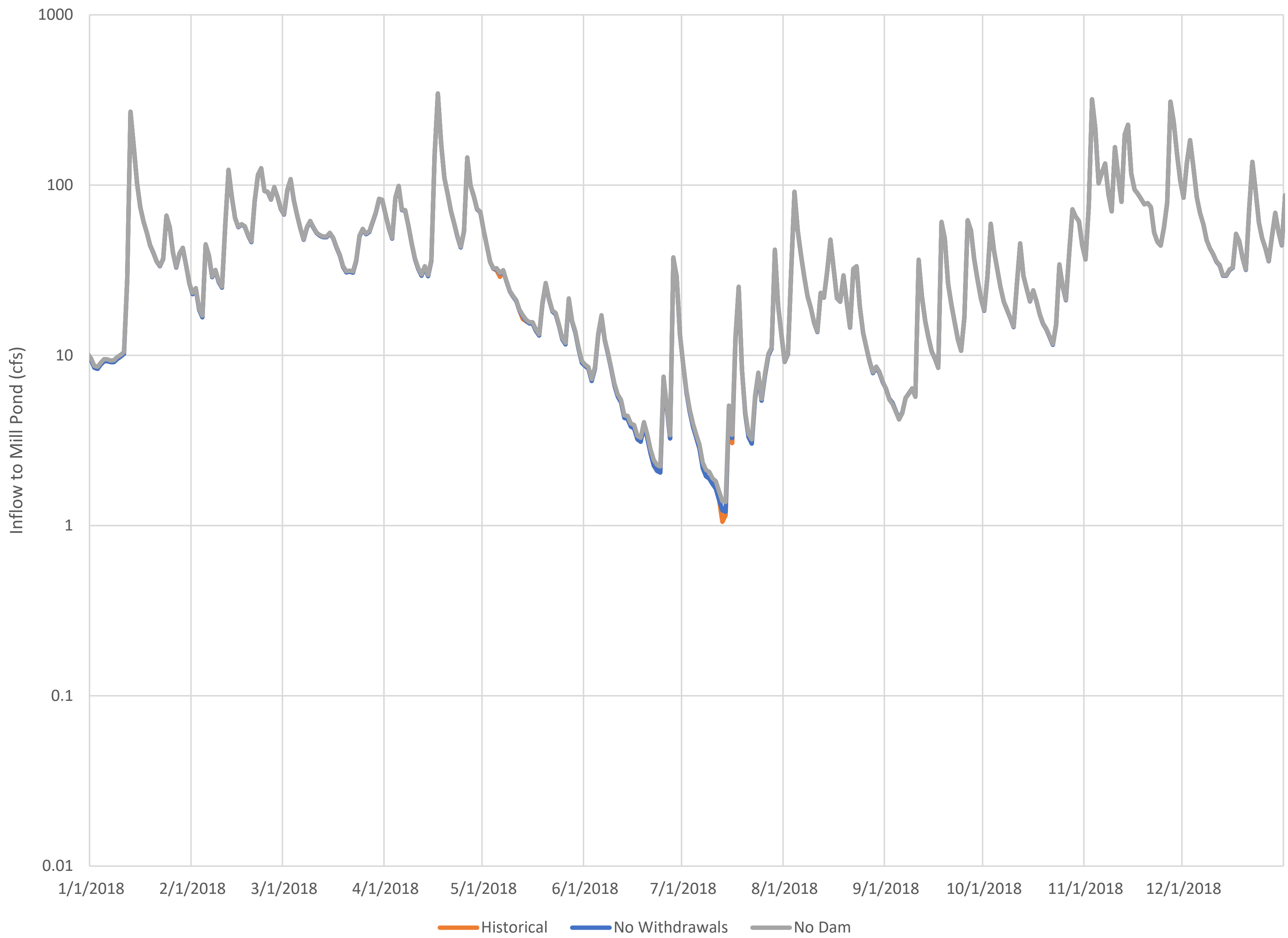
Appendix B – Oyster Reservoir Hydrological Mass Balance Model Results

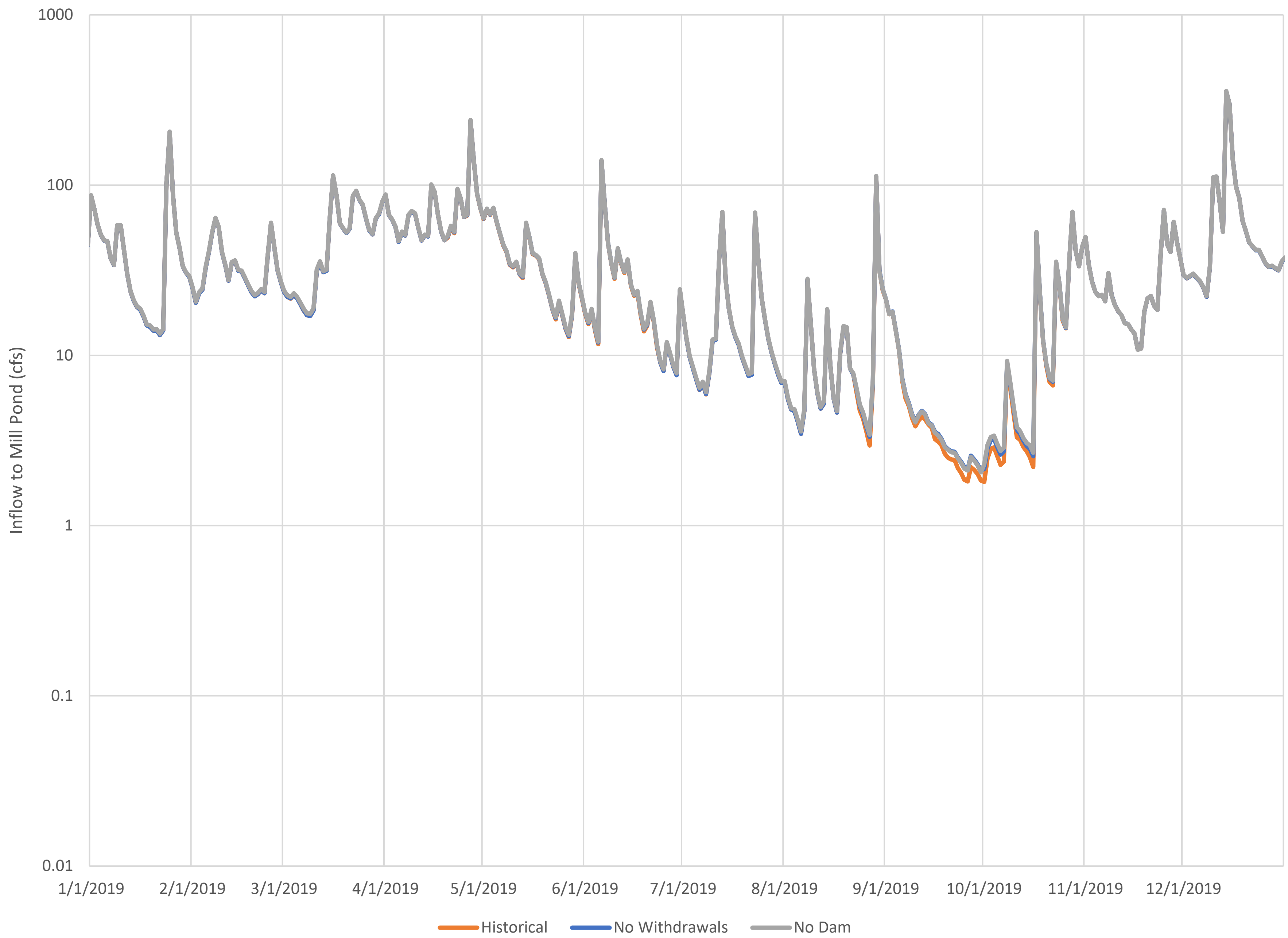


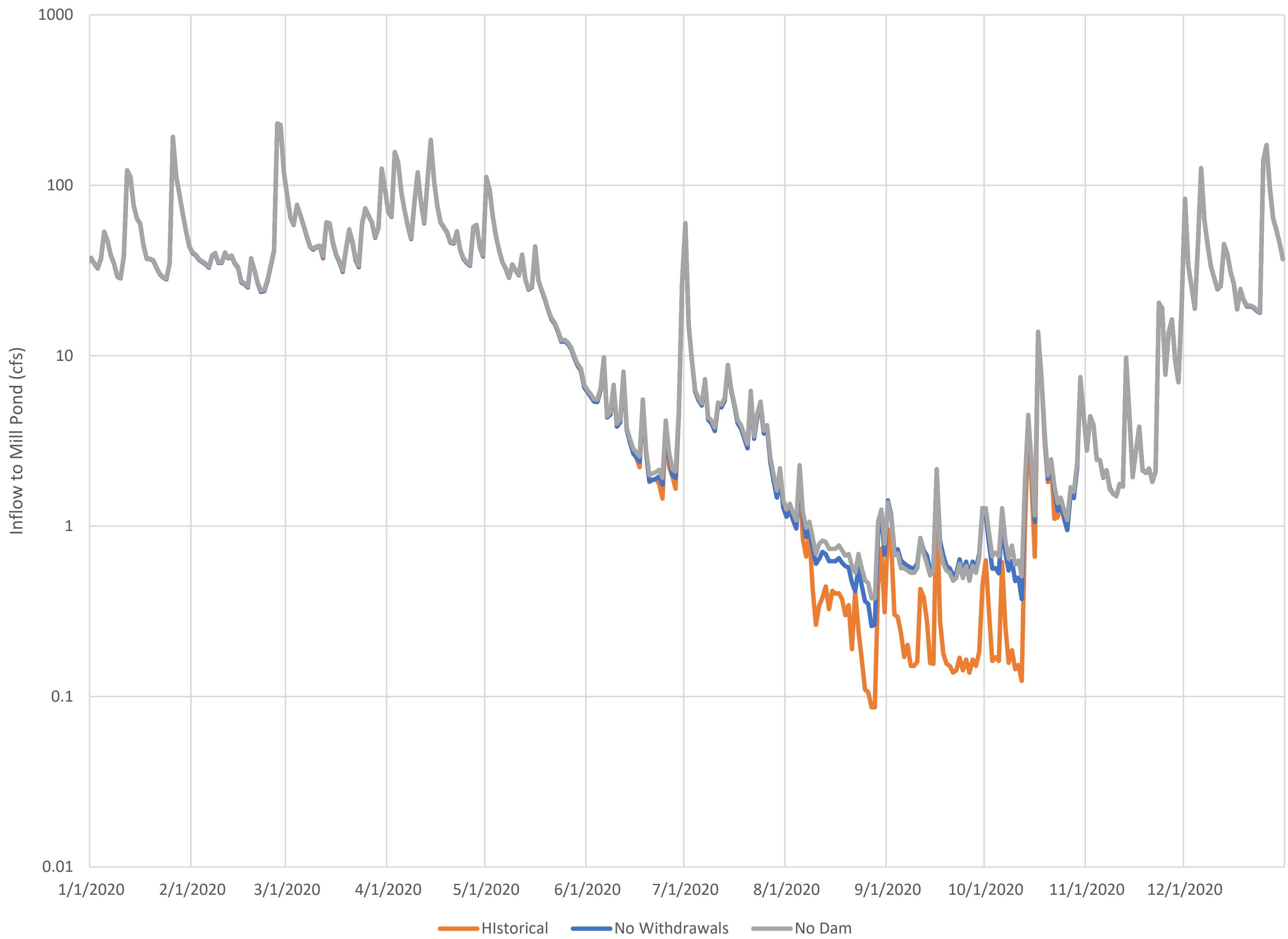
Inflow to Mill Pond (cfs)
1000
100
10
1
0.1
0.01
1/1/2016
2/1/2016
3/1/2016
4/1/2016
5/1/2016
6/1/2016
7/1/2016
8/1/2016
9/1/2016
10/1/2016
11/1/2016
12/1/2016
Historical
No Withdrawals
No Dam



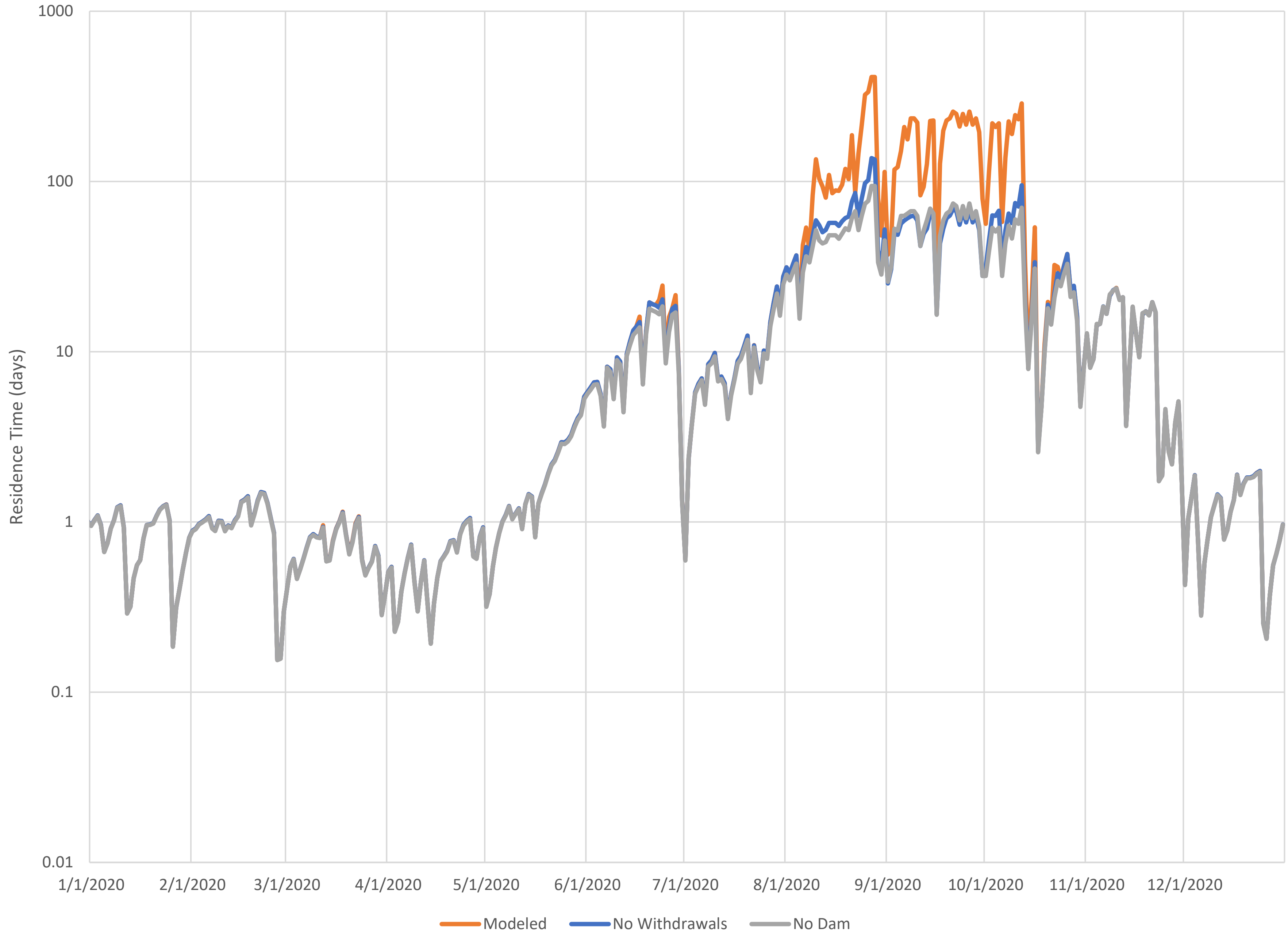
1000
100
10
1
0.1
0.01
Inflow to Mill Pond (cfs)
1/1/2017
2/1/2017
3/1/2017
4/1/2017
5/1/2017
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
12/1/2017
Historical
No Withdrawals
No Dam


1000
100
10
1
0.1
0.01
Inflow to Mill Pond (cfs)
1/1/2018
2/1/2018
3/1/2018
4/1/2018
5/1/2018
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
12/1/2018
Historical
No Withdrawals
No Dam


Inflow to Mill Pond (cfs)
1000
100
10
1
0.1
0.01
1/1/2019
2/1/2019
3/1/2019
4/1/2019
5/1/2019
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
12/1/2019
Historical
No Withdrawals
No Dam

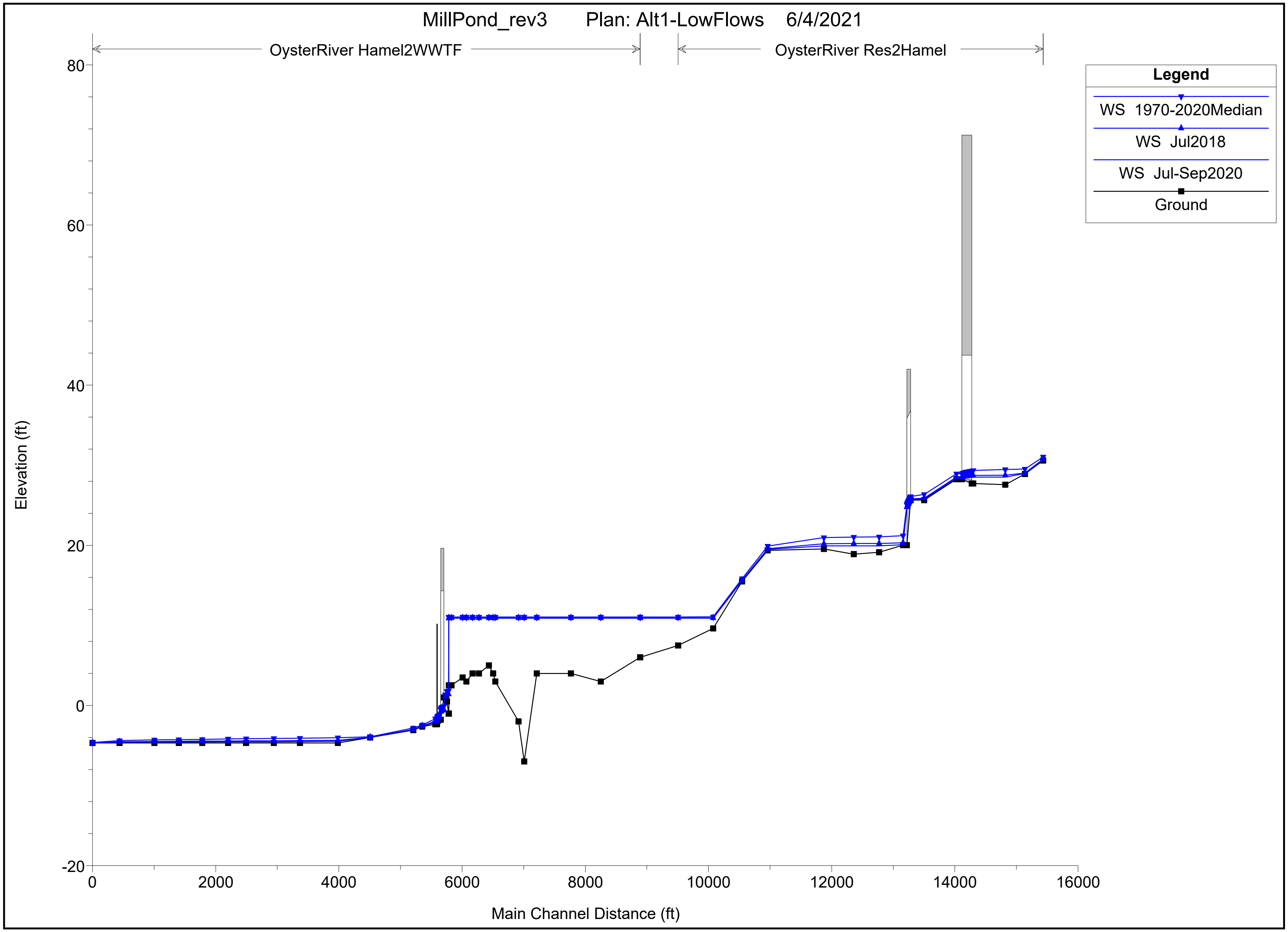


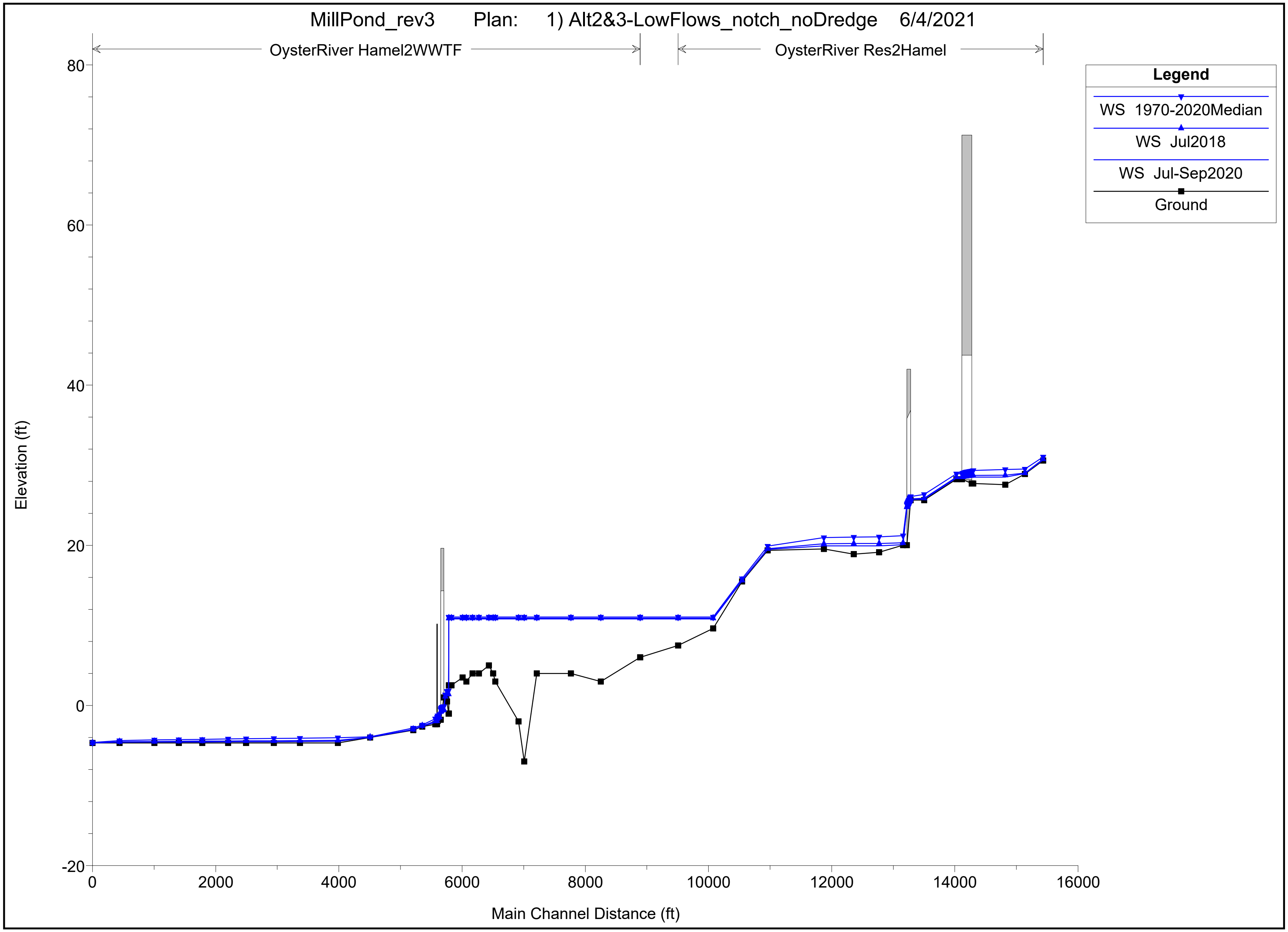
1000
100
10
1
0.1
0.01
Inflow to Mill Pond (cfs)
1/1/2020
2/1/2020
3/1/2020
4/1/2020
5/1/2020
6/1/2020
7/1/2020
8/1/2020
9/1/2020
10/1/2020
11/1/2020
12/1/2020
HIstorical
No Withdrawals
No Dam

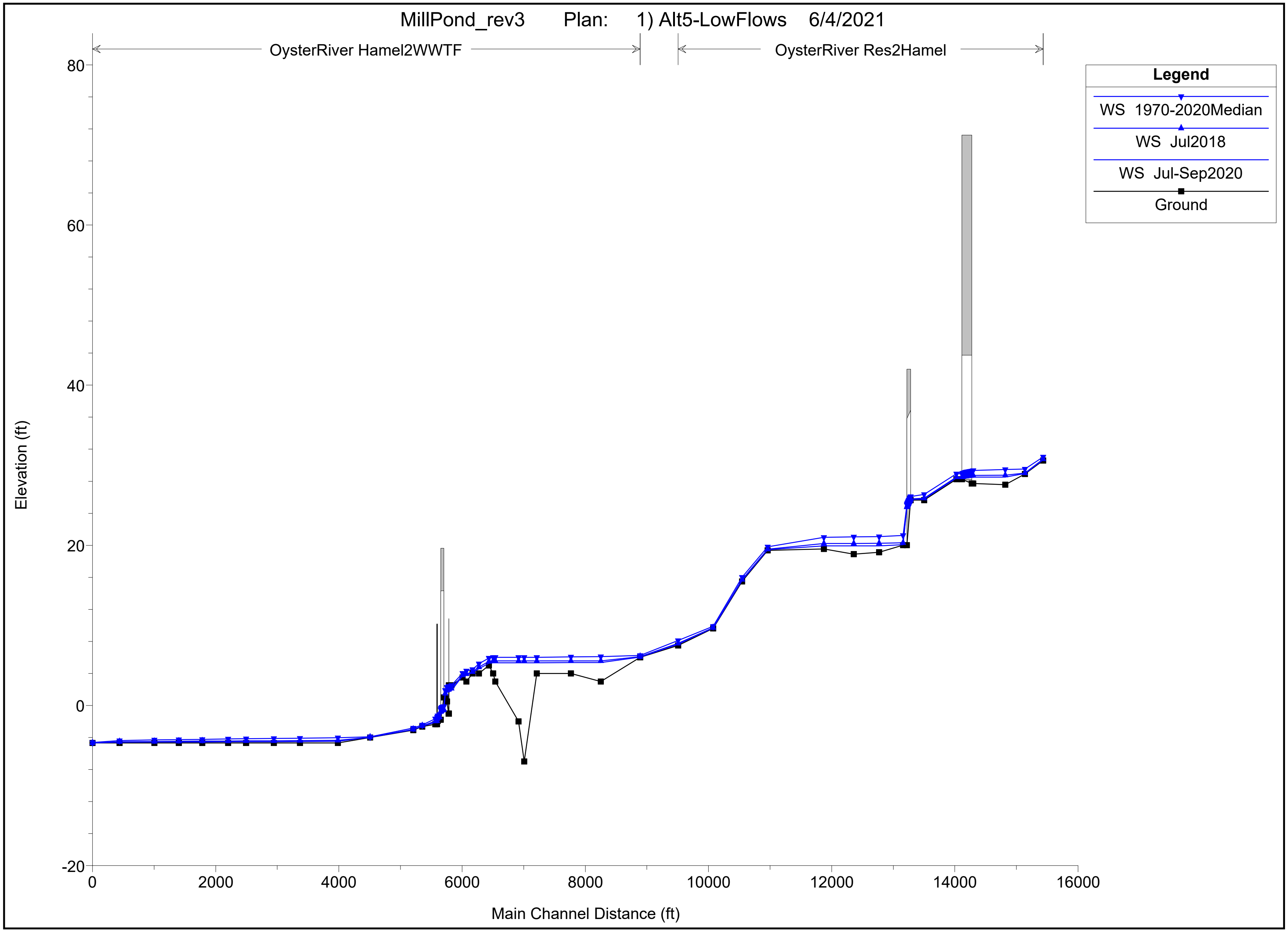


Residence Time (days)
1000
100
10
1
0.1
0.01
1/1/2020
2/1/2020
3/1/2020
4/1/2020
5/1/2020
6/1/2020
7/1/2020
8/1/2020
9/1/2020
10/1/2020
11/1/2020
12/1/2020
Modeled
No Withdrawals
No Dam

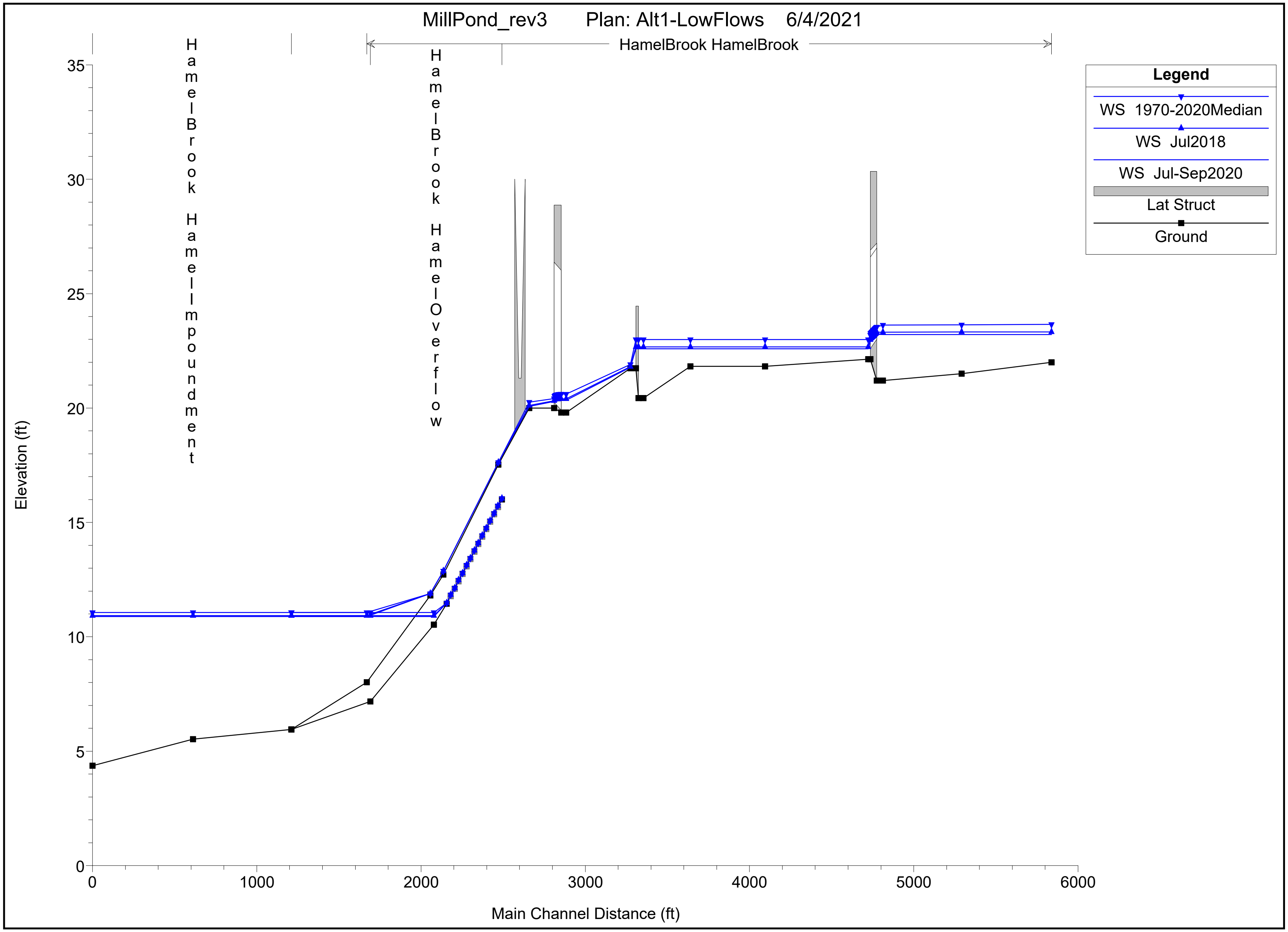
Appendix C – Supplemental Hydraulic Model Results


MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021
OysterRiver Hamel2WWTF
OysterRiver Res2Hamel
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Elevation (ft)
80
60
40
20
0
-20
0
2000
4000
6000
8000
10000
12000
14000
16000
Main Channel Distance (ft)

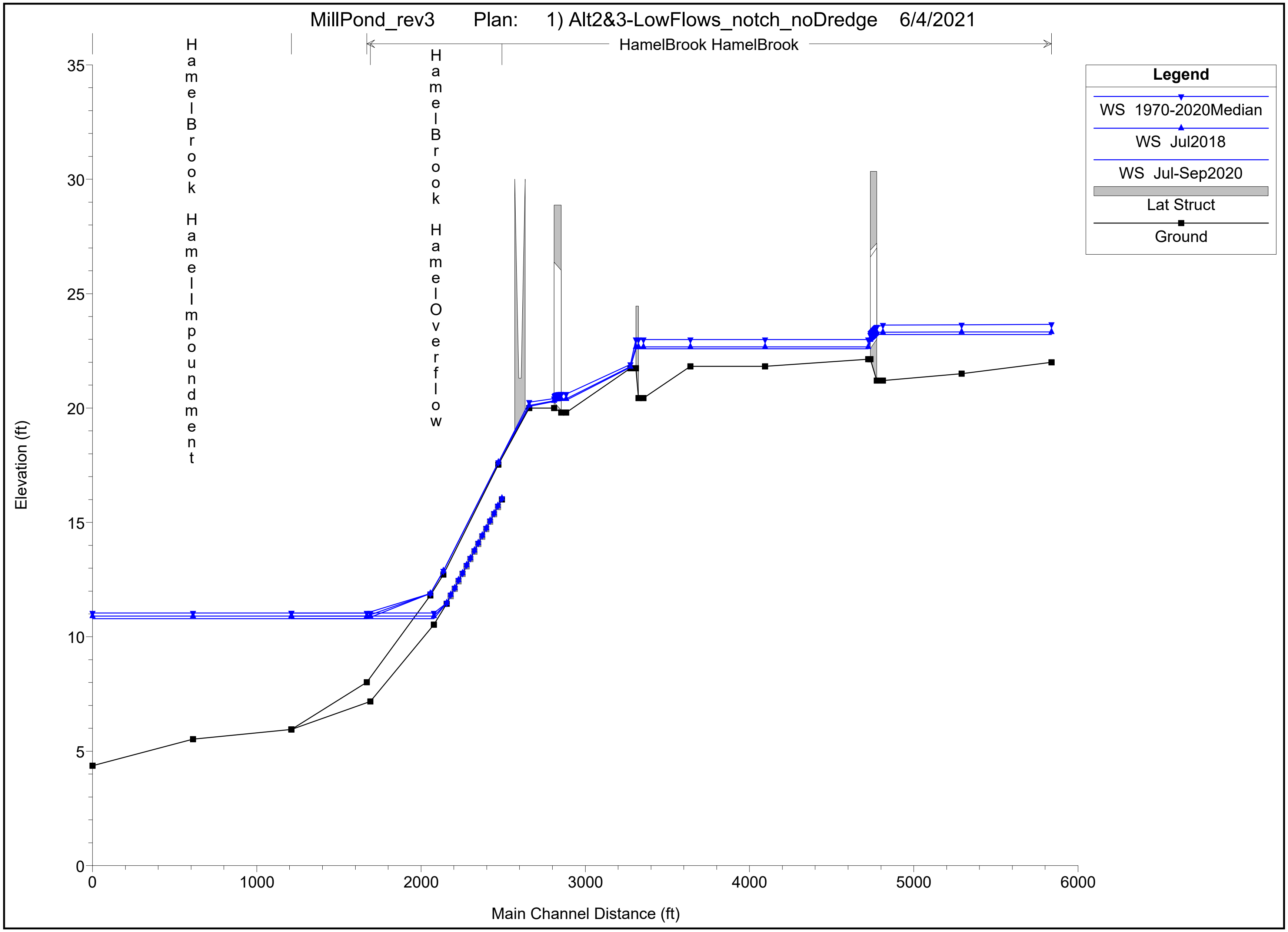

MillPond_rev3 Plan: 1) Alt2&3-LowFlows_notch_noDredge 6/4/2021
OysterRiver Hamel2WWTF
OysterRiver Res2Hamel
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Elevation (ft)
80
60
40
20
0
-20
0
2000
4000
6000
8000
10000
12000
14000
16000
Main Channel Distance (ft)

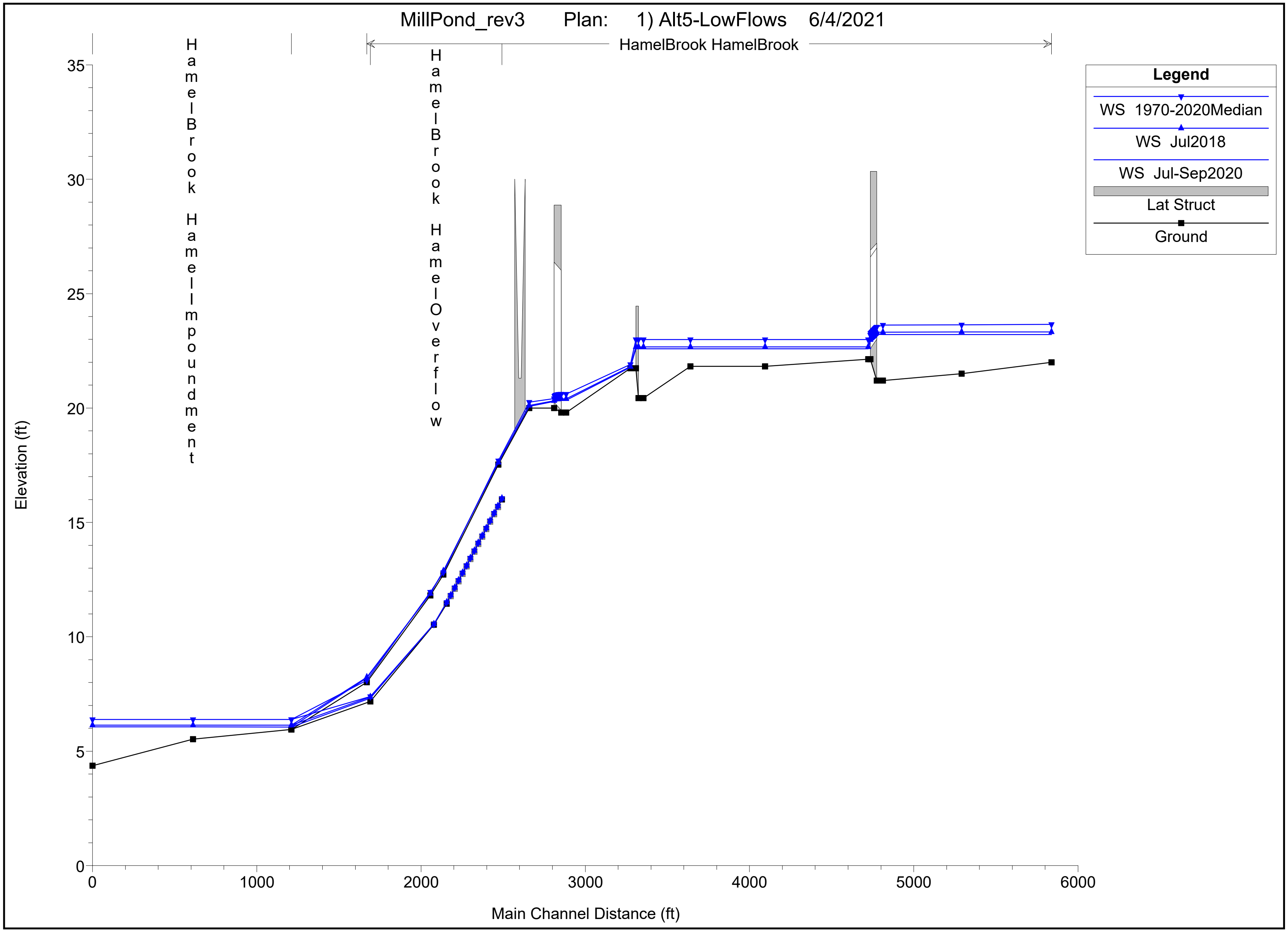


MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
OysterRiver Hamel2WWTF
OysterRiver Res2Hamel
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Elevation (ft)
80
60
40
20
0
-20
0
2000
4000
6000
8000
10000
12000
14000
16000
Main Channel Distance (ft)

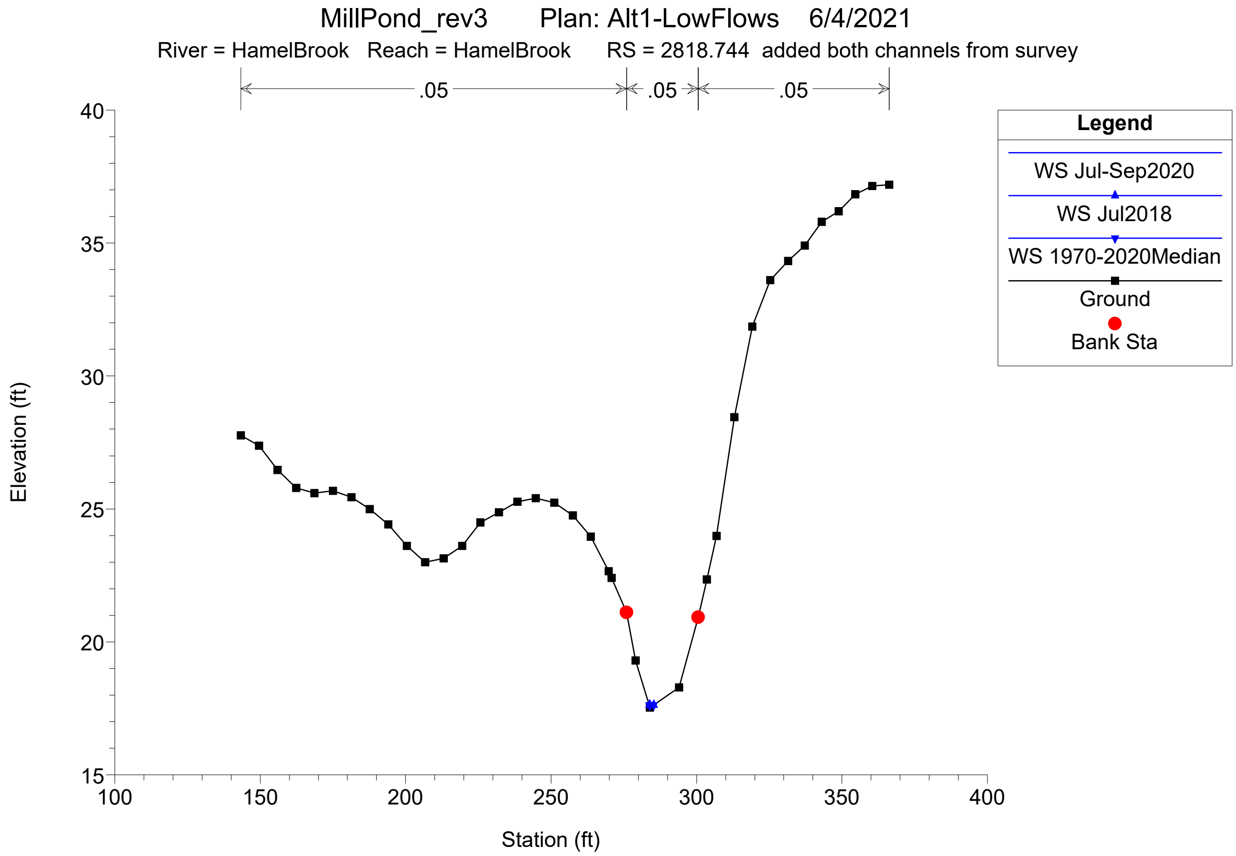


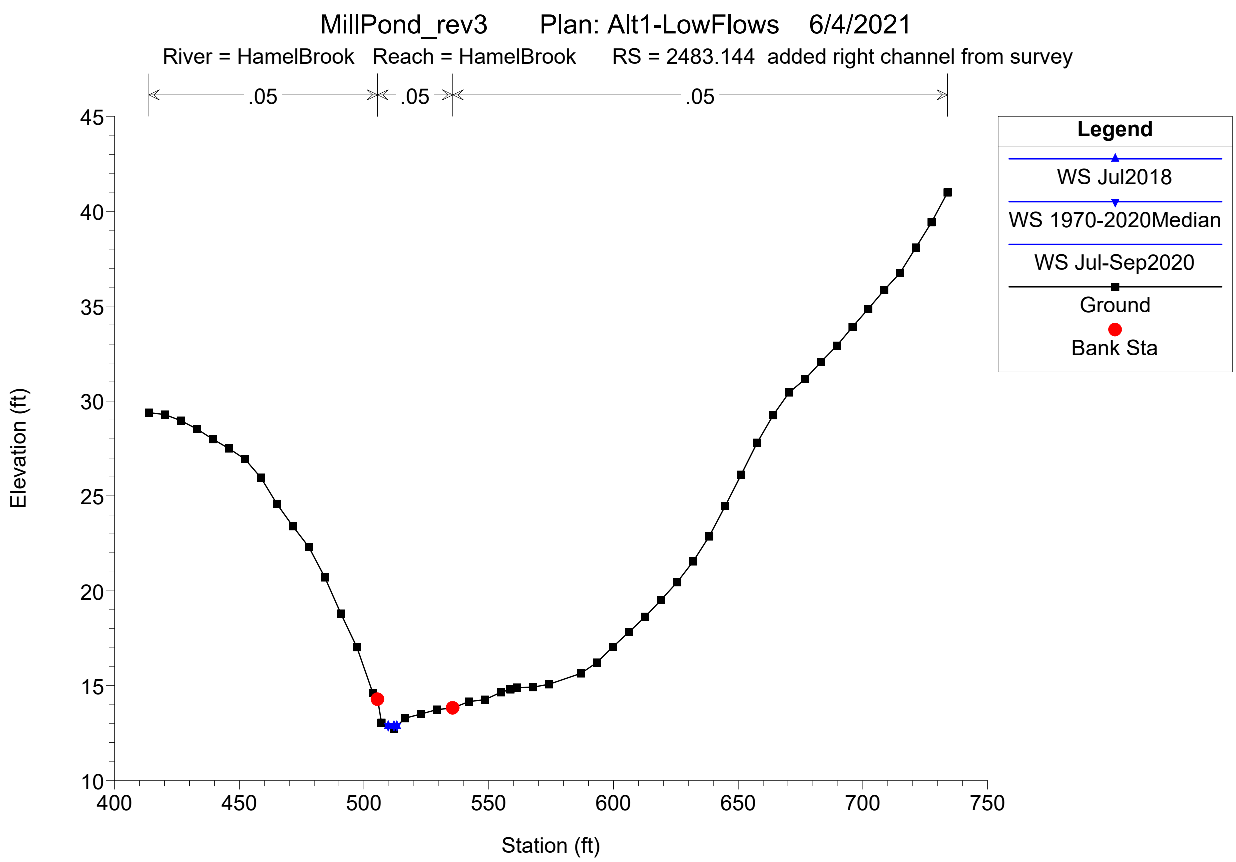
MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021
HamelBrook HamelBrook
HamelBrook HamelImpoundment
HamelBrook HamelOverflow
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Lat Struct
Ground
Elevation (ft)
Main Channel Distance (ft)
0
5
10
15
20
25
30
35
0
1000
2000
3000
4000
5000
6000

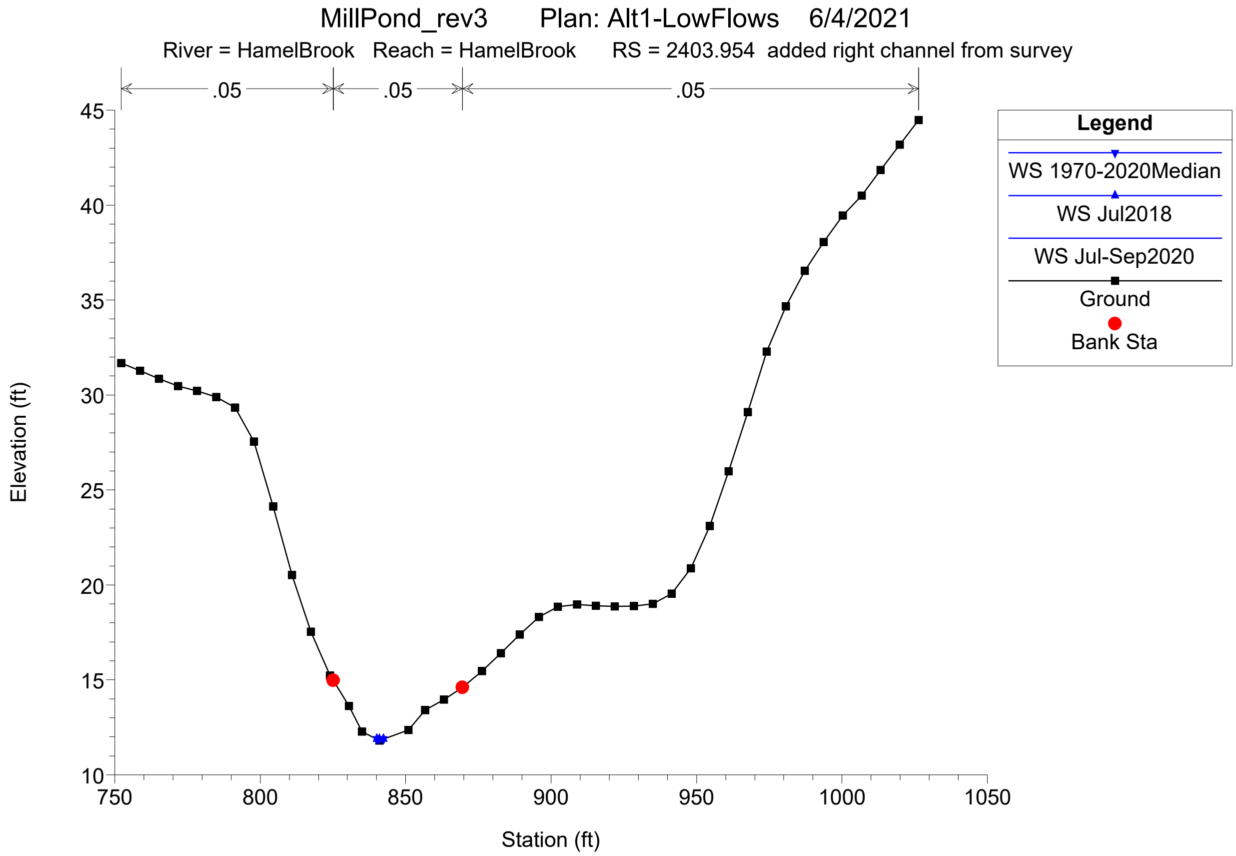

MillPond_rev3 Plan: 1) Alt2&3-LowFlows_notch_noDredge 6/4/2021
HamelBrook HamelBrook
HamelBrook HamelImpoundment
HamelBrook HamelOverflow
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Lat Struct
Ground
Elevation (ft)
Main Channel Distance (ft)
0
5
10
15
20
25
30
35
0
1000
2000
3000
4000
5000
6000

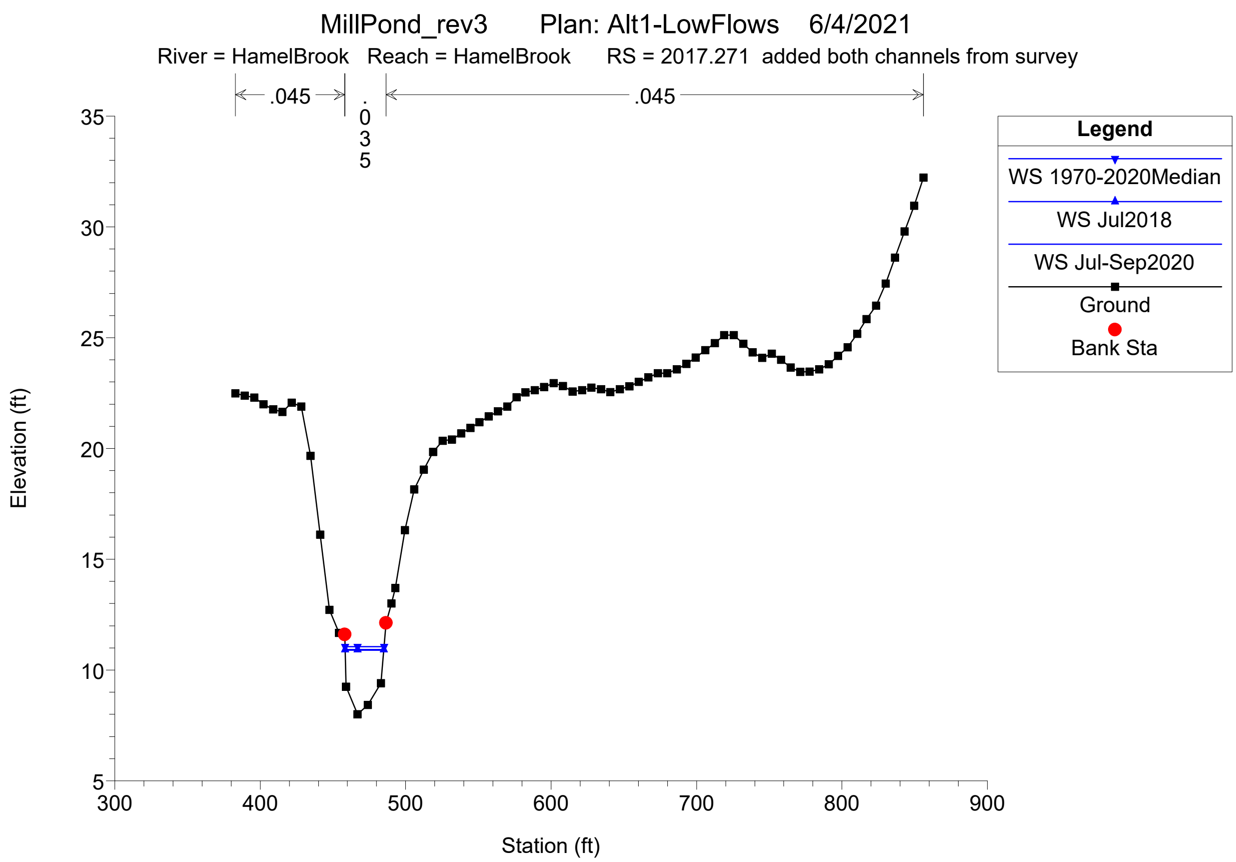


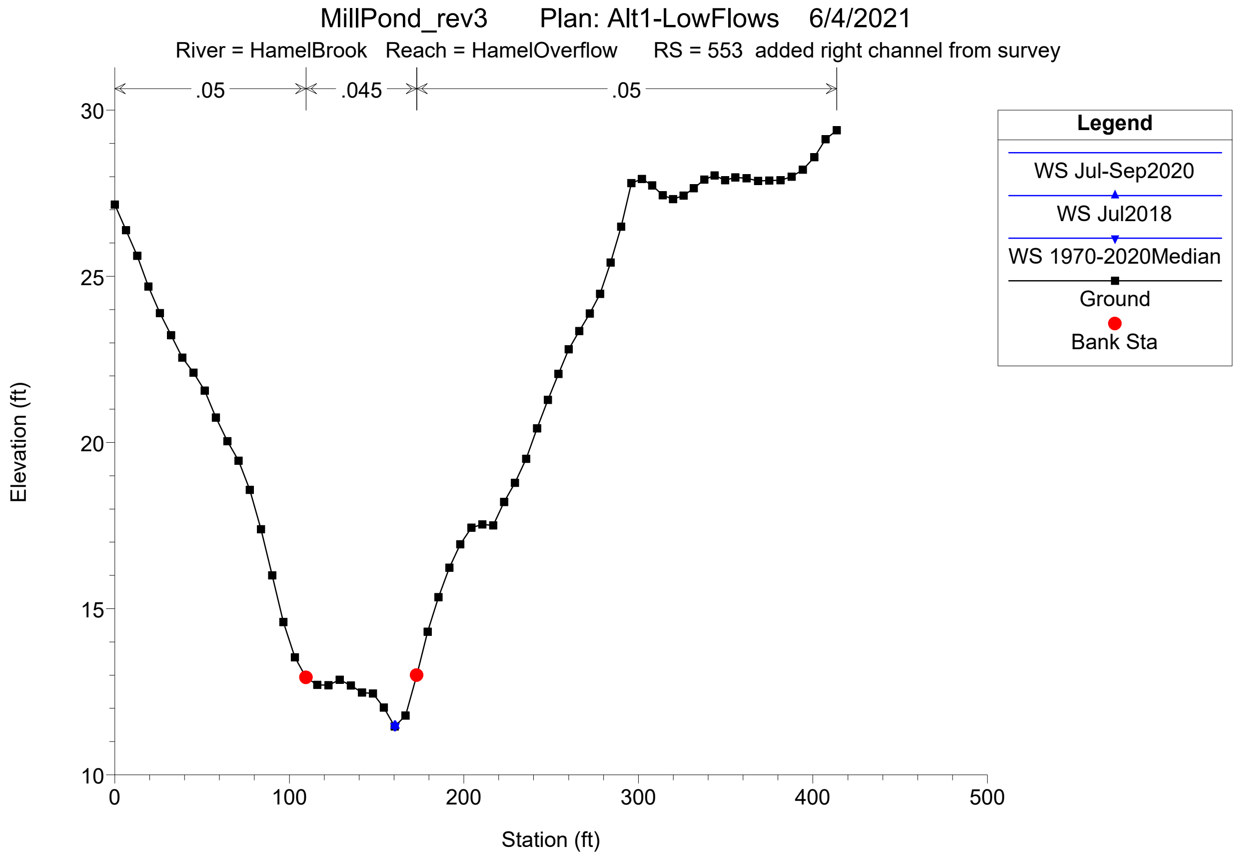
MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
HamelBrook HamelBrook
HamelBrook HamelImpoundment
HamelBrook HamelOverflow
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Lat Struct
Ground
Elevation (ft)
Main Channel Distance (ft)
0
5
10
15
20
25
30
35
0
1000
2000
3000
4000
5000
6000

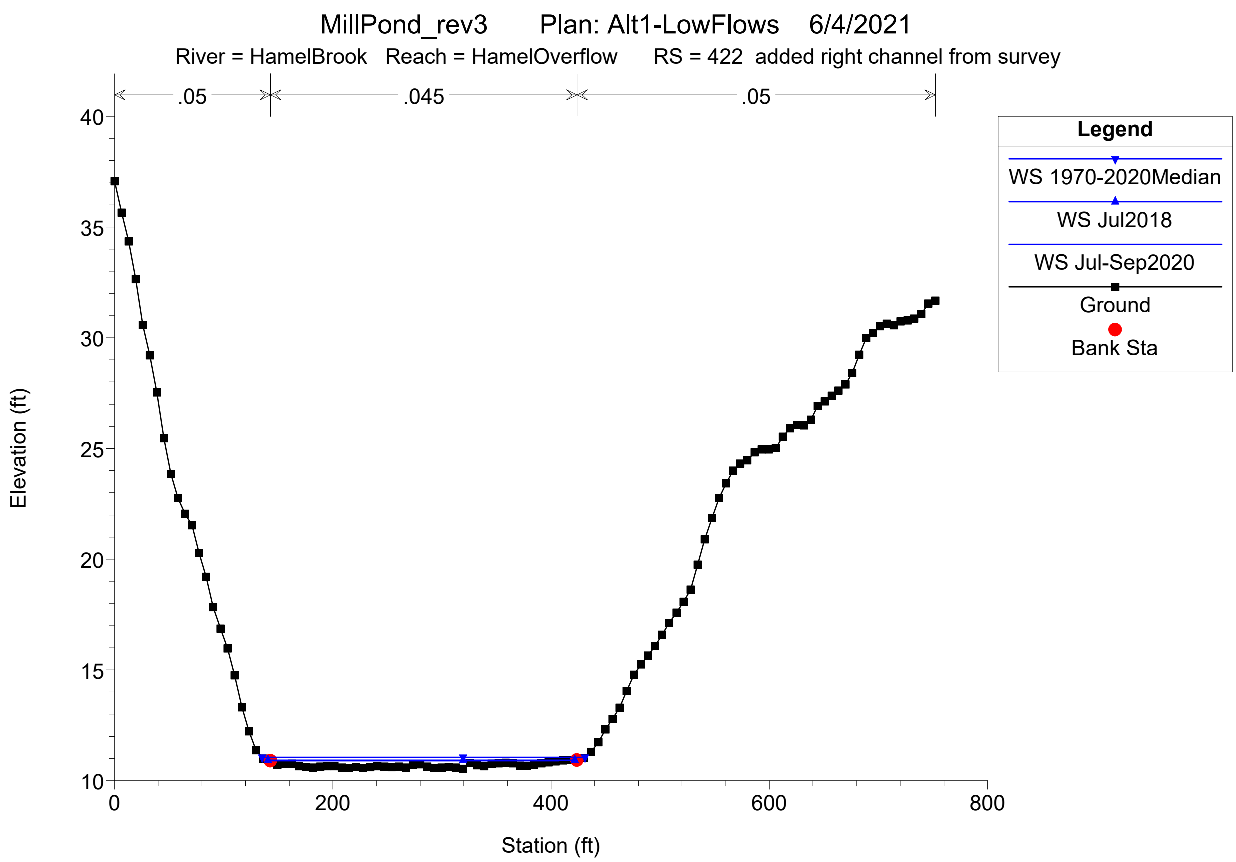

MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021
River = HamelBrook Reach = HamelBrook RS = 2818.744 added both channels from survey
.05
.05
.05
Legend
WS Jul-Sep2020
WS Jul2018
WS 1970-2020Median
Ground
Bank Sta
Elevation (ft)
Station (ft)
40
35
30
25
20
15
100
150
200
250
300
350
400

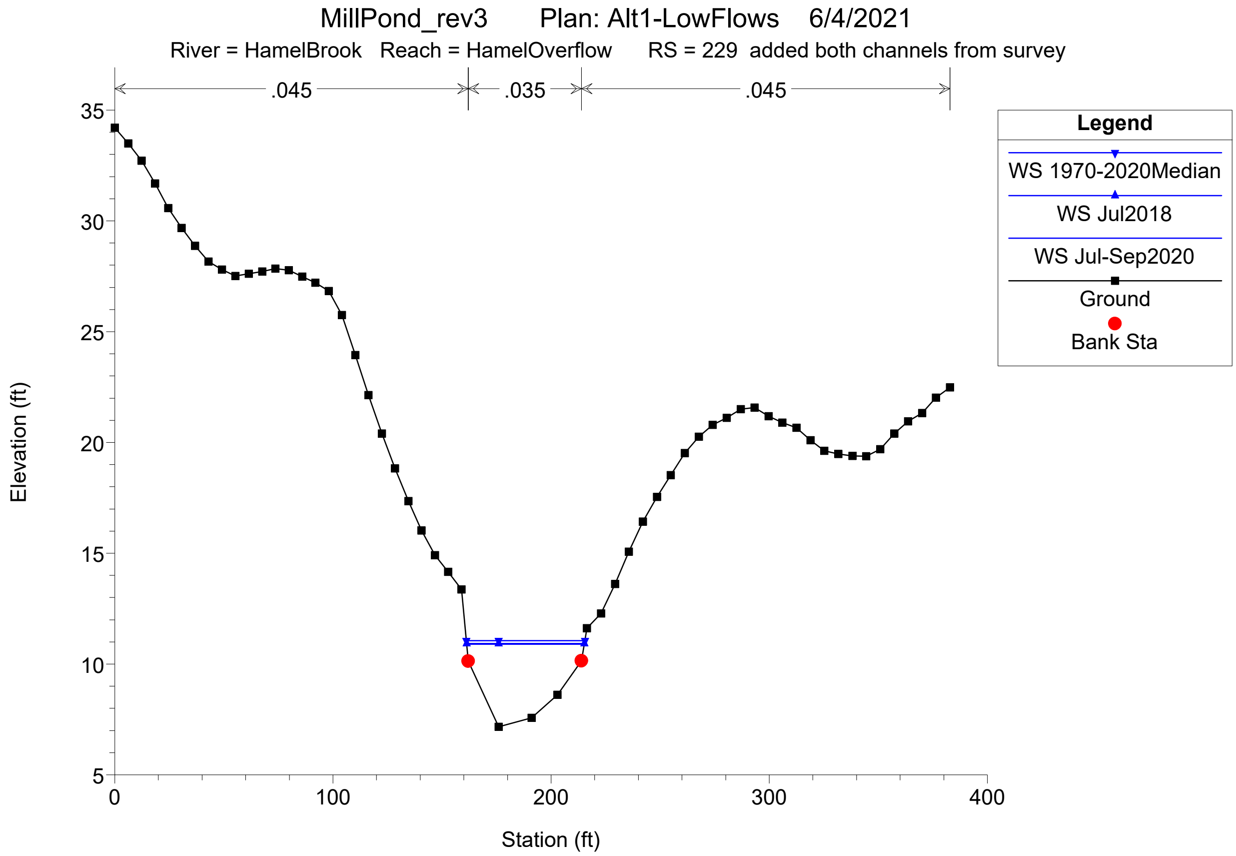

MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021
River = HamelBrook Reach = HamelBrook RS = 2483.144 added right channel from survey
.05
.05
.05
Legend
WS Jul2018
WS 1970-2020Median
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)
45
40
35
30
25
20
15
10
400
450
500
550
600
650
700
750

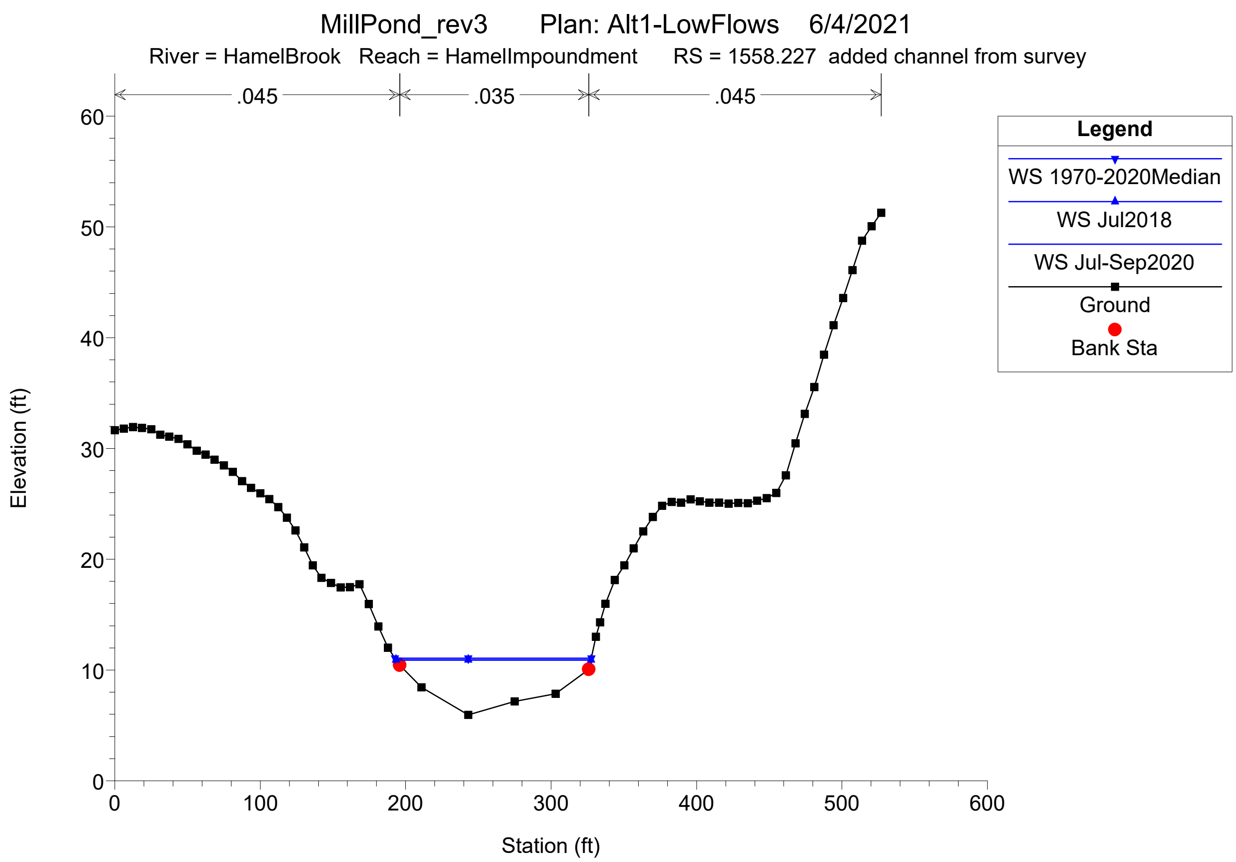

MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021
River = HamelBrook Reach = HamelBrook RS = 2403.954 added right channel from survey
.05
.05
.05
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)
45
40
35
30
25
20
15
10
750
800
850
900
950
1000
1050

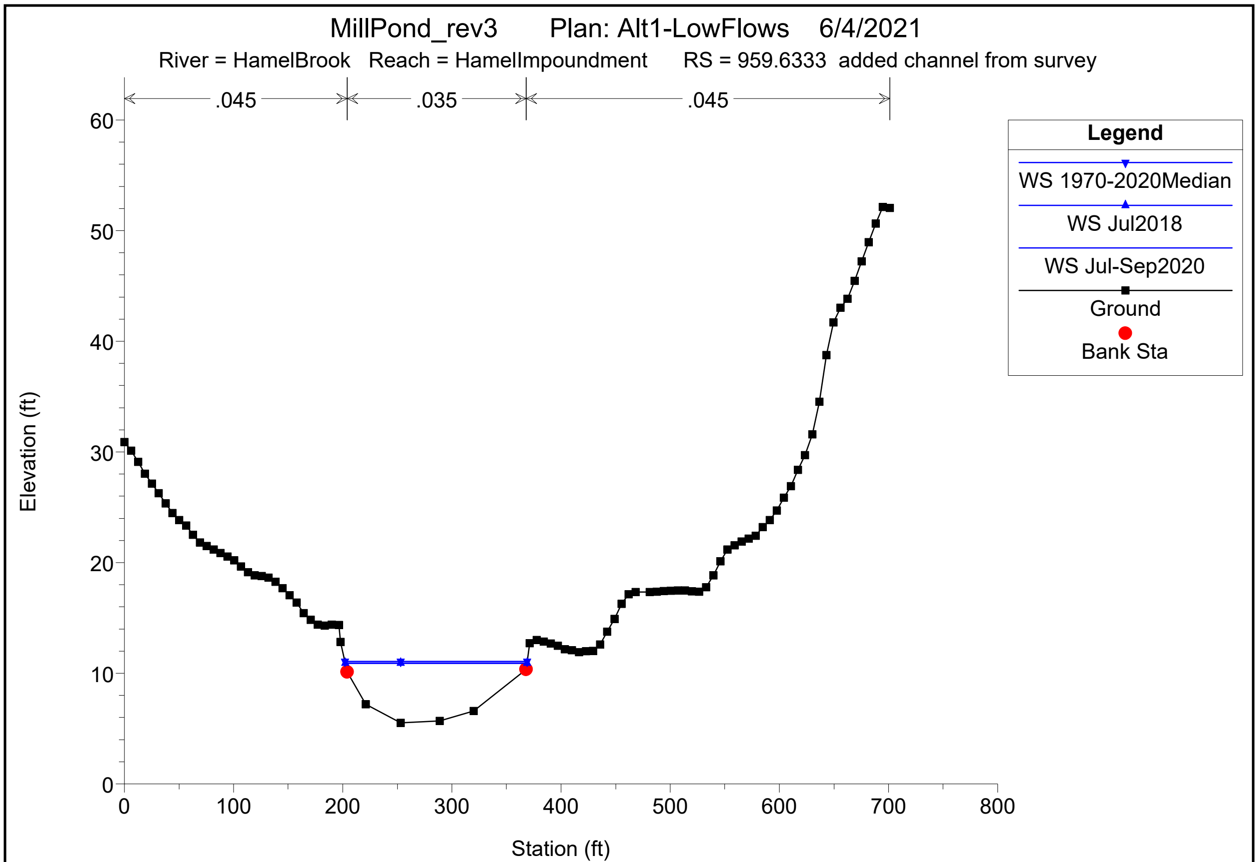

MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021
River = HamelBrook Reach = HamelBrook RS = 2017.271 added both channels from survey
.045
.035
.045
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)
35
30
25
20
15
10
5
300
400
500
600
700
800
900

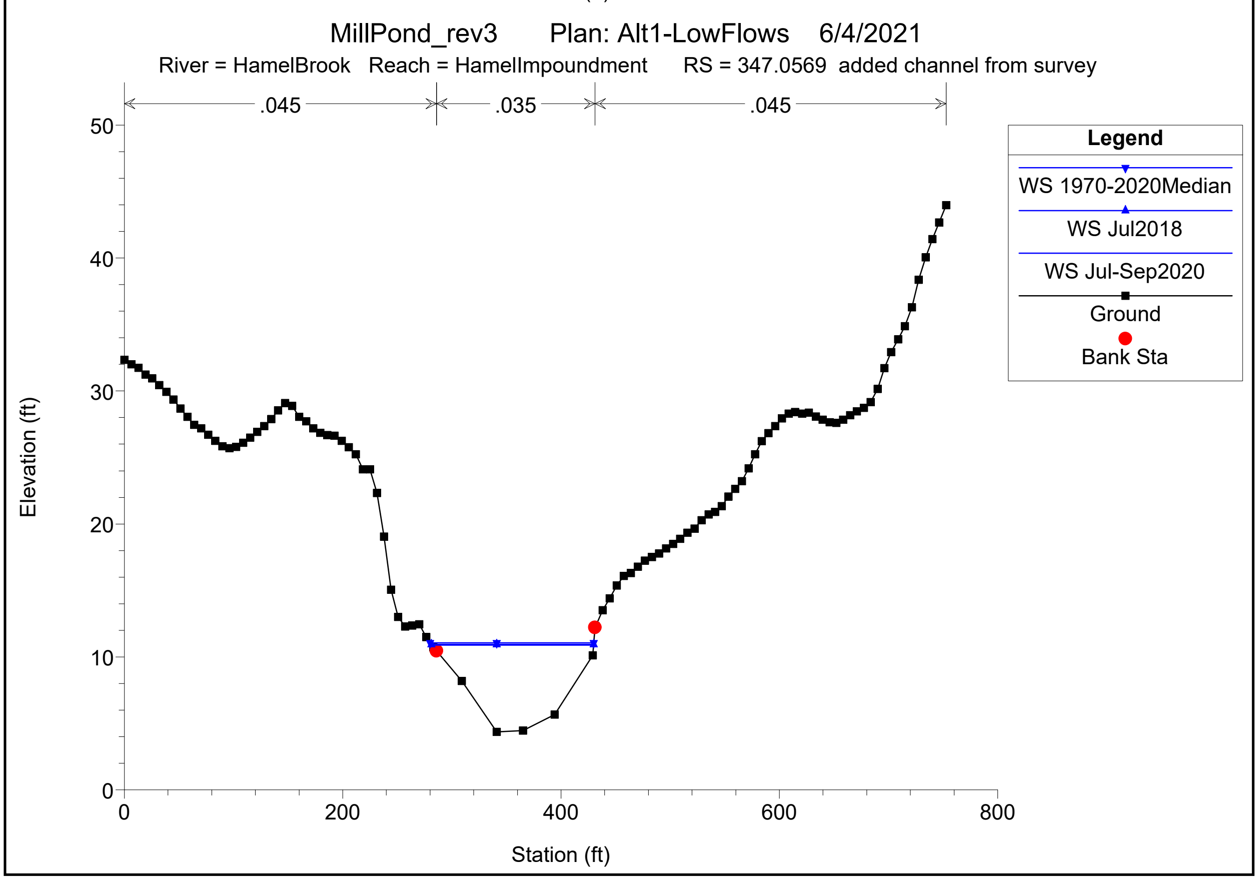

MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021
River = HamelBrook Reach = HamelOverflow RS = 553 added right channel from survey
.05
.045
.05
Legend
WS Jul-Sep2020
WS Jul2018
WS 1970-2020Median
Ground
Bank Sta
Elevation (ft)
Station (ft)
10
15
20
25
30
0
100
200
300
400
500

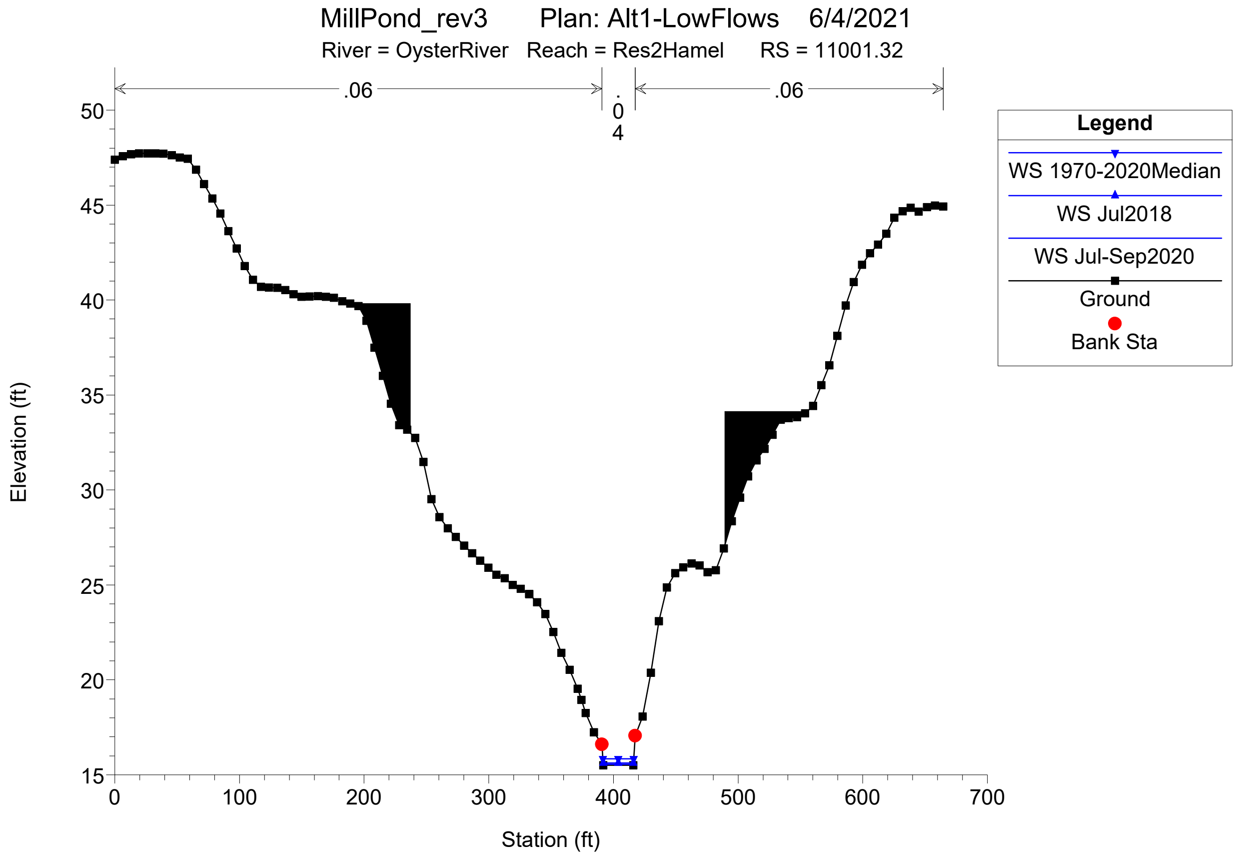

MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021
River = HamelBrook Reach = HamelOverflow RS = 422 added right channel from survey
.05
.045
.05
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)
10
15
20
25
30
35
40
0
200
400
600
800

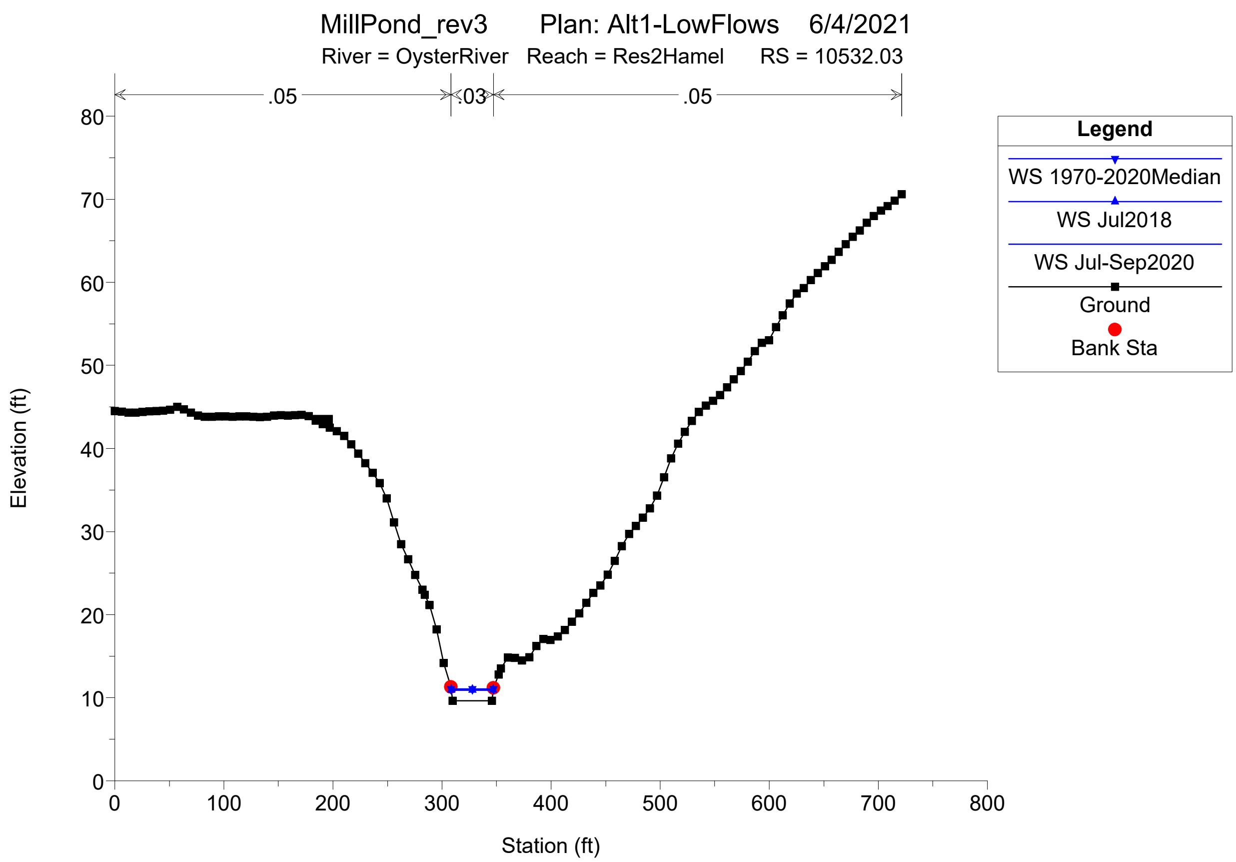

MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021
River = HamelBrook Reach = HamelOverflow RS = 229 added both channels from survey
.045
.035
.045
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)
35
30
25
20
15
10
5
0
100
200
300
400

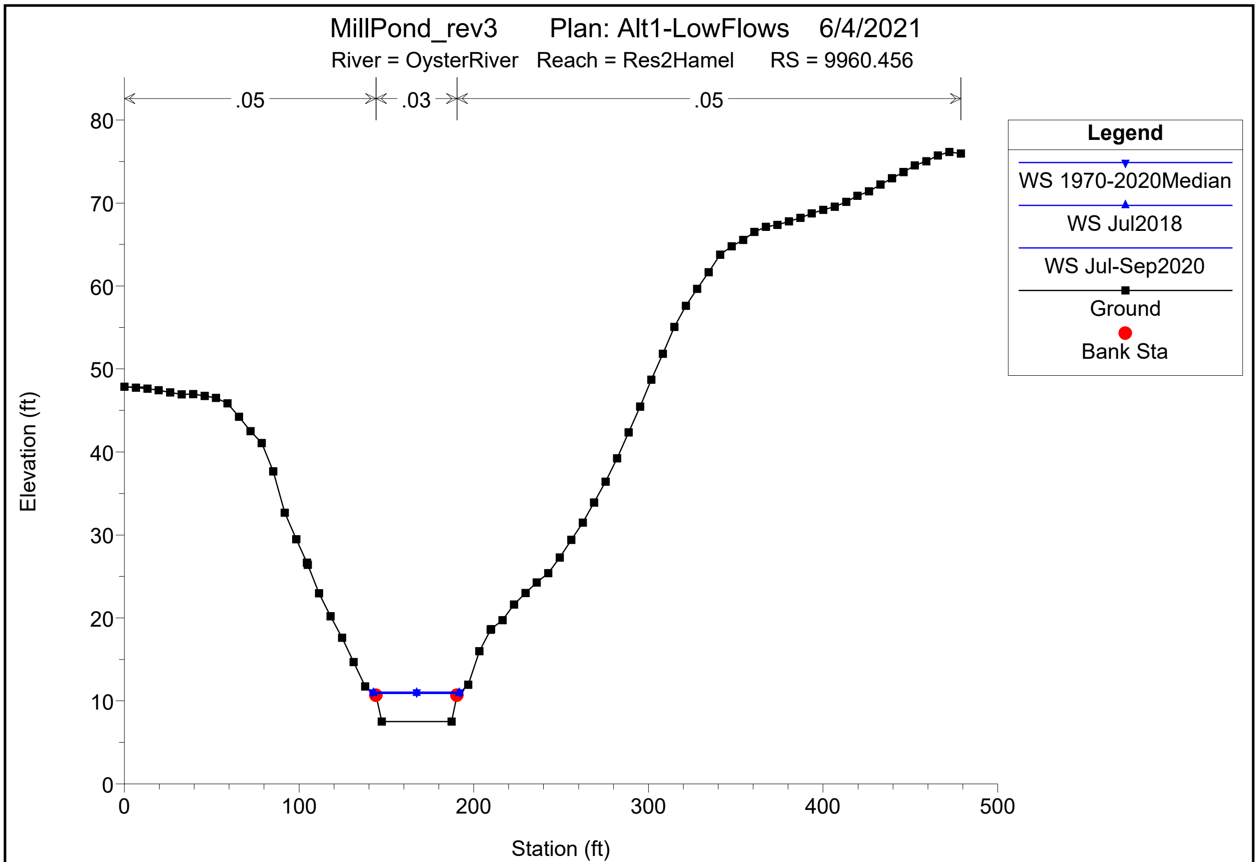

MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021
River = HamelBrook Reach = HamelImpoundment RS = 1558.227 added channel from survey
.045
.035
.045
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)
60
50
40
30
20
10
0
0
100
200
300
400
500
600

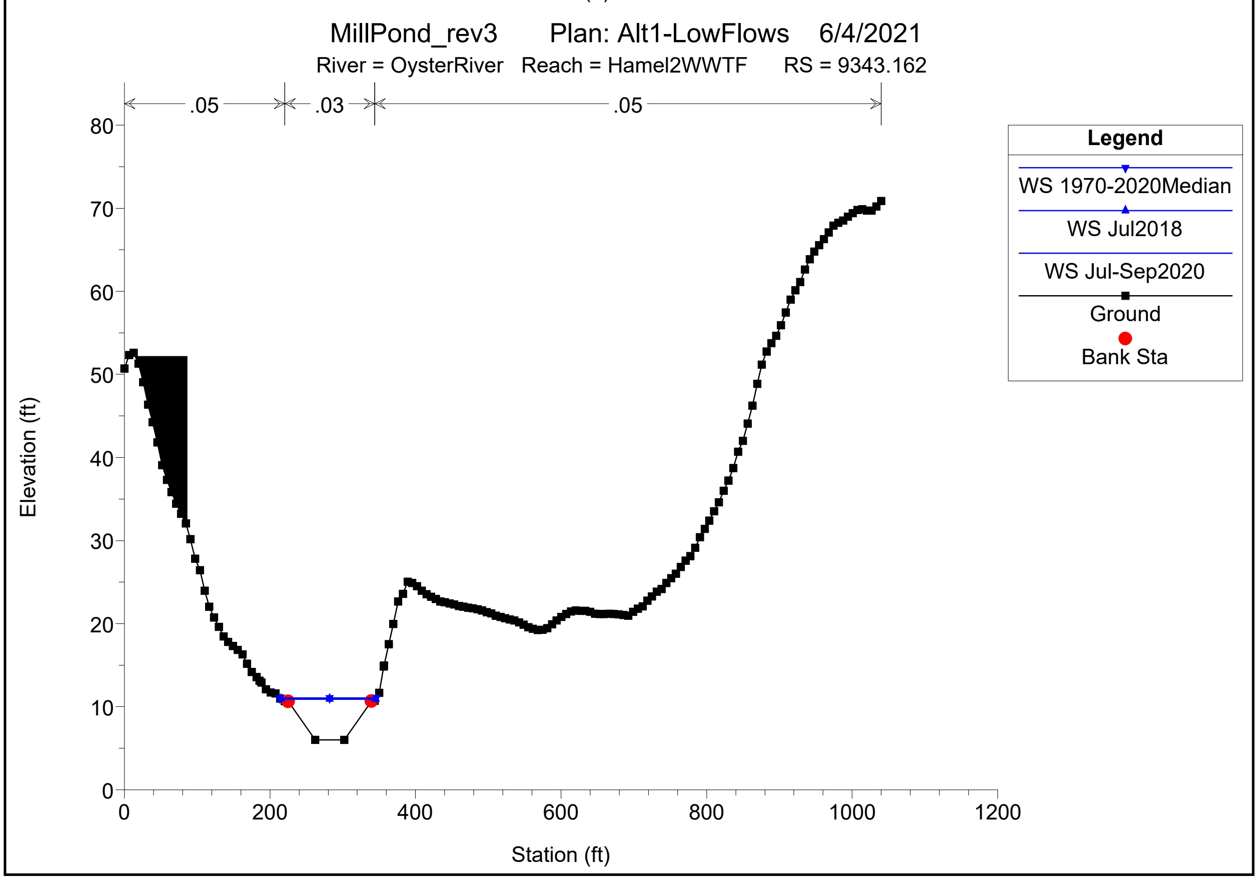

MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021
River = HamelBrook Reach = HamelImpoundment RS = 959.6333 added channel from survey
.045
.035
.045
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
0
10
20
30
40
50
60
0
100
200
300
400
500
600
700
800
Station (ft)

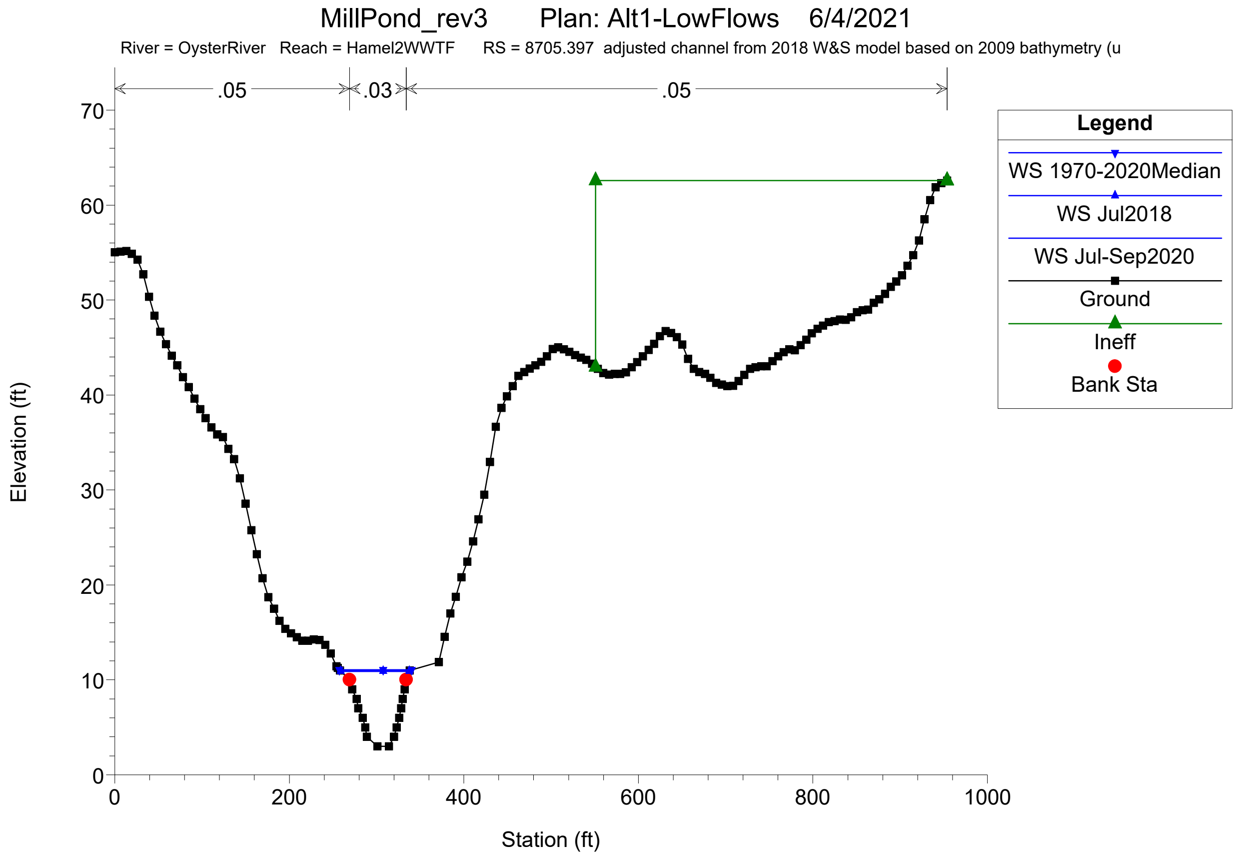

MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021
River = HamelBrook Reach = HamelImpoundment RS = 347.0569 added channel from survey
.045
.035
.045
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
0
10
20
30
40
50
0
200
400
600
800
Station (ft)


MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021
River = OysterRiver Reach = Res2Hamel RS = 11001.32
.06
.04
.06
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)

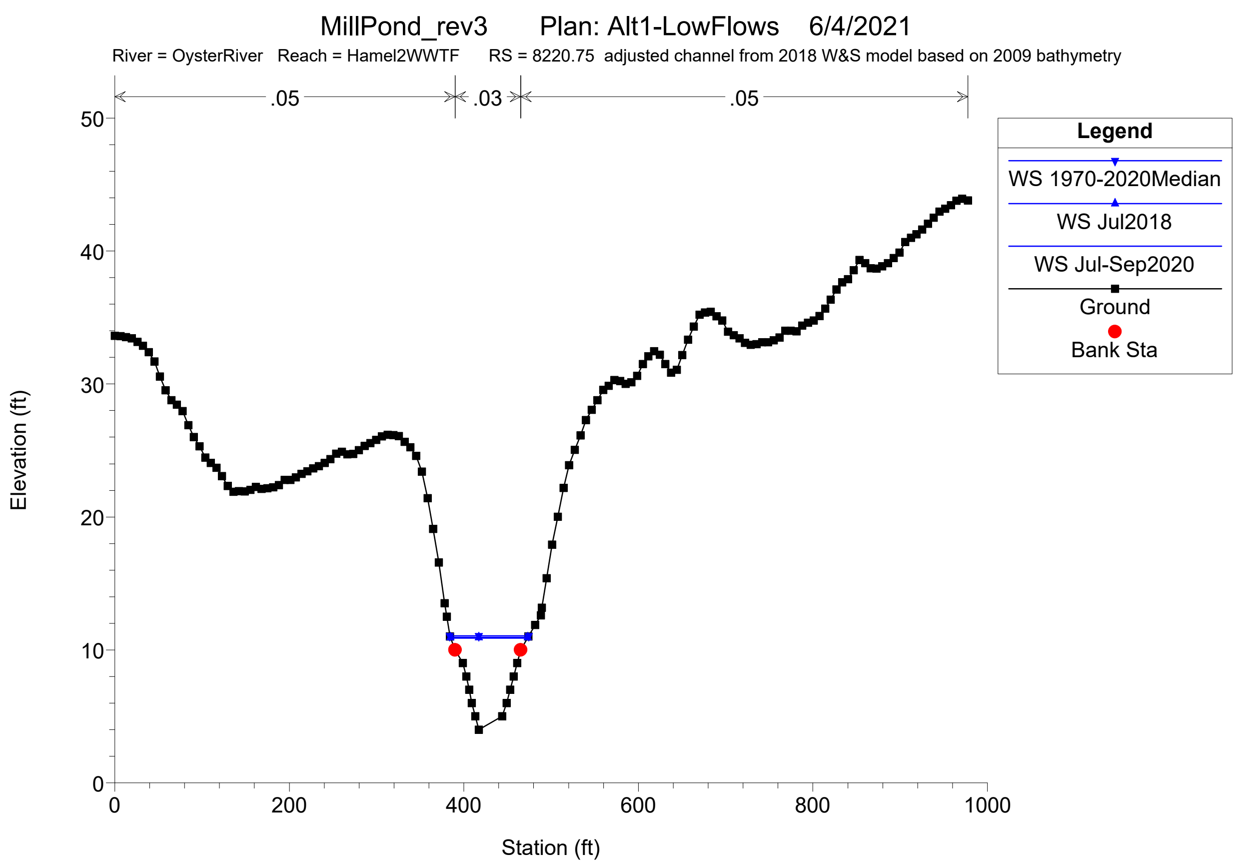

MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021
River = OysterRiver Reach = Res2Hamel RS = 10532.03
.05
.03
.05
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)


MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021
River = OysterRiver Reach = Res2Hamel RS = 9960.456
.05
.03
.05
Elevation (ft)
Station (ft)
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta

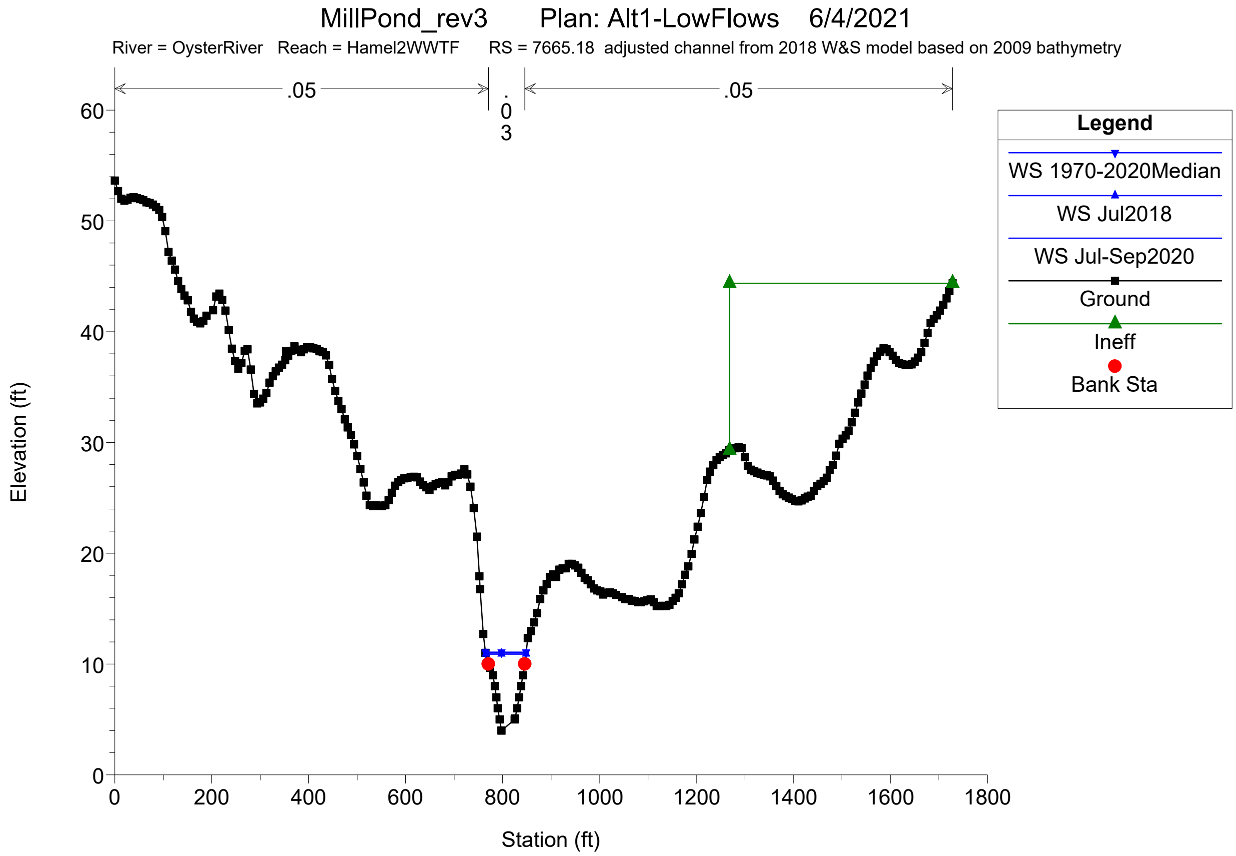

MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 9343.162
.05
.03
.05
Elevation (ft)
Station (ft)
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta

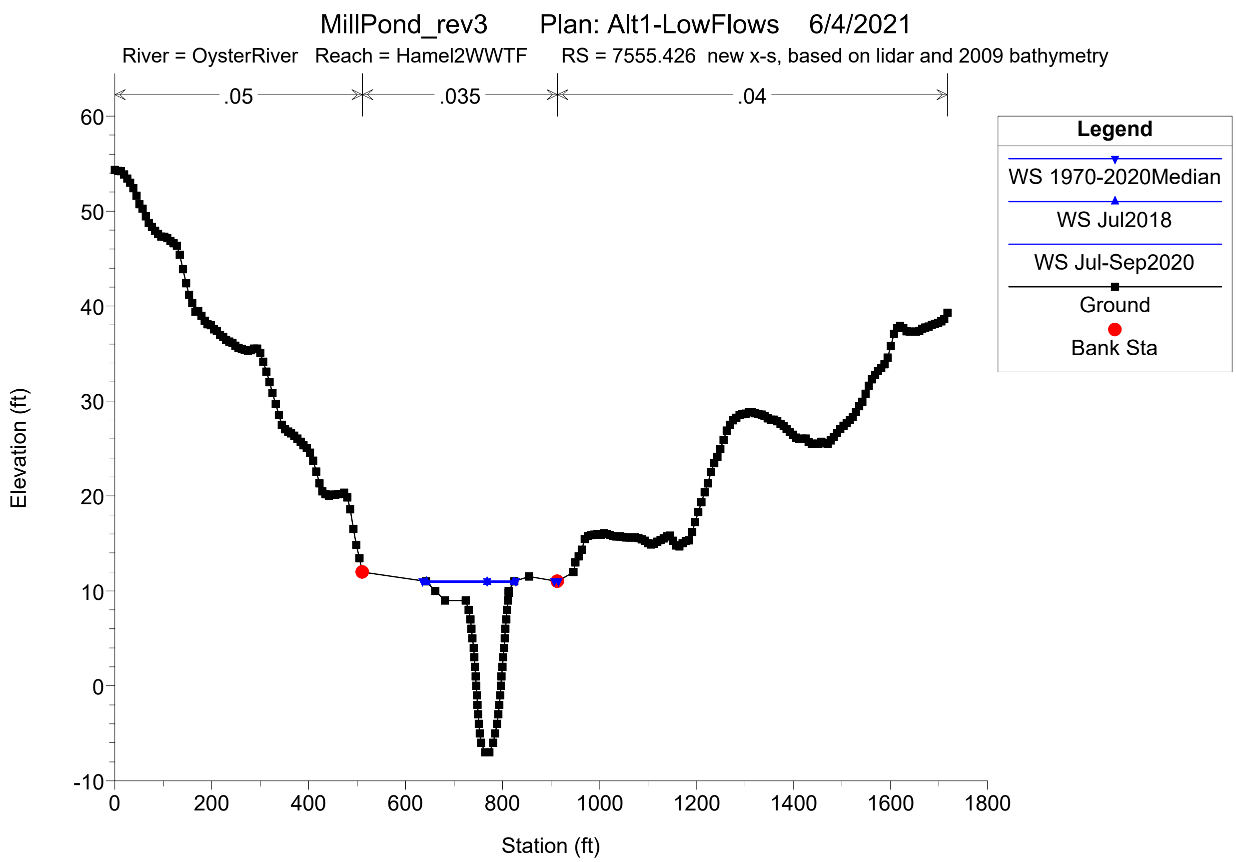


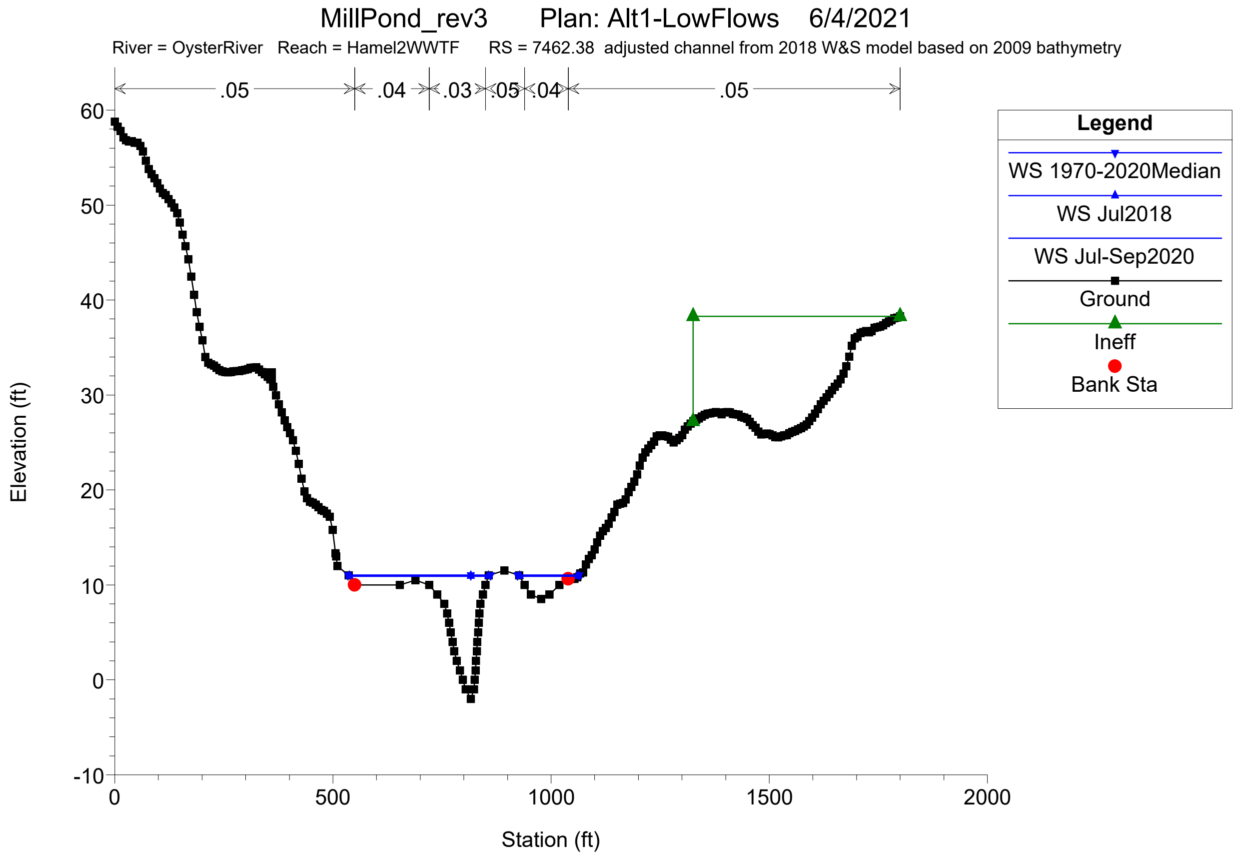
MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 8705.397 adjusted channel from 2018 W&S model based on 2009 bathymetry (u
.05
.03
.05
Elevation (ft)
Station (ft)
0
10
20
30
40
50
60
70
0
200
400
600
800
1000
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Ineff
Bank Sta

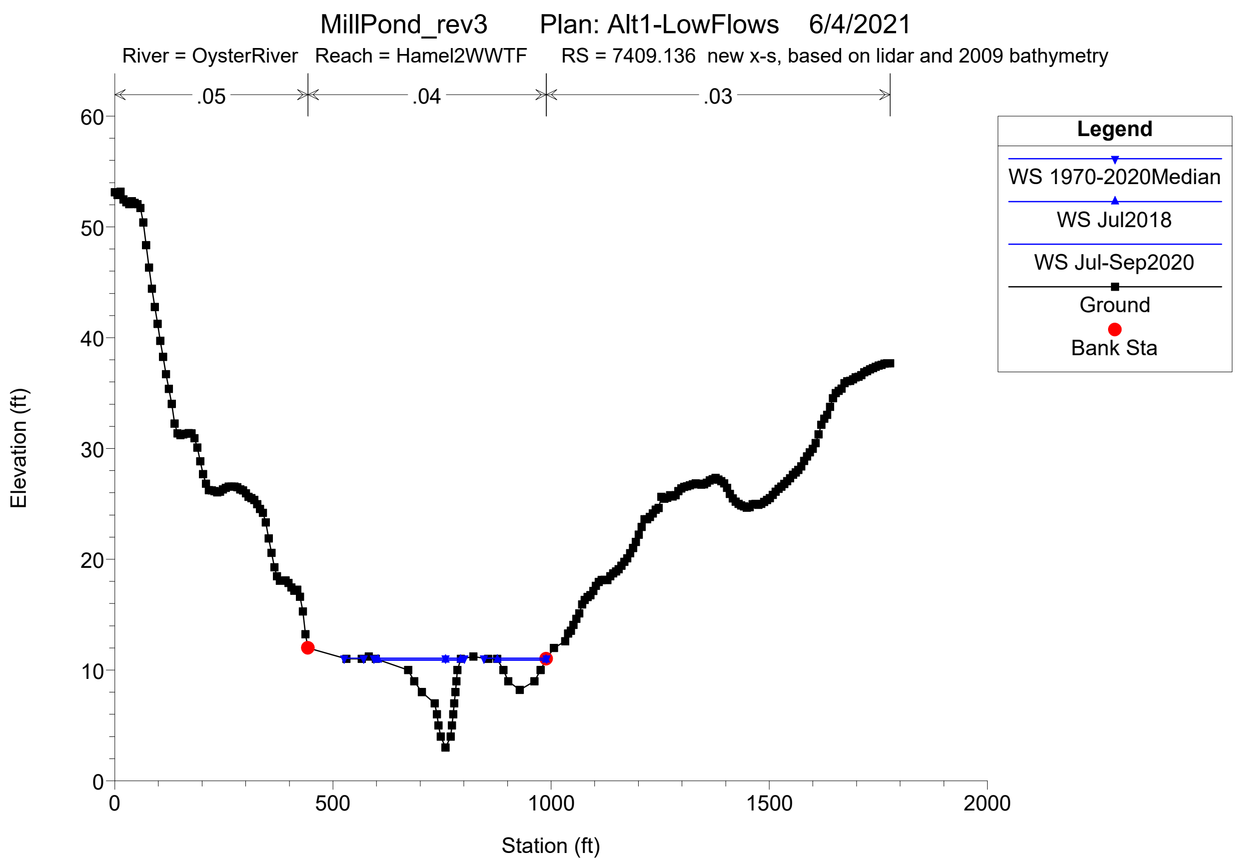


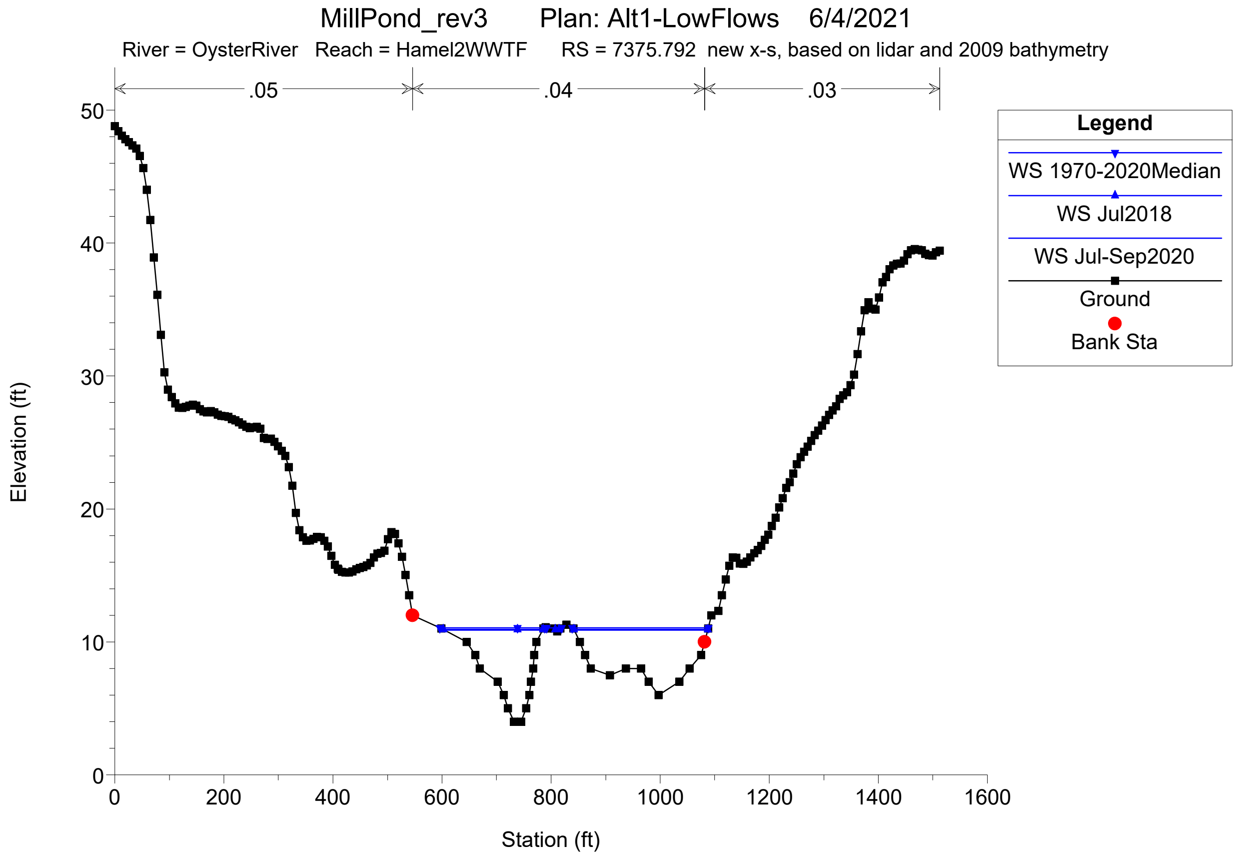
MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 8220.75 adjusted channel from 2018 W&S model based on 2009 bathymetry
.05
.03
.05
Elevation (ft)
Station (ft)
0
10
20
30
40
50
0
200
400
600
800
1000
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta

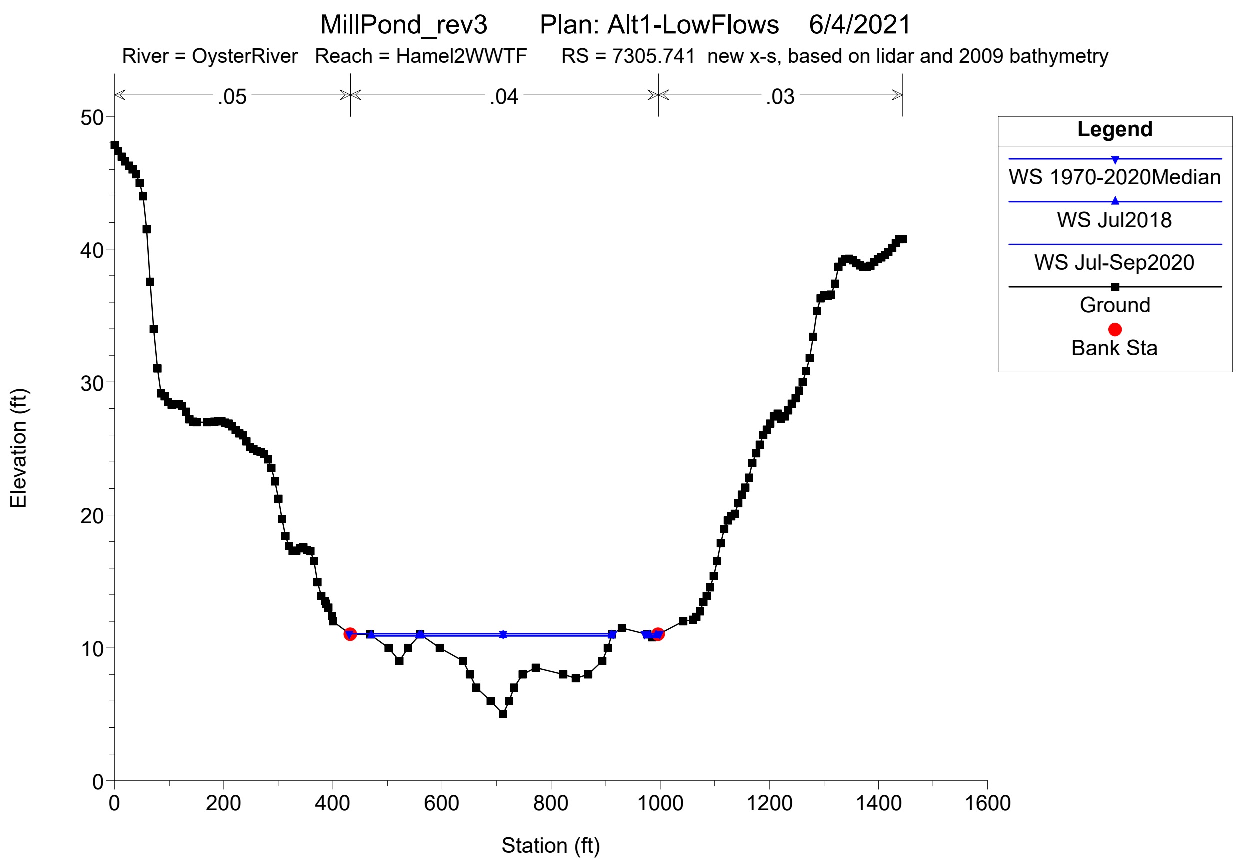

MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 7665.18 adjusted channel from 2018 W&S model based on 2009 bathymetry
.05
.03
.05
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
0
10
20
30
40
50
60
0
200
400
600
800
1000
1200
1400
1600
1800

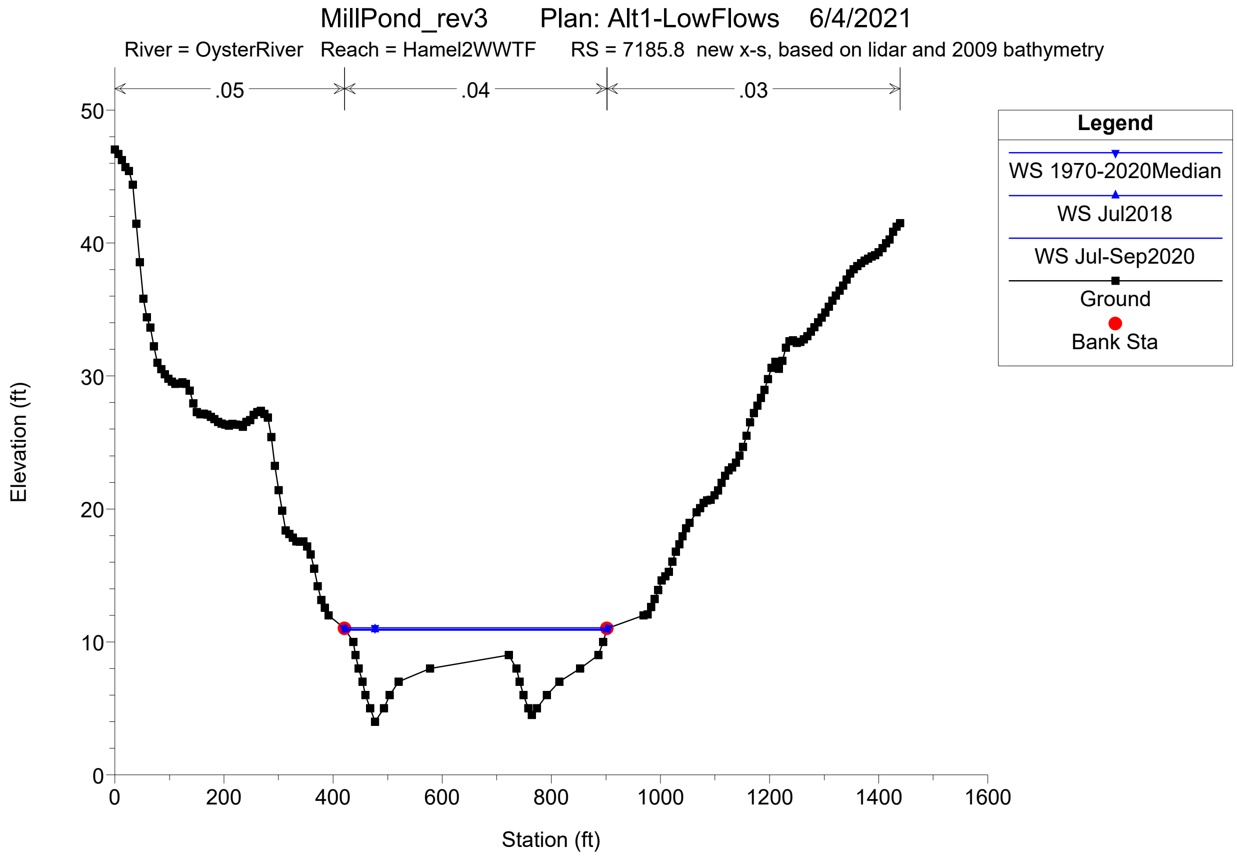

MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 7555.426 new x-s, based on lidar and 2009 bathymetry
.05
.035
.04
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)
-10
0
10
20
30
40
50
60
0
200
400
600
800
1000
1200
1400
1600
1800

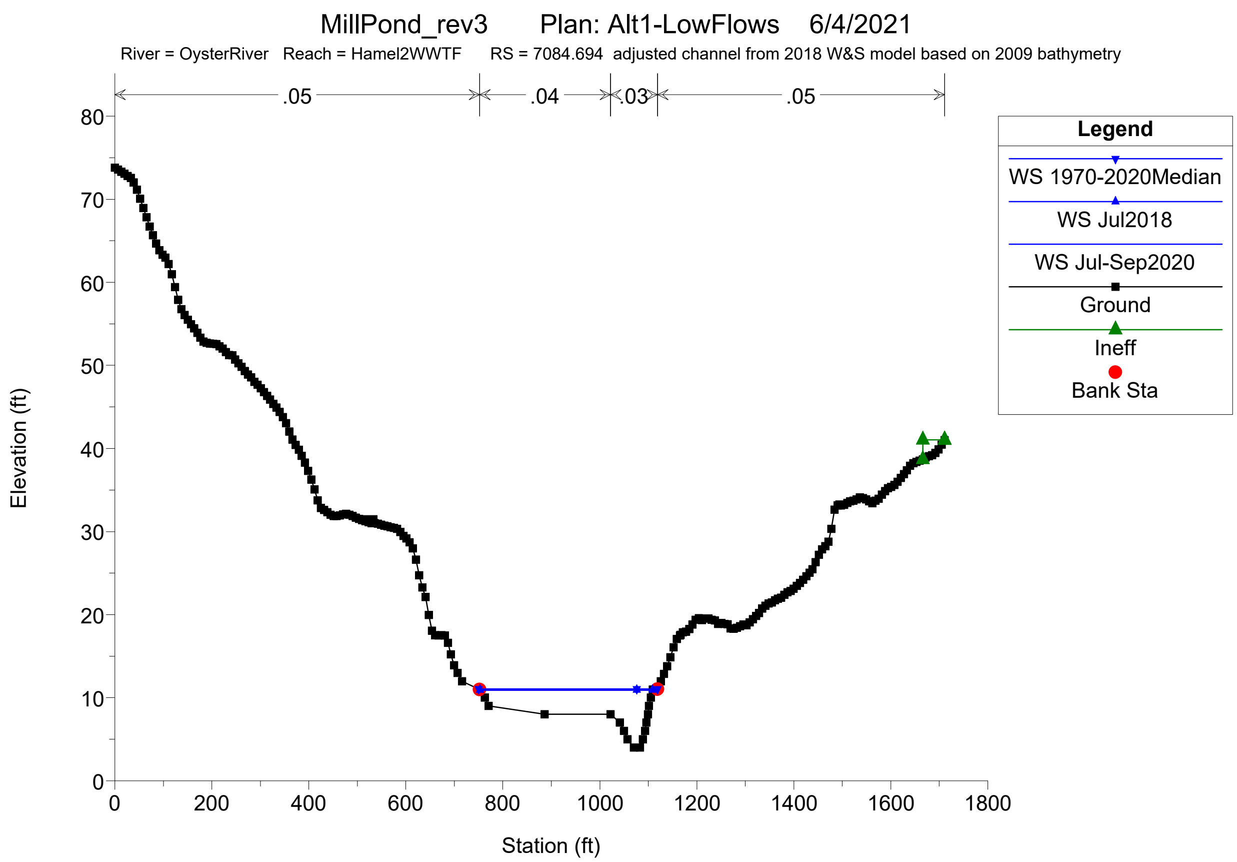

MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 7462.38 adjusted channel from 2018 W&S model based on 2009 bathymetry
.05
.04
.03
.05
.04
.05
Elevation (ft)
Station (ft)
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Ineff
Bank Sta

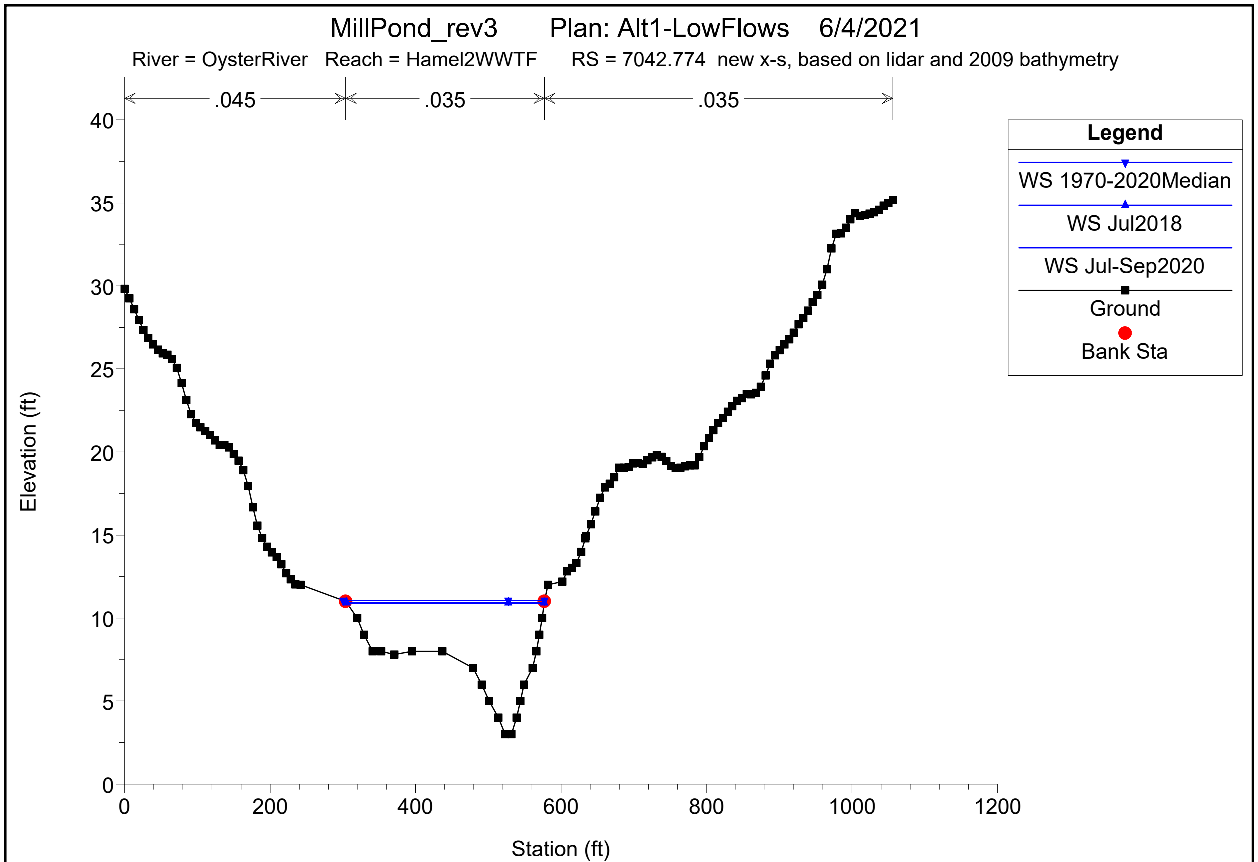

MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 7409.136 new x-s, based on lidar and 2009 bathymetry
.05
.04
.03
Elevation (ft)
Station (ft)
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta

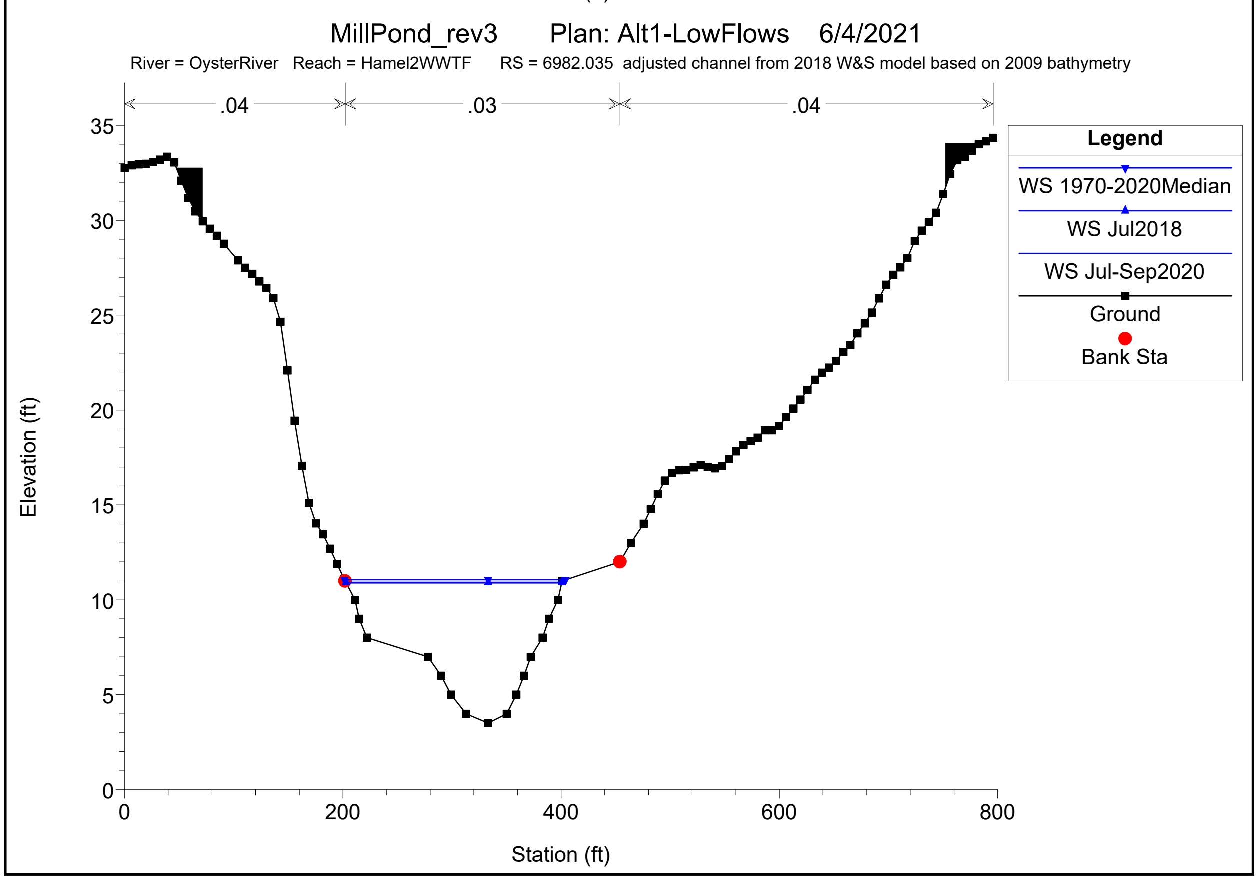

MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 7375.792 new x-s, based on lidar and 2009 bathymetry
.05
.04
.03
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)
0
10
20
30
40
50
0
200
400
600
800
1000
1200
1400
1600

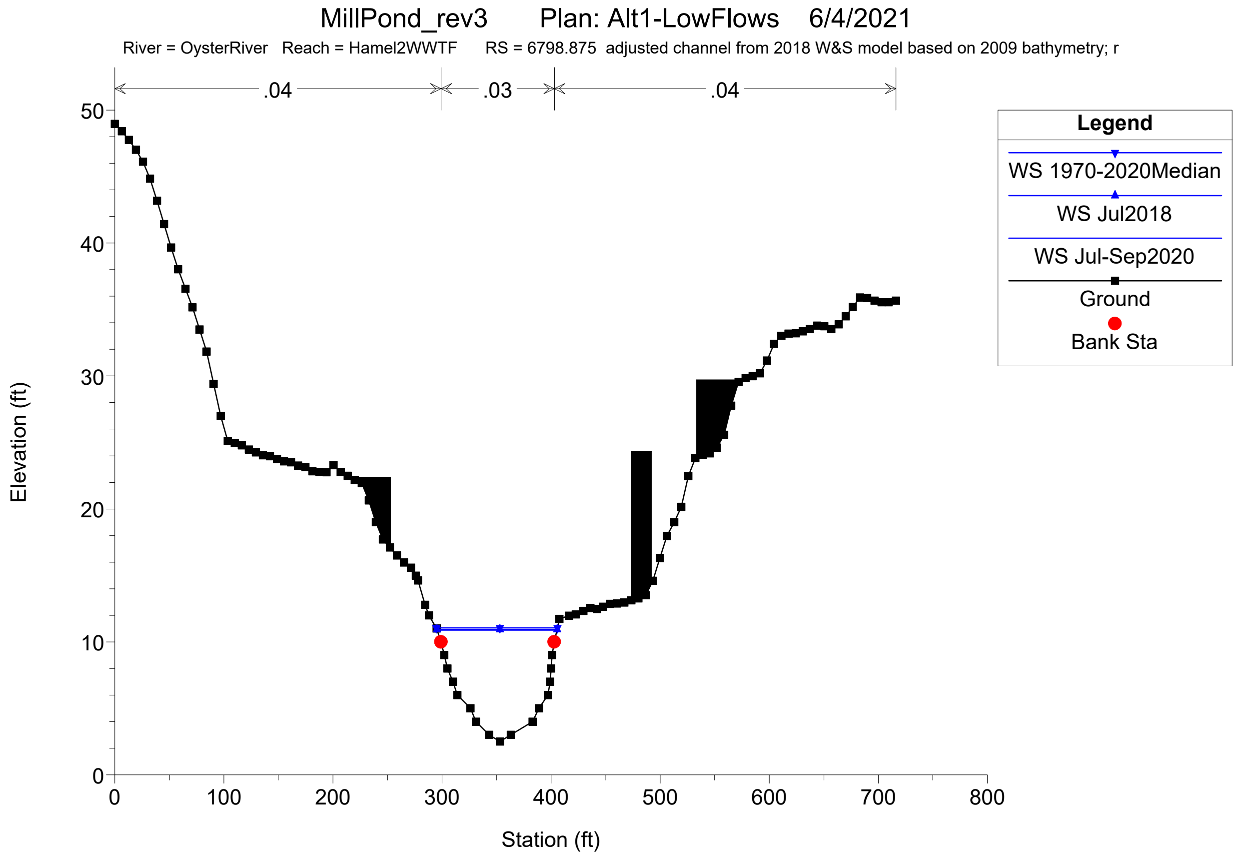

MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 7305.741 new x-s, based on lidar and 2009 bathymetry
.05
.04
.03
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)
0
10
20
30
40
50
0
200
400
600
800
1000
1200
1400
1600

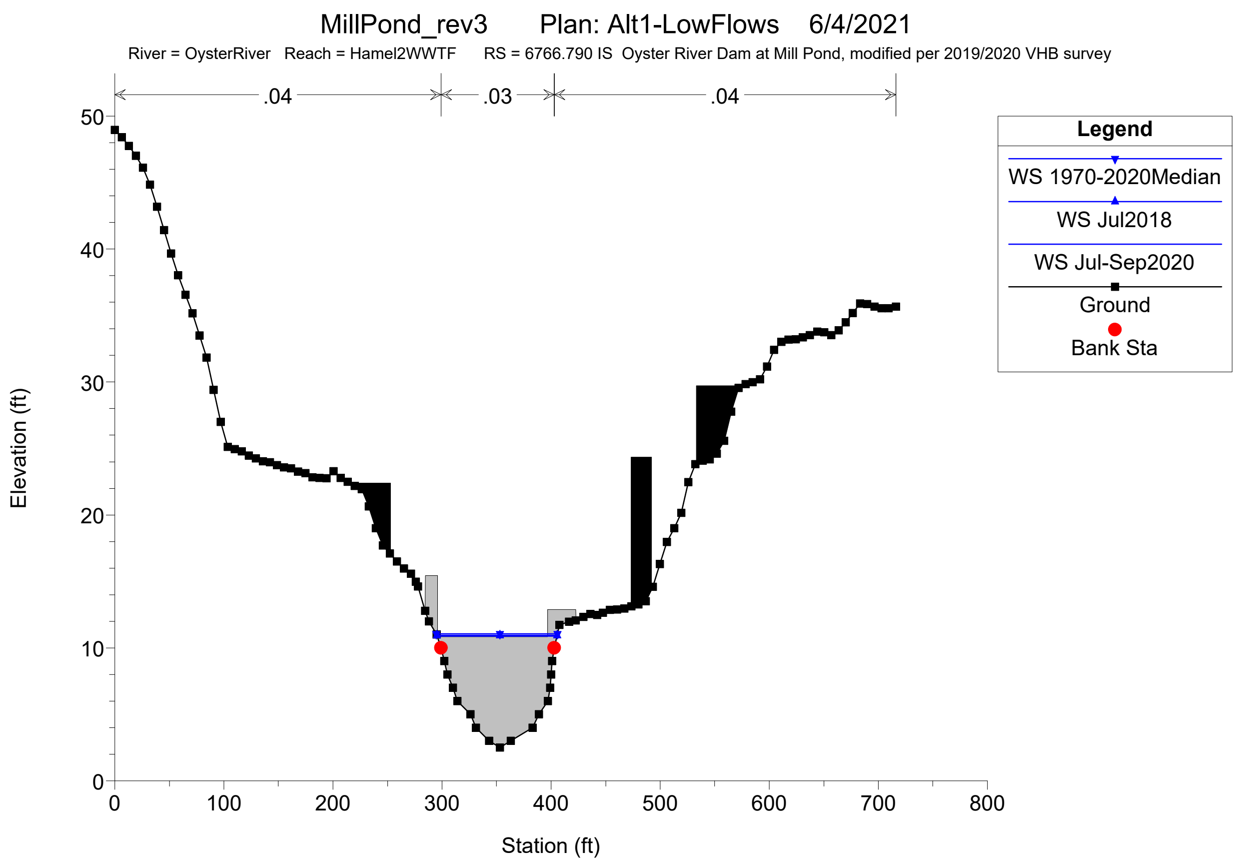

MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 7185.8 new x-s, based on lidar and 2009 bathymetry
.05
.04
.03
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)
0
10
20
30
40
50
0
200
400
600
800
1000
1200
1400
1600

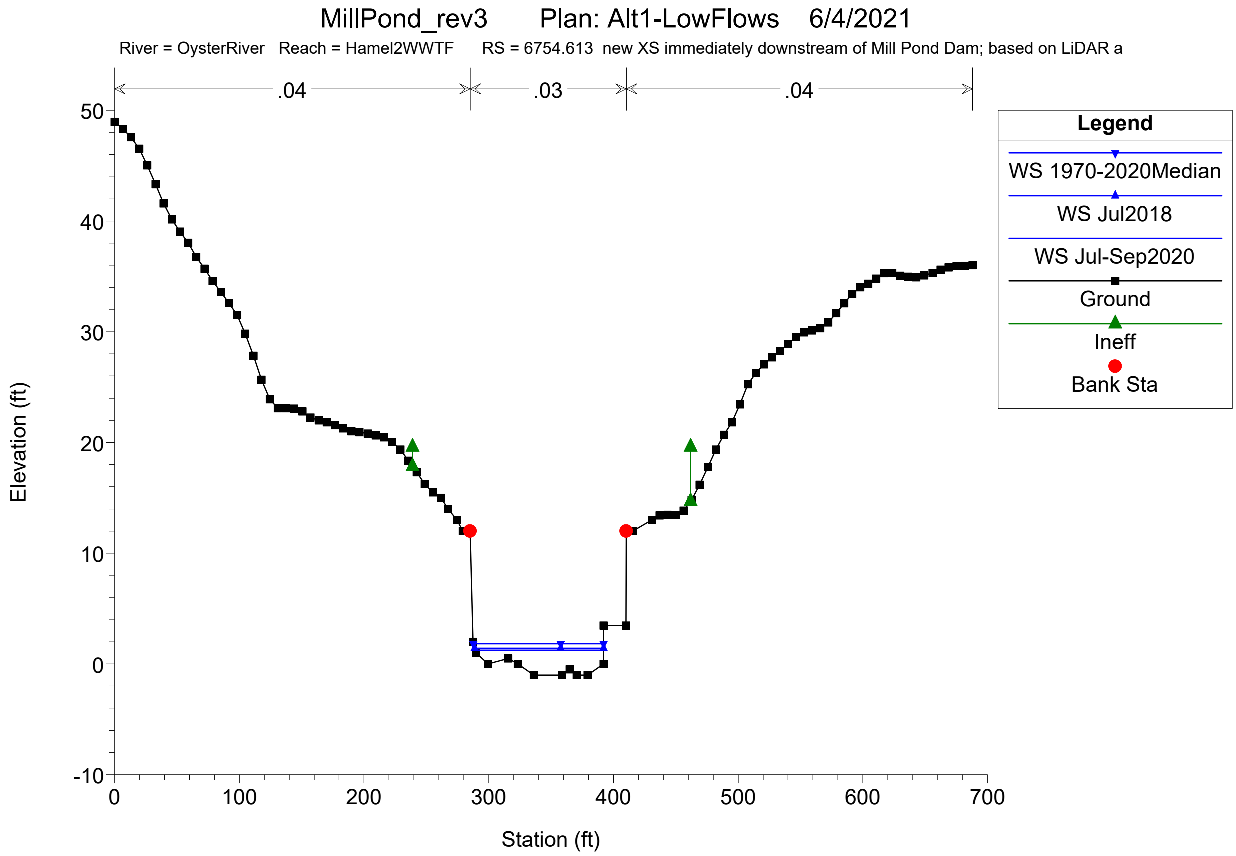

MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 7084.694 adjusted channel from 2018 W&S model based on 2009 bathymetry
.05
.04
.03
.05
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
0
10
20
30
40
50
60
70
80
0
200
400
600
800
1000
1200
1400
1600
1800

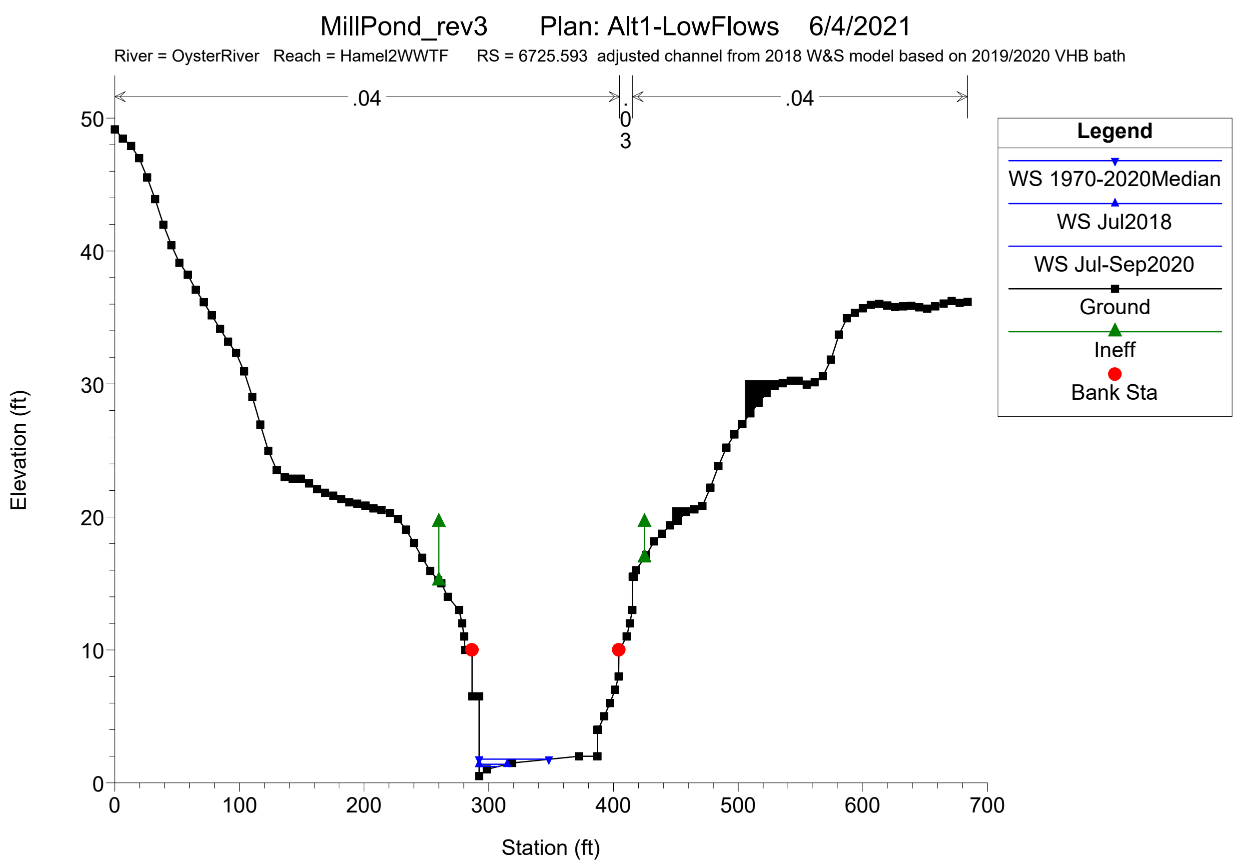

MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 7042.774 new x-s, based on lidar and 2009 bathymetry
.045
.035
.035
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)


MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6982.035 adjusted channel from 2018 W&S model based on 2009 bathymetry
.04
.03
.04
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)


MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6798.875 adjusted channel from 2018 W&S model based on 2009 bathymetry; r
.04
.03
.04
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)
0
10
20
30
40
50
0
100
200
300
400
500
600
700
800

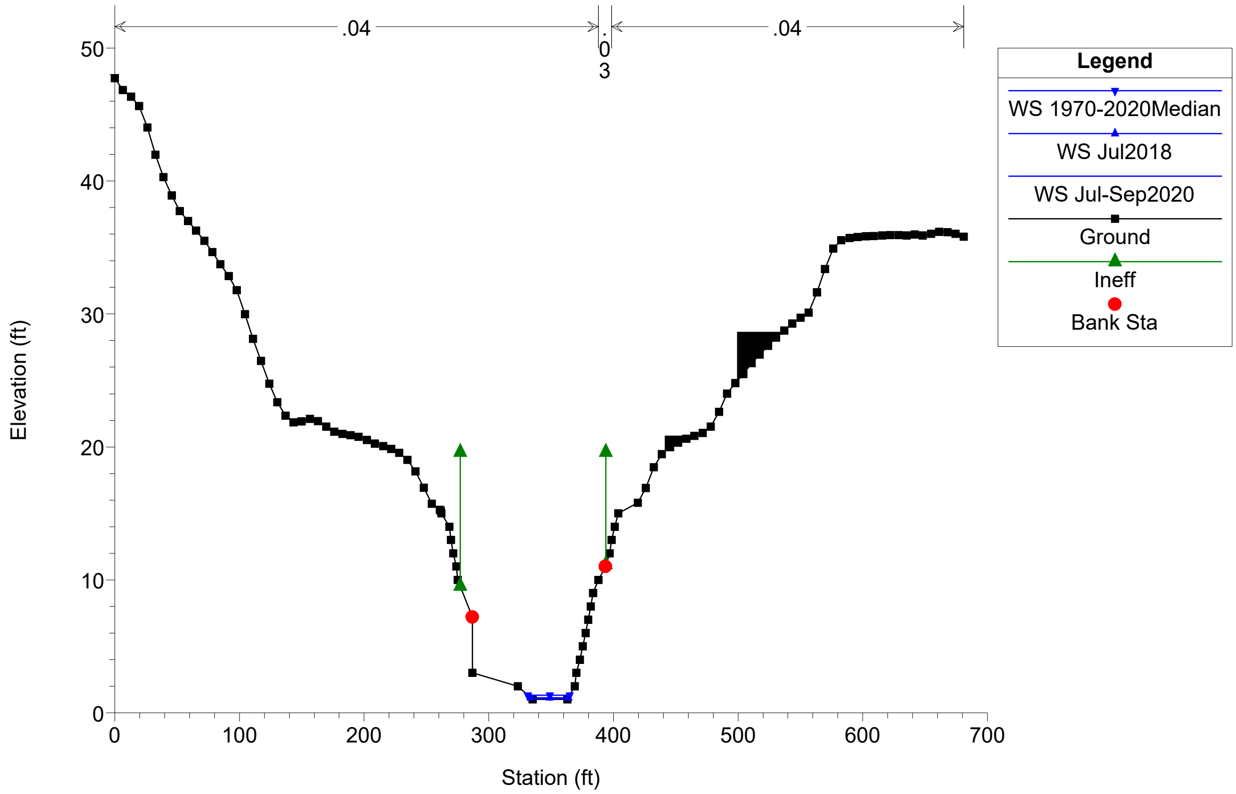

MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6766.790 IS Oyster River Dam at Mill Pond, modified per 2019/2020 VHB survey
.04
.03
.04
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)
0
10
20
30
40
50
0
100
200
300
400
500
600
700
800


MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6754.613 new XS immediately downstream of Mill Pond Dam; based on LiDAR a
.04
.03
.04
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)


MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6725.593 adjusted channel from 2018 W&S model based on 2019/2020 VHB bath
.04
.03
.04
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)

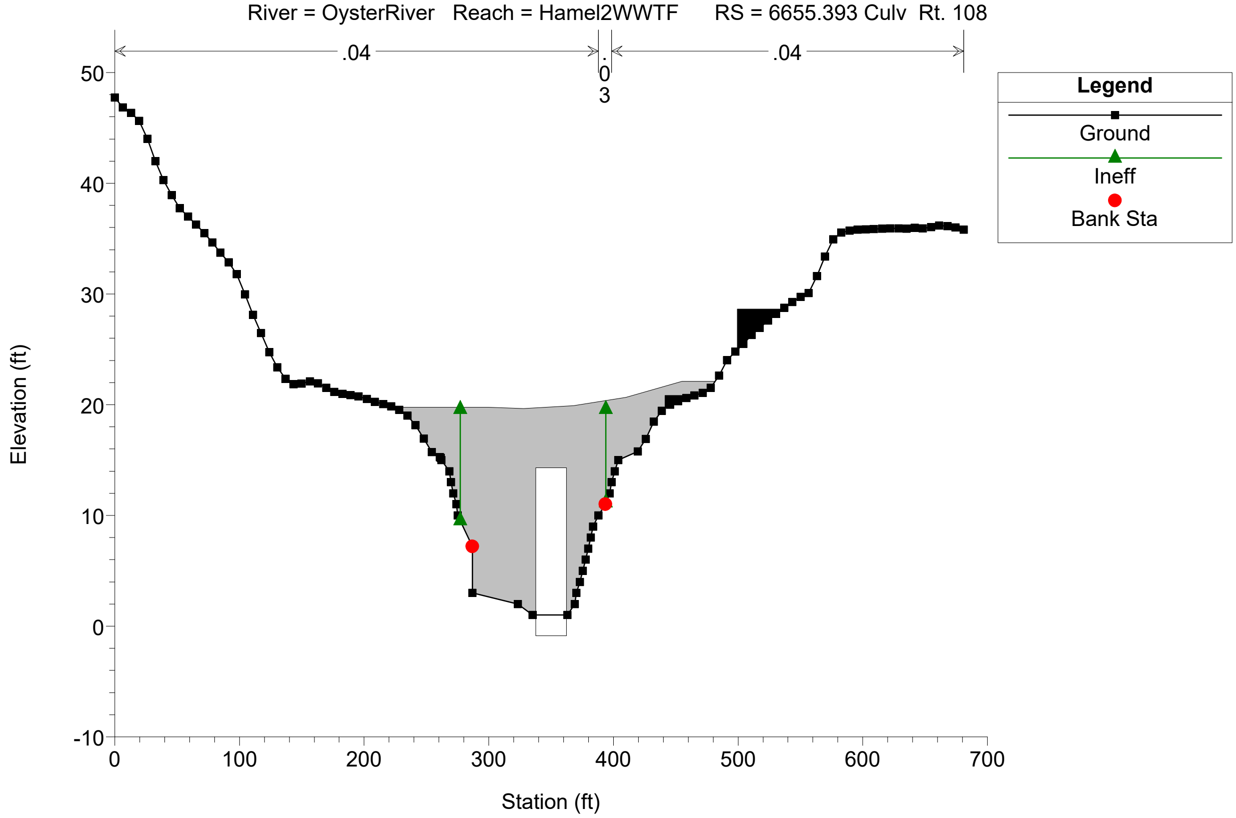
MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021

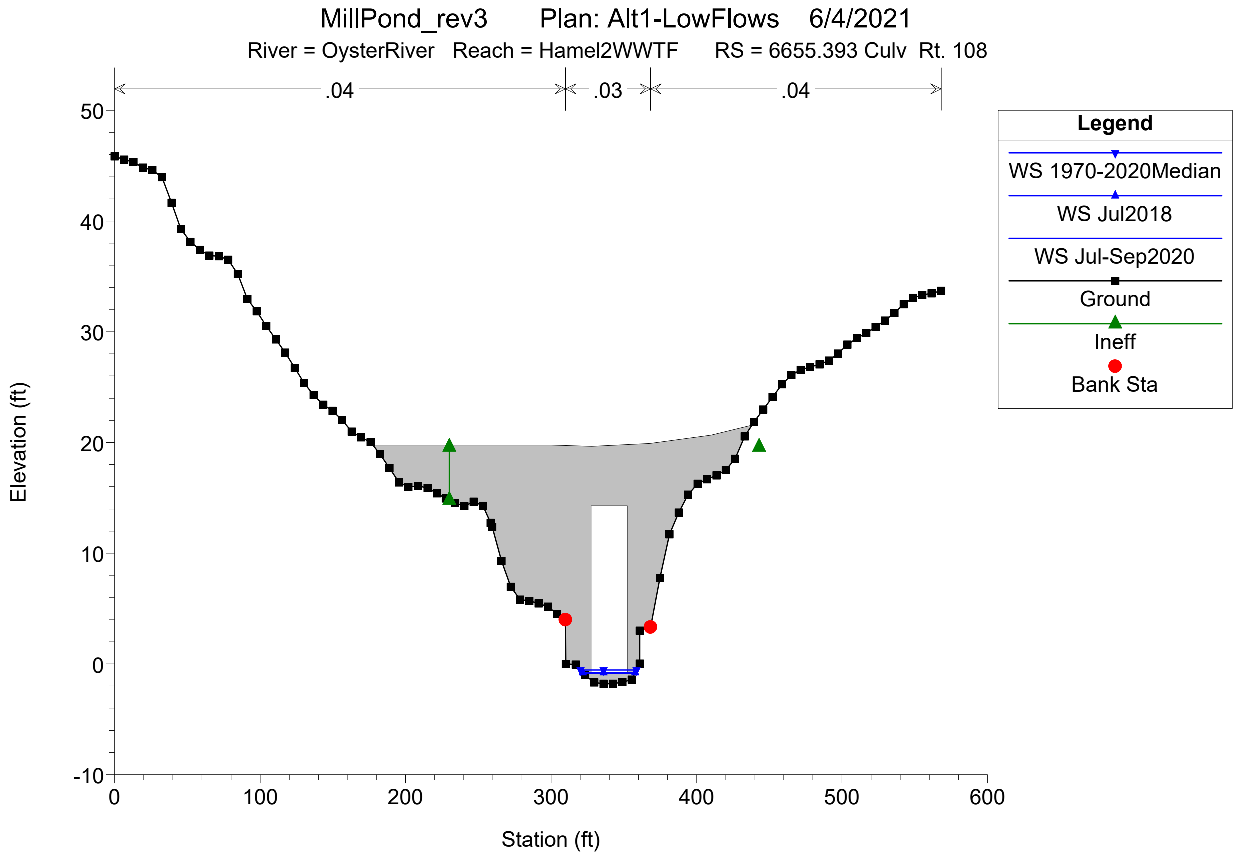
River = OysterRiver Reach = Hamel2WWTF RS = 6701.054 adjusted channel from 2018 W&S model based on 2019/2020 VHB bath

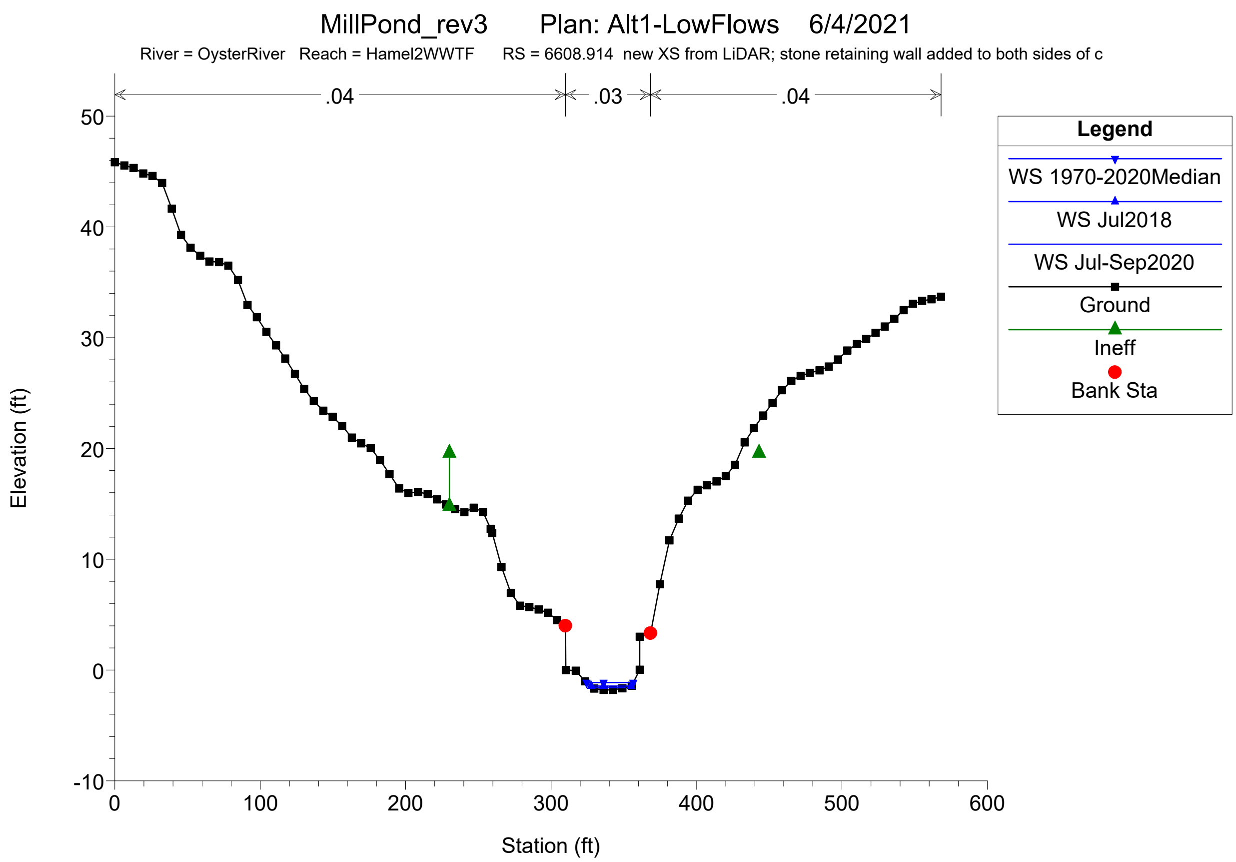


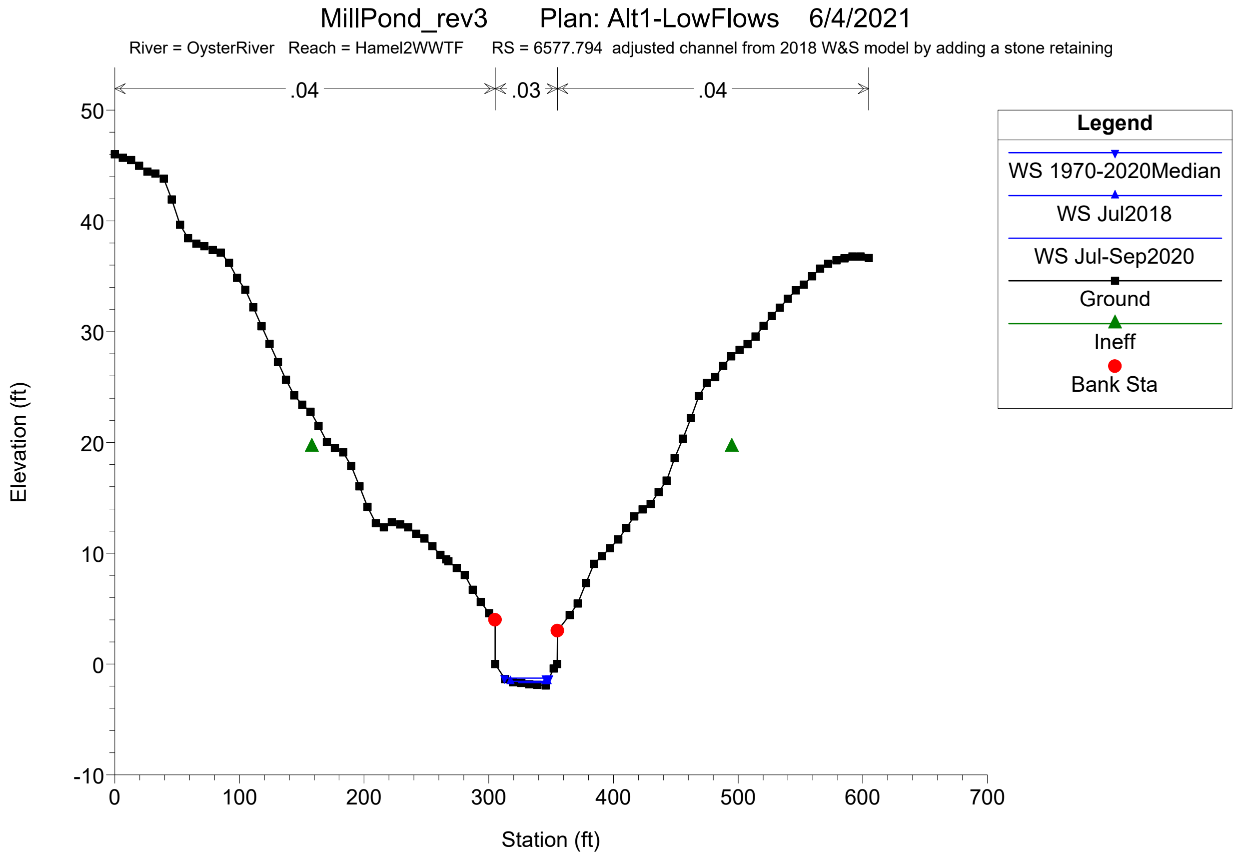
MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021

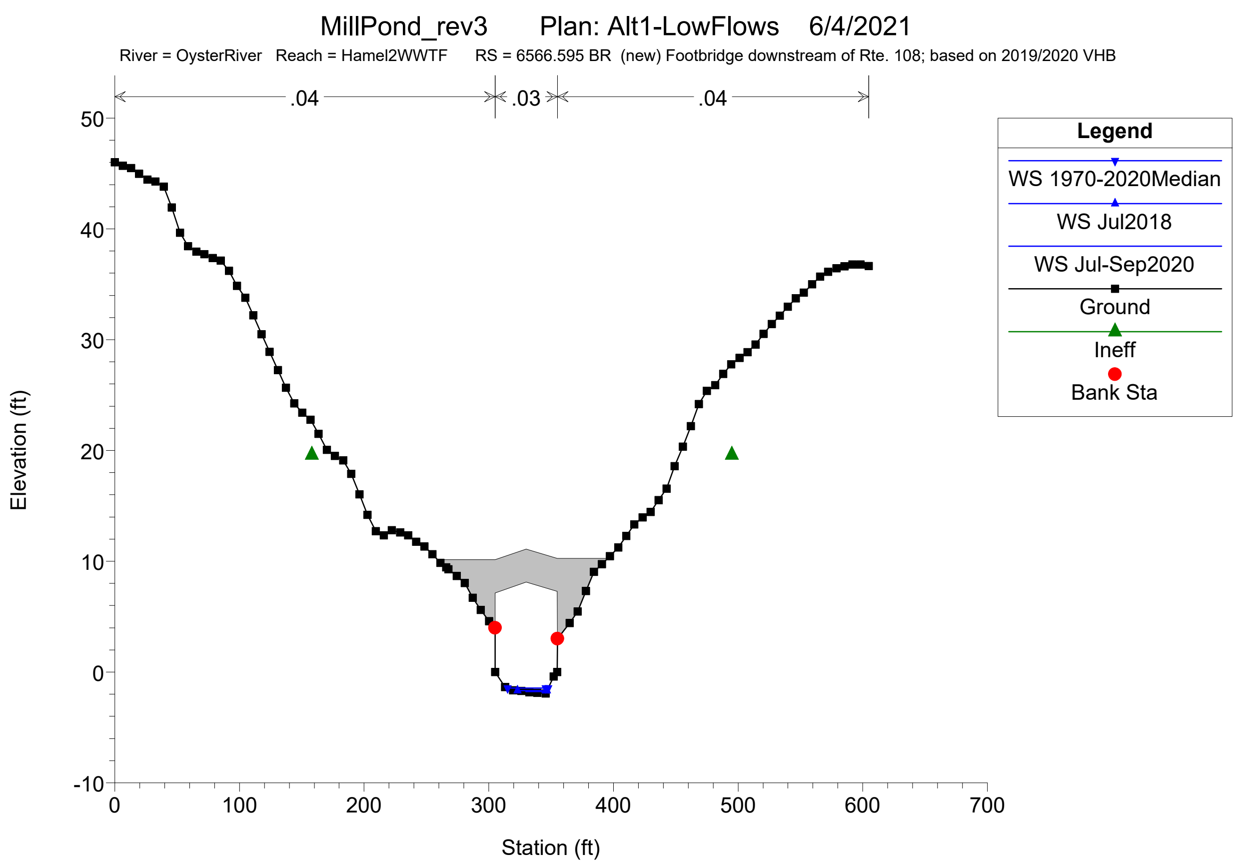
River = OysterRiver Reach = Hamel2WWTF RS = 6655.393 Culv Rt. 108

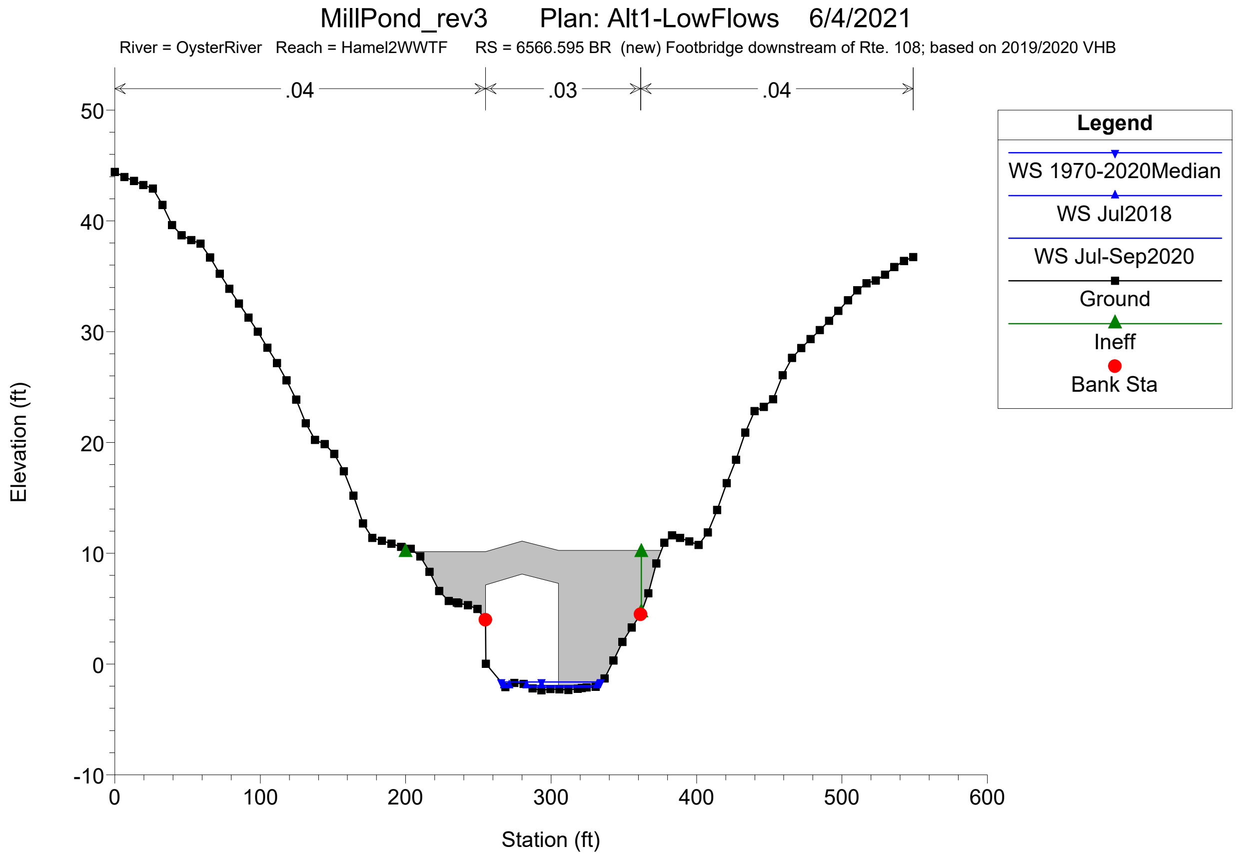


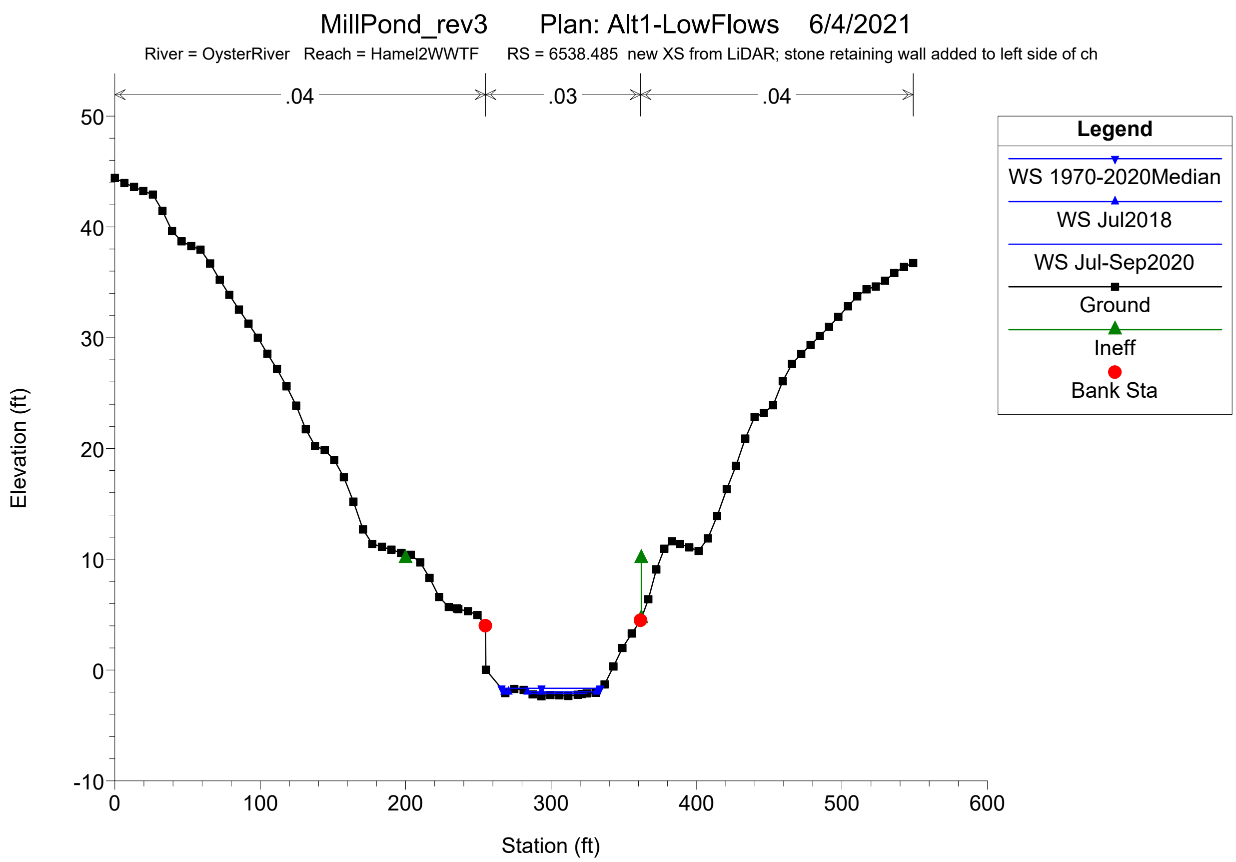

MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6655.393 Culv Rt. 108
.04
.03
.04
Elevation (ft)
Station (ft)
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Ineff
Bank Sta

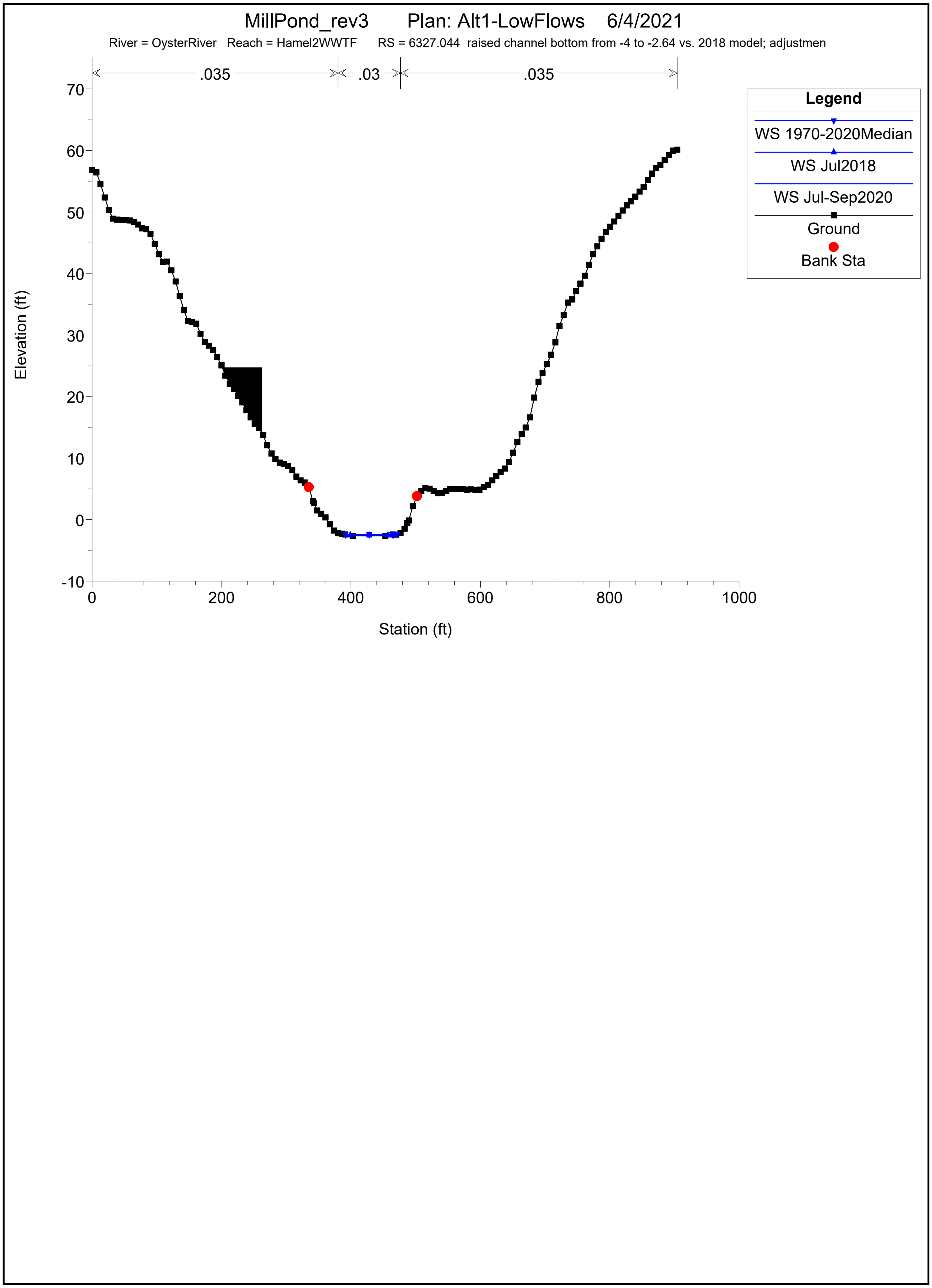

MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6608.914 new XS from LiDAR; stone retaining wall added to both sides of c
.04
.03
.04
Elevation (ft)
Station (ft)
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Ineff
Bank Sta


MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6577.794 adjusted channel from 2018 W&S model by adding a stone retaining
.04
.03
.04
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
50
40
30
20
10
0
-10
0
100
200
300
400
500
600
700

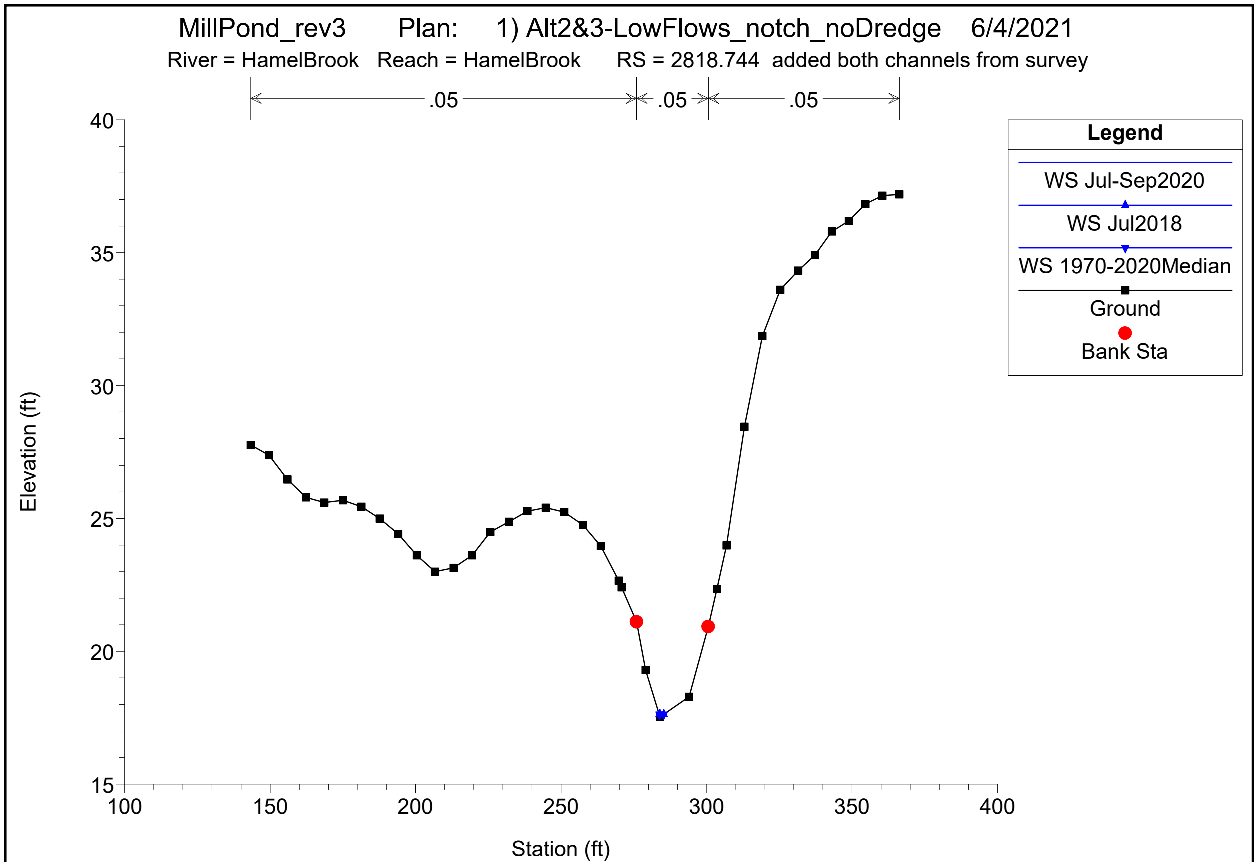

MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6566.595 BR (new) Footbridge downstream of Rte. 108; based on 2019/2020 VHB
.04
.03
.04
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
50
40
30
20
10
0
-10
0
100
200
300
400
500
600
700

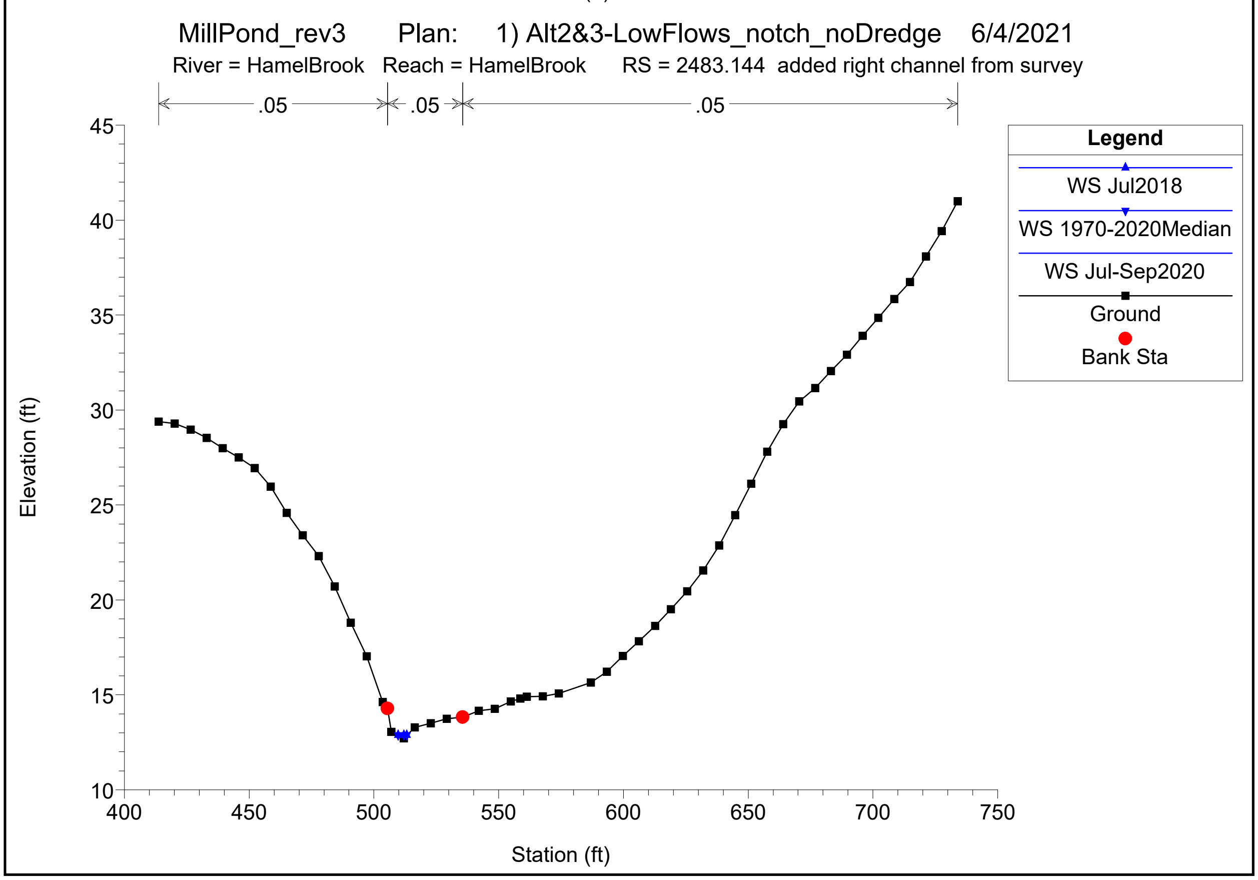

MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6566.595 BR (new) Footbridge downstream of Rte. 108; based on 2019/2020 VHB
.04
.03
.04
Elevation (ft)
Station (ft)
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Ineff
Bank Sta

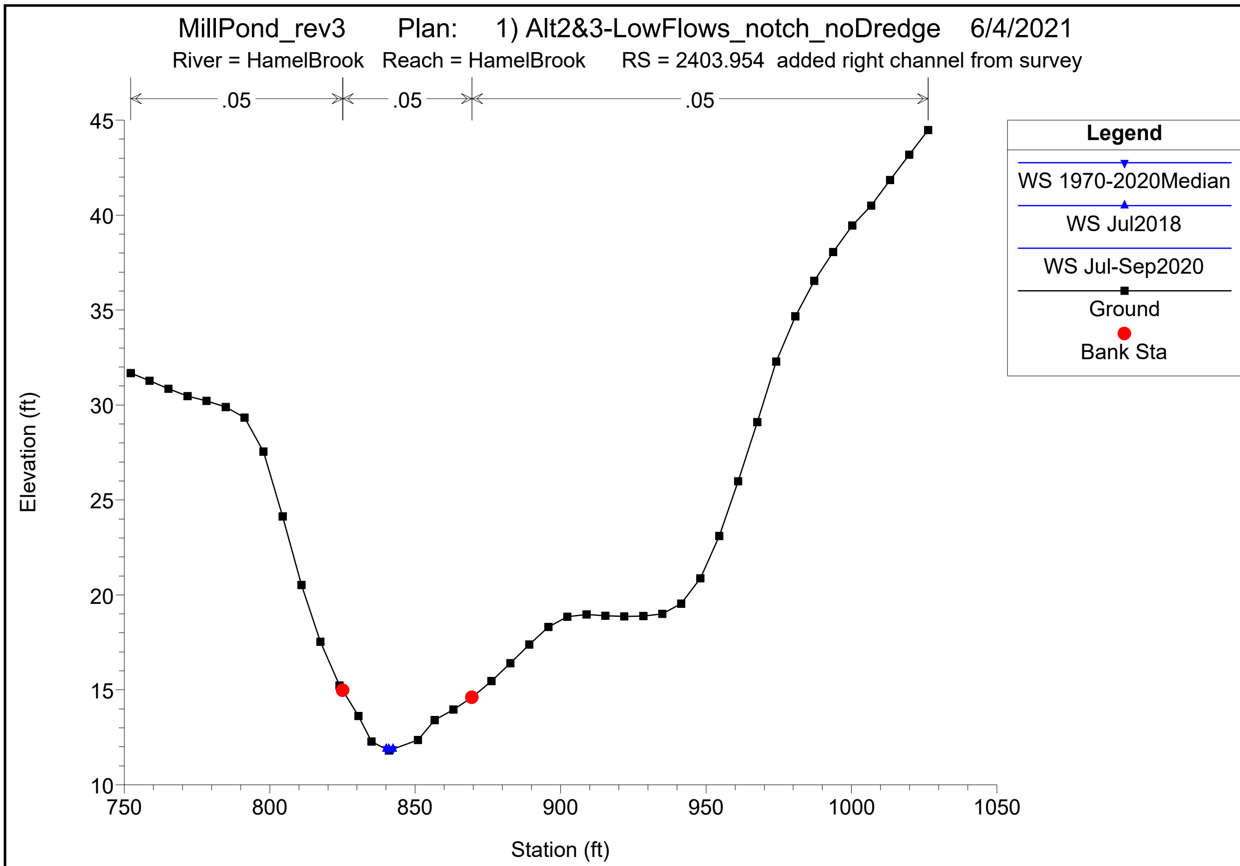

MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6538.485 new XS from LiDAR; stone retaining wall added to left side of ch
.04
.03
.04
Elevation (ft)
Station (ft)
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Ineff
Bank Sta

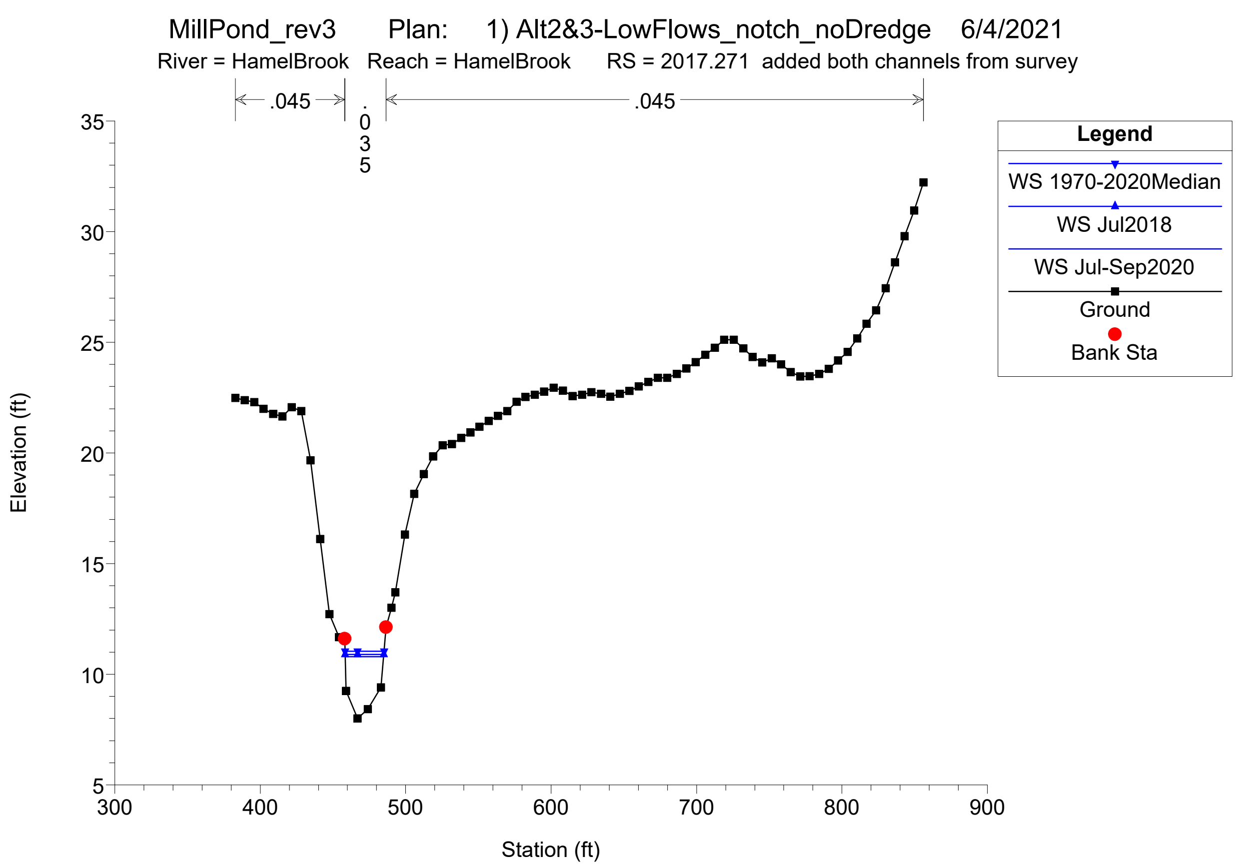


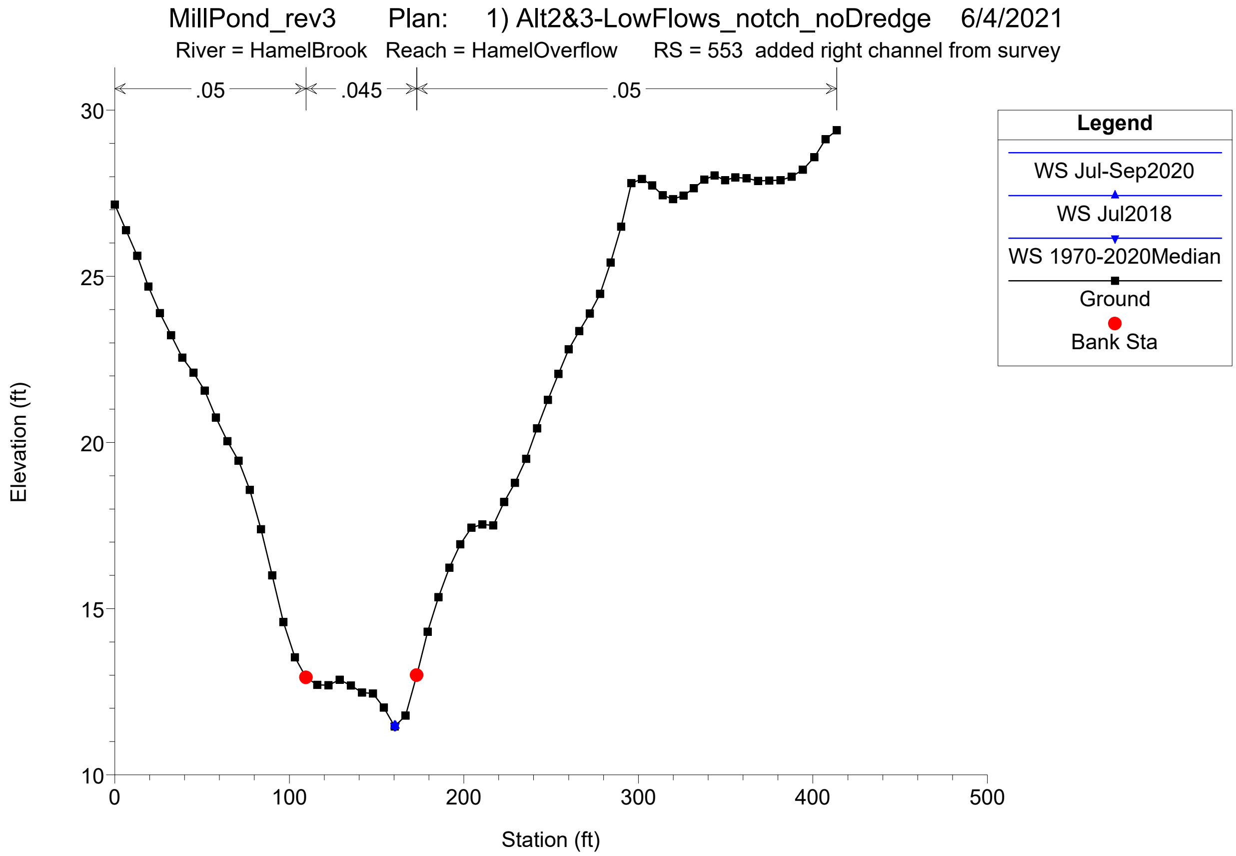
MillPond_rev3 Plan: Alt1-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6327.044 raised channel bottom from -4 to -2.64 vs. 2018 model; adjustmen
.035
.03
.035
Elevation (ft)
Station (ft)
70
60
50
40
30
20
10
0
-10
0
200
400
600
800
1000
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta

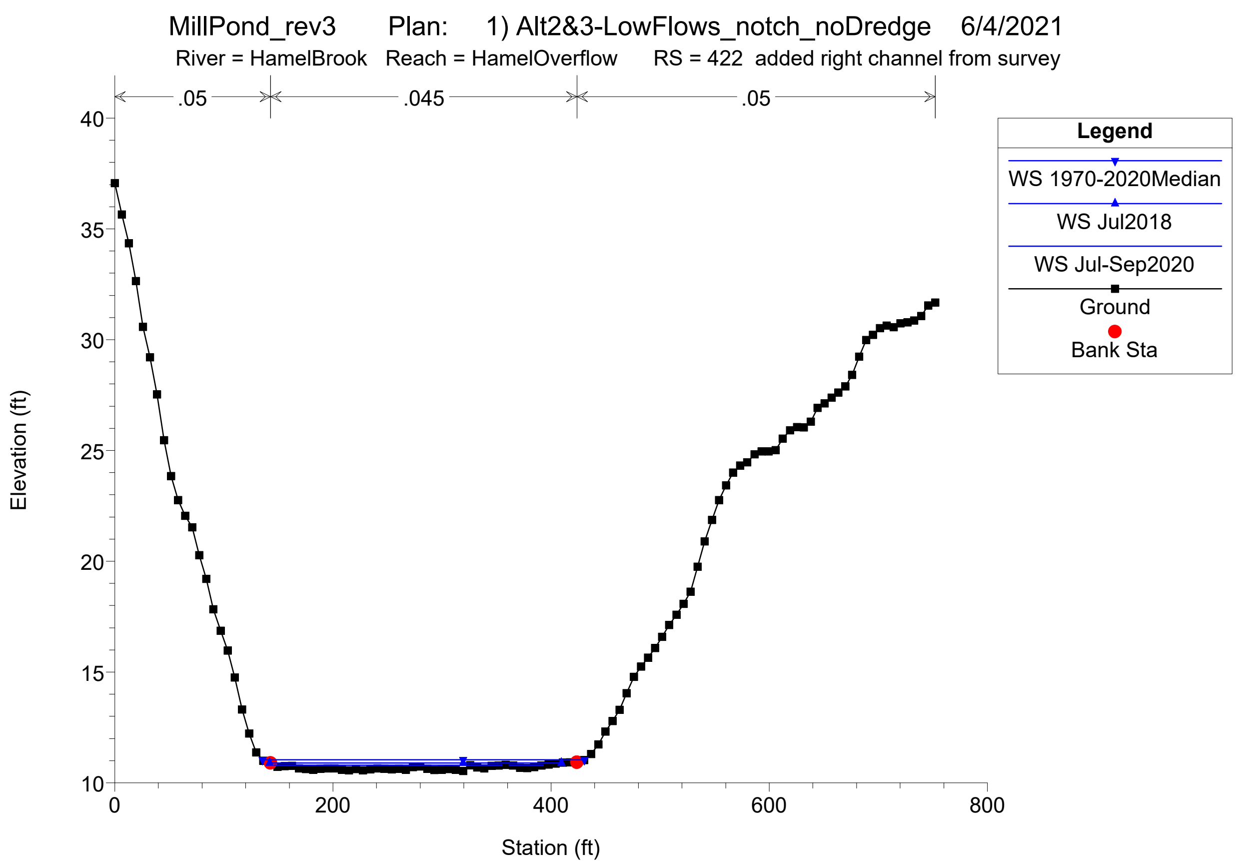

MillPond_rev3 Plan: 1) Alt2&3-LowFlows_notch_noDredge 6/4/2021
River = HamelBrook Reach = HamelBrook RS = 2818.744 added both channels from survey
.05
.05
.05
Legend
WS Jul-Sep2020
WS Jul2018
WS 1970-2020Median
Ground
Bank Sta
Elevation (ft)
Station (ft)
15
20
25
30
35
40
100
150
200
250
300
350
400

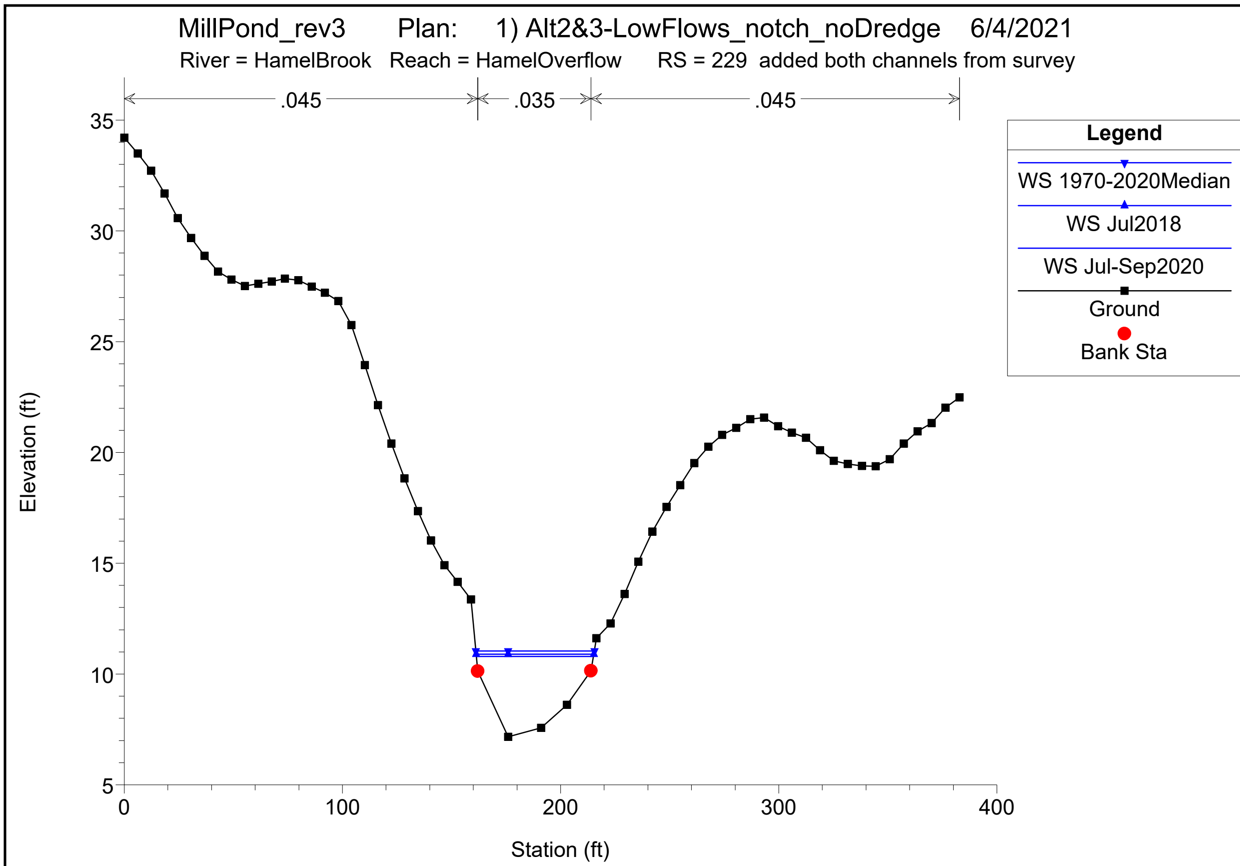

MillPond_rev3 Plan: 1) Alt2&3-LowFlows_notch_noDredge 6/4/2021
River = HamelBrook Reach = HamelBrook RS = 2483.144 added right channel from survey
.05
.05
.05
Legend
WS Jul2018
WS 1970-2020Median
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)
10
15
20
25
30
35
40
45
400
450
500
550
600
650
700
750


MillPond_rev3 Plan: 1) Alt2&3-LowFlows_notch_noDredge 6/4/2021
River = HamelBrook Reach = HamelBrook RS = 2403.954 added right channel from survey
.05
.05
.05
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)
45
40
35
30
25
20
15
10
750
800
850
900
950
1000
1050

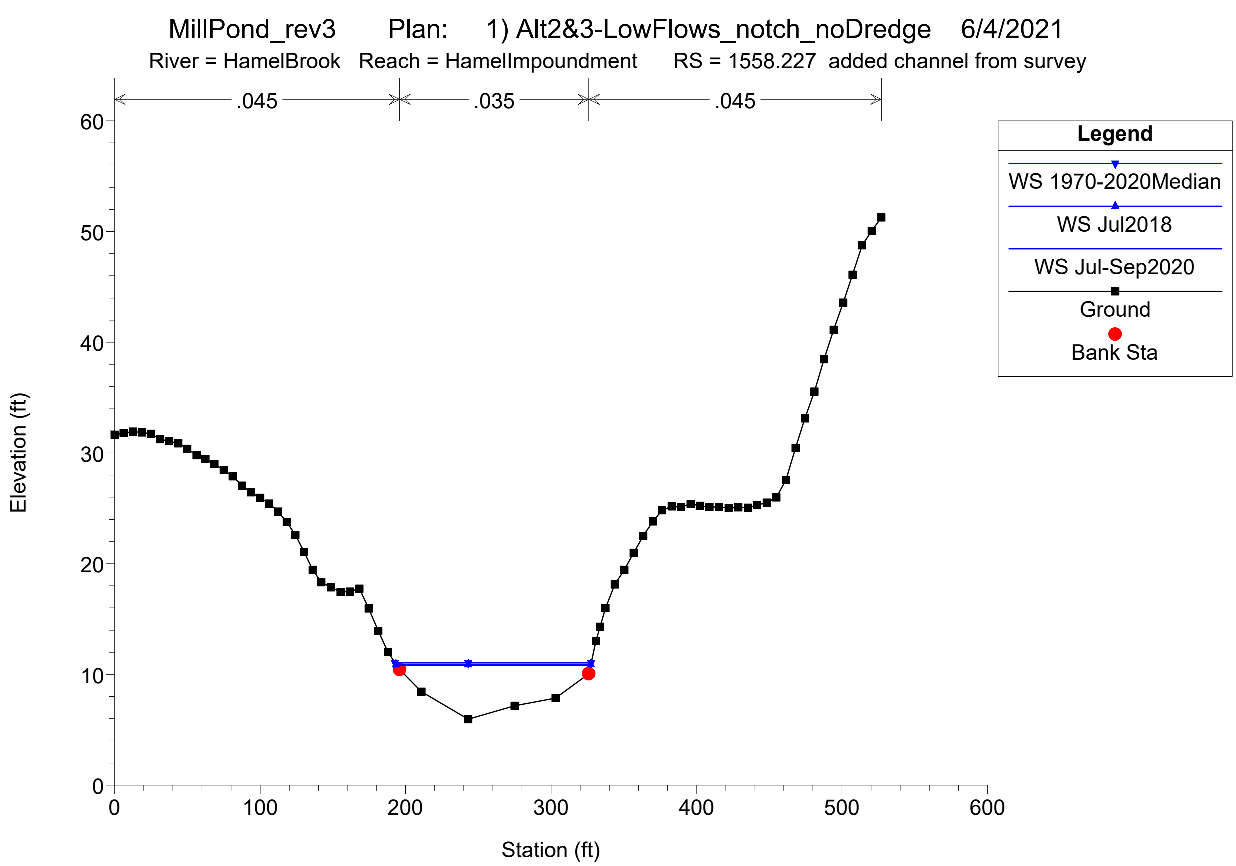

MillPond_rev3 Plan: 1) Alt2&3-LowFlows_notch_noDredge 6/4/2021
River = HamelBrook Reach = HamelBrook RS = 2017.271 added both channels from survey
.045
.035
.045
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)
35
30
25
20
15
10
5
300
400
500
600
700
800
900


MillPond_rev3 Plan: 1) Alt2&3-LowFlows_notch_noDredge 6/4/2021
River = HamelBrook Reach = HamelOverflow RS = 553 added right channel from survey
.05
.045
.05
Legend
WS Jul-Sep2020
WS Jul2018
WS 1970-2020Median
Ground
Bank Sta
Elevation (ft)
Station (ft)
30
25
20
15
10
0
100
200
300
400
500


MillPond_rev3 Plan: 1) Alt2&3-LowFlows_notch_noDredge 6/4/2021
River = HamelBrook Reach = HamelOverflow RS = 422 added right channel from survey
.05
.045
.05
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)
40
35
30
25
20
15
10
0
200
400
600
800



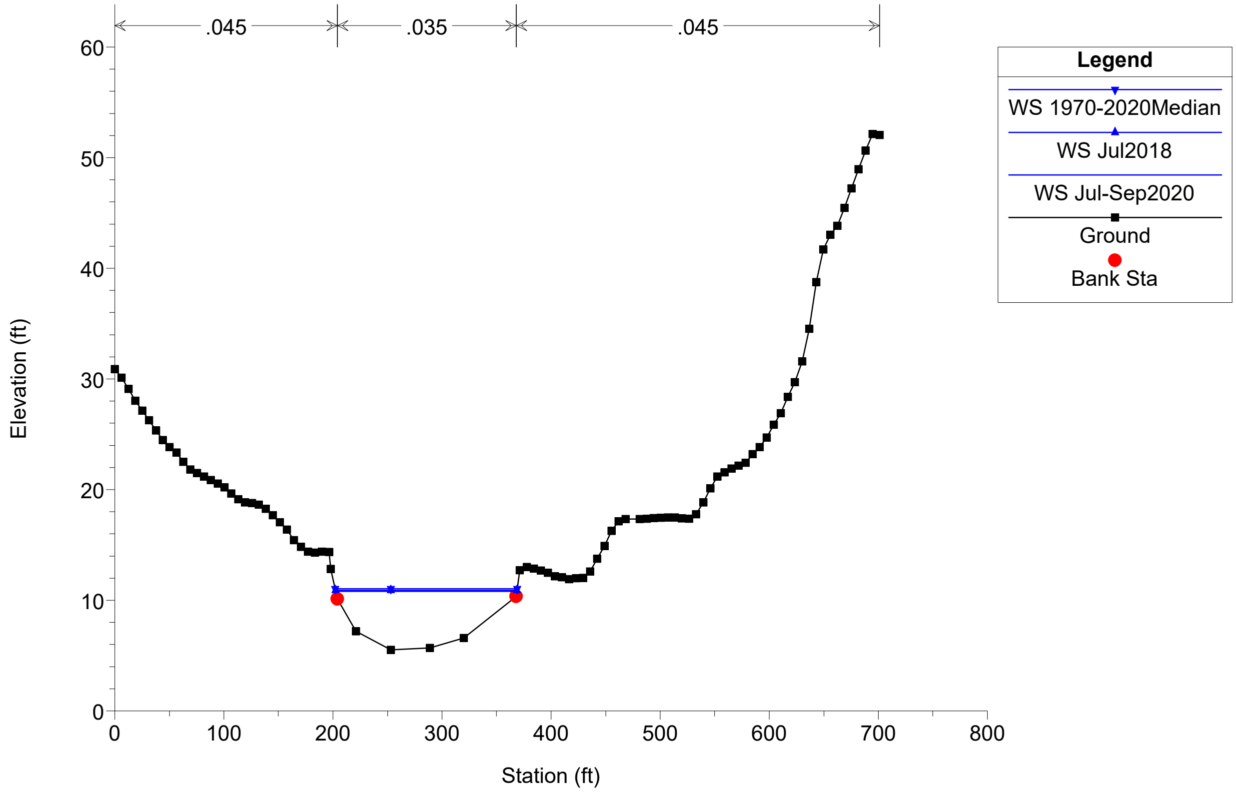
MillPond_rev3 Plan: 1) Alt2&3-LowFlows_notch_noDredge 6/4/2021
River = HamelBrook Reach = HamelOverflow RS = 229 added both channels from survey
.045
.035
.045
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)
35
30
25
20
15
10
5
0
100
200
300
400



MillPond_rev3 Plan: 1) Alt2&3-LowFlows_notch_noDredge 6/4/2021
River = HamelBrook Reach = HamelImpoundment RS = 1558.227 added channel from survey
.045
.035
.045
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)
60
50
40
30
20
10
0
0
100
200
300
400
500
600

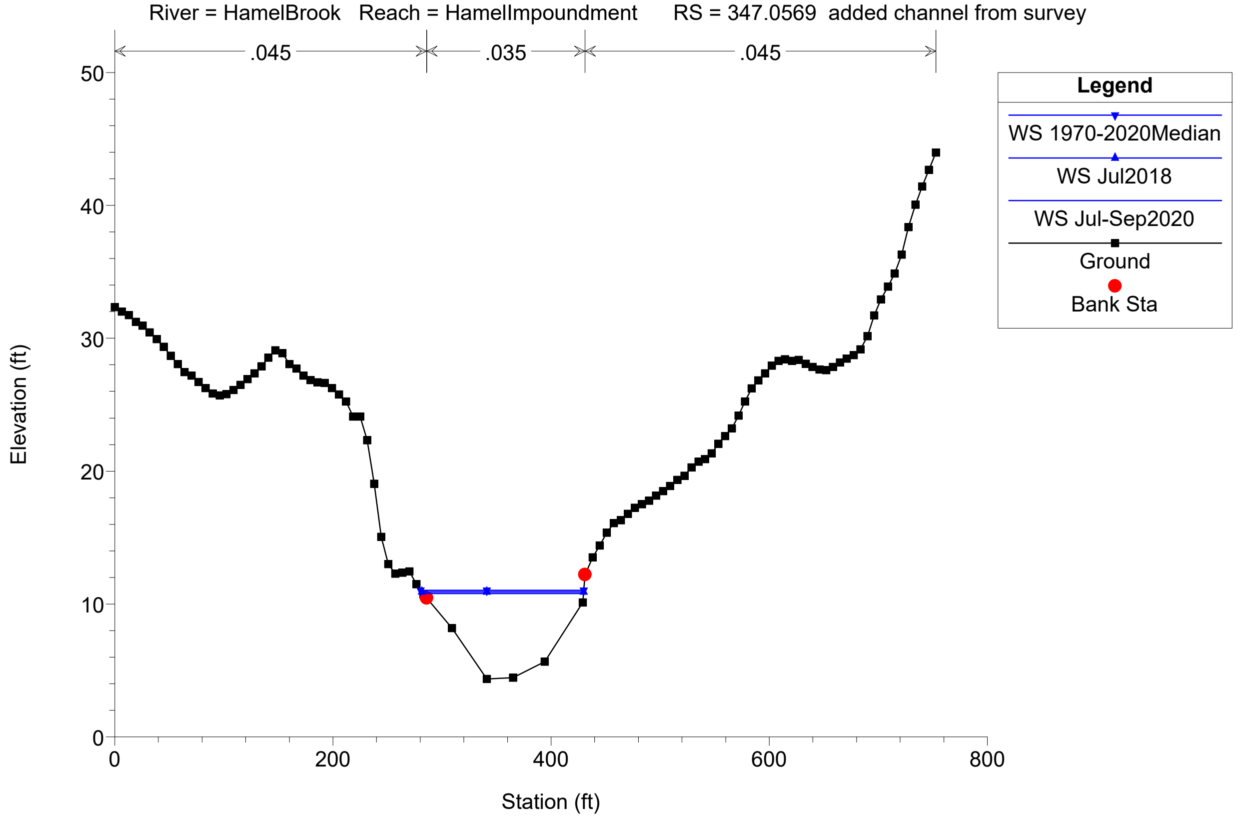
MillPond_rev3   Plan: 1) Alt2&3-LowFlows_notch_noDredge   6/4/2021

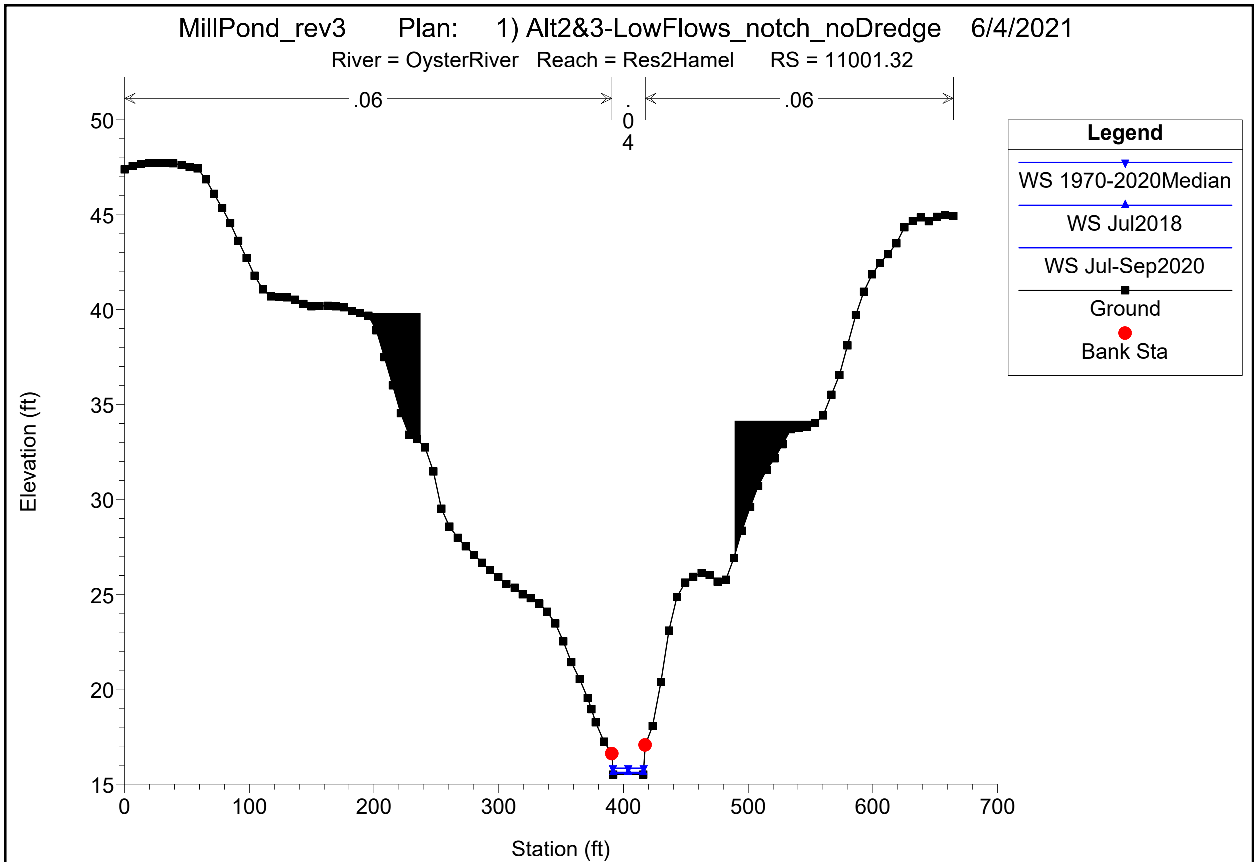
River = HamelBrook   Reach = HamelImpoundment   RS = 959.6333 added channel from survey



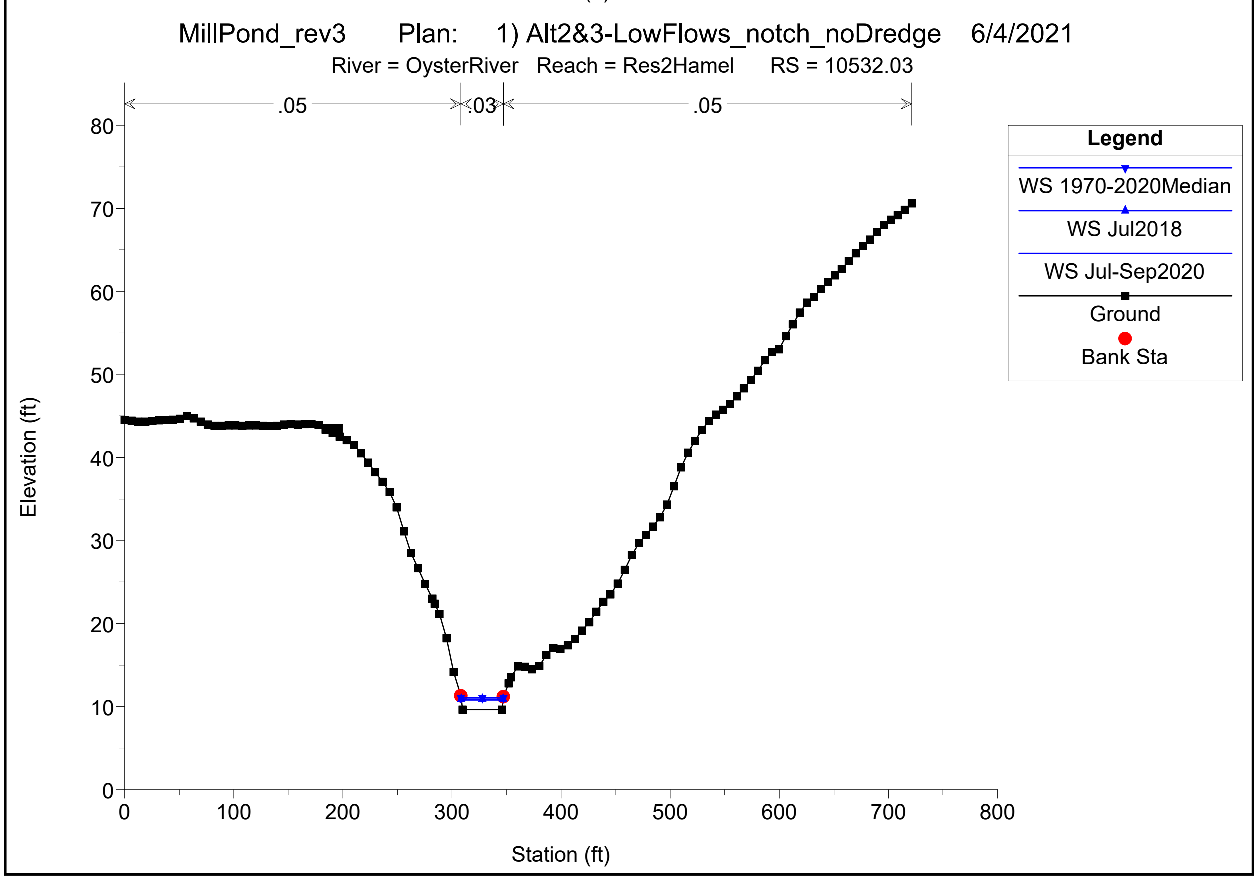
MillPond_rev3   Plan: 1) Alt2&3-LowFlows_notch_noDredge   6/4/2021

River = HamelBrook   Reach = HamelImpoundment   RS = 347.0569 added channel from survey

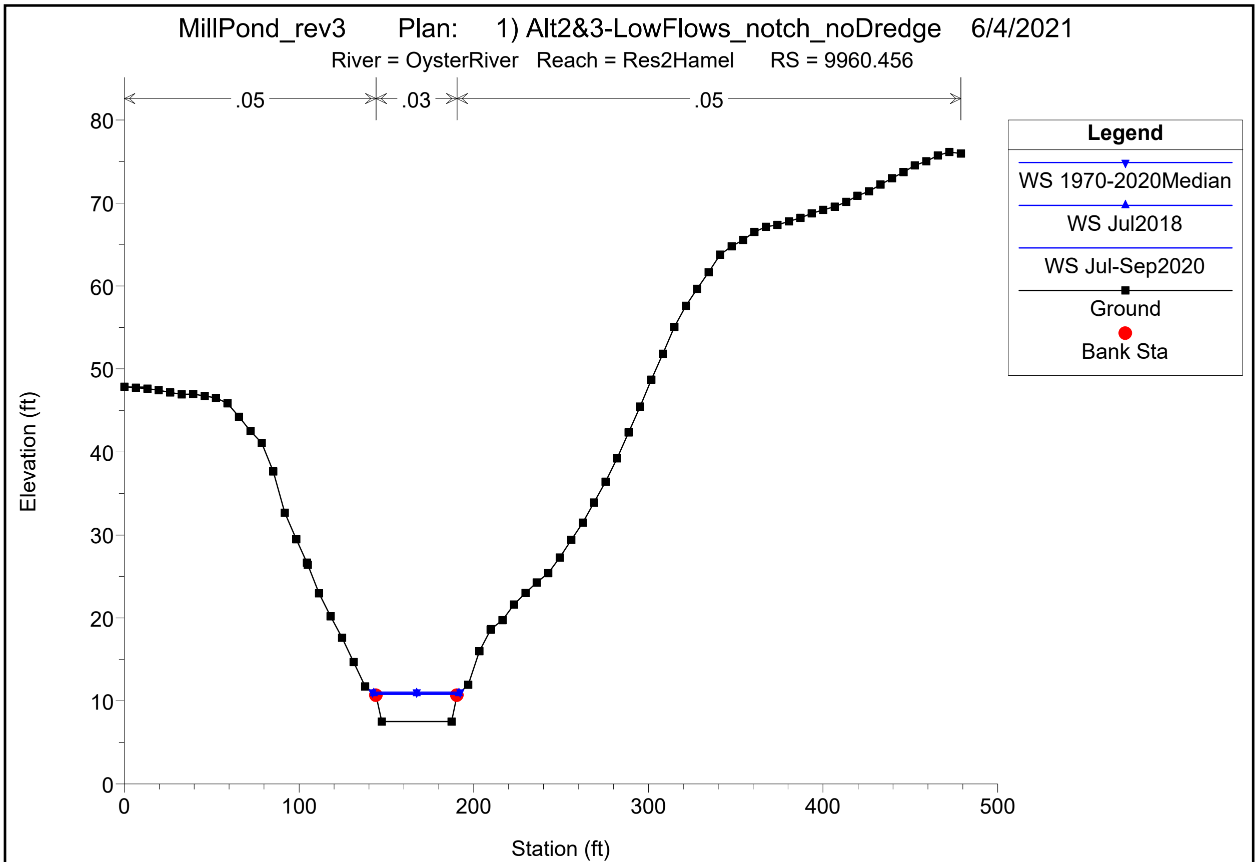


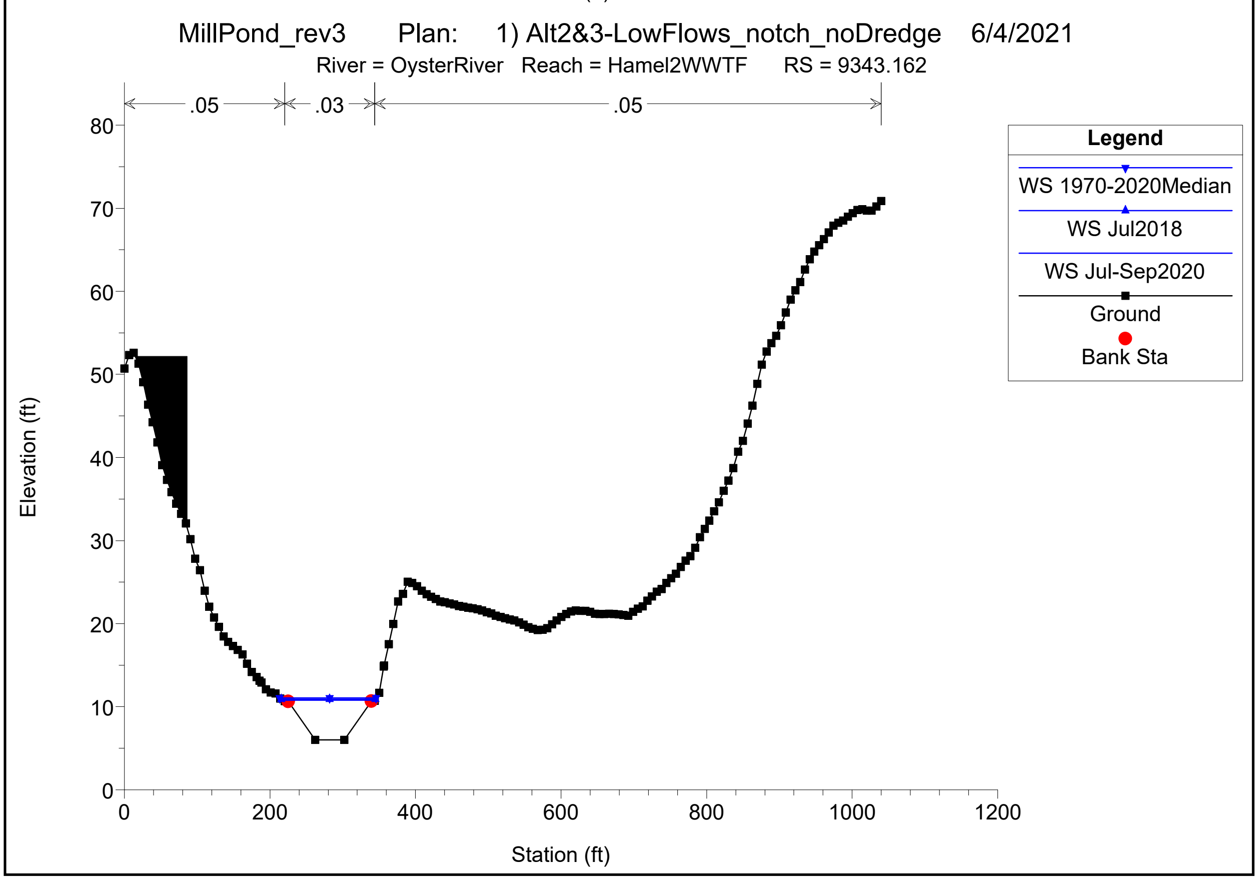


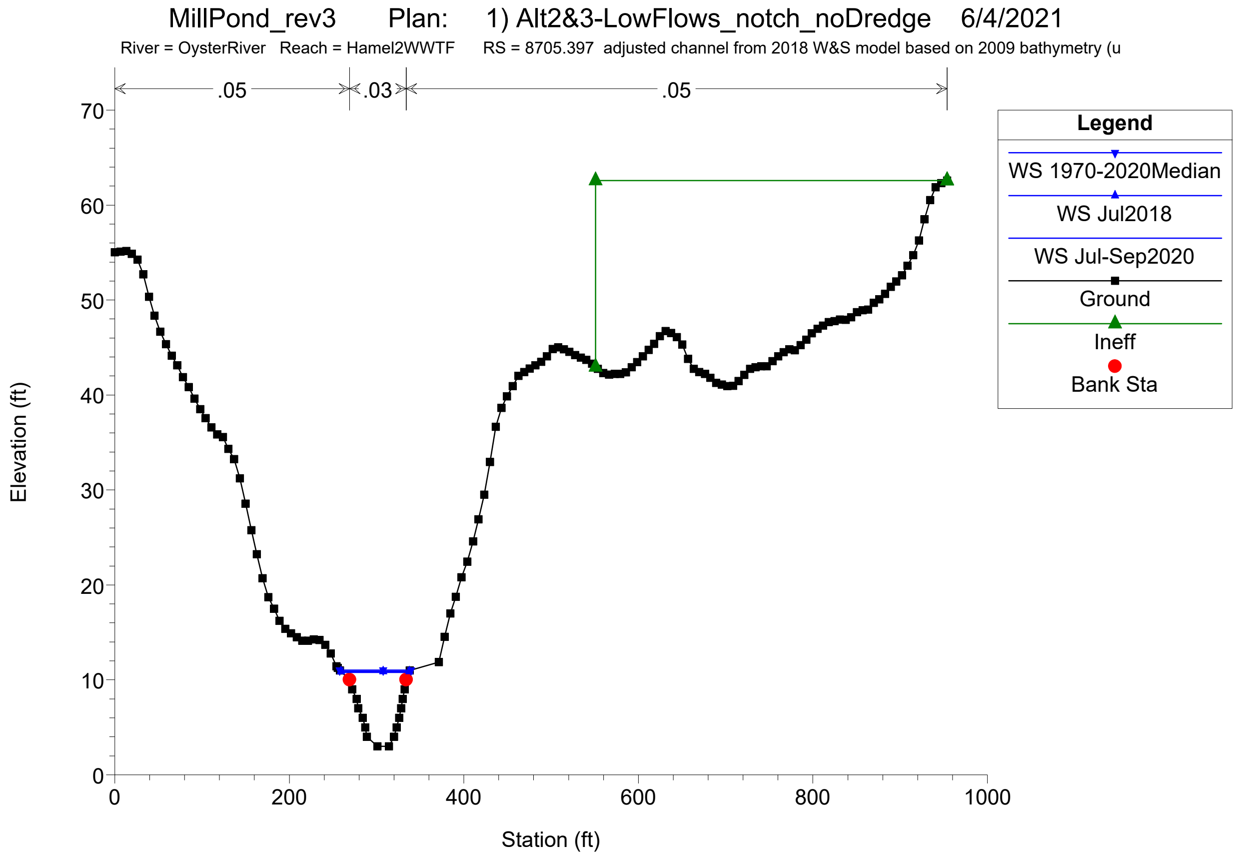
MillPond_rev3 Plan: 1) Alt2&3-LowFlows_notch_noDredge 6/4/2021
River = OysterRiver Reach = Res2Hamel RS = 11001.32
.06
.
0
4
.06
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
50
45
40
35
30
25
20
15
0
100
200
300
400
500
600
700
Station (ft)

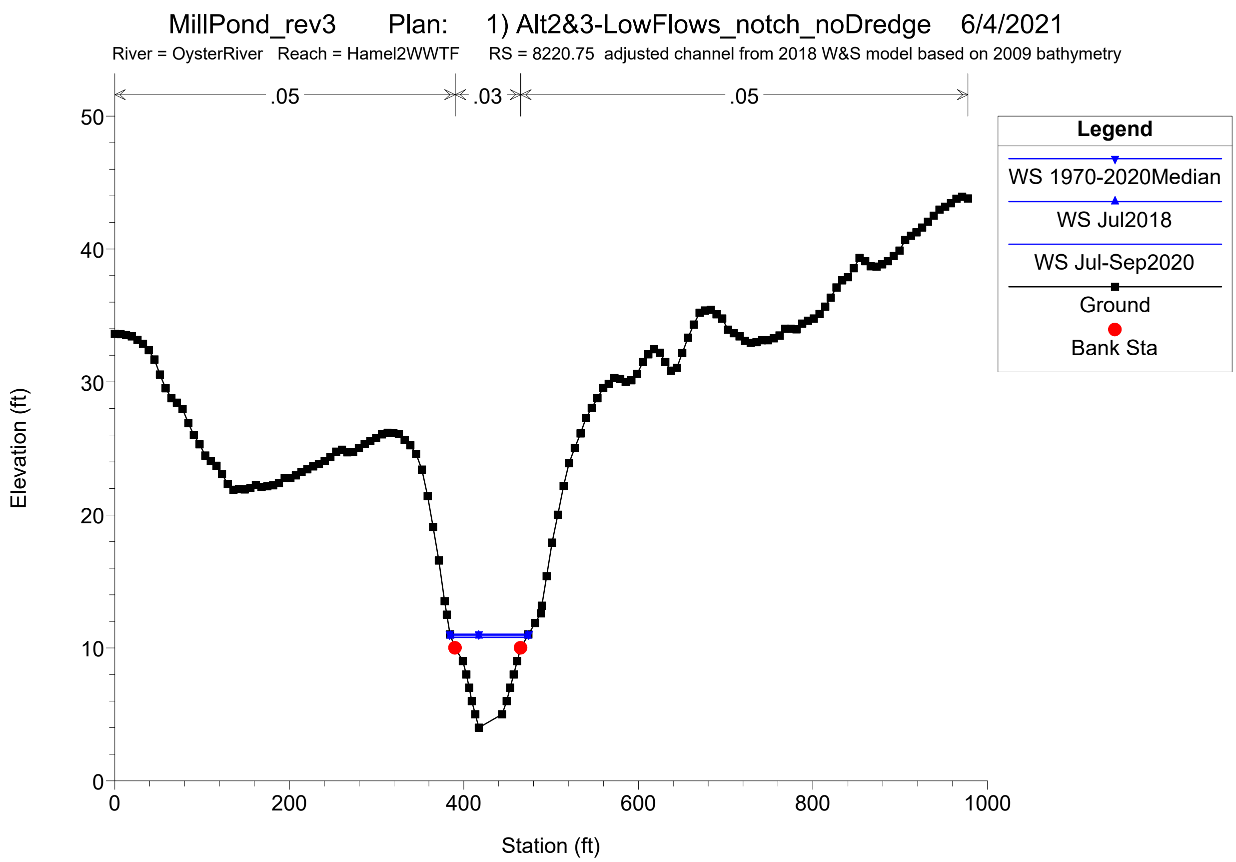


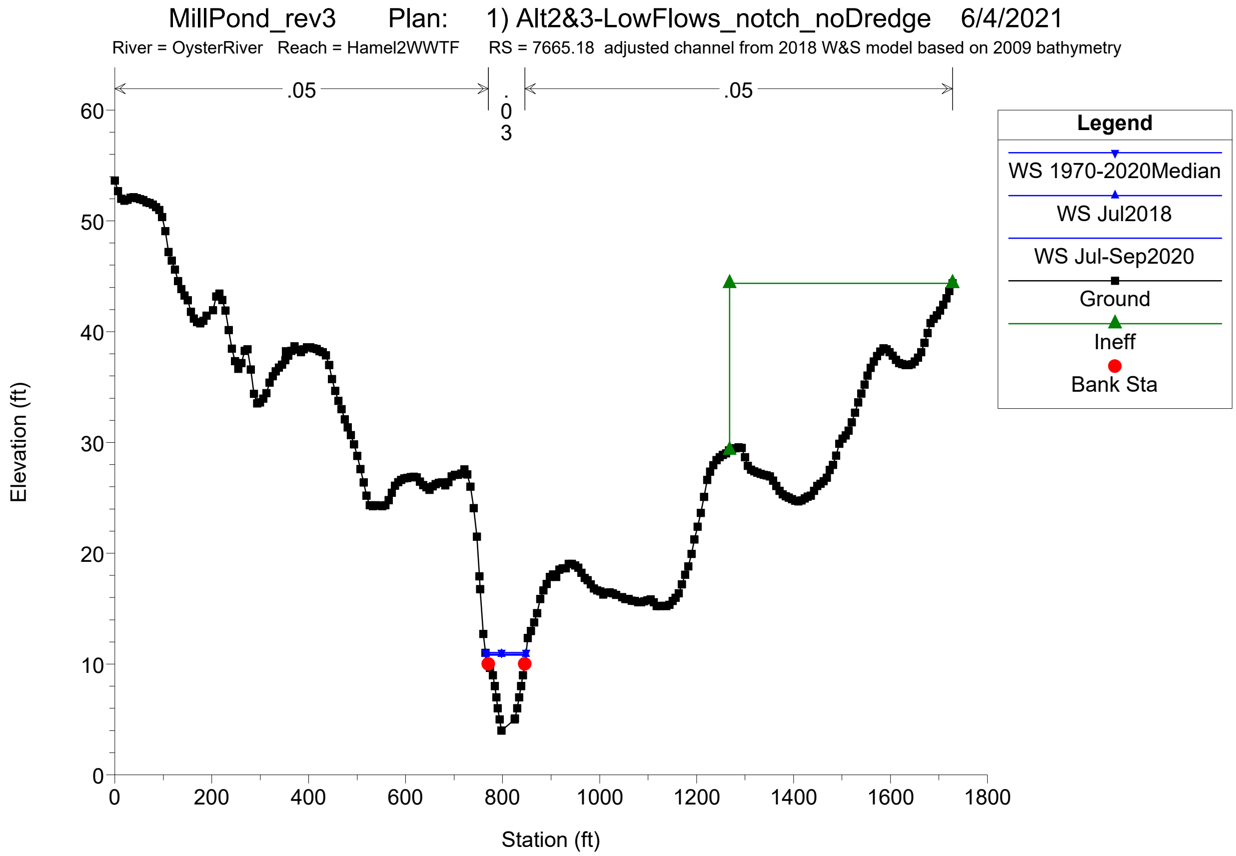
MillPond_rev3 Plan: 1) Alt2&3-LowFlows_notch_noDredge 6/4/2021
River = OysterRiver Reach = Res2Hamel RS = 10532.03
.05
.03
.05
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
80
70
60
50
40
30
20
10
0
0
100
200
300
400
500
600
700
800
Station (ft)


MillPond_rev3 Plan: 1) Alt2&3-LowFlows_notch_noDredge 6/4/2021
River = OysterRiver Reach = Res2Hamel RS = 9960.456
.05
.03
.05
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)
0
10
20
30
40
50
60
70
80
0
100
200
300
400
500

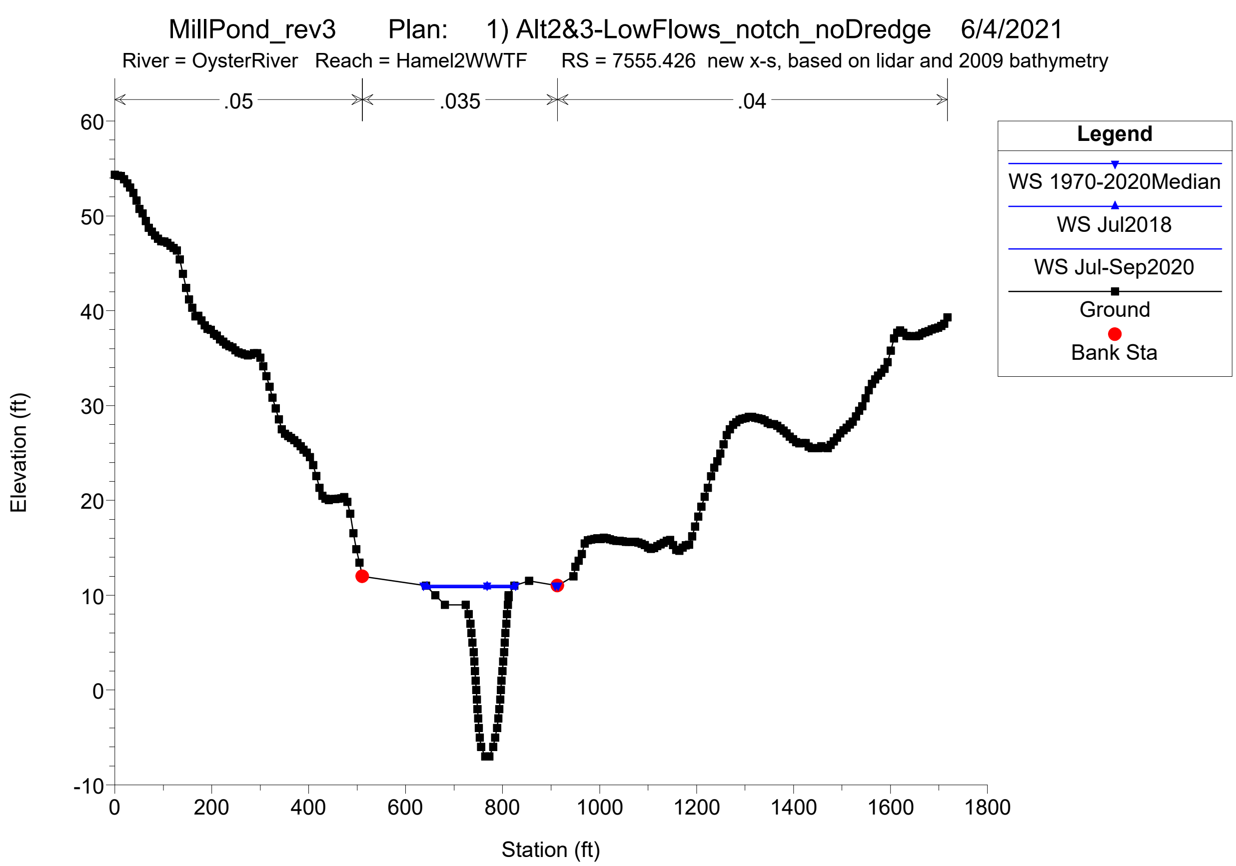

MillPond_rev3 Plan: 1) Alt2&3-LowFlows_notch_noDredge 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 9343.162
.05
.03
.05
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)
0
10
20
30
40
50
60
70
80
0
200
400
600
800
1000
1200


MillPond_rev3 Plan: 1) Alt2&3-LowFlows_notch_noDredge 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 8705.397 adjusted channel from 2018 W&S model based on 2009 bathymetry (u
.05
.03
.05
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
0
10
20
30
40
50
60
70
0
200
400
600
800
1000

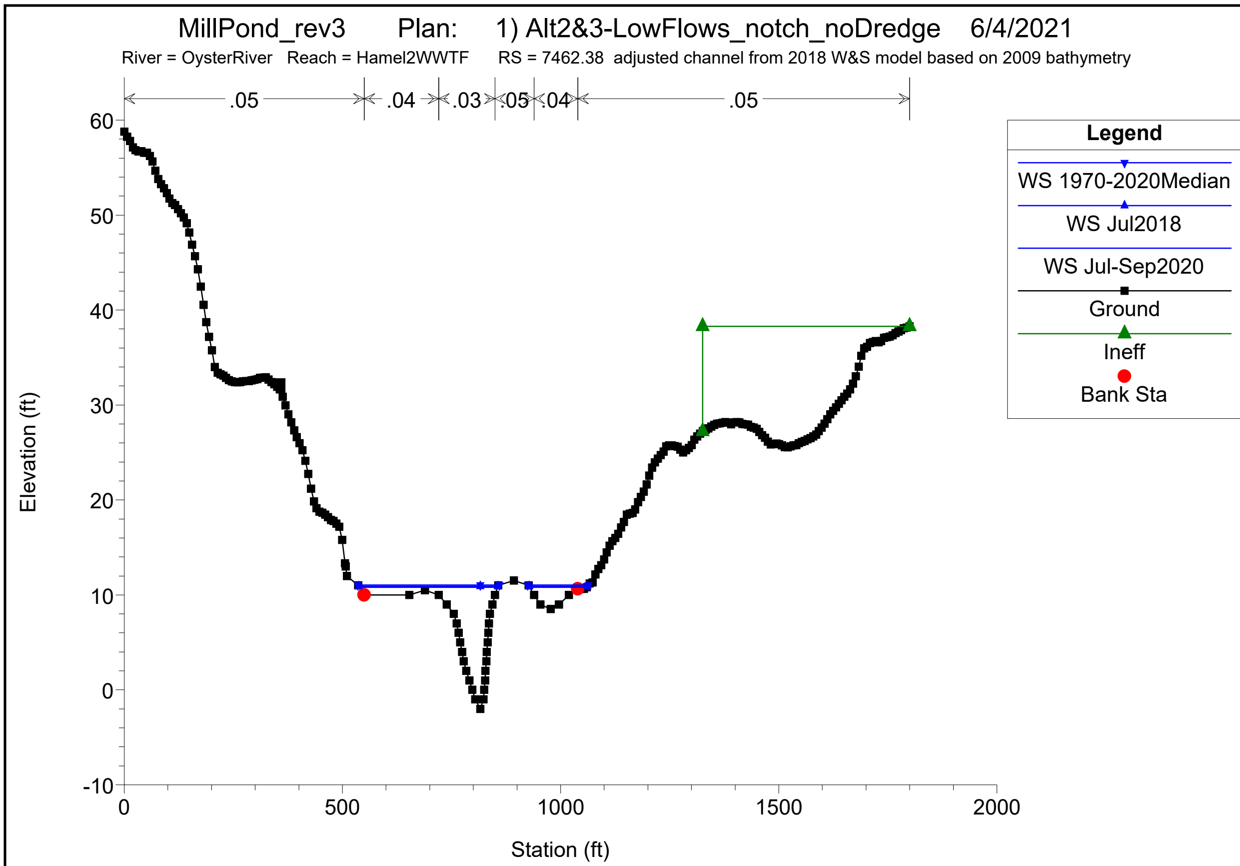

MillPond_rev3 Plan: 1) Alt2&3-LowFlows_notch_noDredge 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 8220.75 adjusted channel from 2018 W&S model based on 2009 bathymetry
.05
.03
.05
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)
0
10
20
30
40
50
0
200
400
600
800
1000



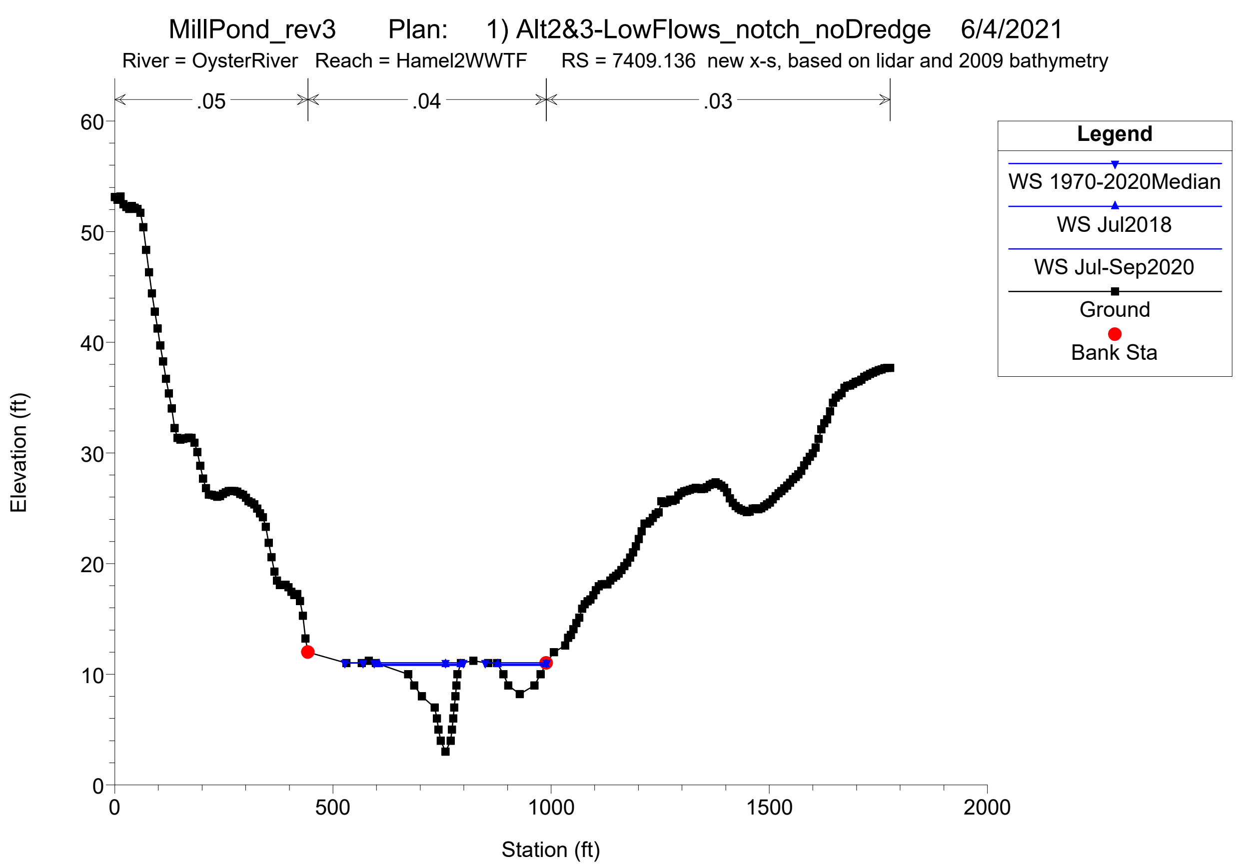
MillPond_rev3 Plan: 1) Alt2&3-LowFlows_notch_noDredge 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 7665.18 adjusted channel from 2018 W&S model based on 2009 bathymetry
.05
.03
.05
Elevation (ft)
Station (ft)
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Ineff
Bank Sta



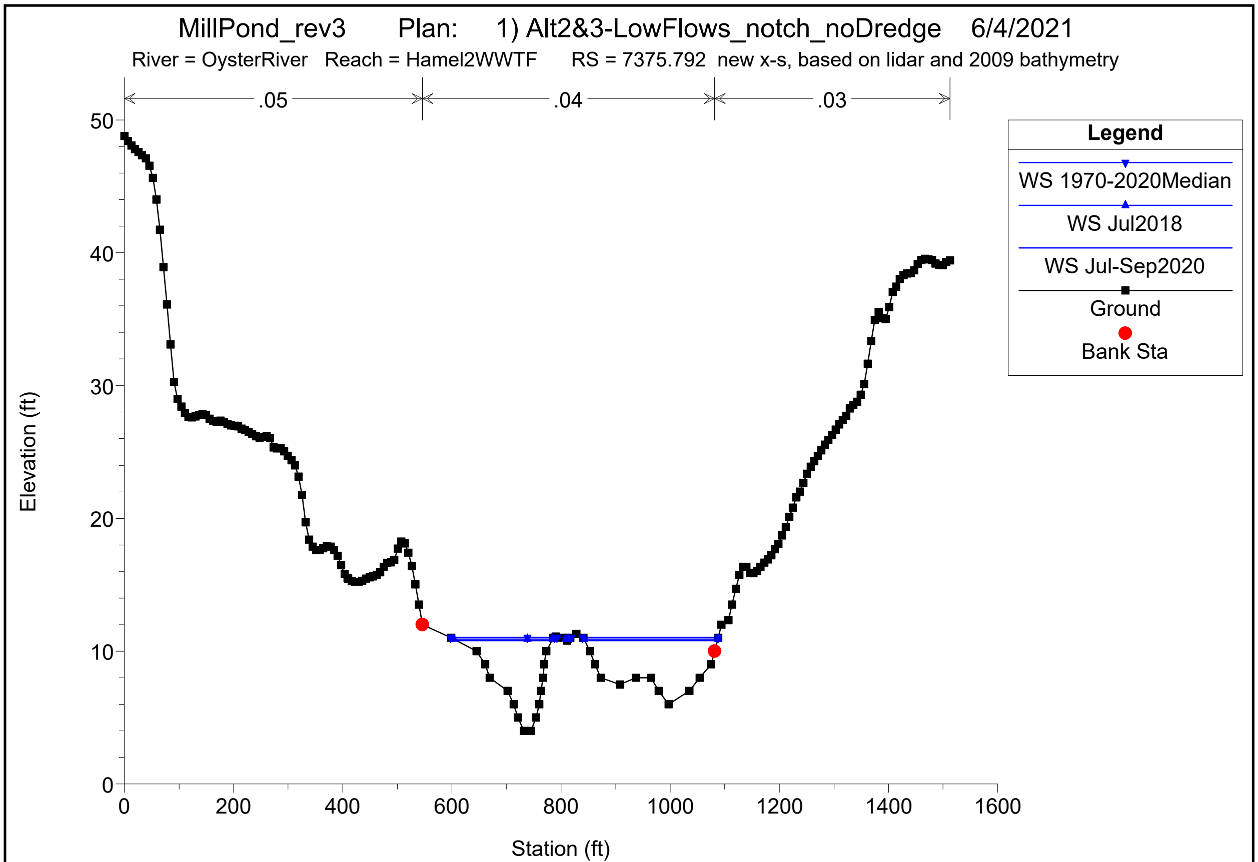
MillPond_rev3 Plan: 1) Alt2&3-LowFlows_notch_noDredge 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 7555.426 new x-s, based on lidar and 2009 bathymetry
.05
.035
.04
Elevation (ft)
Station (ft)
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta



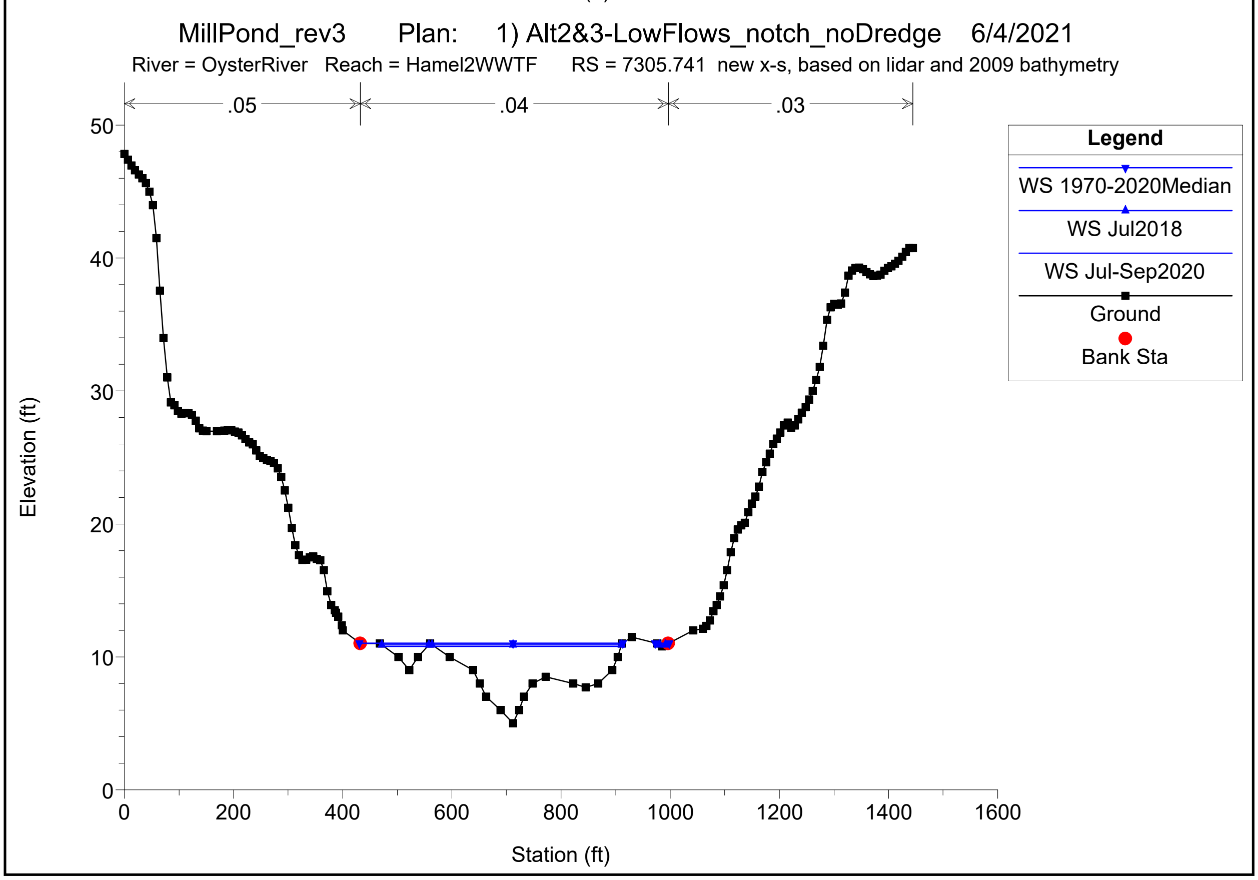
MillPond_rev3 Plan: 1) Alt2&3-LowFlows_notch_noDredge 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 7462.38 adjusted channel from 2018 W&S model based on 2009 bathymetry
.05
.04
.03
.05
.04
.05
Elevation (ft)
Station (ft)
60
50
40
30
20
10
0
-10
0
500
1000
1500
2000
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Ineff
Bank Sta



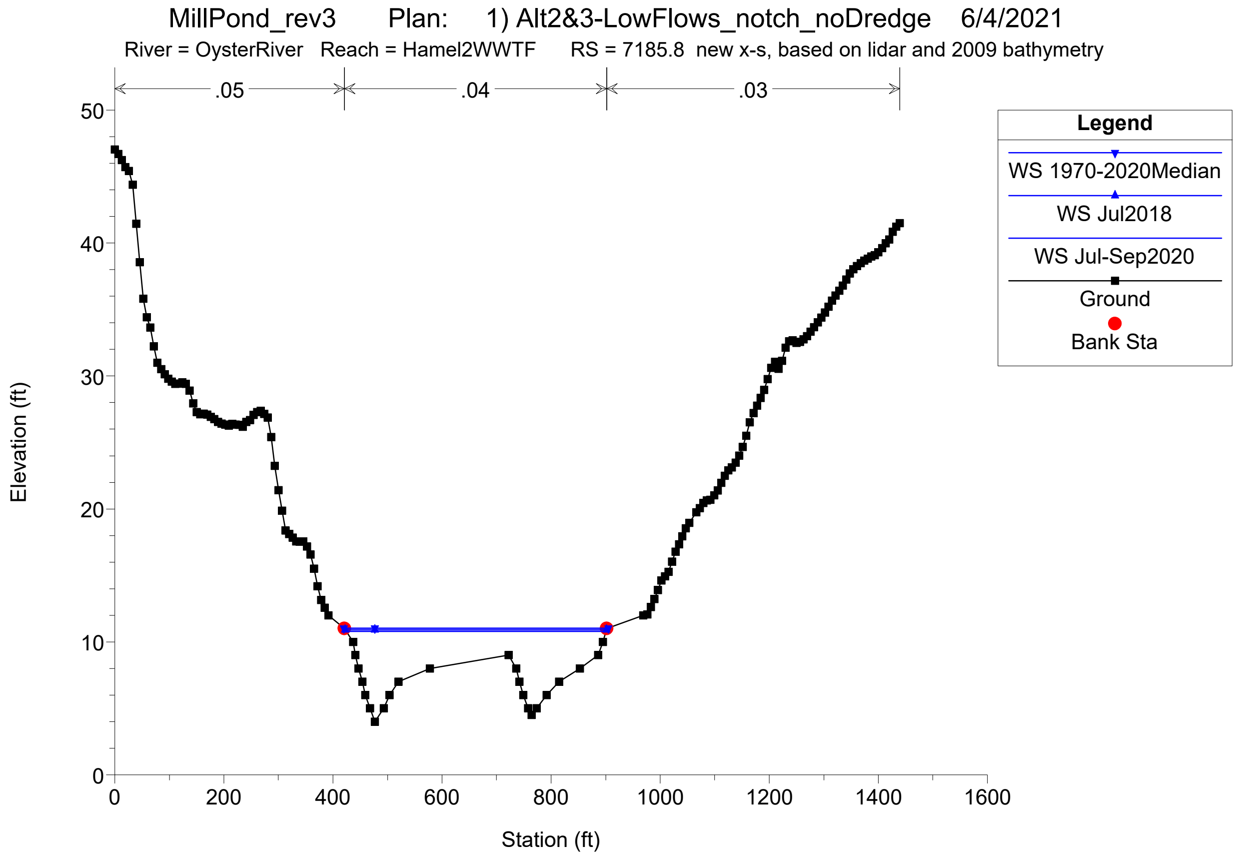
MillPond_rev3 Plan: 1) Alt2&3-LowFlows_notch_noDredge 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 7409.136 new x-s, based on lidar and 2009 bathymetry
.05
.04
.03
Elevation (ft)
Station (ft)
60
50
40
30
20
10
0
0
500
1000
1500
2000
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta

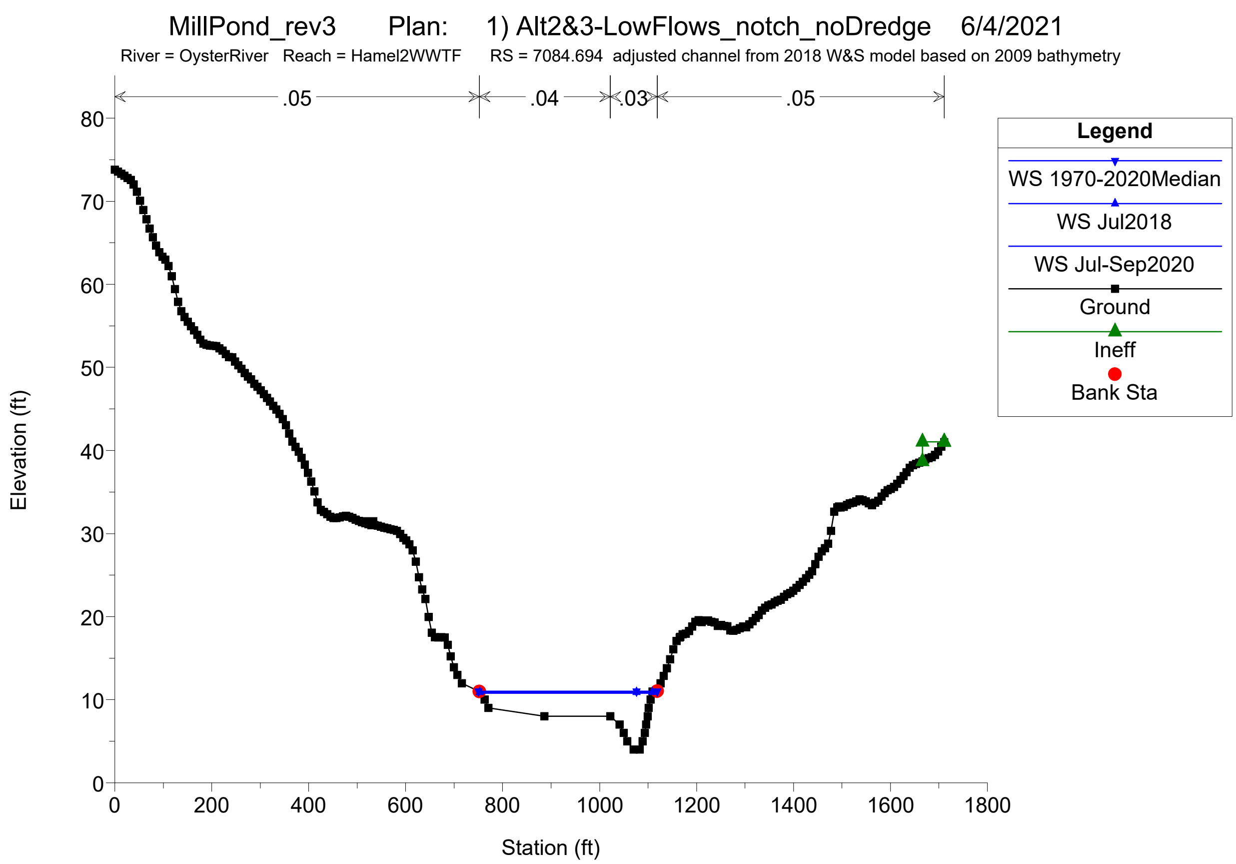


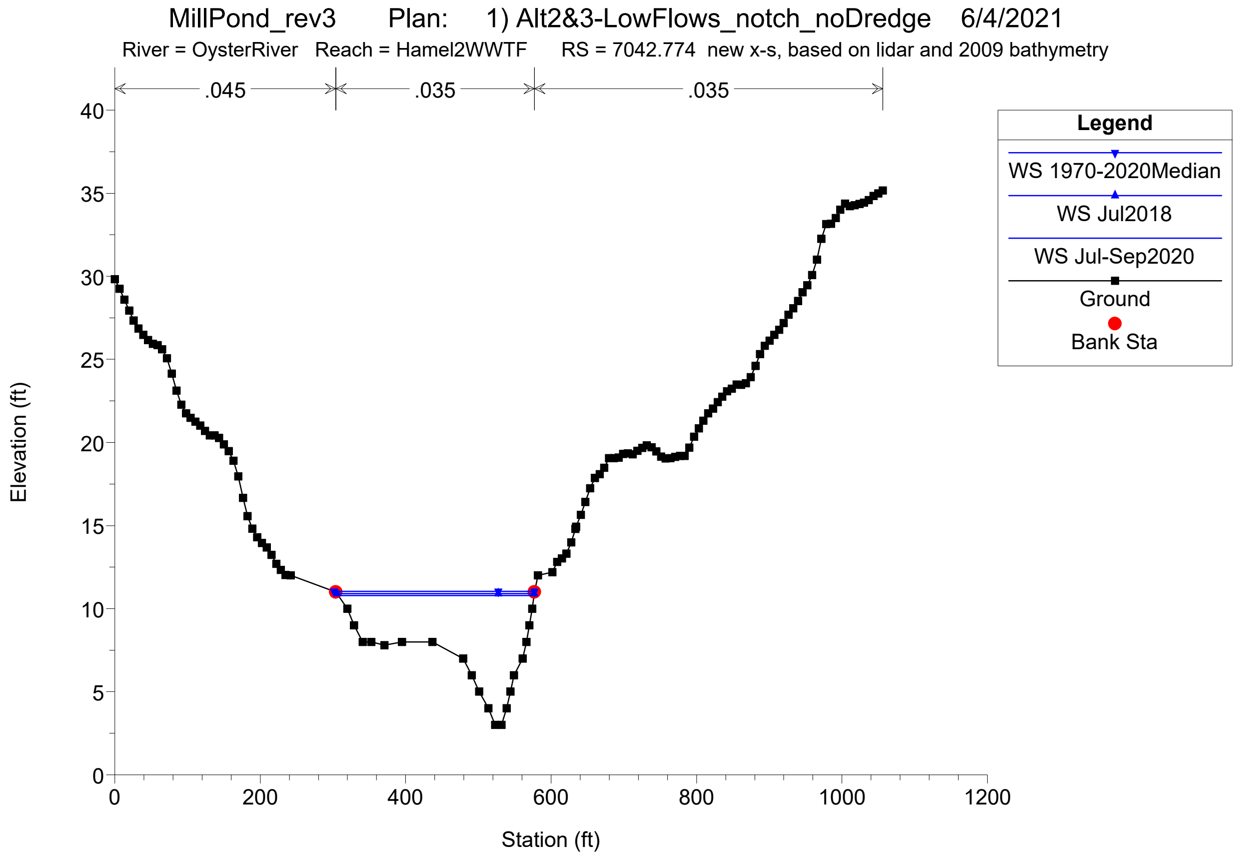
MillPond_rev3 Plan: 1) Alt2&3-LowFlows_notch_noDredge 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 7375.792 new x-s, based on lidar and 2009 bathymetry
.05
.04
.03
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)

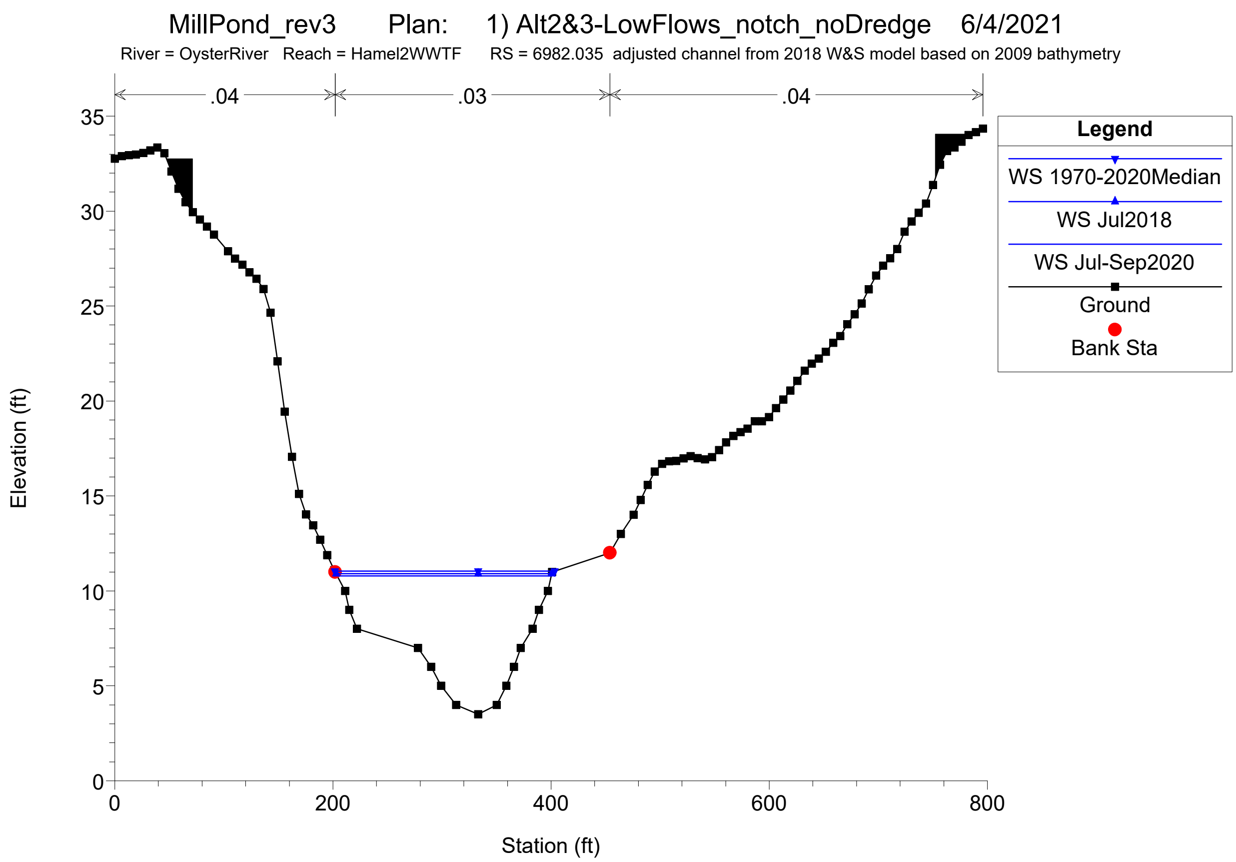


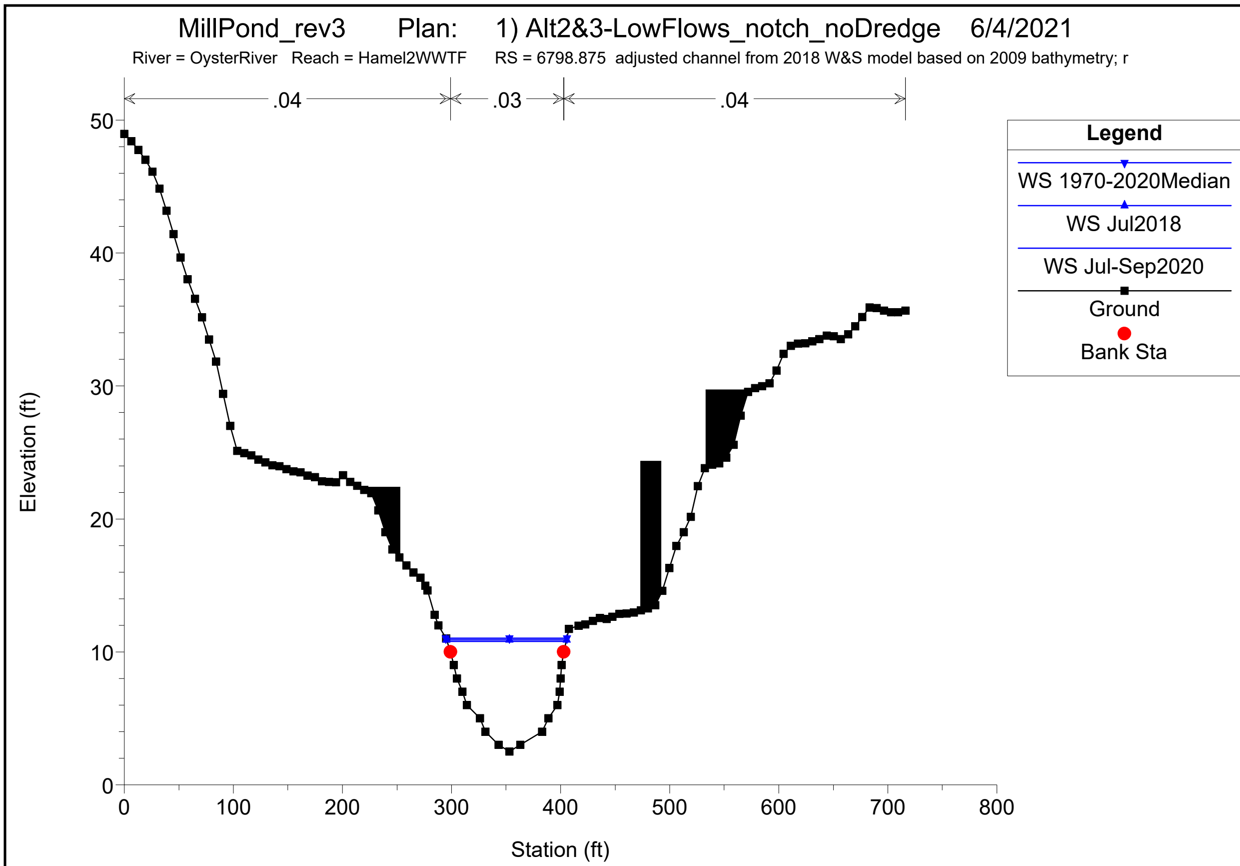
MillPond_rev3 Plan: 1) Alt2&3-LowFlows_notch_noDredge 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 7305.741 new x-s, based on lidar and 2009 bathymetry
.05
.04
.03
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)


MillPond_rev3 Plan: 1) Alt2&3-LowFlows_notch_noDredge 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 7185.8 new x-s, based on lidar and 2009 bathymetry
.05
.04
.03
Elevation (ft)
Station (ft)
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta

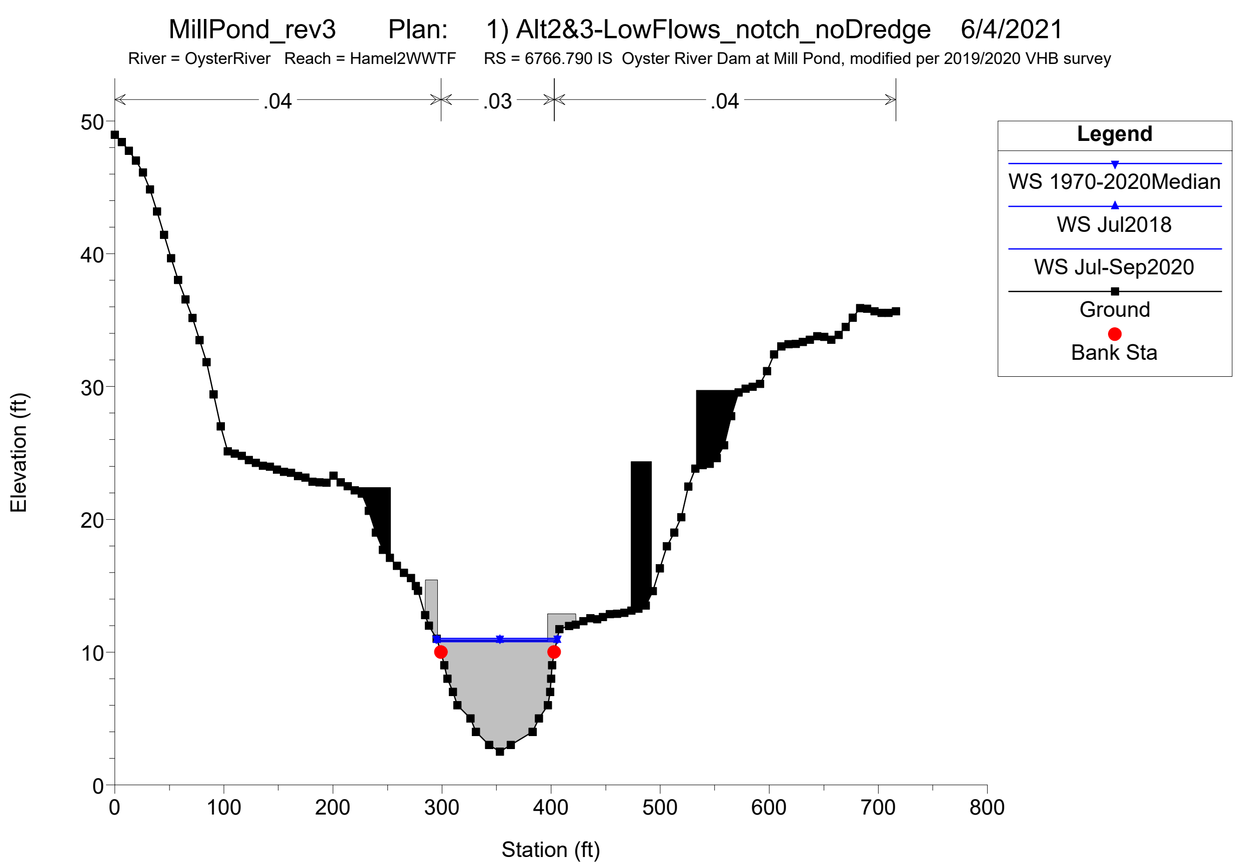

MillPond_rev3 Plan: 1) Alt2&3-LowFlows_notch_noDredge 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 7084.694 adjusted channel from 2018 W&S model based on 2009 bathymetry
.05
.04
.03
.05
Elevation (ft)
Station (ft)
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Ineff
Bank Sta


MillPond_rev3 Plan: 1) Alt2&3-LowFlows_notch_noDredge 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 7042.774 new x-s, based on lidar and 2009 bathymetry
.045
.035
.035
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200

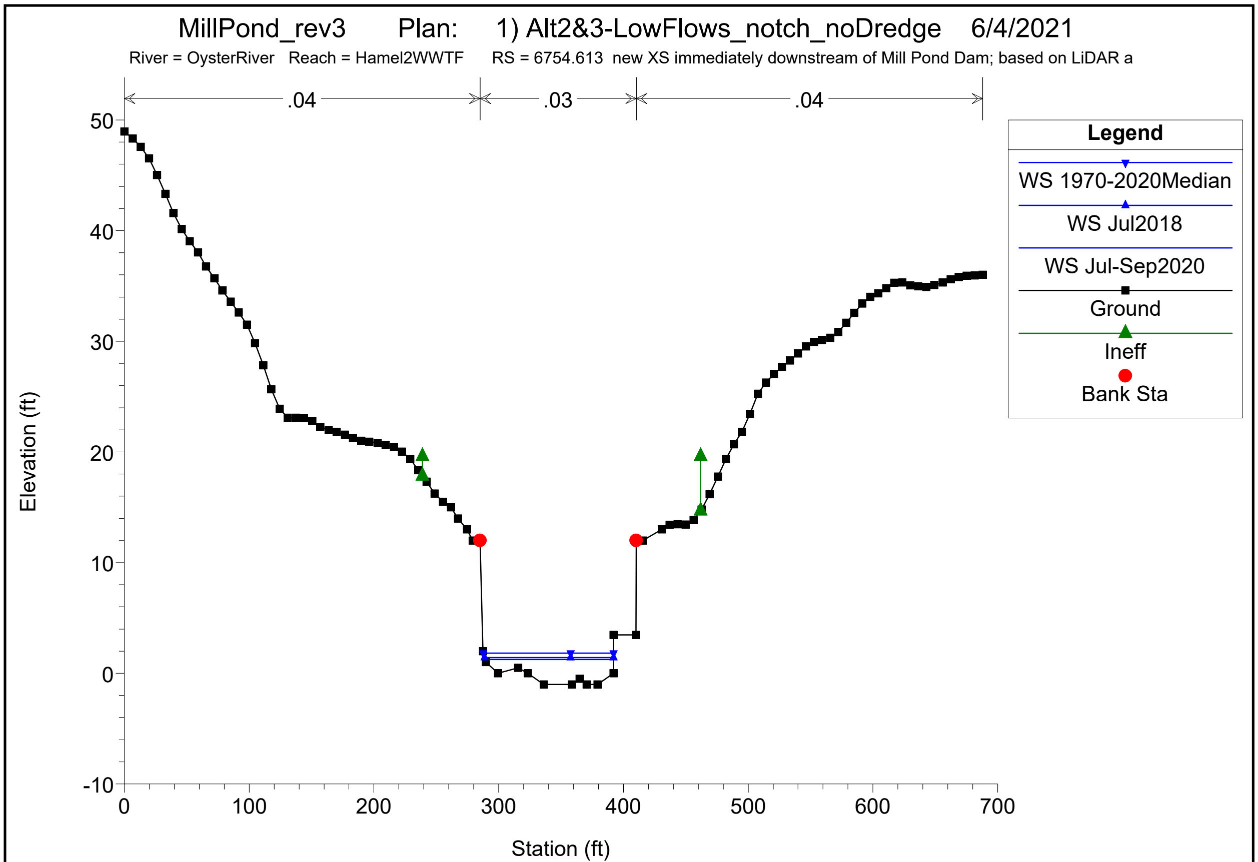

MillPond_rev3 Plan: 1) Alt2&3-LowFlows_notch_noDredge 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6982.035 adjusted channel from 2018 W&S model based on 2009 bathymetry
.04
.03
.04
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)
0
5
10
15
20
25
30
35
0
200
400
600
800

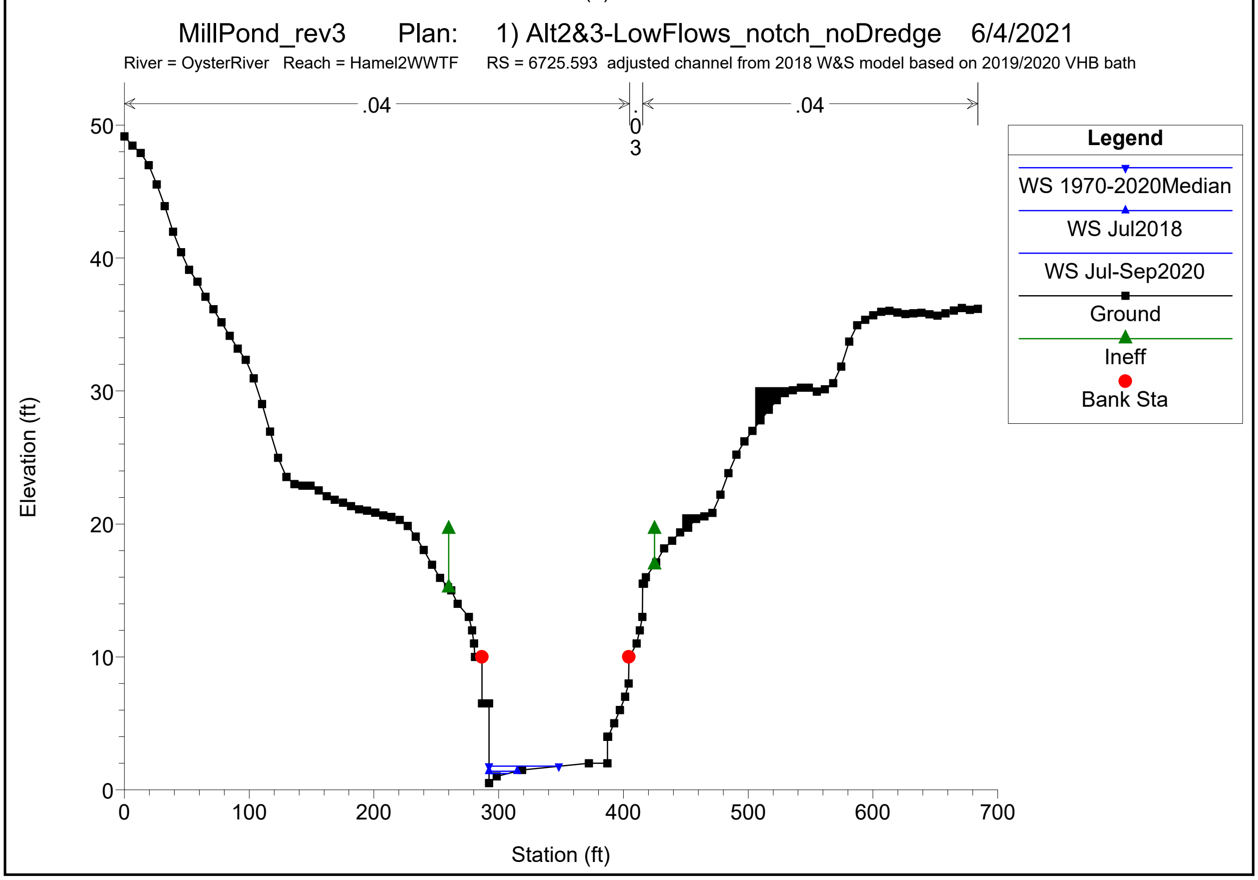


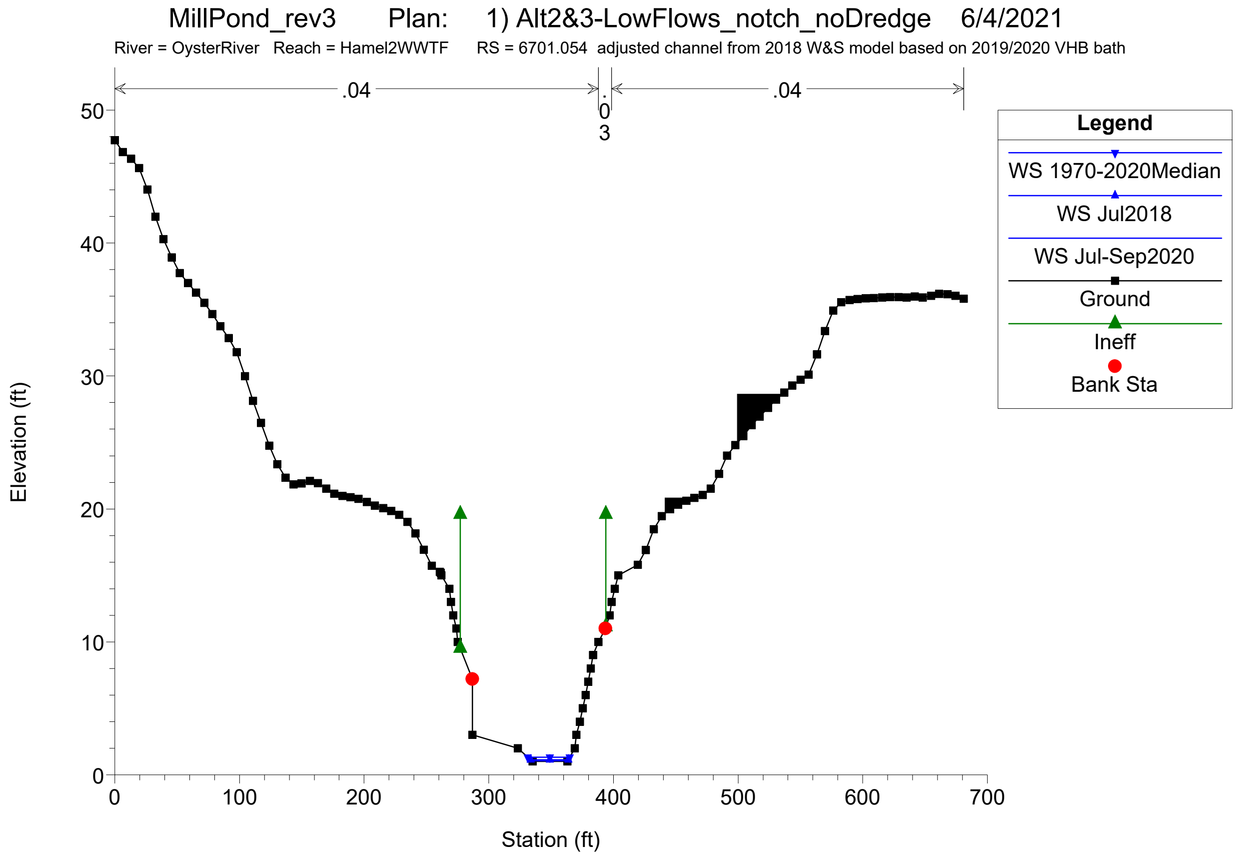
MillPond_rev3 Plan: 1) Alt2&3-LowFlows_notch_noDredge 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6798.875 adjusted channel from 2018 W&S model based on 2009 bathymetry; r
.04
.03
.04
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)
0
10
20
30
40
50
0
100
200
300
400
500
600
700
800



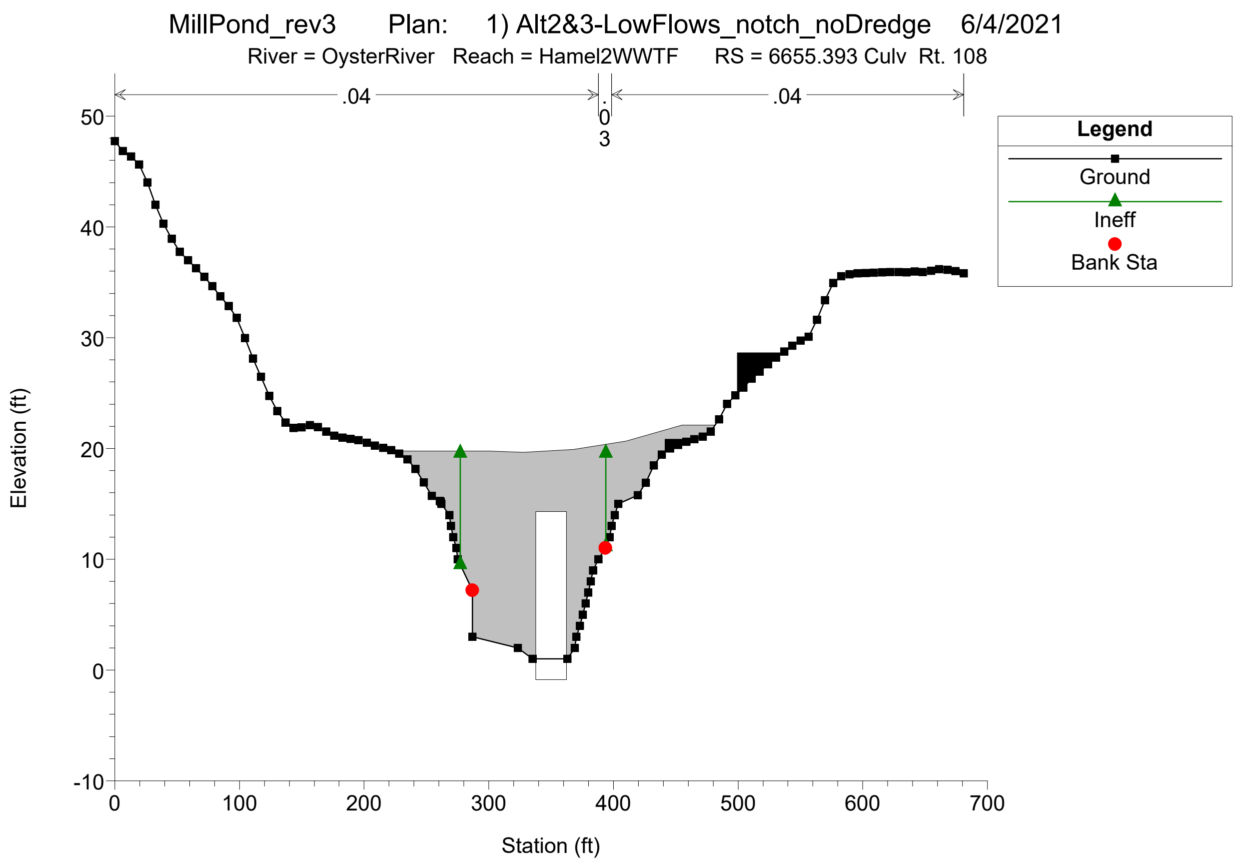
MillPond_rev3 Plan: 1) Alt2&3-LowFlows_notch_noDredge 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6766.790 IS Oyster River Dam at Mill Pond, modified per 2019/2020 VHB survey
.04
.03
.04
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)
0
10
20
30
40
50
0
100
200
300
400
500
600
700
800


MillPond_rev3 Plan: 1) Alt2&3-LowFlows_notch_noDredge 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6754.613 new XS immediately downstream of Mill Pond Dam; based on LiDAR a
.04
.03
.04
Elevation (ft)
Station (ft)
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Ineff
Bank Sta

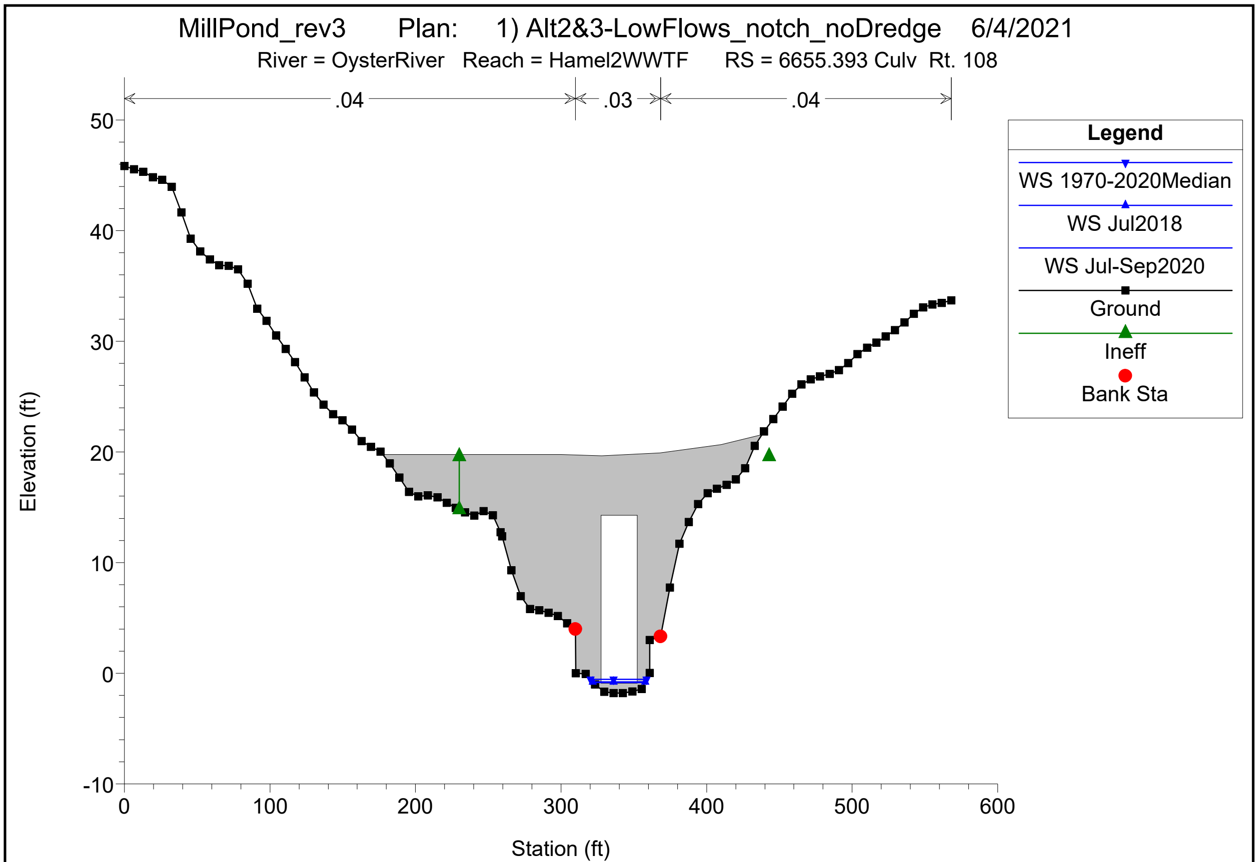

MillPond_rev3 Plan: 1) Alt2&3-LowFlows_notch_noDredge 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6725.593 adjusted channel from 2018 W&S model based on 2019/2020 VHB bath
.04
.03
.04
Elevation (ft)
Station (ft)
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Ineff
Bank Sta



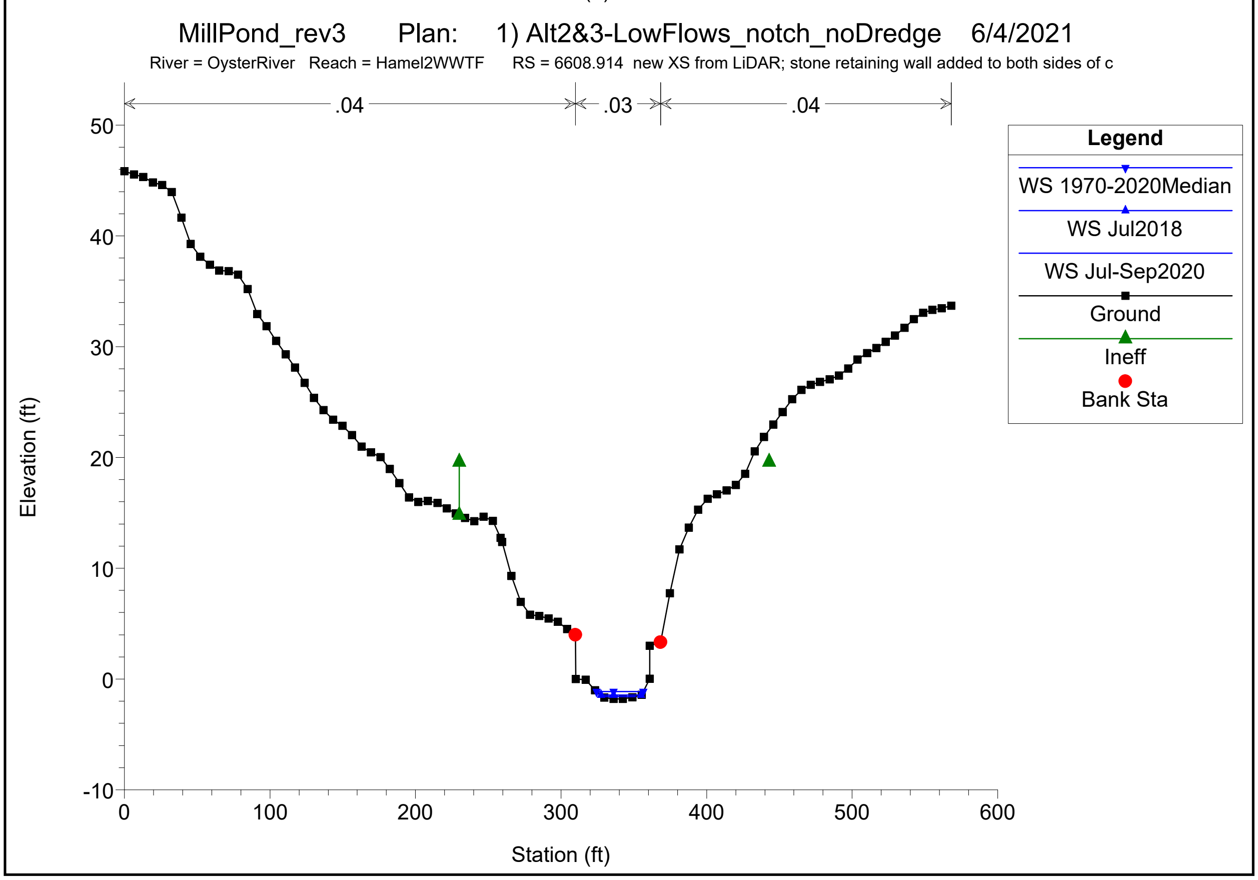
MillPond_rev3 Plan: 1) Alt2&3-LowFlows_notch_noDredge 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6701.054 adjusted channel from 2018 W&S model based on 2019/2020 VHB bath
.04
.03
.04
Elevation (ft)
Station (ft)
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Ineff
Bank Sta



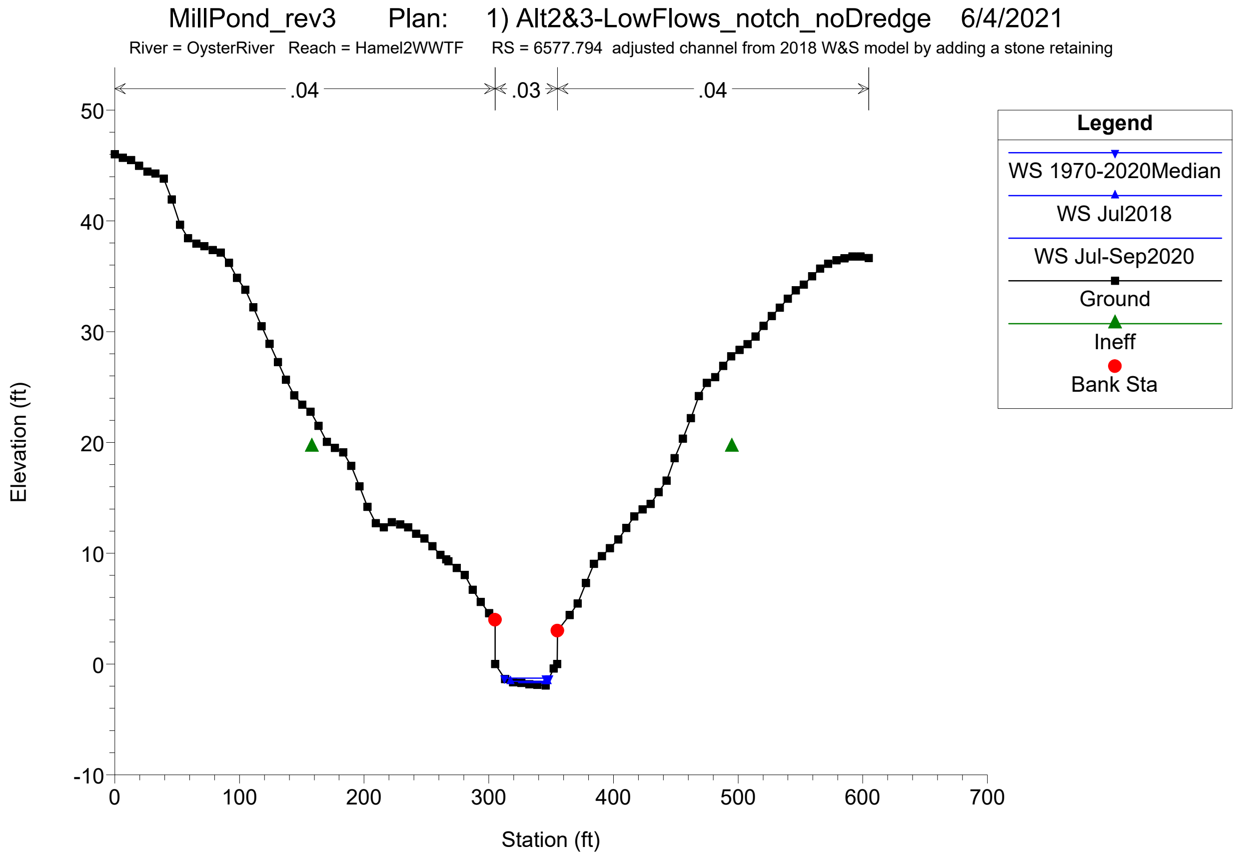
MillPond_rev3 Plan: 1) Alt2&3-LowFlows_notch_noDredge 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6655.393 Culv Rt. 108
.04
.03
.04
Elevation (ft)
Station (ft)
Legend
Ground
Ineff
Bank Sta

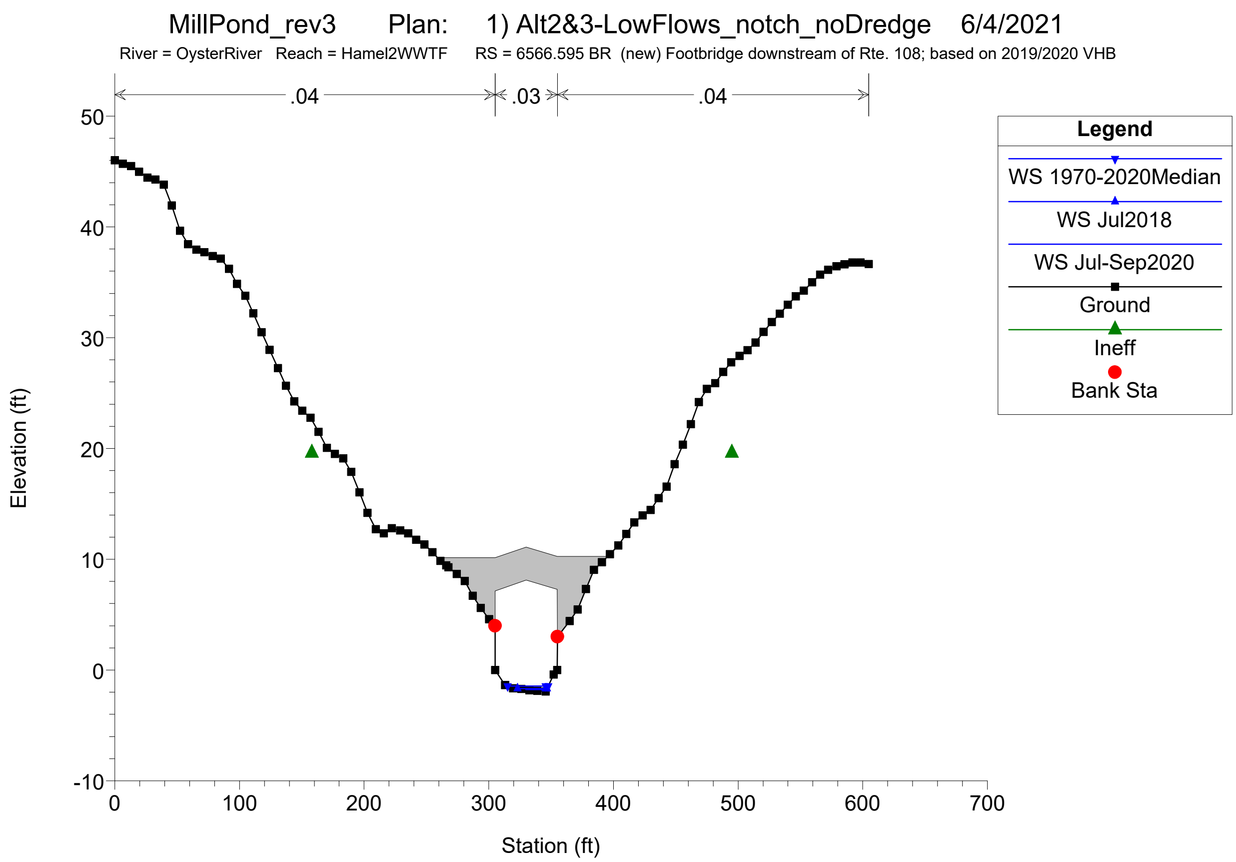


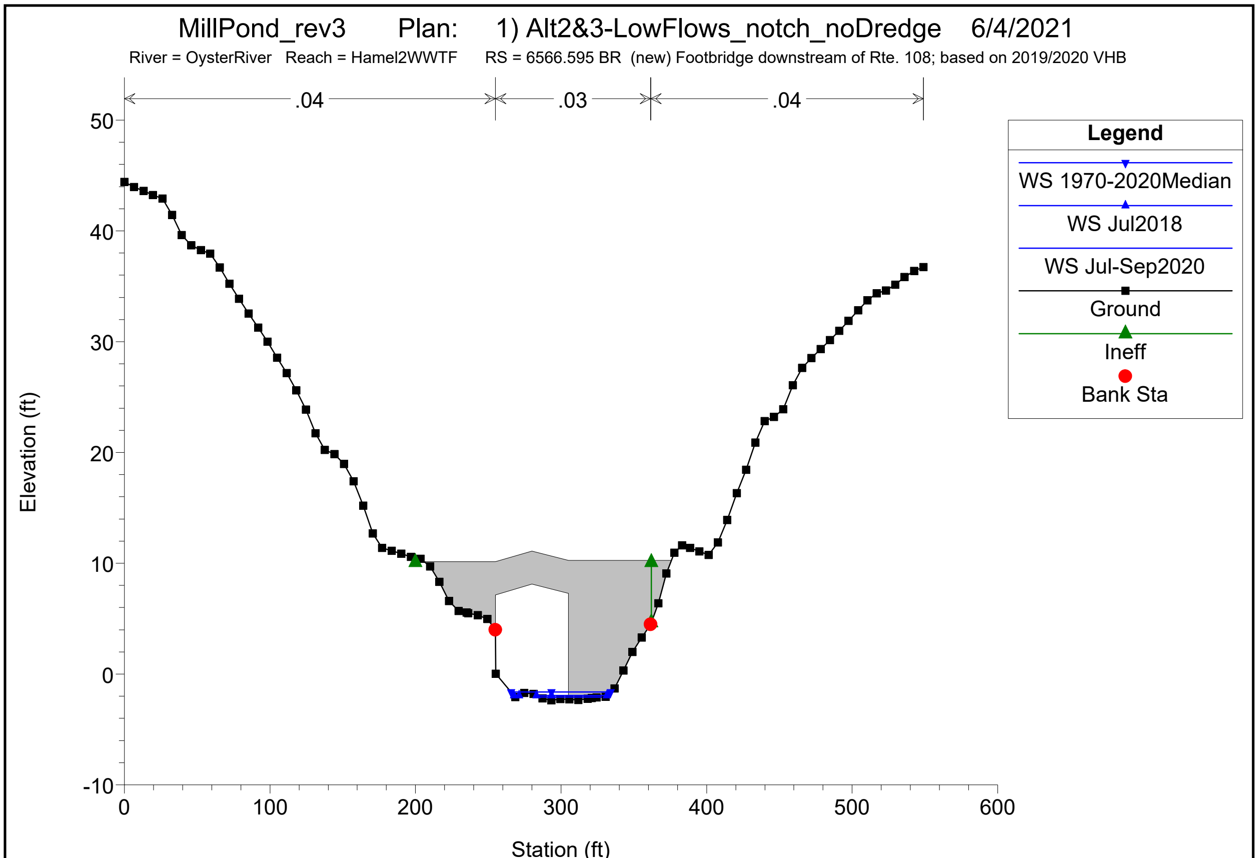
MillPond_rev3 Plan: 1) Alt2&3-LowFlows_notch_noDredge 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6655.393 Culv Rt. 108
.04
.03
.04
Elevation (ft)
Station (ft)
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Ineff
Bank Sta

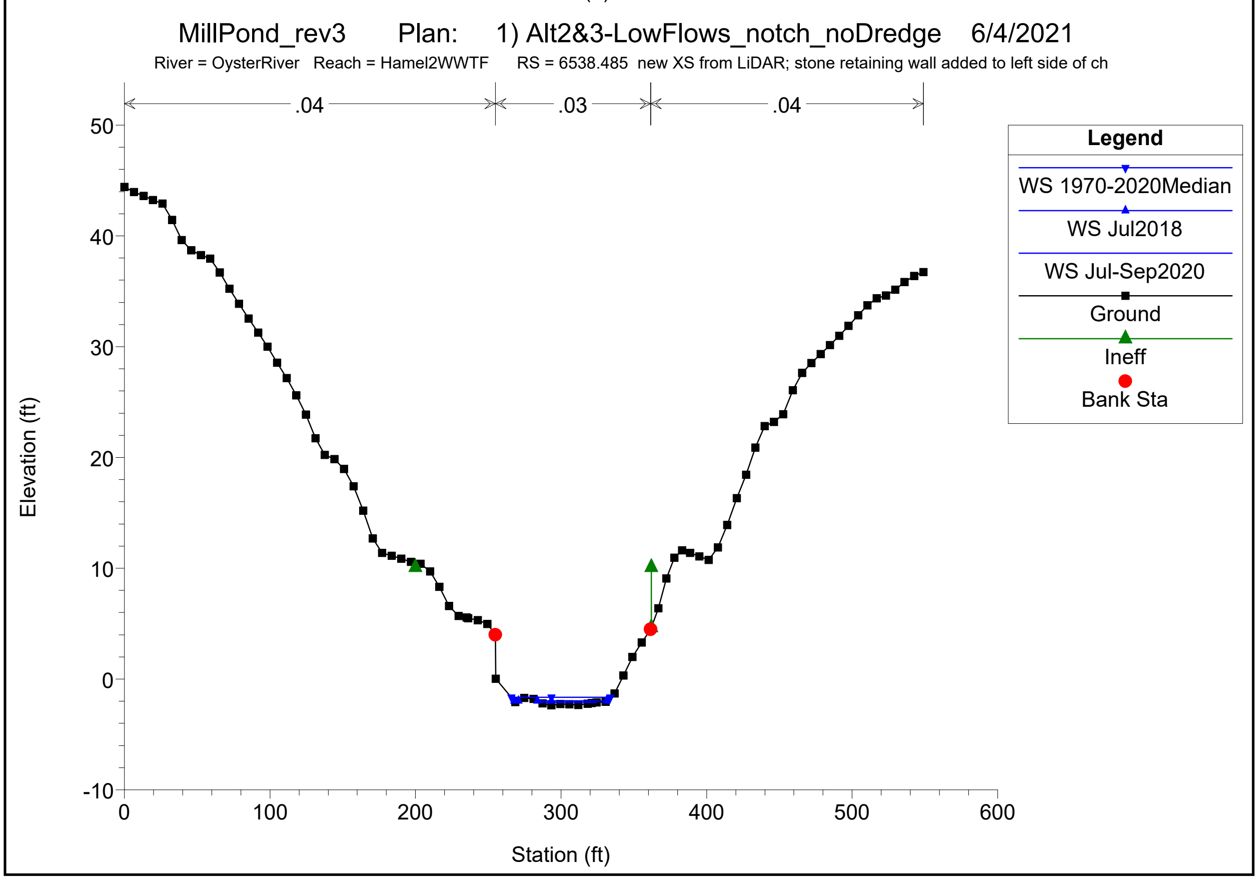


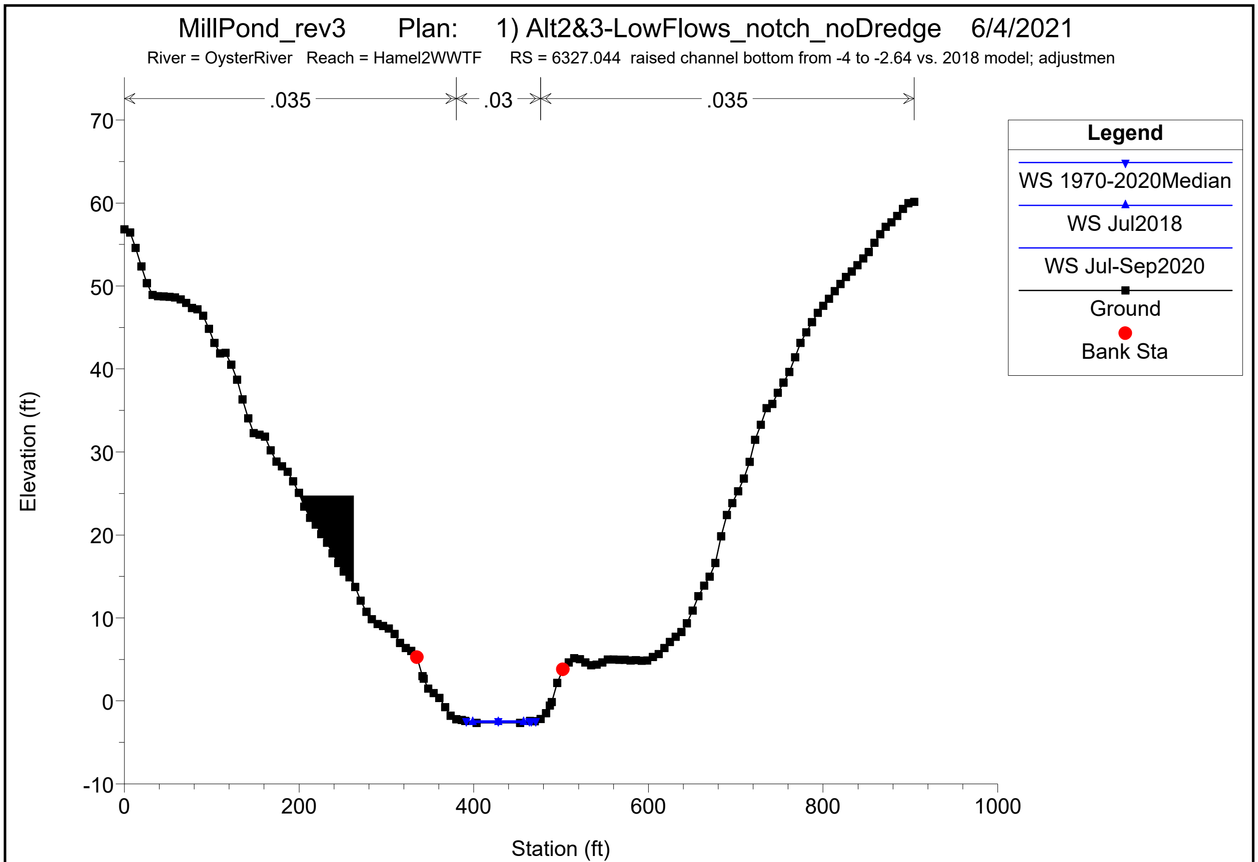
MillPond_rev3 Plan: 1) Alt2&3-LowFlows_notch_noDredge 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6608.914 new XS from LiDAR; stone retaining wall added to both sides of c
.04
.03
.04
Elevation (ft)
Station (ft)
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Ineff
Bank Sta

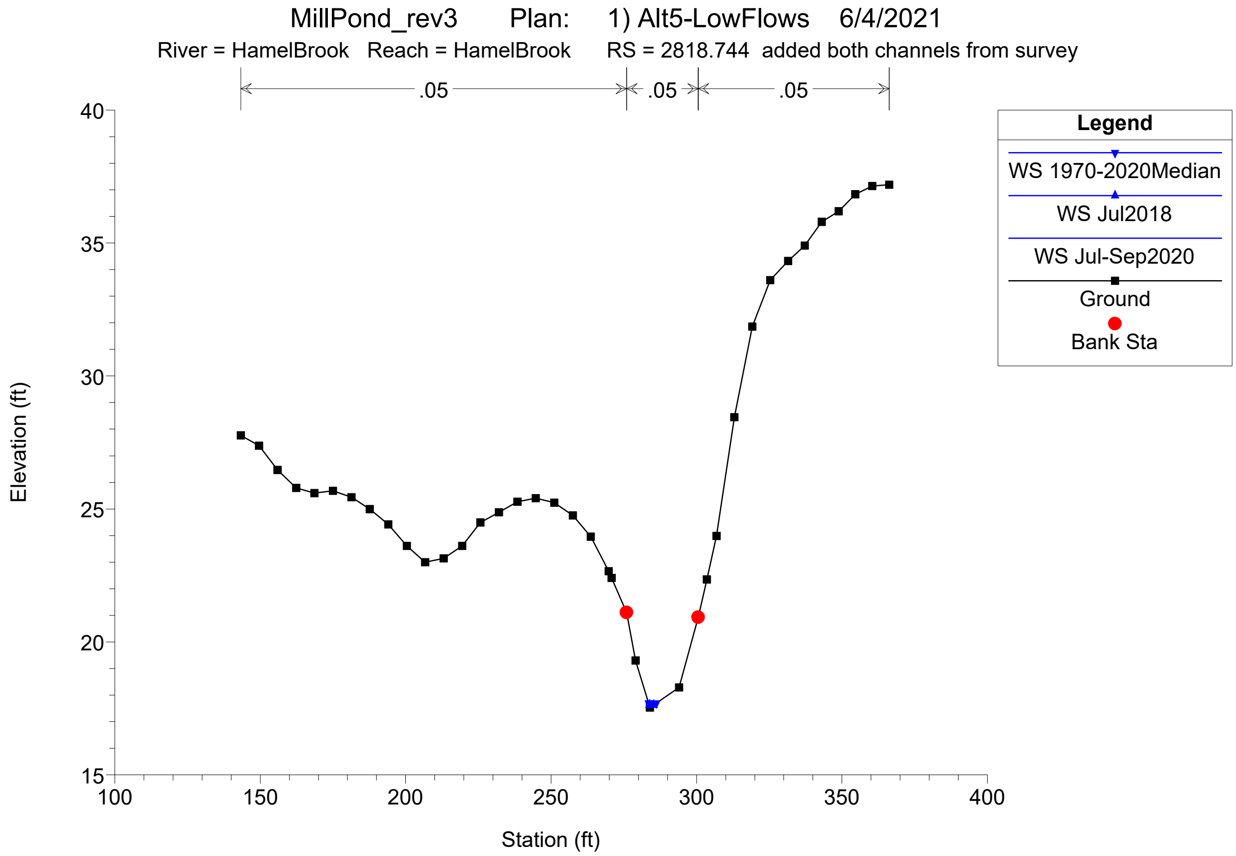

MillPond_rev3 Plan: 1) Alt2&3-LowFlows_notch_noDredge 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6577.794 adjusted channel from 2018 W&S model by adding a stone retaining
.04
.03
.04
Elevation (ft)
Station (ft)
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Ineff
Bank Sta

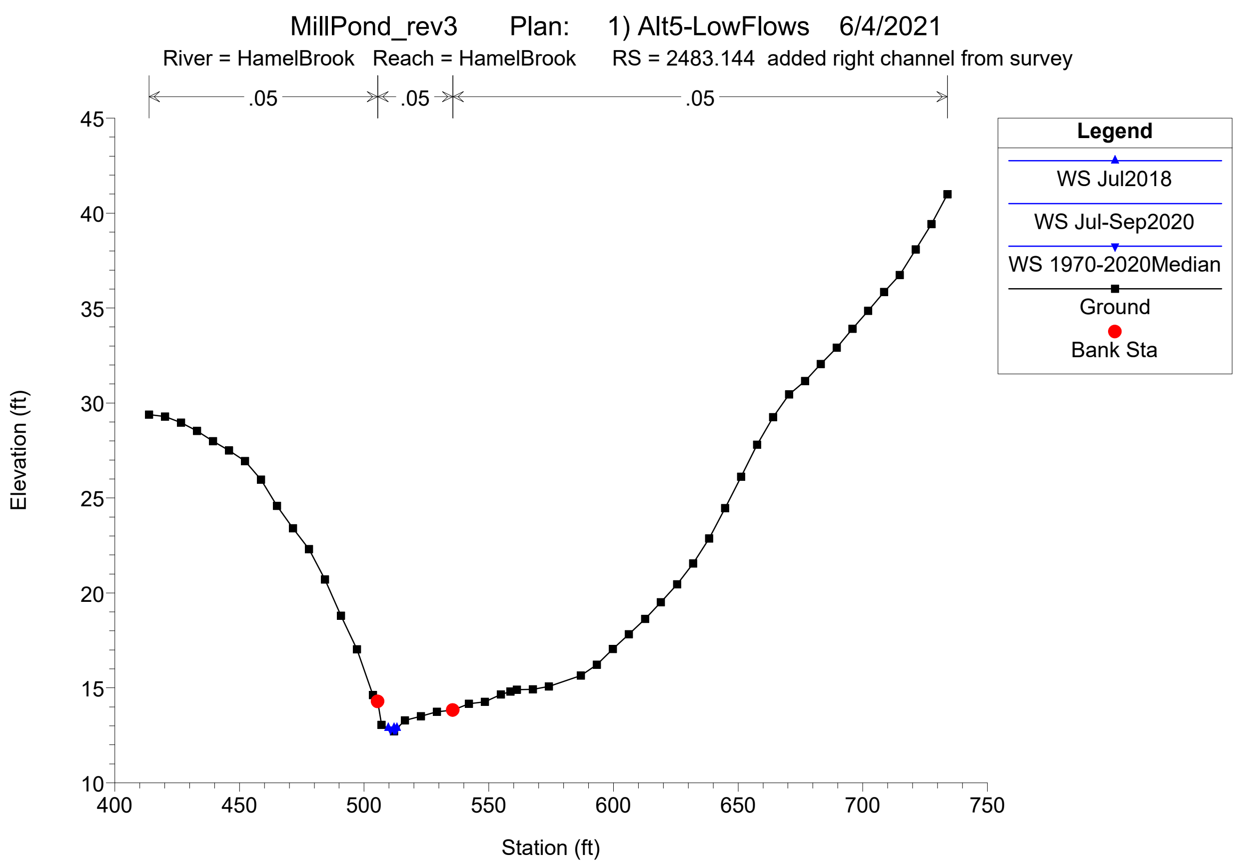

MillPond_rev3 Plan: 1) Alt2&3-LowFlows_notch_noDredge 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6566.595 BR (new) Footbridge downstream of Rte. 108; based on 2019/2020 VHB
.04
.03
.04
Elevation (ft)
Station (ft)
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Ineff
Bank Sta

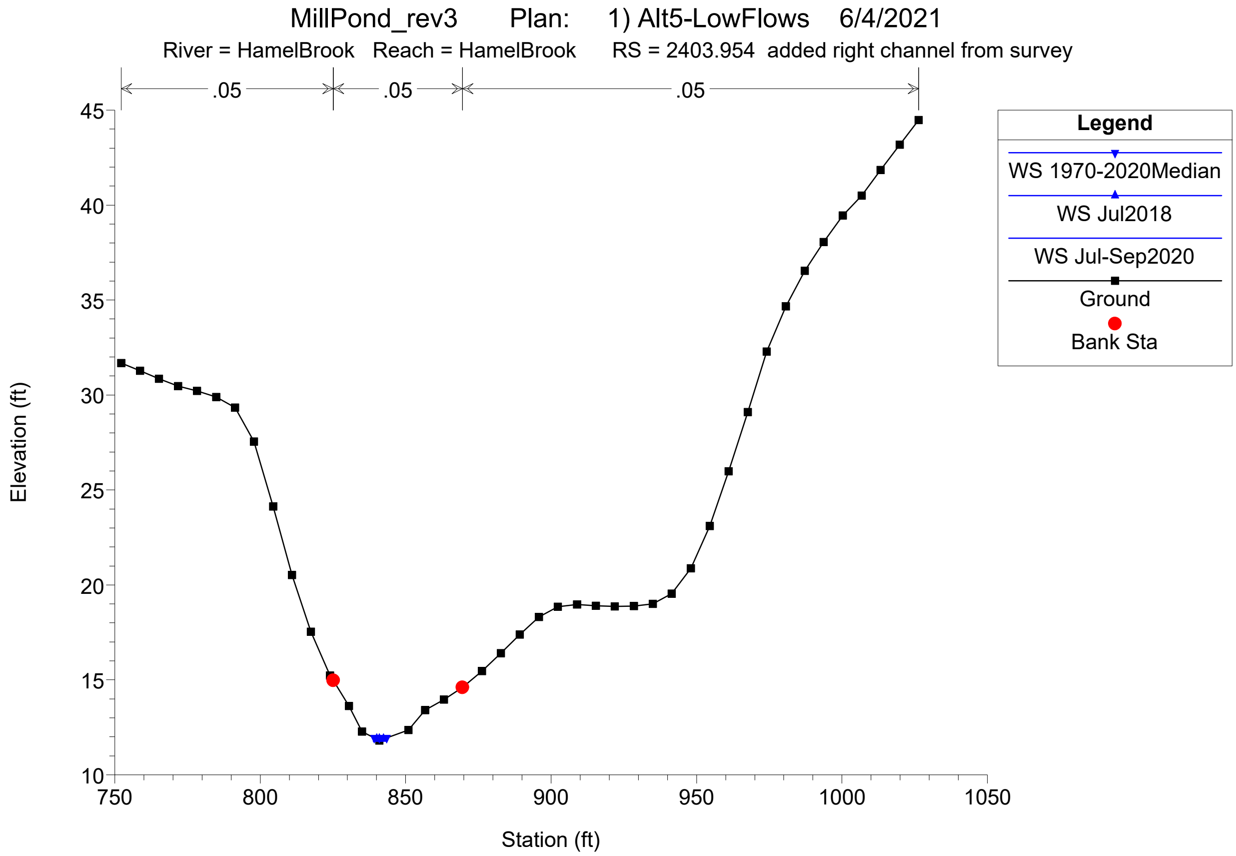

MillPond_rev3 Plan: 1) Alt2&3-LowFlows_notch_noDredge 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6566.595 BR (new) Footbridge downstream of Rte. 108; based on 2019/2020 VHB
.04
.03
.04
Elevation (ft)
Station (ft)
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Ineff
Bank Sta


MillPond_rev3 Plan: 1) Alt2&3-LowFlows_notch_noDredge 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6538.485 new XS from LiDAR; stone retaining wall added to left side of ch
.04
.03
.04
Elevation (ft)
Station (ft)
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Ineff
Bank Sta

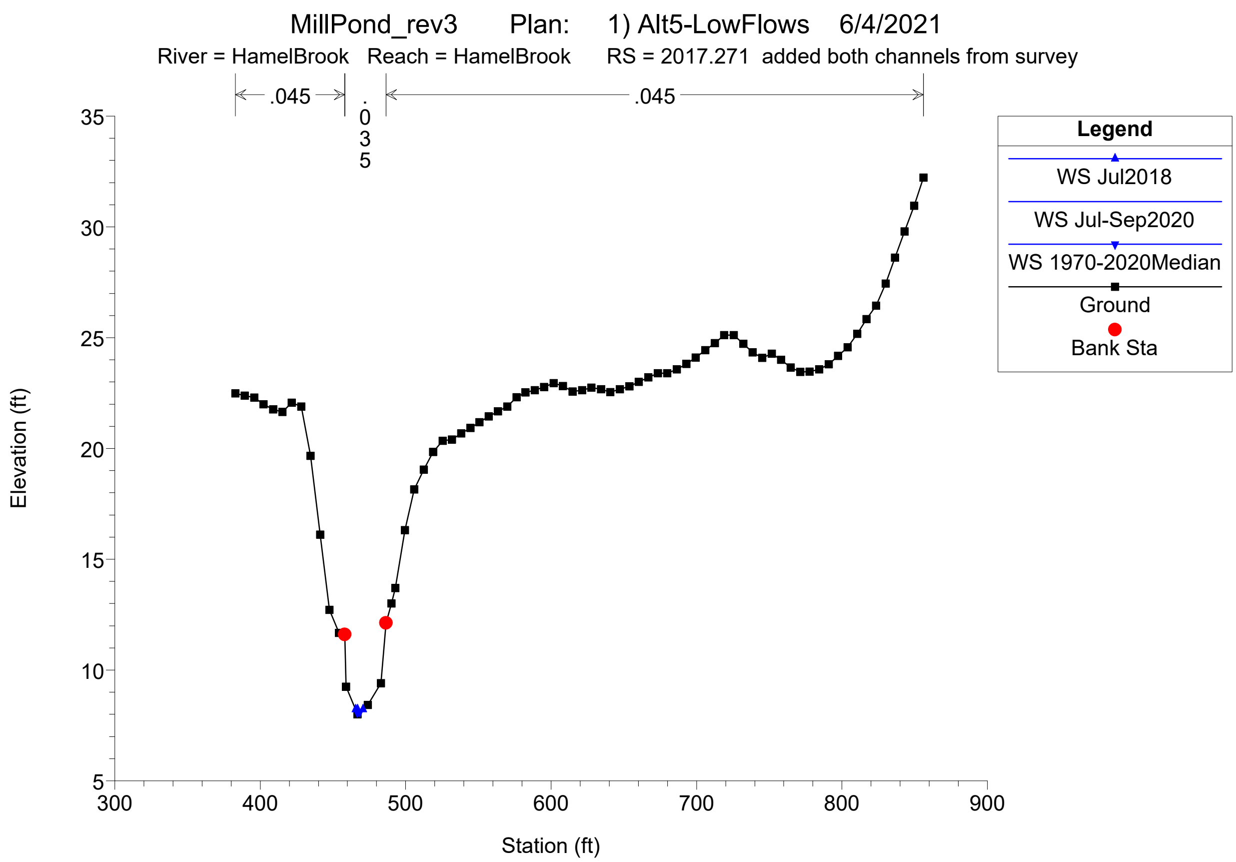

MillPond_rev3 Plan: 1) Alt2&3-LowFlows_notch_noDredge 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6327.044 raised channel bottom from -4 to -2.64 vs. 2018 model; adjustmen
.035
.03
.035
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)
70
60
50
40
30
20
10
0
-10
0
200
400
600
800
1000


MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
River = HamelBrook Reach = HamelBrook RS = 2818.744 added both channels from survey
.05
.05
.05
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)
40
35
30
25
20
15
100
150
200
250
300
350
400

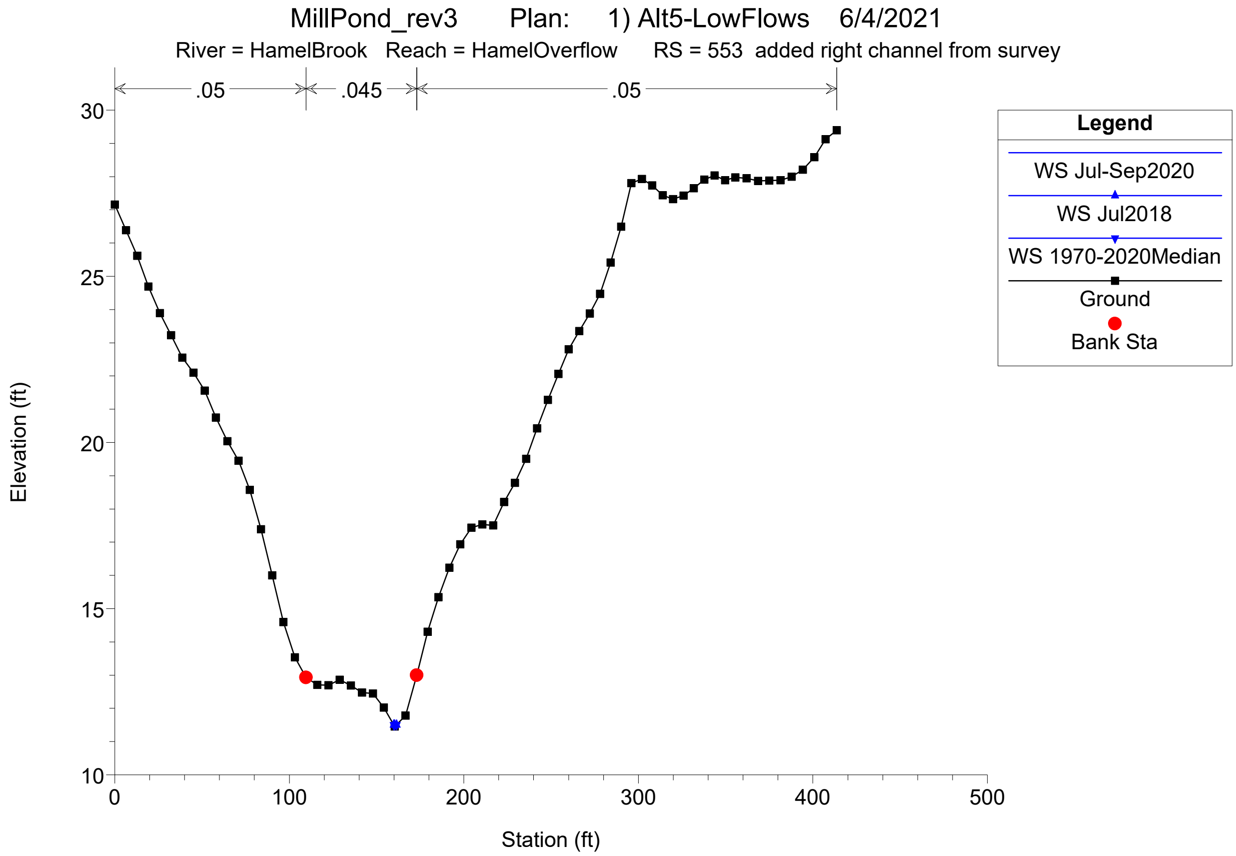

MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
River = HamelBrook Reach = HamelBrook RS = 2483.144 added right channel from survey
.05
.05
.05
Legend
WS Jul2018
WS Jul-Sep2020
WS 1970-2020Median
Ground
Bank Sta
Elevation (ft)
Station (ft)
45
40
35
30
25
20
15
10
400
450
500
550
600
650
700
750

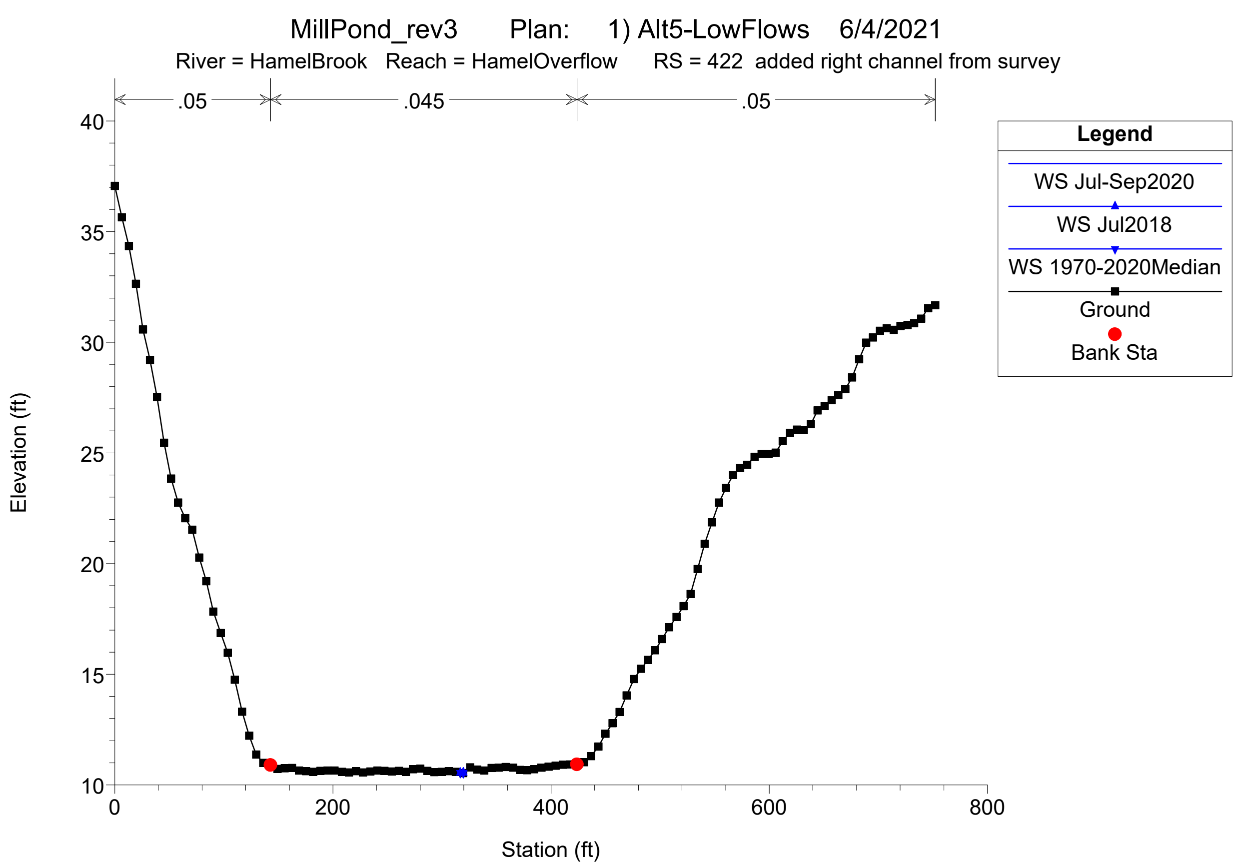


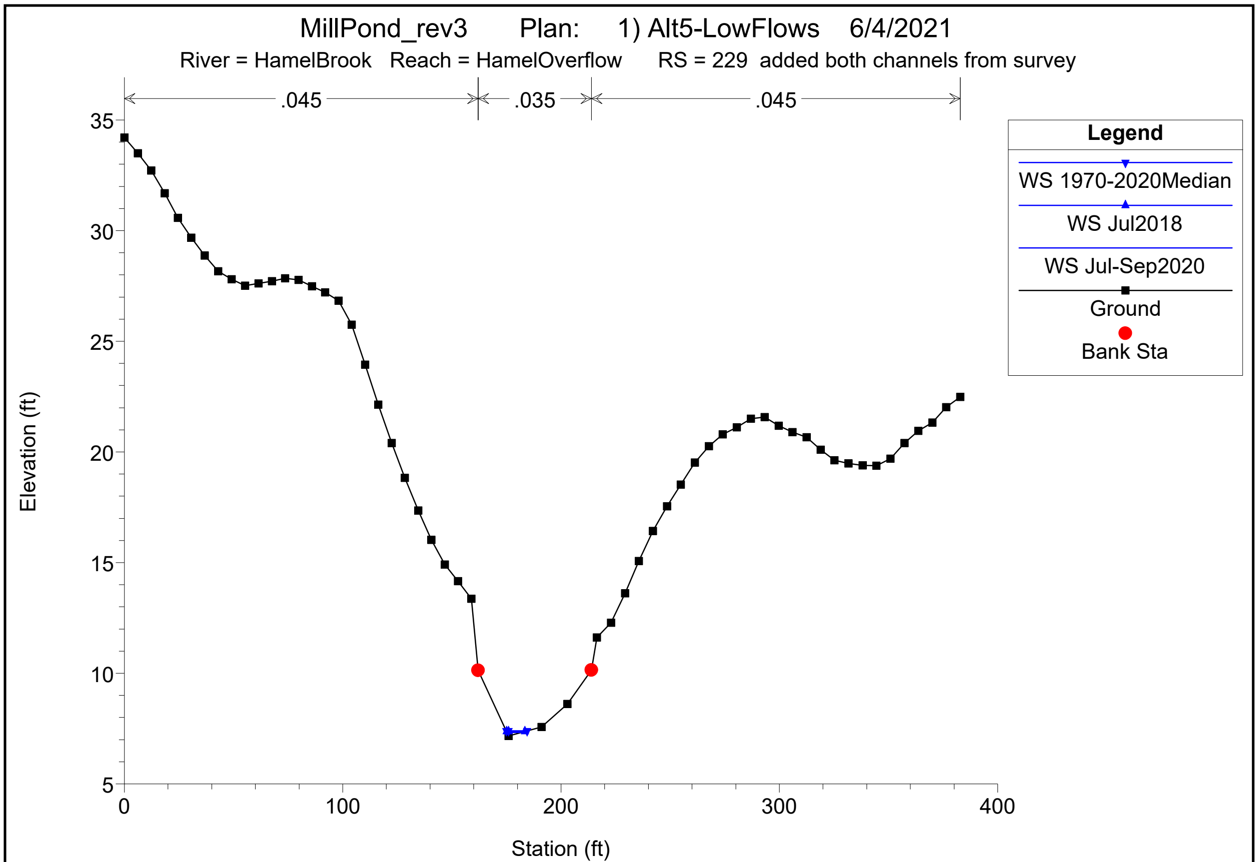
MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
River = HamelBrook Reach = HamelBrook RS = 2403.954 added right channel from survey
.05
.05
.05
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)
45
40
35
30
25
20
15
10
750
800
850
900
950
1000
1050

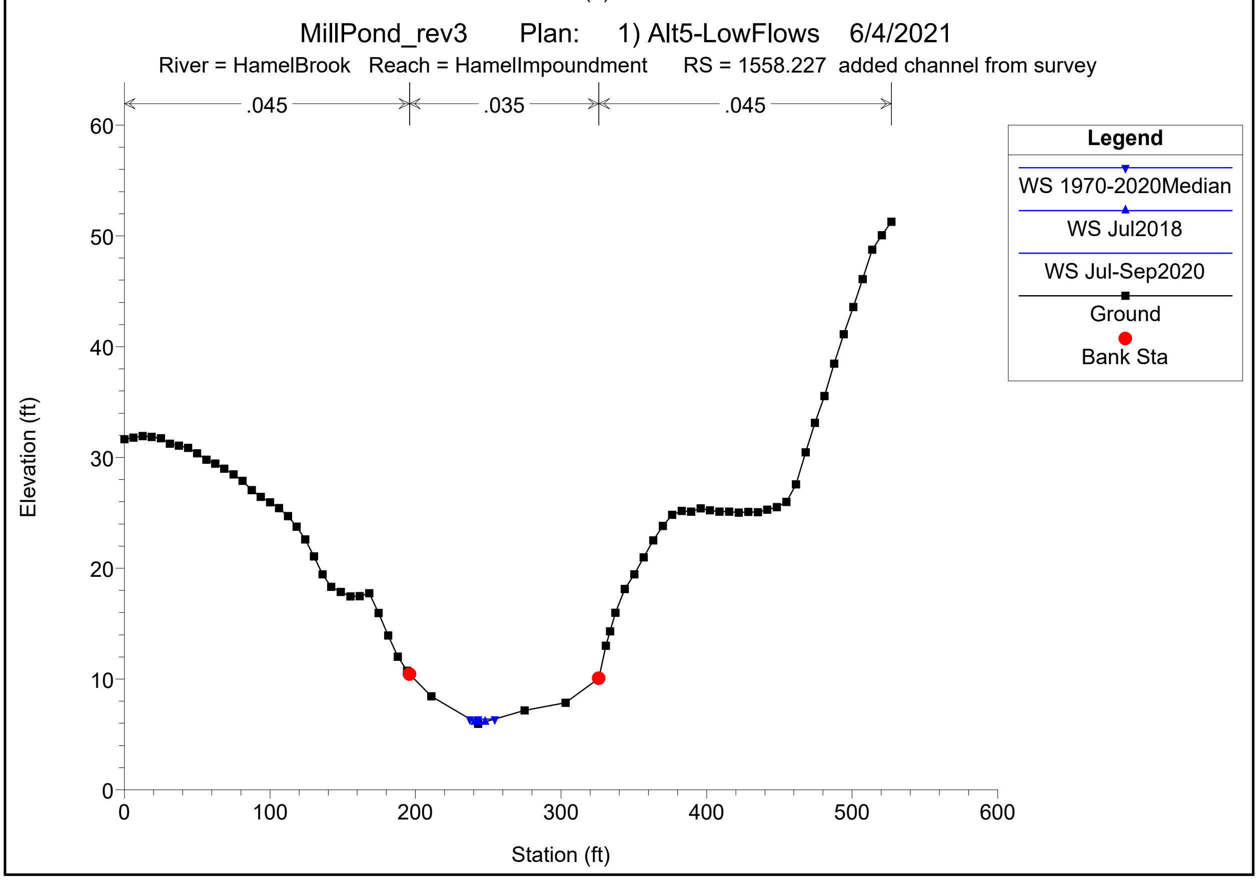


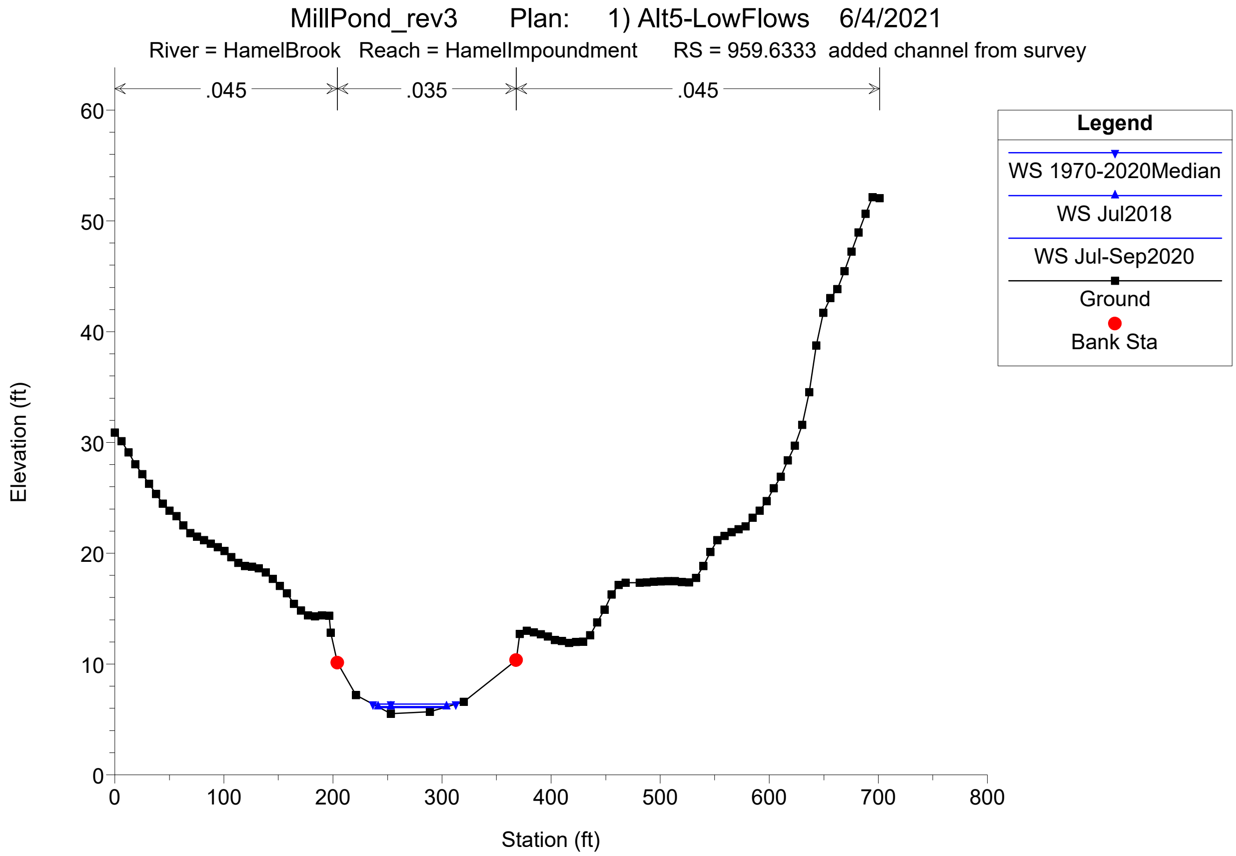
MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
River = HamelBrook Reach = HamelBrook RS = 2017.271 added both channels from survey
.045
.035
.045
Legend
WS Jul2018
WS Jul-Sep2020
WS 1970-2020Median
Ground
Bank Sta
Elevation (ft)
Station (ft)
35
30
25
20
15
10
5
300
400
500
600
700
800
900

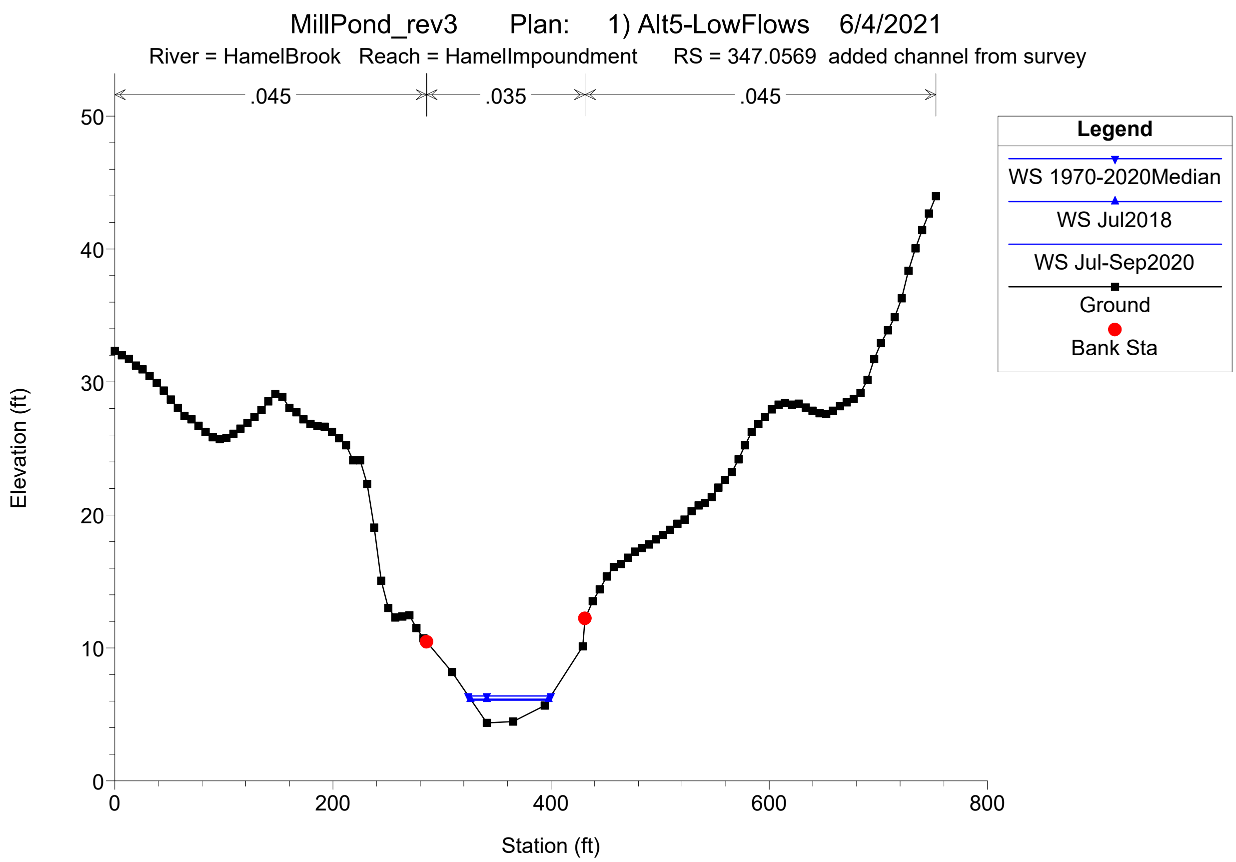

MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
River = HamelBrook Reach = HamelOverflow RS = 553 added right channel from survey
.05
.045
.05
Legend
WS Jul-Sep2020
WS Jul2018
WS 1970-2020Median
Ground
Bank Sta
Elevation (ft)
Station (ft)
10
15
20
25
30
0
100
200
300
400
500

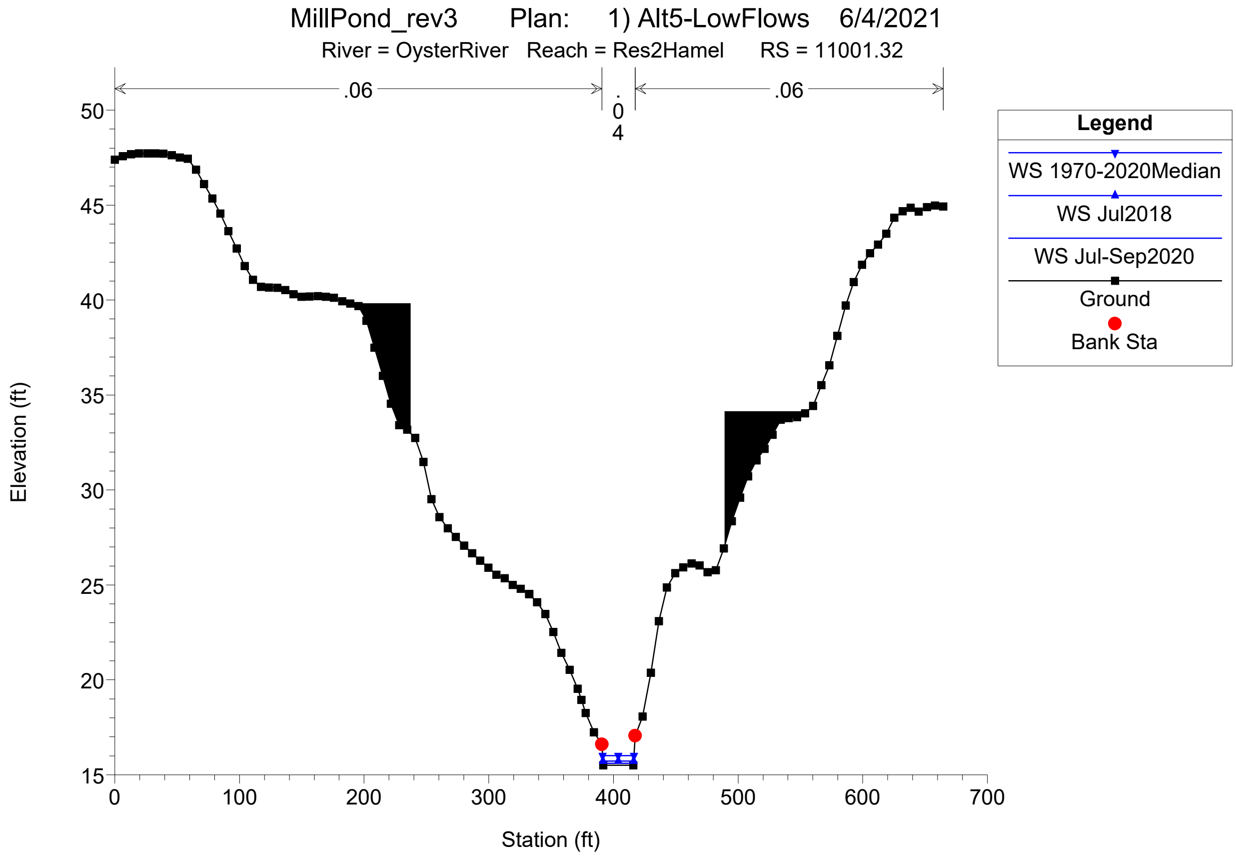

MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
River = HamelBrook Reach = HamelOverflow RS = 422 added right channel from survey
.05
.045
.05
Legend
WS Jul-Sep2020
WS Jul2018
WS 1970-2020Median
Ground
Bank Sta
Elevation (ft)
Station (ft)
10
15
20
25
30
35
40
0
200
400
600
800

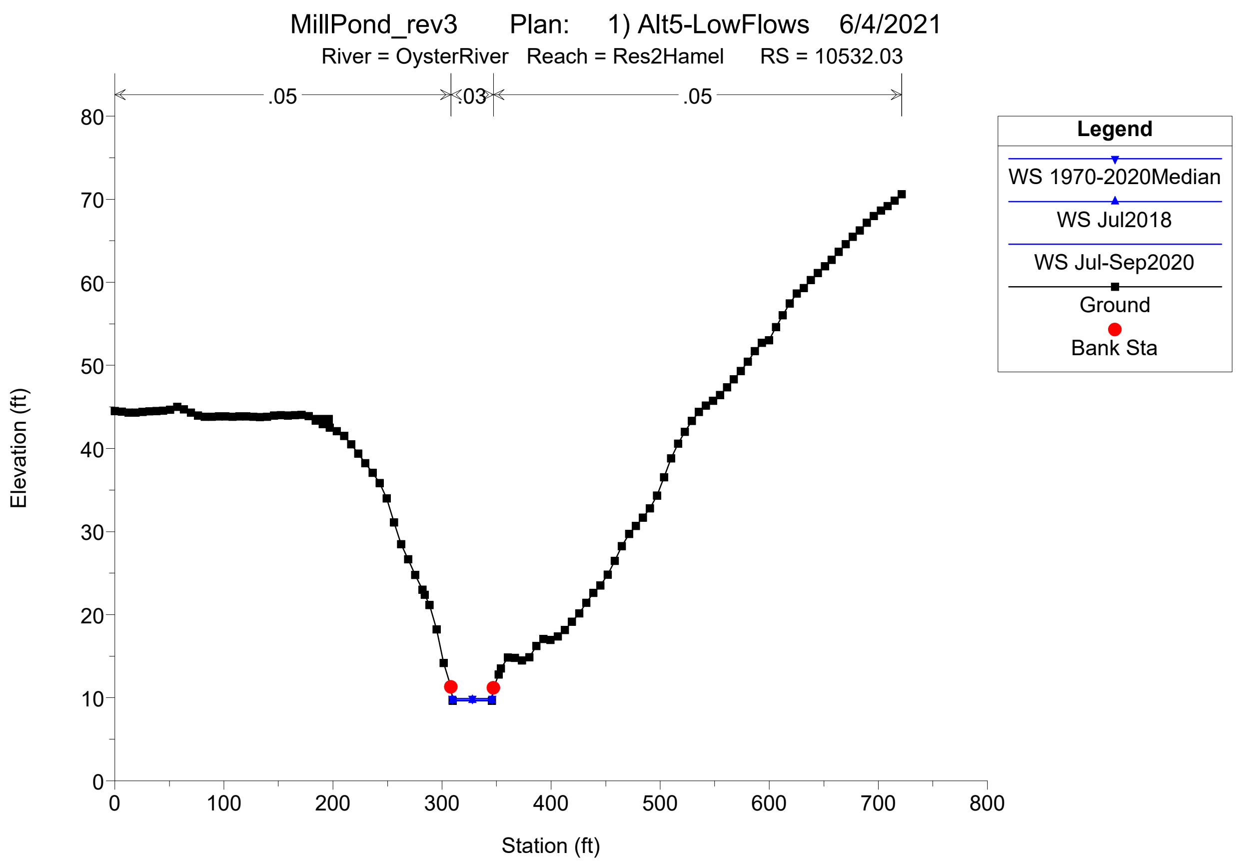

MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
River = HamelBrook Reach = HamelOverflow RS = 229 added both channels from survey
.045
.035
.045
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)

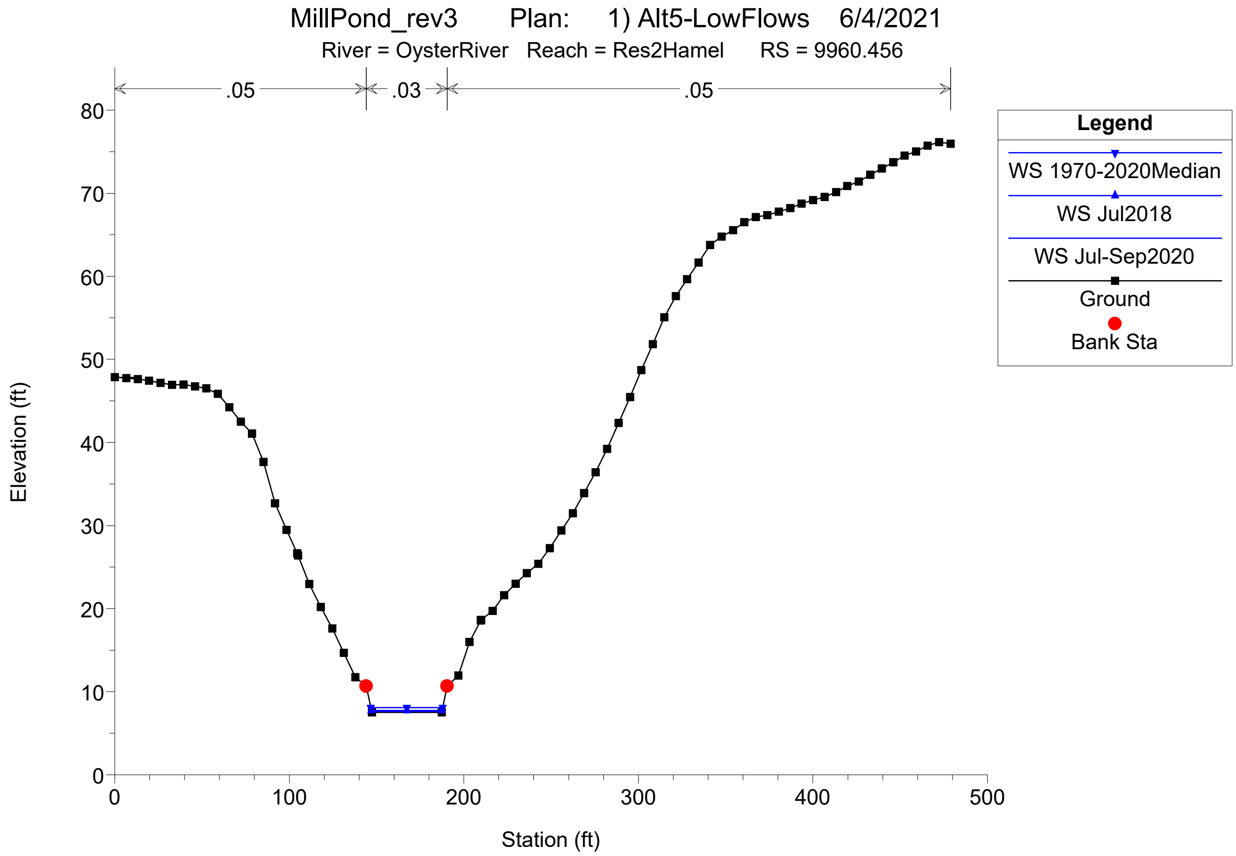

MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
River = HamelBrook Reach = HamelImpoundment RS = 1558.227 added channel from survey
.045
.035
.045
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)

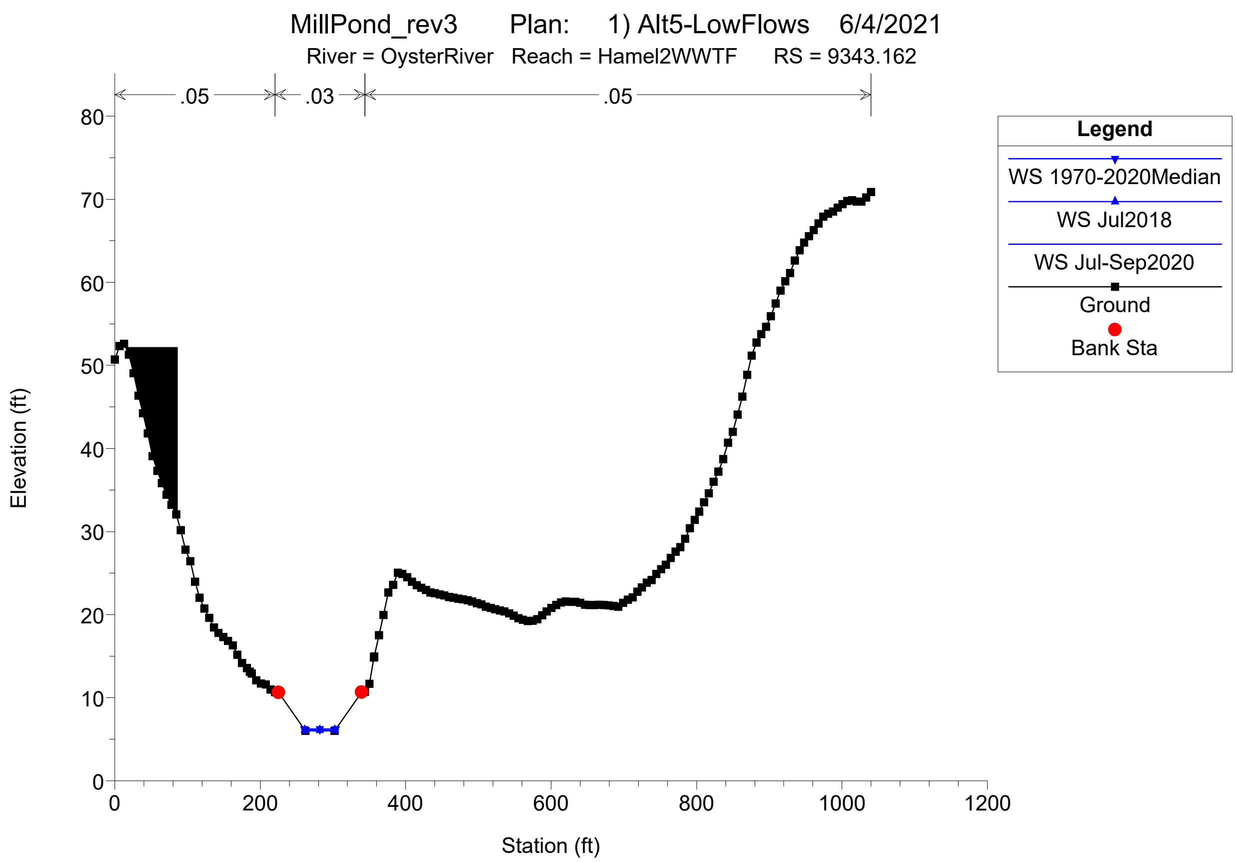

MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
River = HamelBrook Reach = HamelImpoundment RS = 959.6333 added channel from survey
.045
.035
.045
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)
0
10
20
30
40
50
60
0
100
200
300
400
500
600
700
800

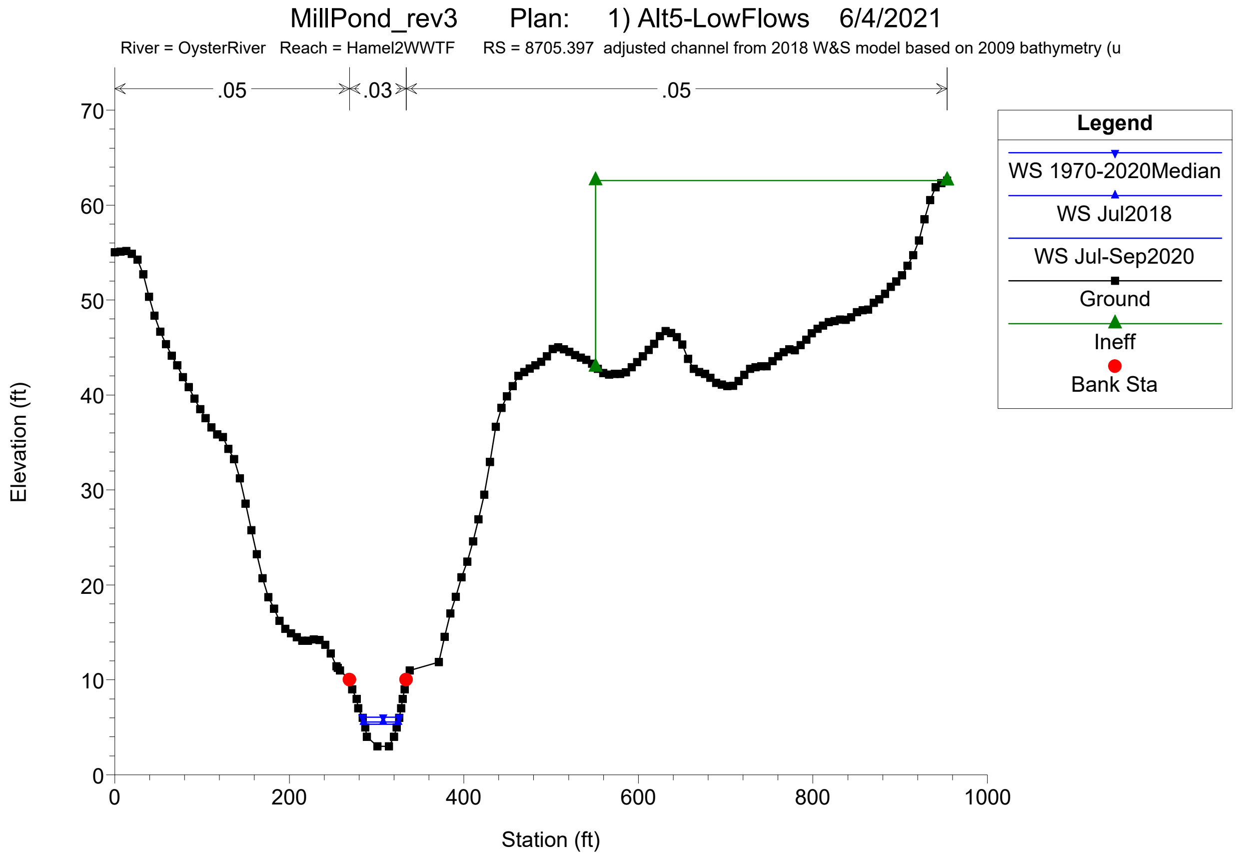

MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
River = HamelBrook Reach = HamelImpoundment RS = 347.0569 added channel from survey
.045
.035
.045
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)
0
10
20
30
40
50
0
200
400
600
800

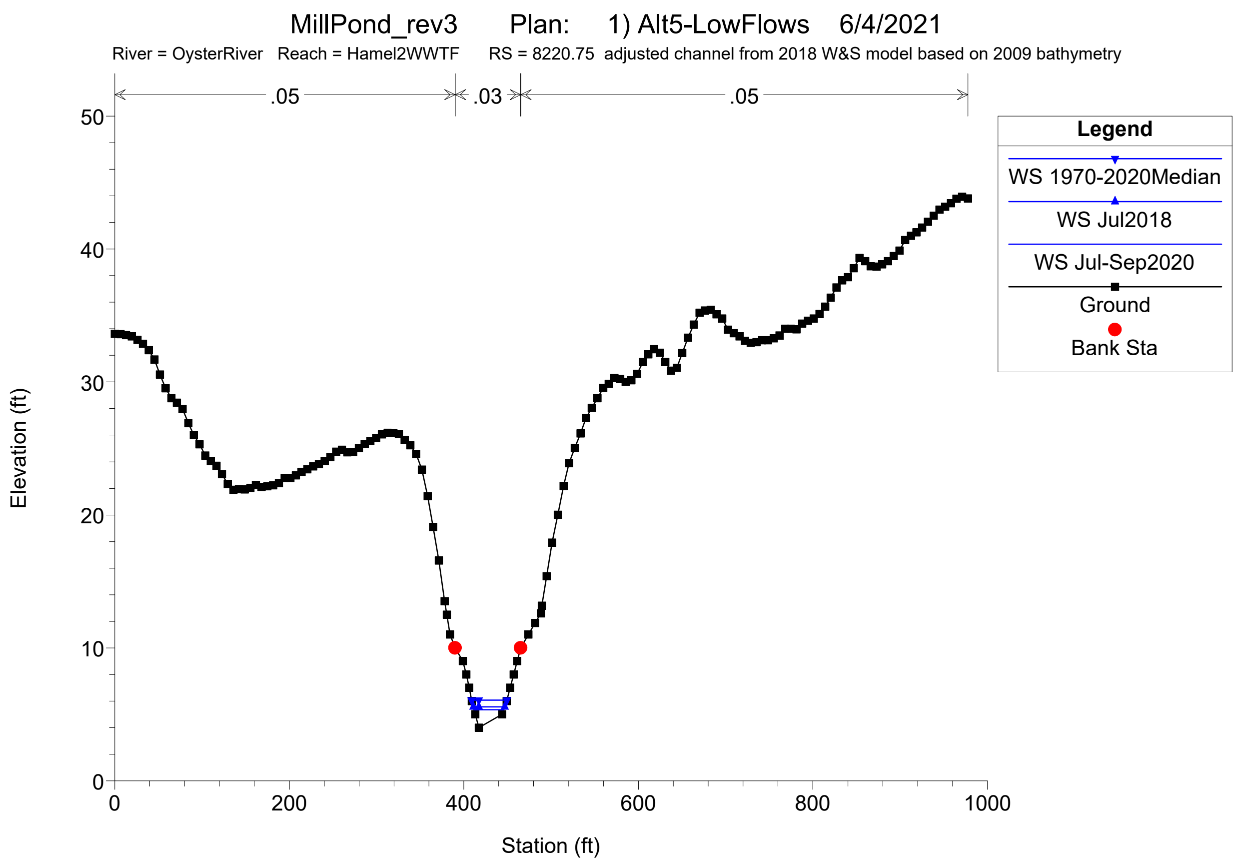

MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
River = OysterRiver Reach = Res2Hamel RS = 11001.32
.06
.
0
4
.06
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)
50
45
40
35
30
25
20
15
0
100
200
300
400
500
600
700

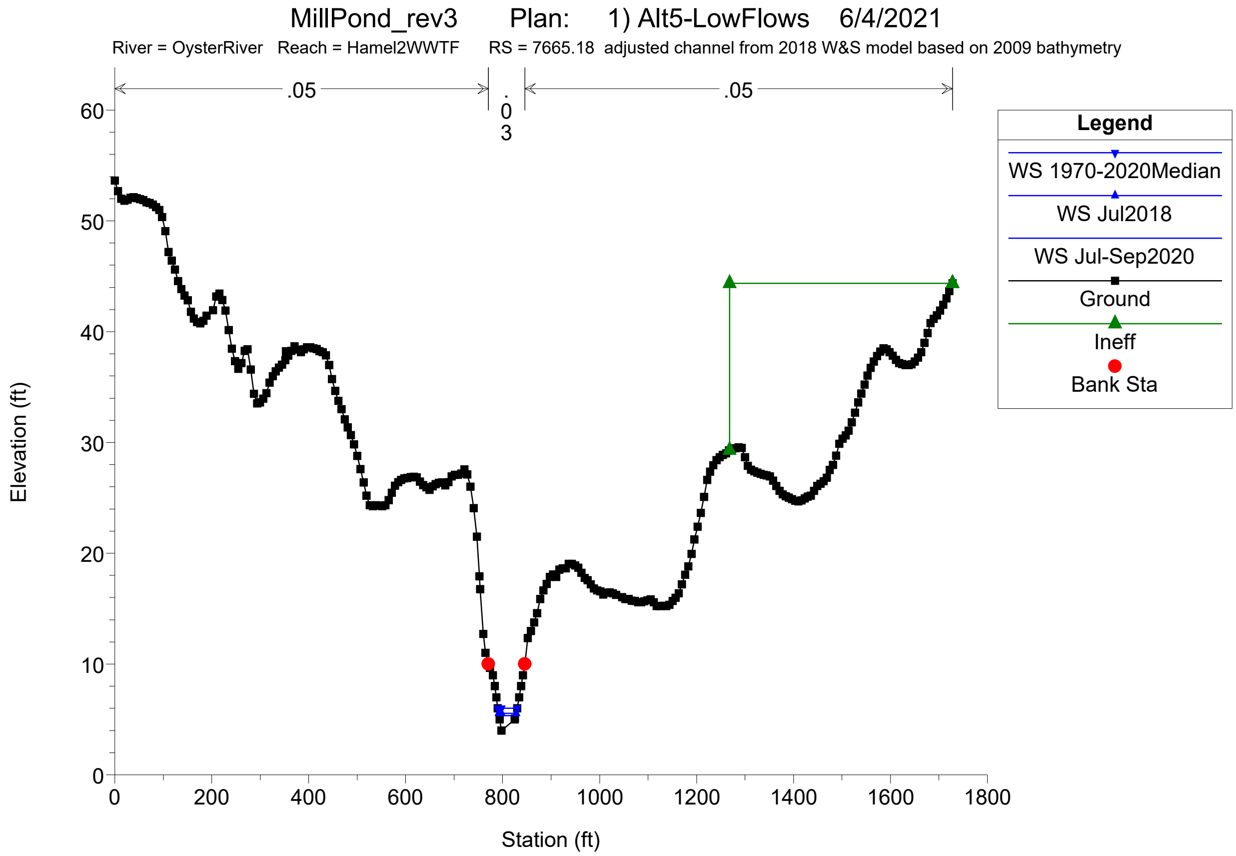

MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
River = OysterRiver Reach = Res2Hamel RS = 10532.03
.05
.03
.05
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)
80
70
60
50
40
30
20
10
0
0
100
200
300
400
500
600
700
800


MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
River = OysterRiver Reach = Res2Hamel RS = 9960.456
.05
.03
.05
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)
0
10
20
30
40
50
60
70
80
0
100
200
300
400
500

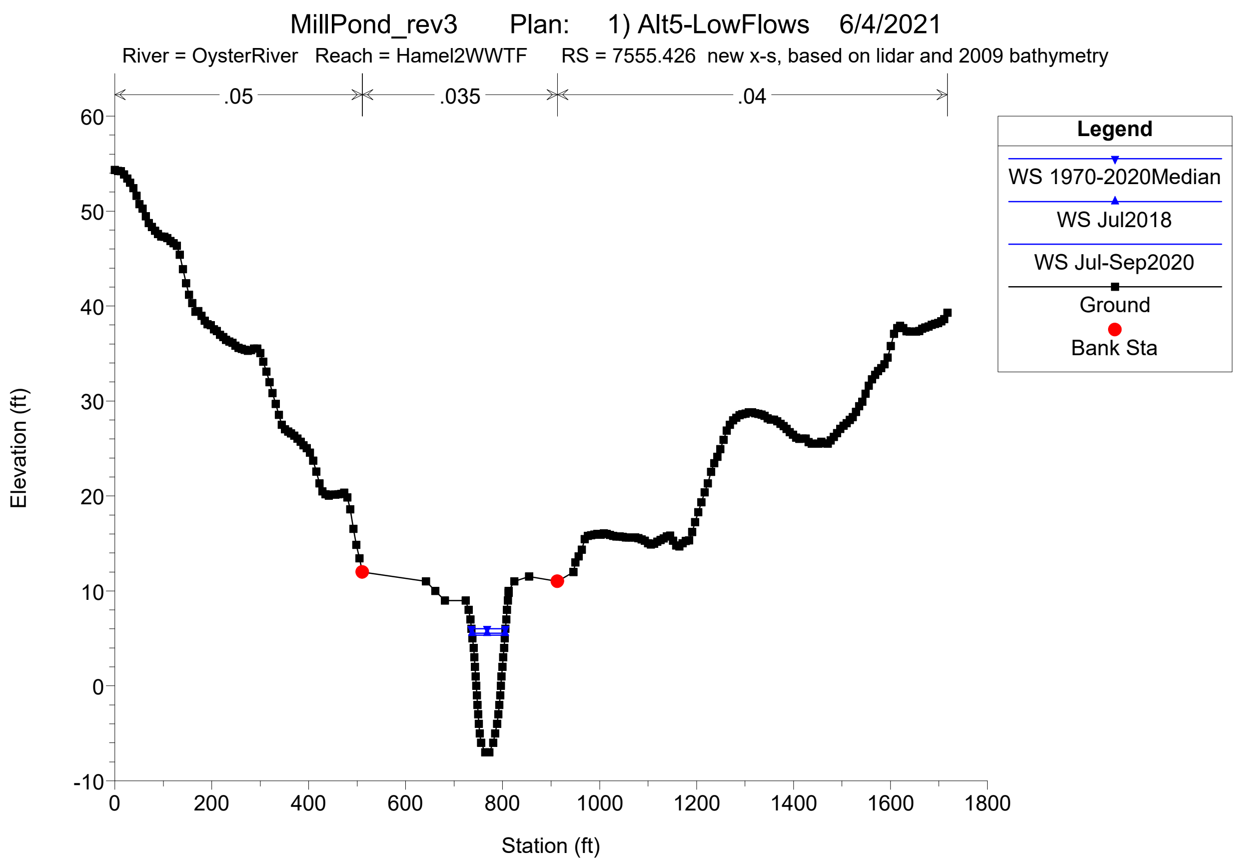

MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 9343.162
.05
.03
.05
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)
0
10
20
30
40
50
60
70
80
0
200
400
600
800
1000
1200


MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 8705.397 adjusted channel from 2018 W&S model based on 2009 bathymetry (u
.05
.03
.05
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)

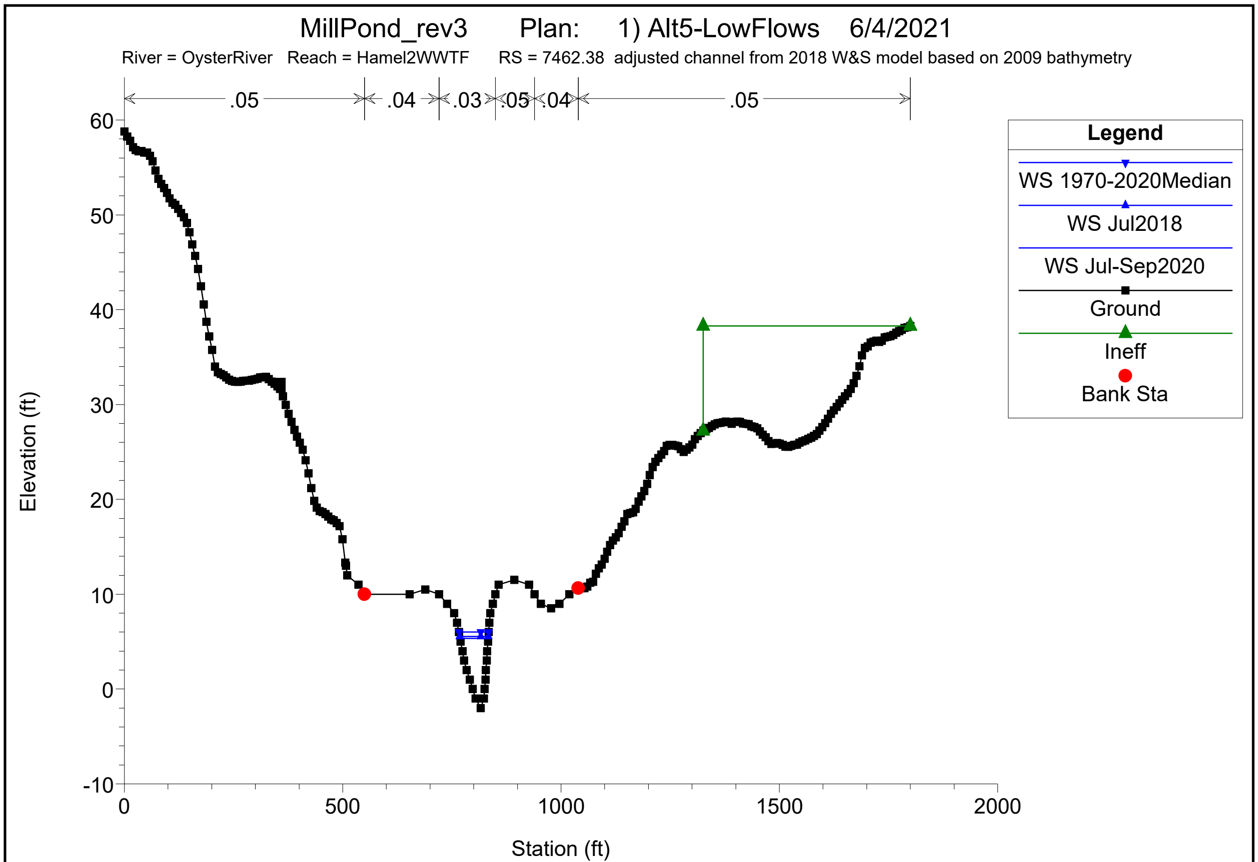

MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 8220.75 adjusted channel from 2018 W&S model based on 2009 bathymetry
.05
.03
.05
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)



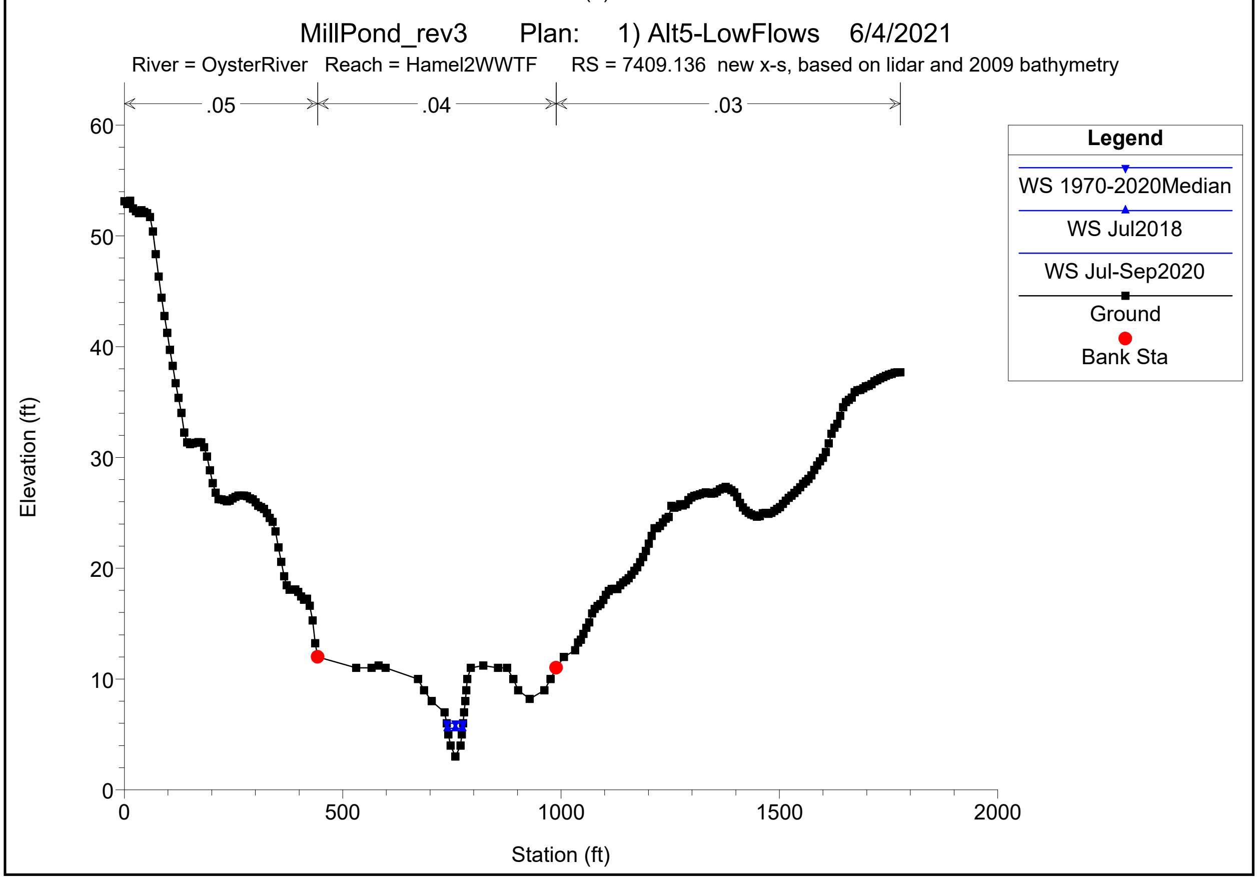
MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 7665.18 adjusted channel from 2018 W&S model based on 2009 bathymetry
.05
.03
.05
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
0
10
20
30
40
50
60
0
200
400
600
800
1000
1200
1400
1600
1800



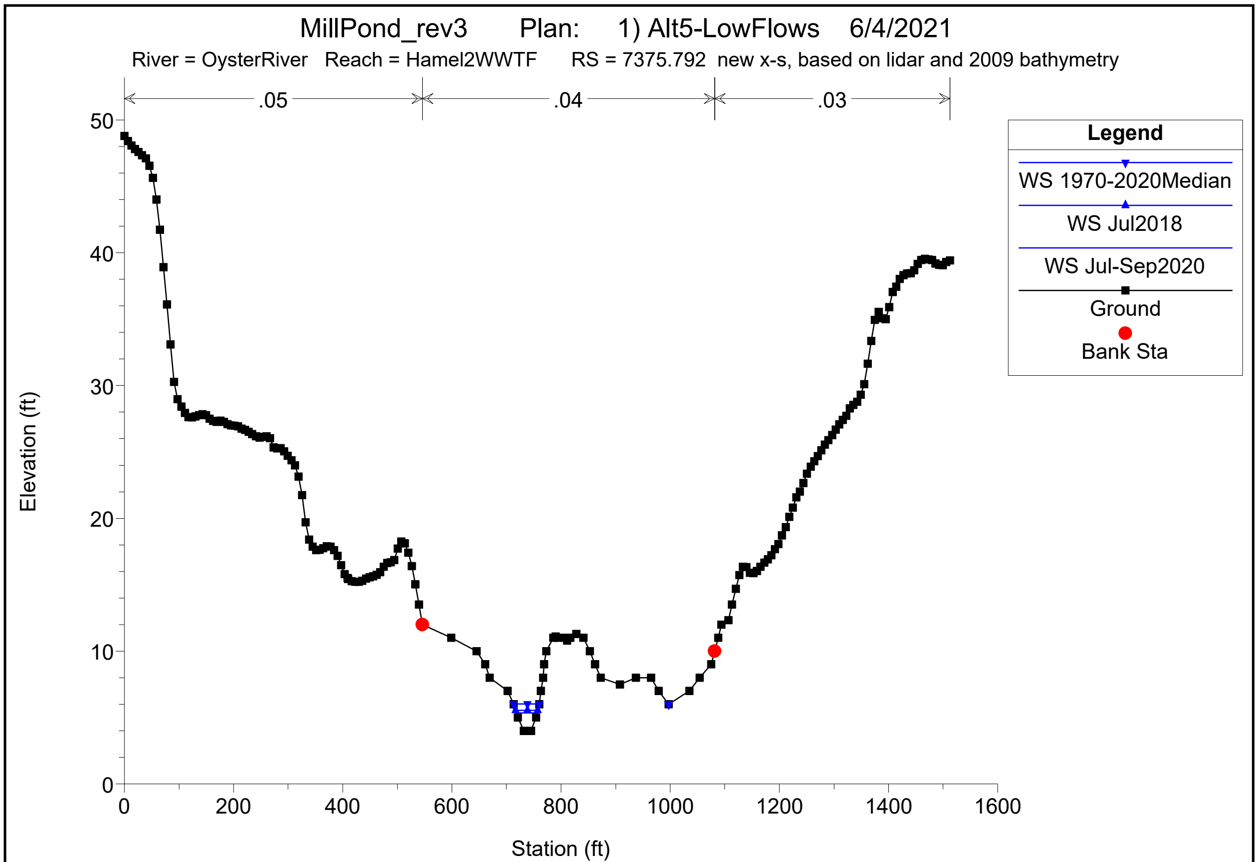
MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 7555.426 new x-s, based on lidar and 2009 bathymetry
.05
.035
.04
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)
-10
0
10
20
30
40
50
60
0
200
400
600
800
1000
1200
1400
1600
1800



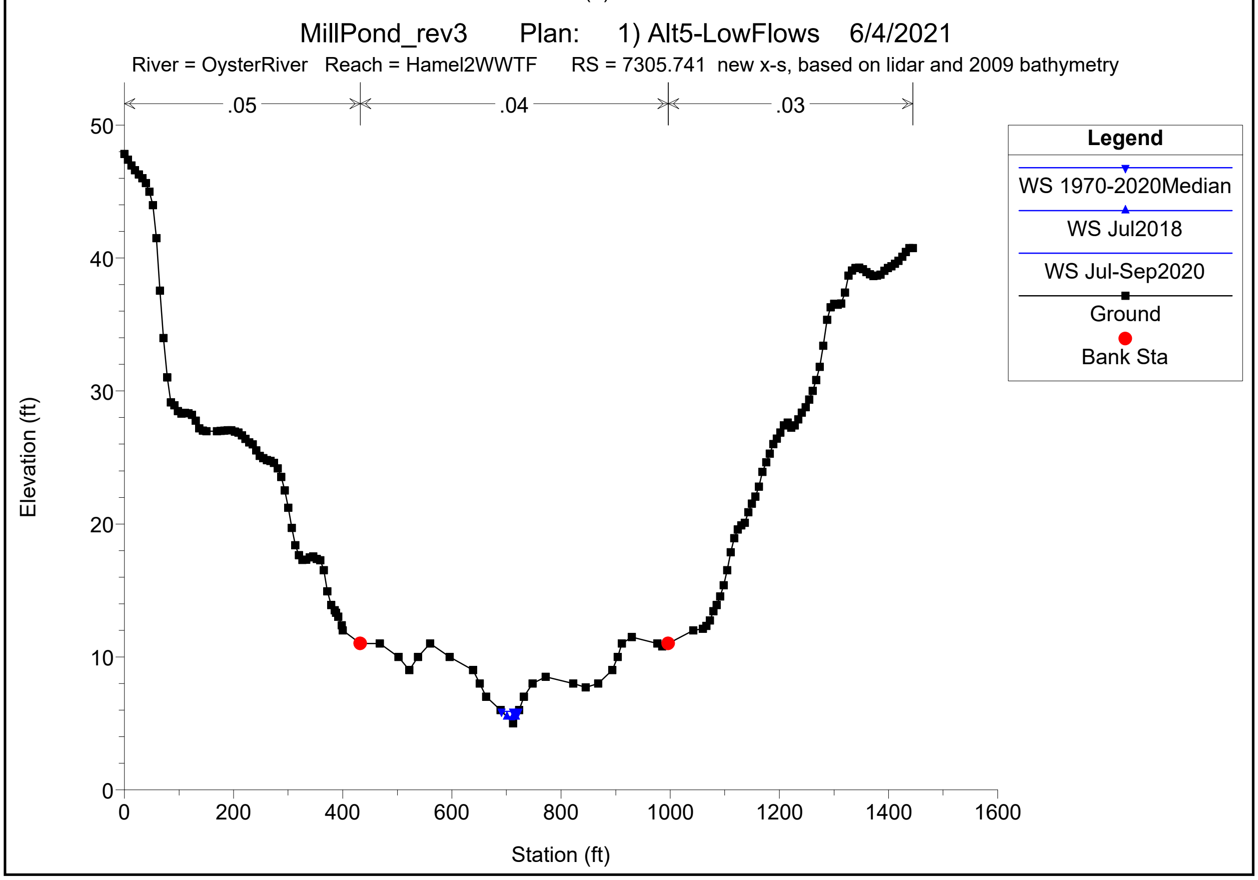
MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 7462.38 adjusted channel from 2018 W&S model based on 2009 bathymetry
.05
.04
.03
.05
.04
.05
Elevation (ft)
Station (ft)
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Ineff
Bank Sta



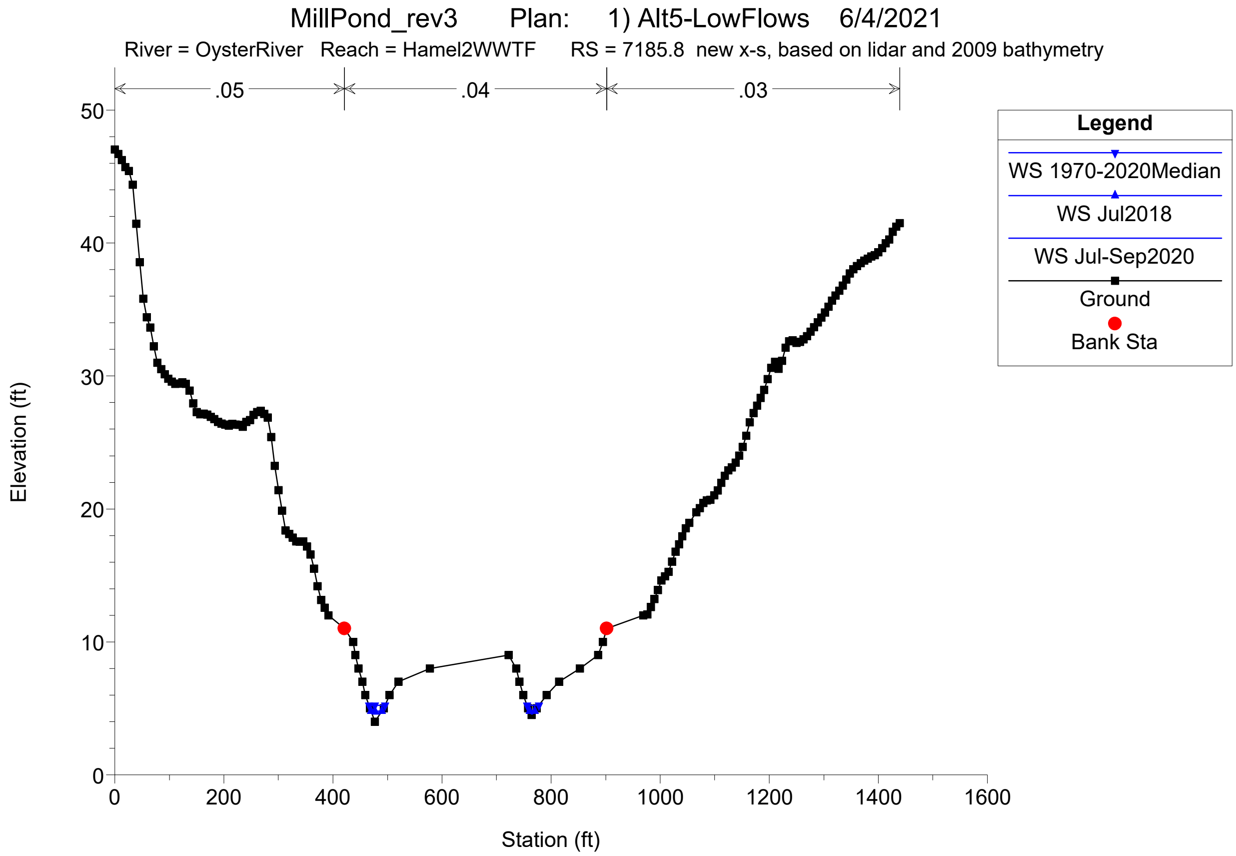
MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 7409.136 new x-s, based on lidar and 2009 bathymetry
.05
.04
.03
Elevation (ft)
Station (ft)
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta



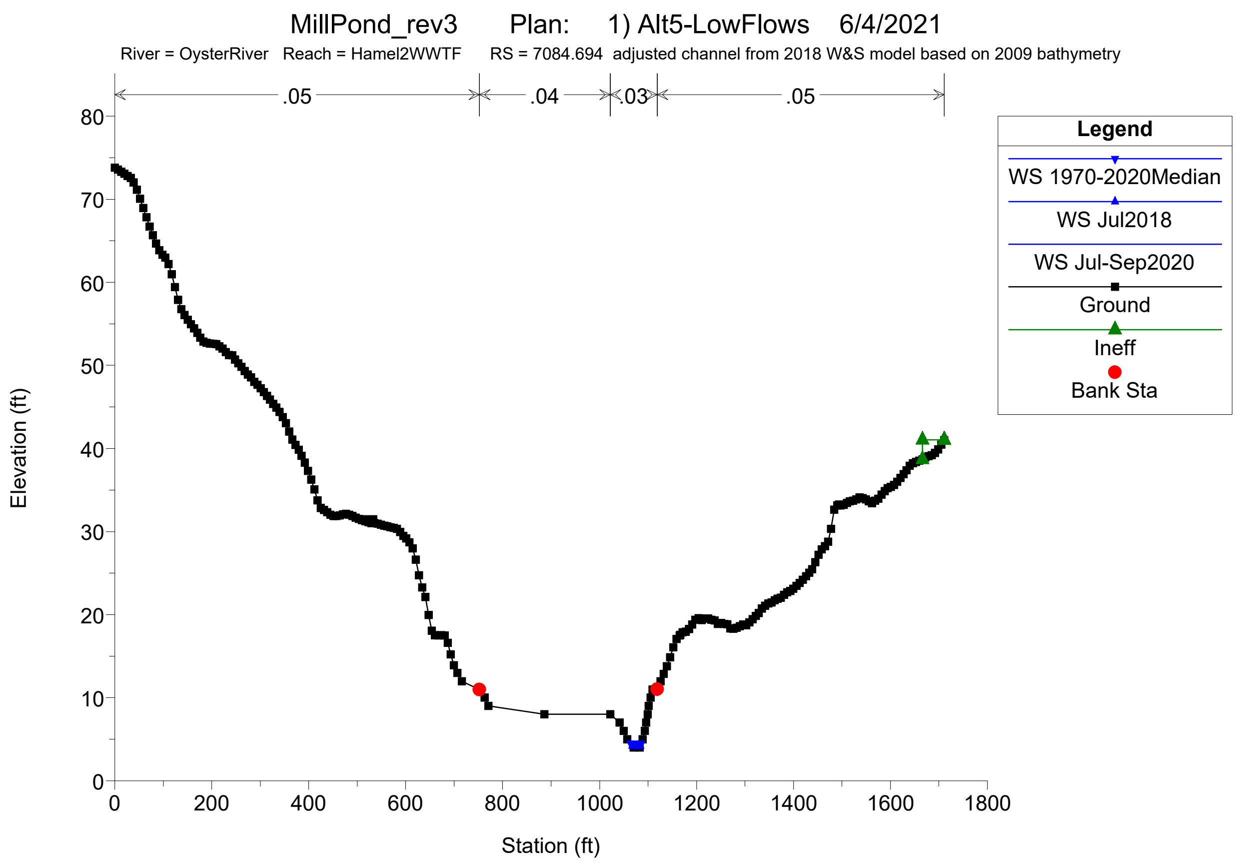
MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 7375.792 new x-s, based on lidar and 2009 bathymetry
.05
.04
.03
Elevation (ft)
Station (ft)
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta



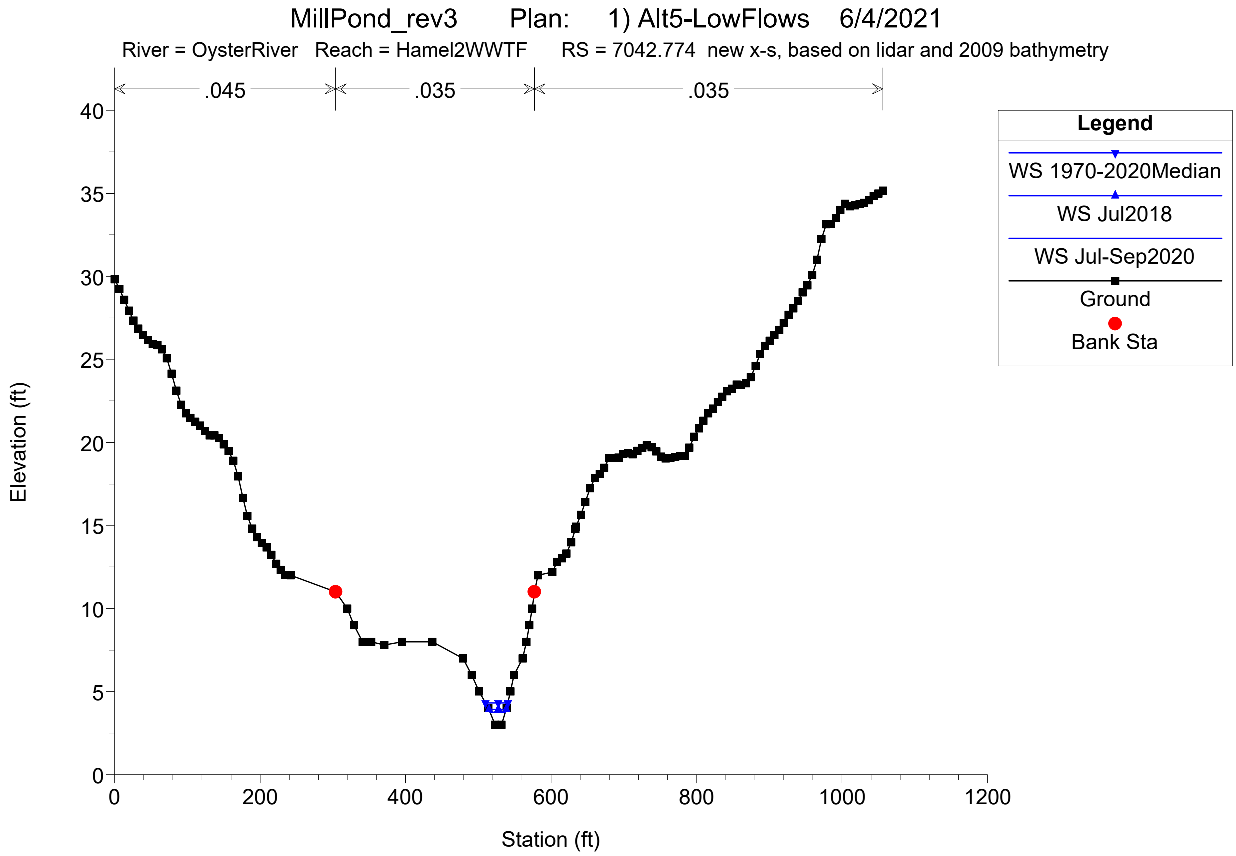
MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 7305.741 new x-s, based on lidar and 2009 bathymetry
.05
.04
.03
Elevation (ft)
Station (ft)
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta

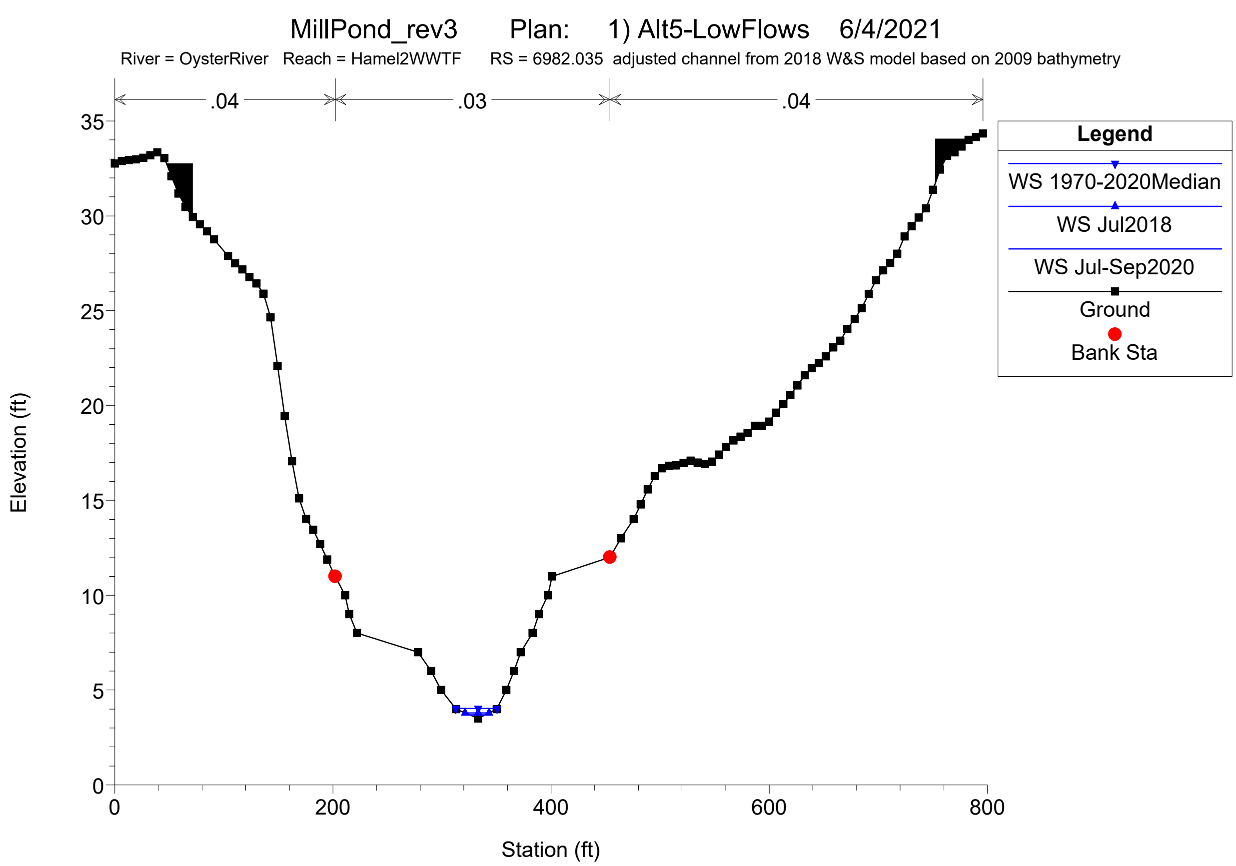


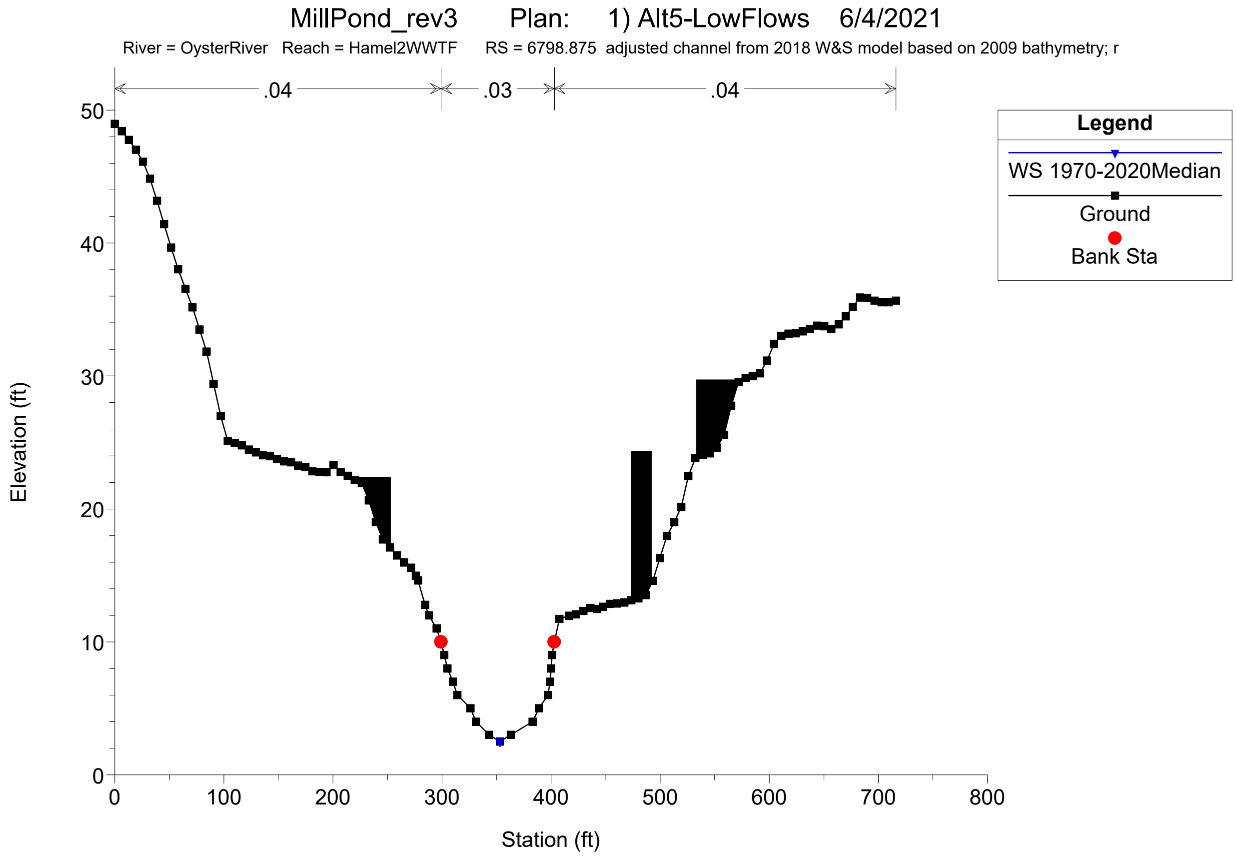
MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 7185.8 new x-s, based on lidar and 2009 bathymetry
.05
.04
.03
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)



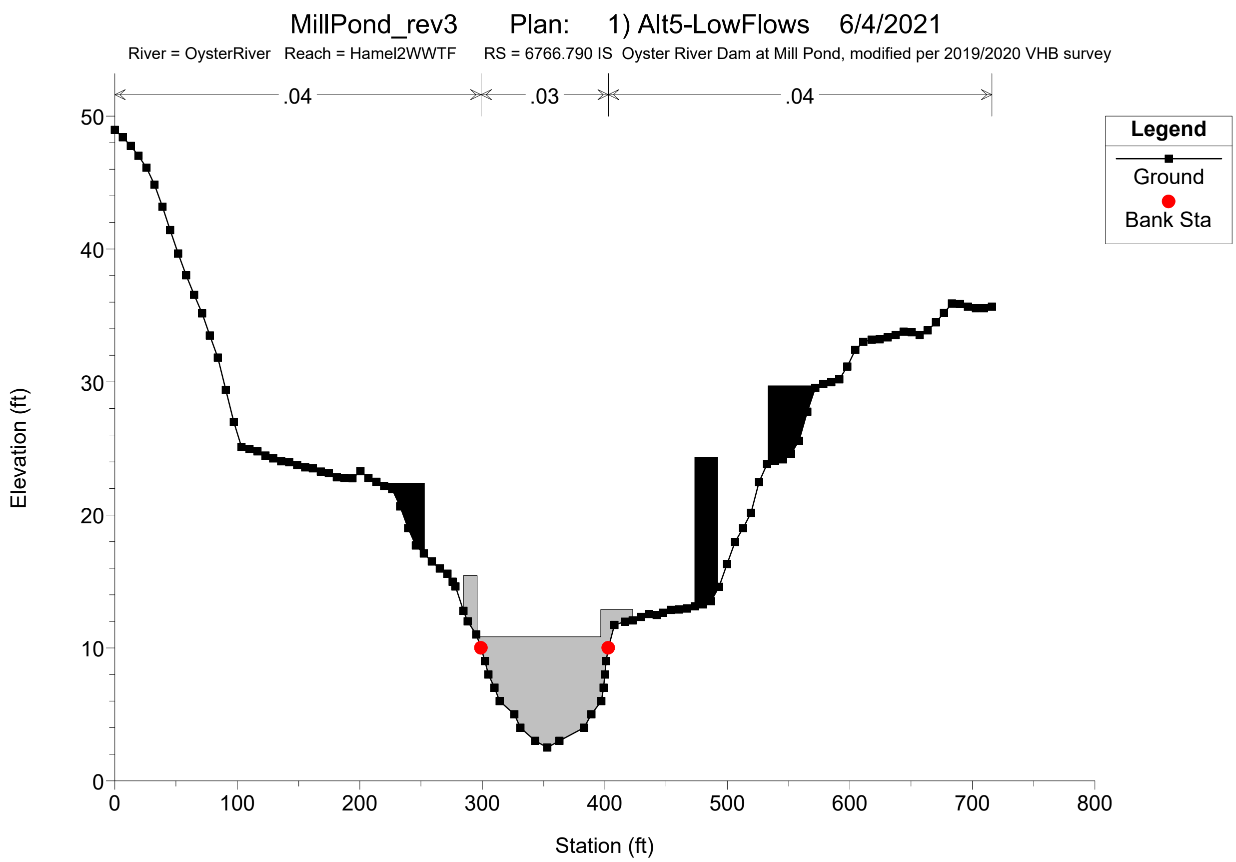
MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 7084.694 adjusted channel from 2018 W&S model based on 2009 bathymetry
.05
.04
.03
.05
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)


MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 7042.774 new x-s, based on lidar and 2009 bathymetry
.045
.035
.035
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)

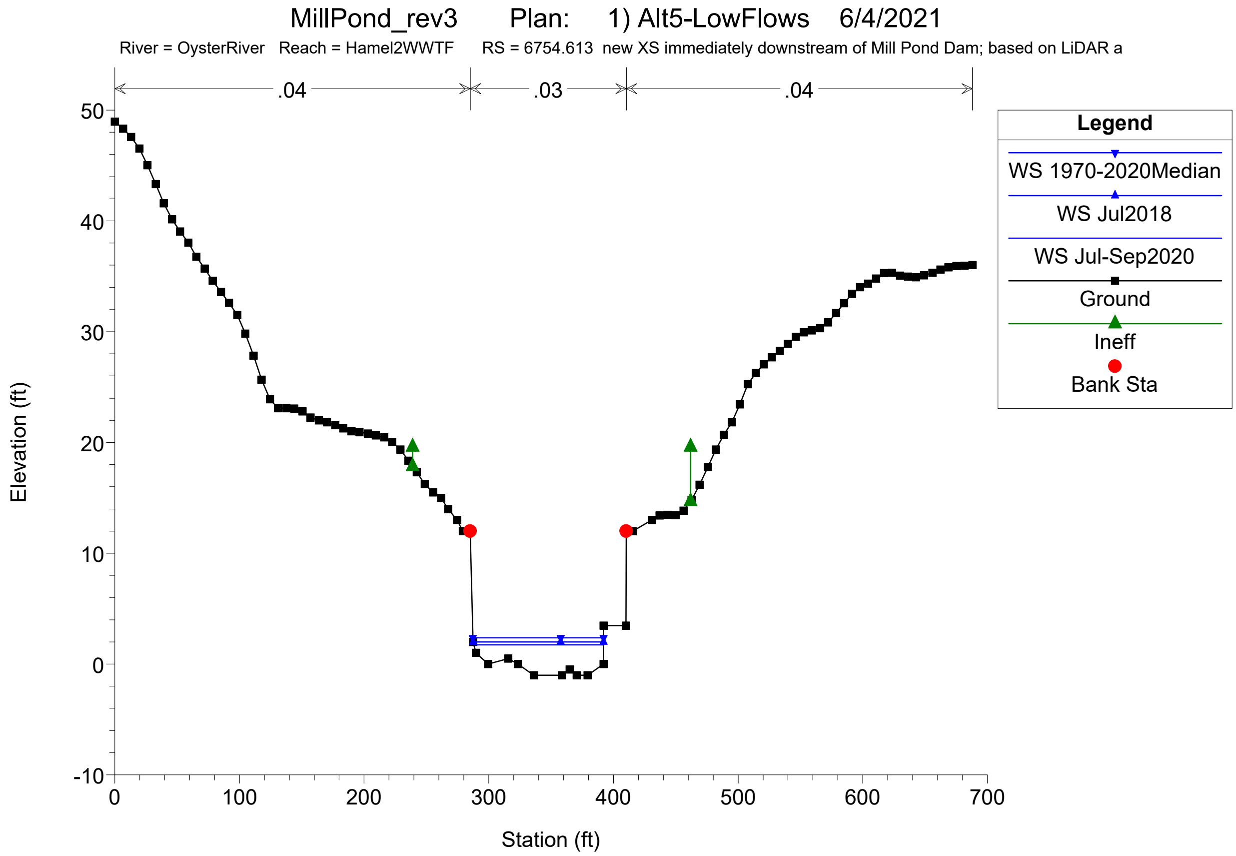

MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6982.035 adjusted channel from 2018 W&S model based on 2009 bathymetry
.04
.03
.04
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
Station (ft)

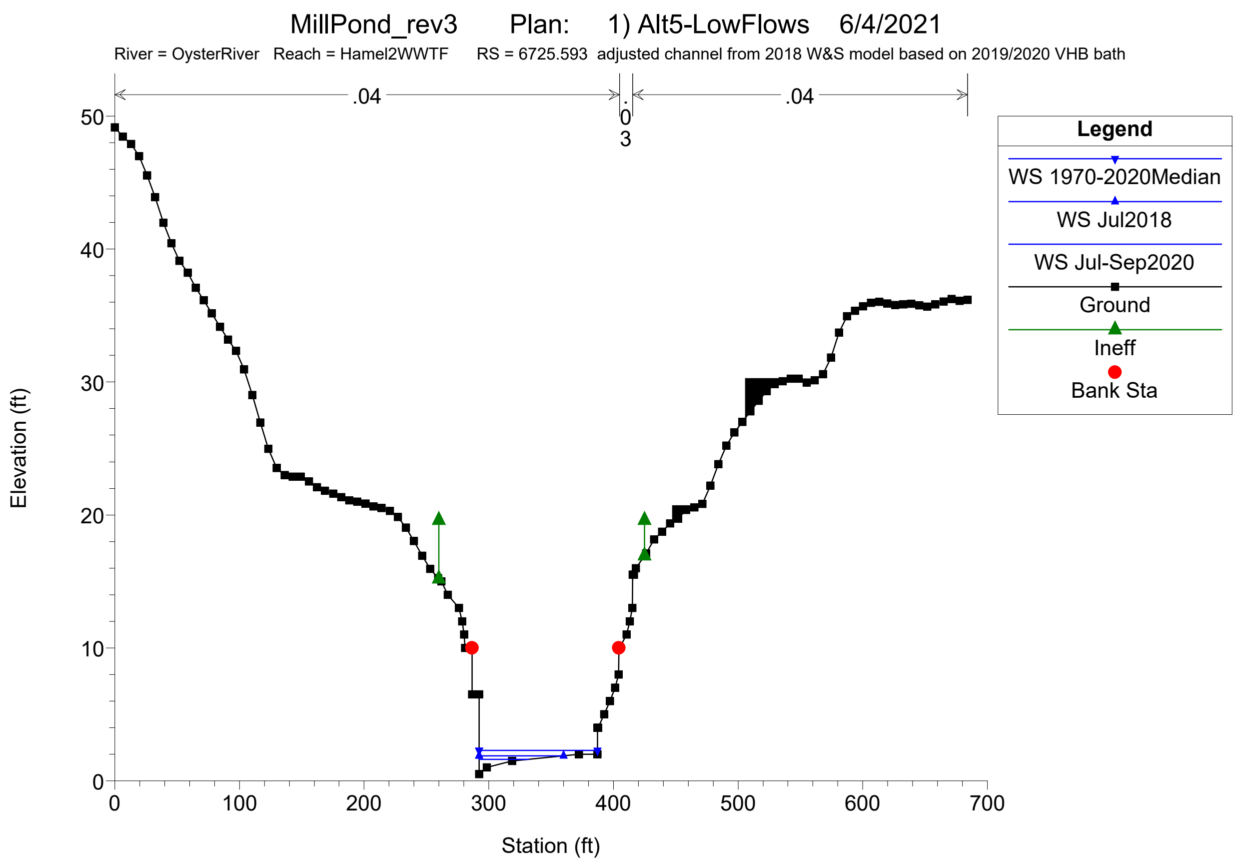


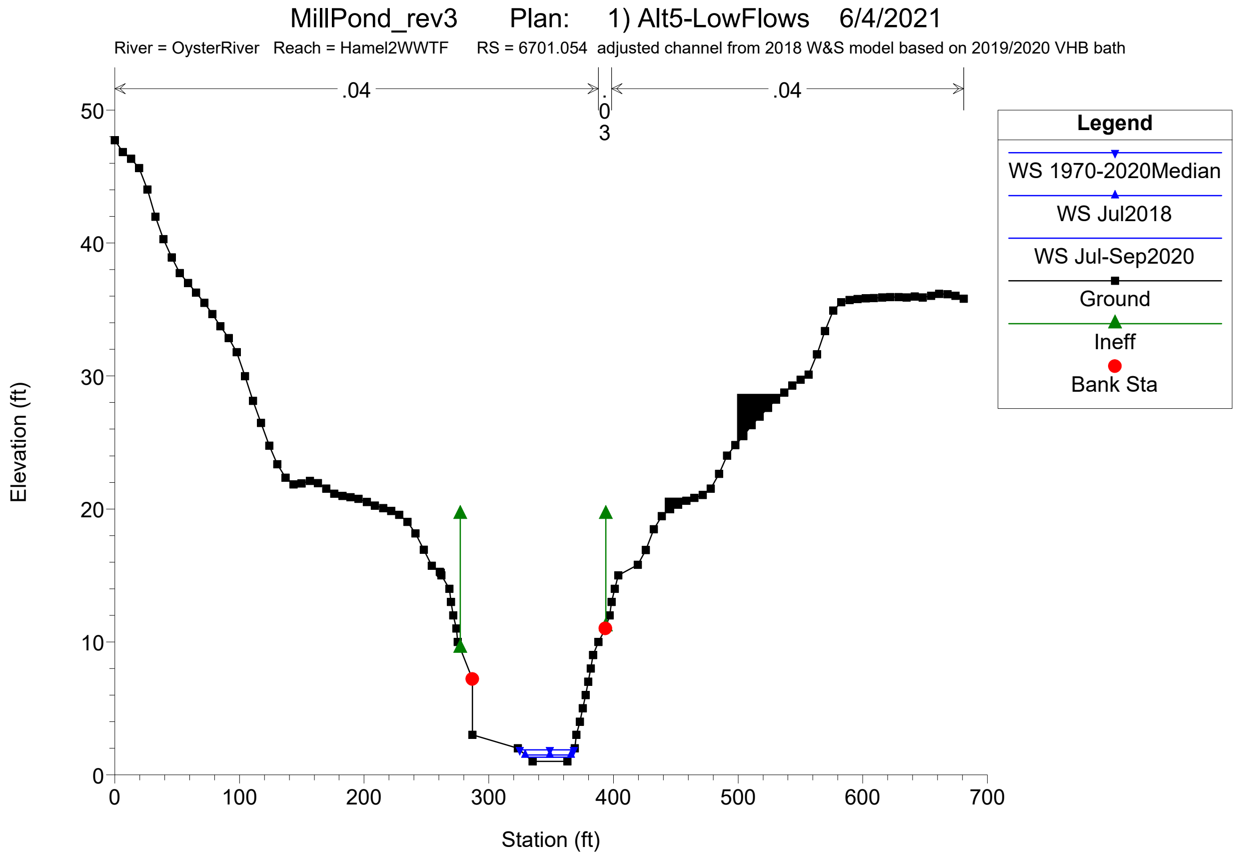
MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6798.875 adjusted channel from 2018 W&S model based on 2009 bathymetry; r
.04
.03
.04
Legend
WS 1970-2020Median
Ground
Bank Sta
Elevation (ft)
Station (ft)
0
10
20
30
40
50
0
100
200
300
400
500
600
700
800

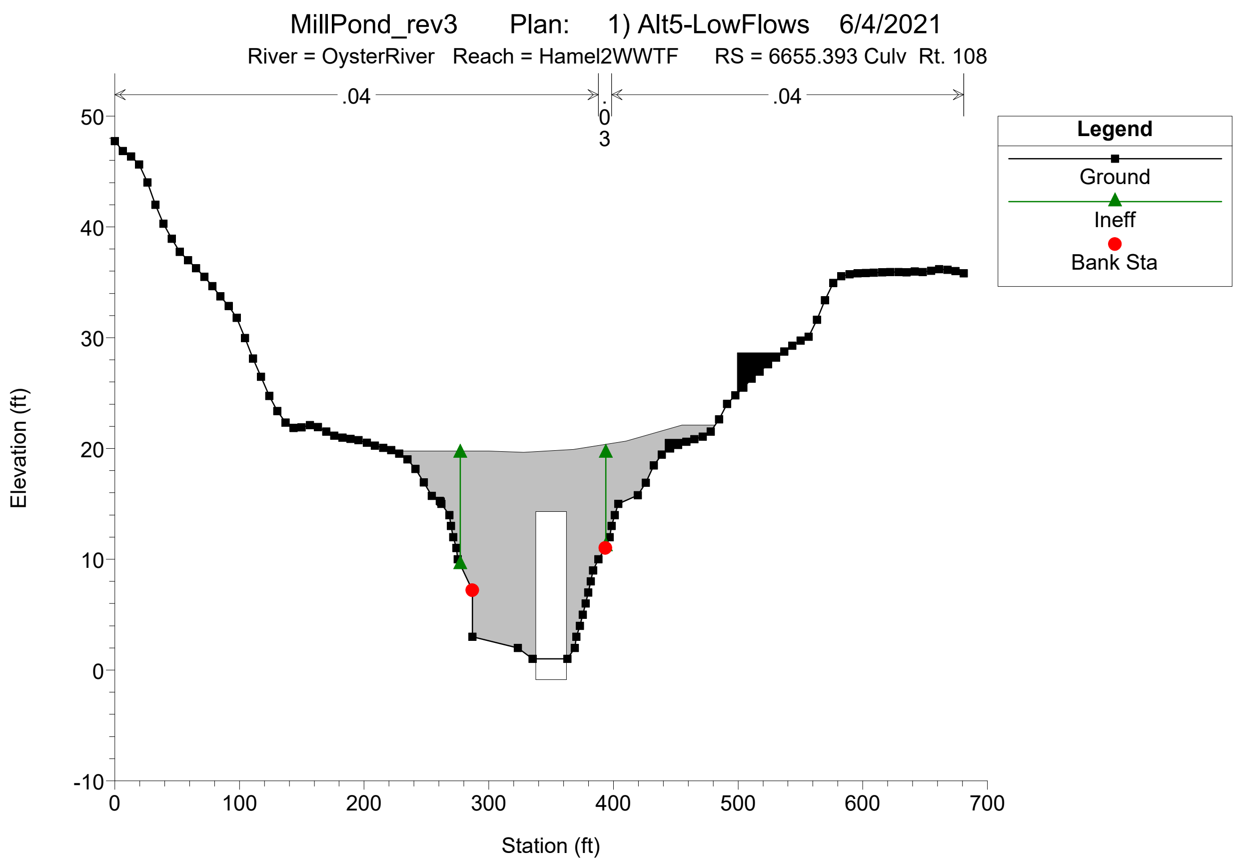


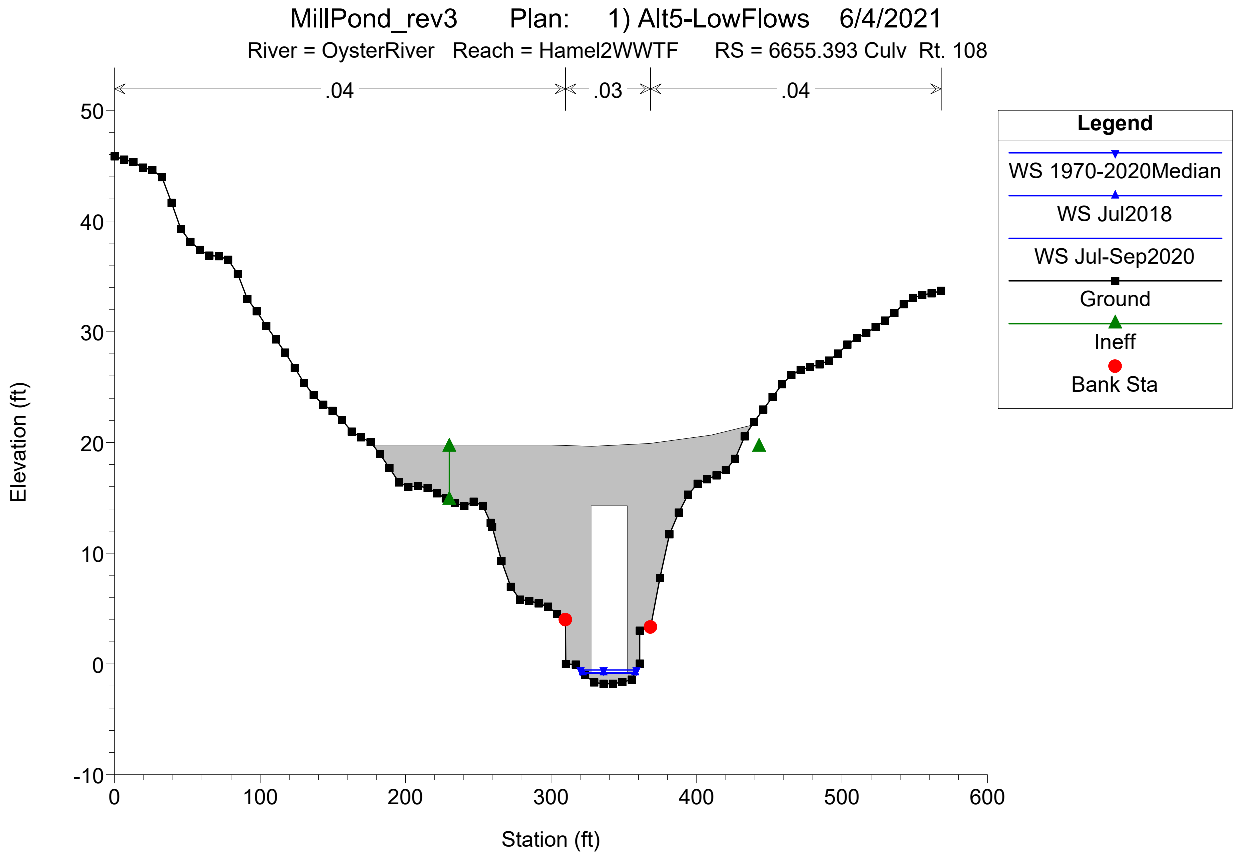
MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6766.790 IS Oyster River Dam at Mill Pond, modified per 2019/2020 VHB survey
.04
.03
.04
Legend
Ground
Bank Sta
Elevation (ft)
Station (ft)
0
10
20
30
40
50
0
100
200
300
400
500
600
700
800

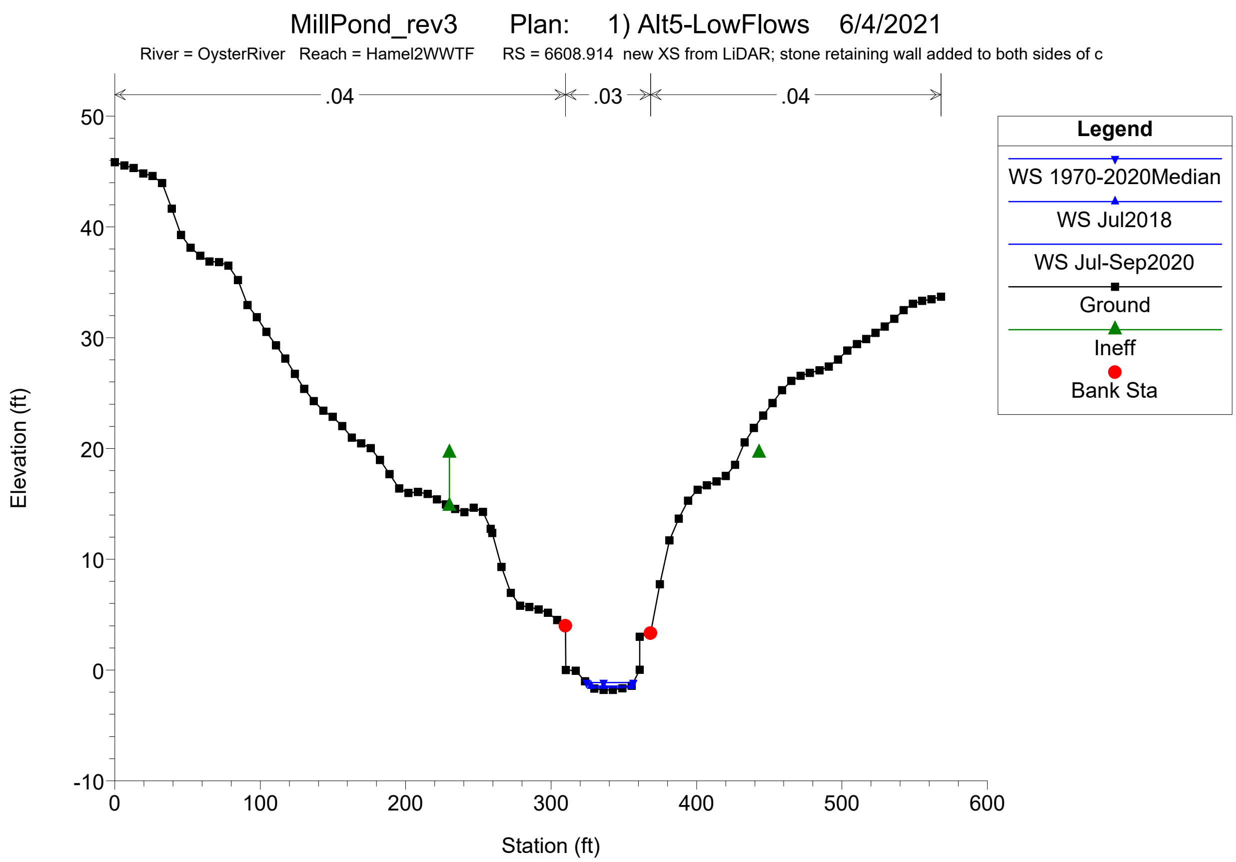

MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6754.613 new XS immediately downstream of Mill Pond Dam; based on LiDAR a
.04
.03
.04
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)

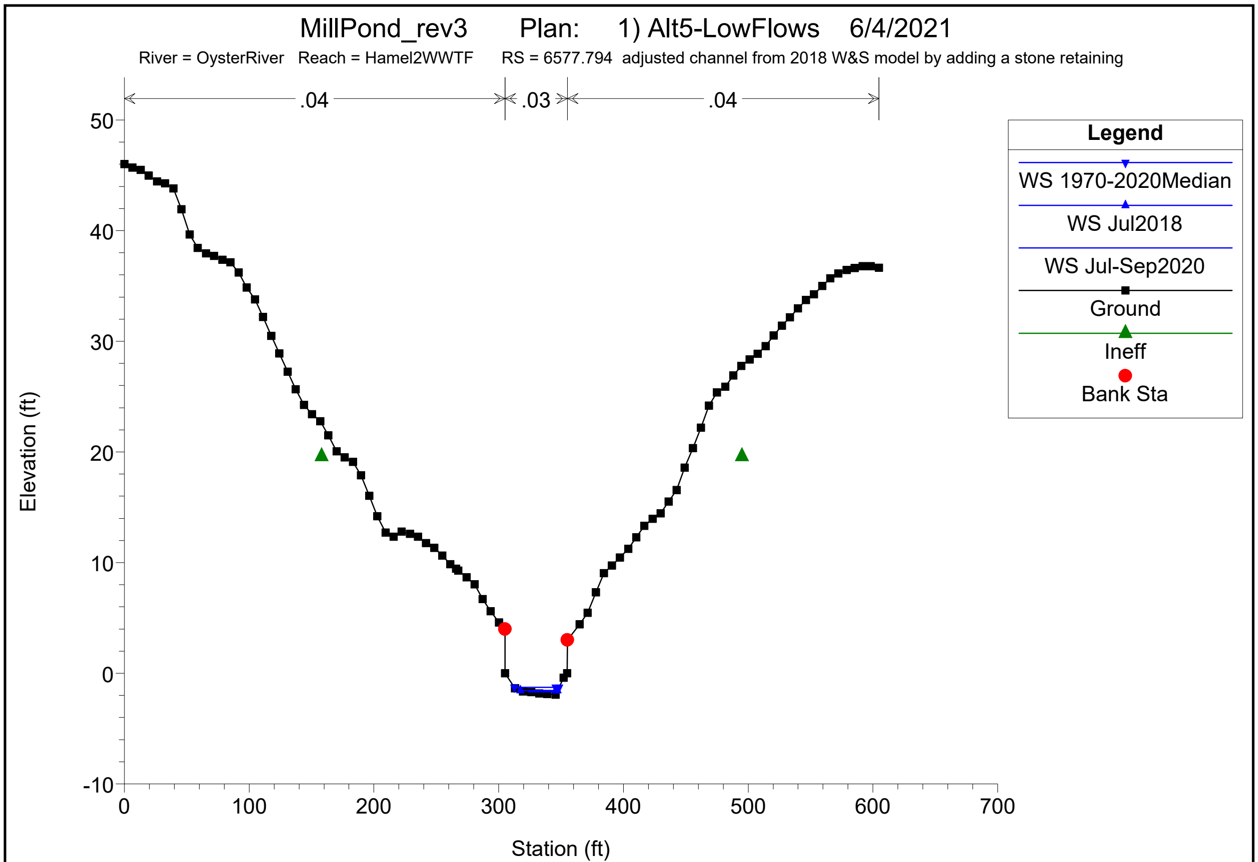

MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6725.593 adjusted channel from 2018 W&S model based on 2019/2020 VHB bath
.04
.03
.04
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)

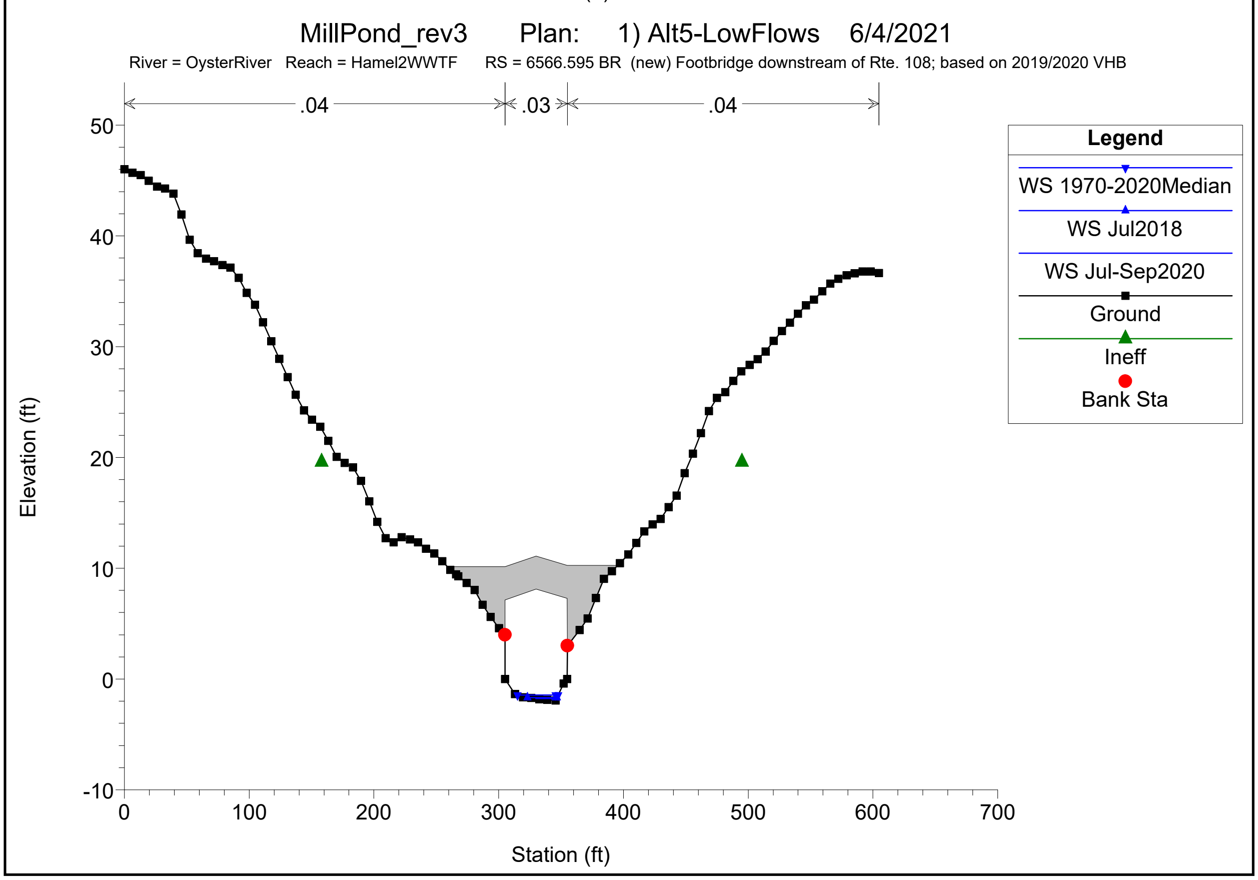

MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6701.054 adjusted channel from 2018 W&S model based on 2019/2020 VHB bath
.04
.03
.04
Elevation (ft)
Station (ft)
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Ineff
Bank Sta

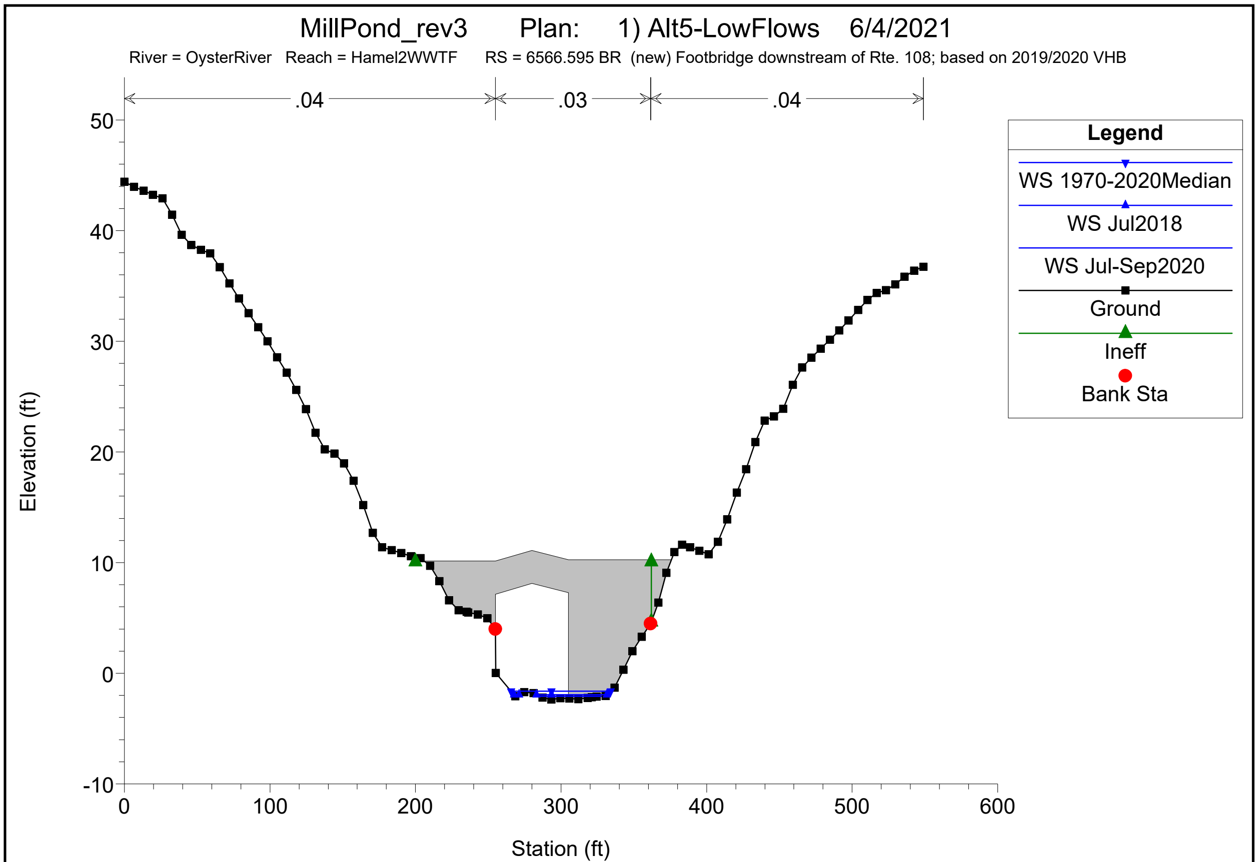

MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6655.393 Culv Rt. 108
.04
.03
.04
Elevation (ft)
Station (ft)
Legend
Ground
Ineff
Bank Sta

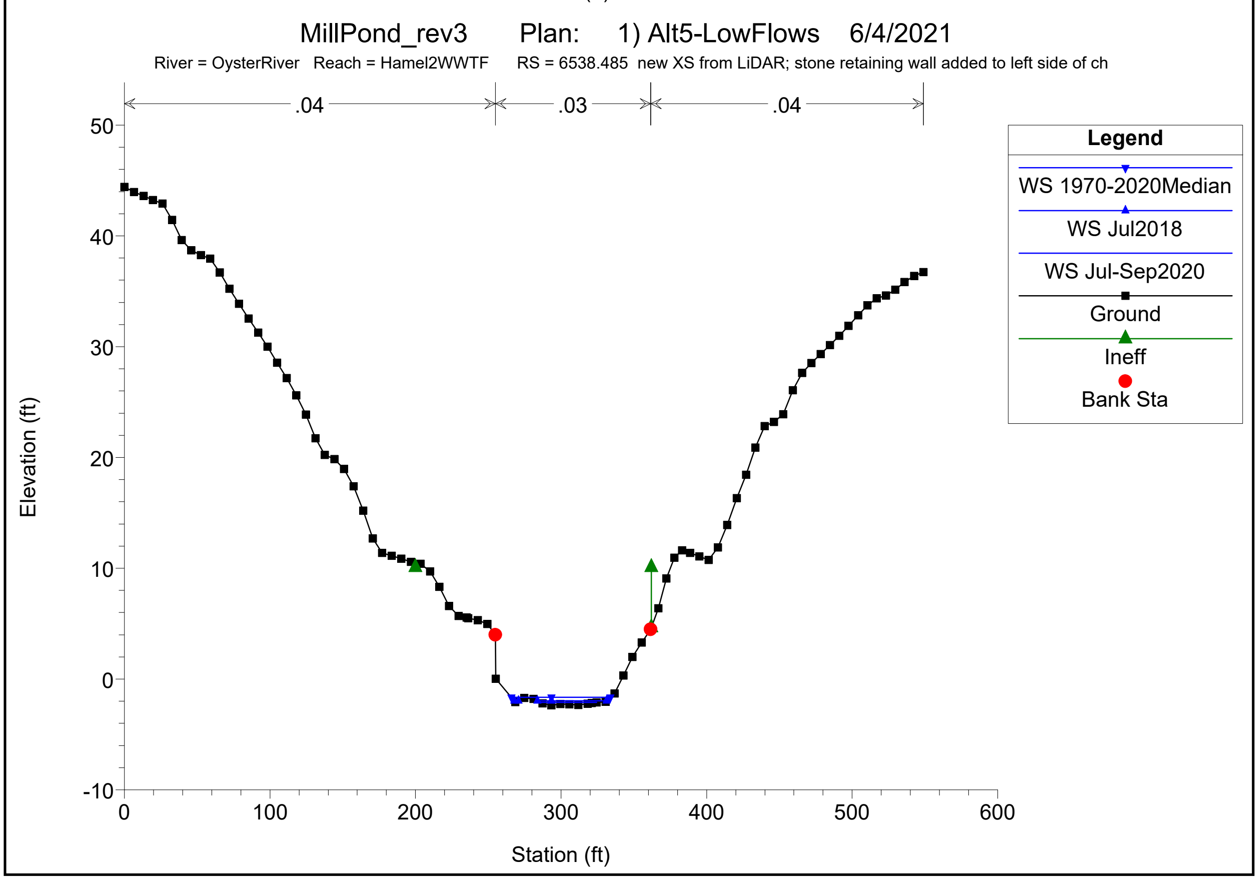

MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6655.393 Culv Rt. 108
.04
.03
.04
Elevation (ft)
Station (ft)
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Ineff
Bank Sta

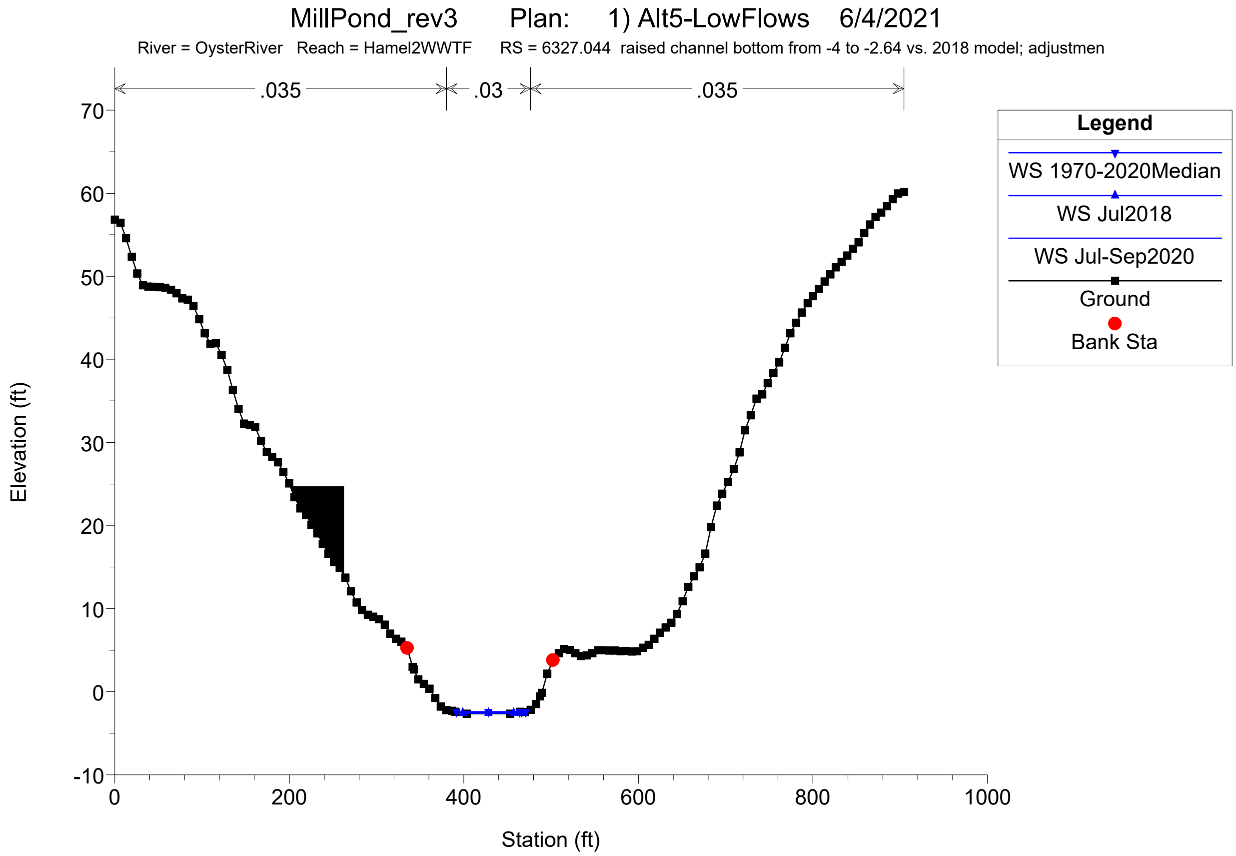

MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6608.914 new XS from LiDAR; stone retaining wall added to both sides of c
.04
.03
.04
Elevation (ft)
Station (ft)
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Ineff
Bank Sta


MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6577.794 adjusted channel from 2018 W&S model by adding a stone retaining
.04
.03
.04
Elevation (ft)
Station (ft)
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Ineff
Bank Sta


MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6566.595 BR (new) Footbridge downstream of Rte. 108; based on 2019/2020 VHB
.04
.03
.04
Elevation (ft)
Station (ft)
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Ineff
Bank Sta

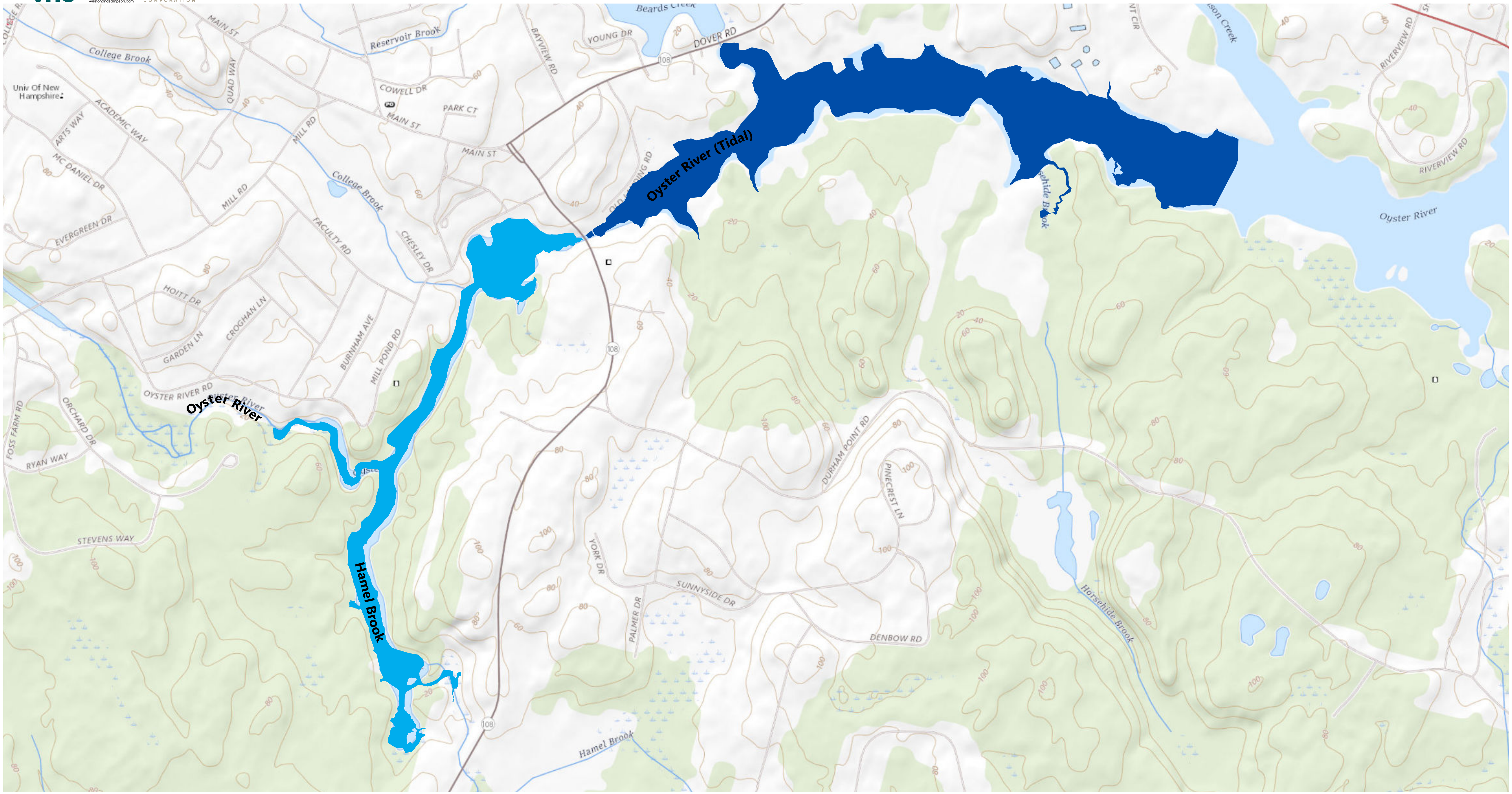

MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6566.595 BR (new) Footbridge downstream of Rte. 108; based on 2019/2020 VHB
.04
.03
.04
Elevation (ft)
Station (ft)
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Ineff
Bank Sta


MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6538.485 new XS from LiDAR; stone retaining wall added to left side of ch
.04
.03
.04
Elevation (ft)
Station (ft)
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Ineff
Bank Sta


MillPond_rev3 Plan: 1) Alt5-LowFlows 6/4/2021
River = OysterRiver Reach = Hamel2WWTF RS = 6327.044 raised channel bottom from -4 to -2.64 vs. 2018 model; adjustmen
.035
.03
.035
Legend
WS 1970-2020Median
WS Jul2018
WS Jul-Sep2020
Ground
Bank Sta
Elevation (ft)
70
60
50
40
30
20
10
0
-10
0
200
400
600
800
1000
Station (ft)

Appendix D – Low Flow Inundation Maps

Figure D-1



0 400 800 1600 Feet

Limit of Inundation

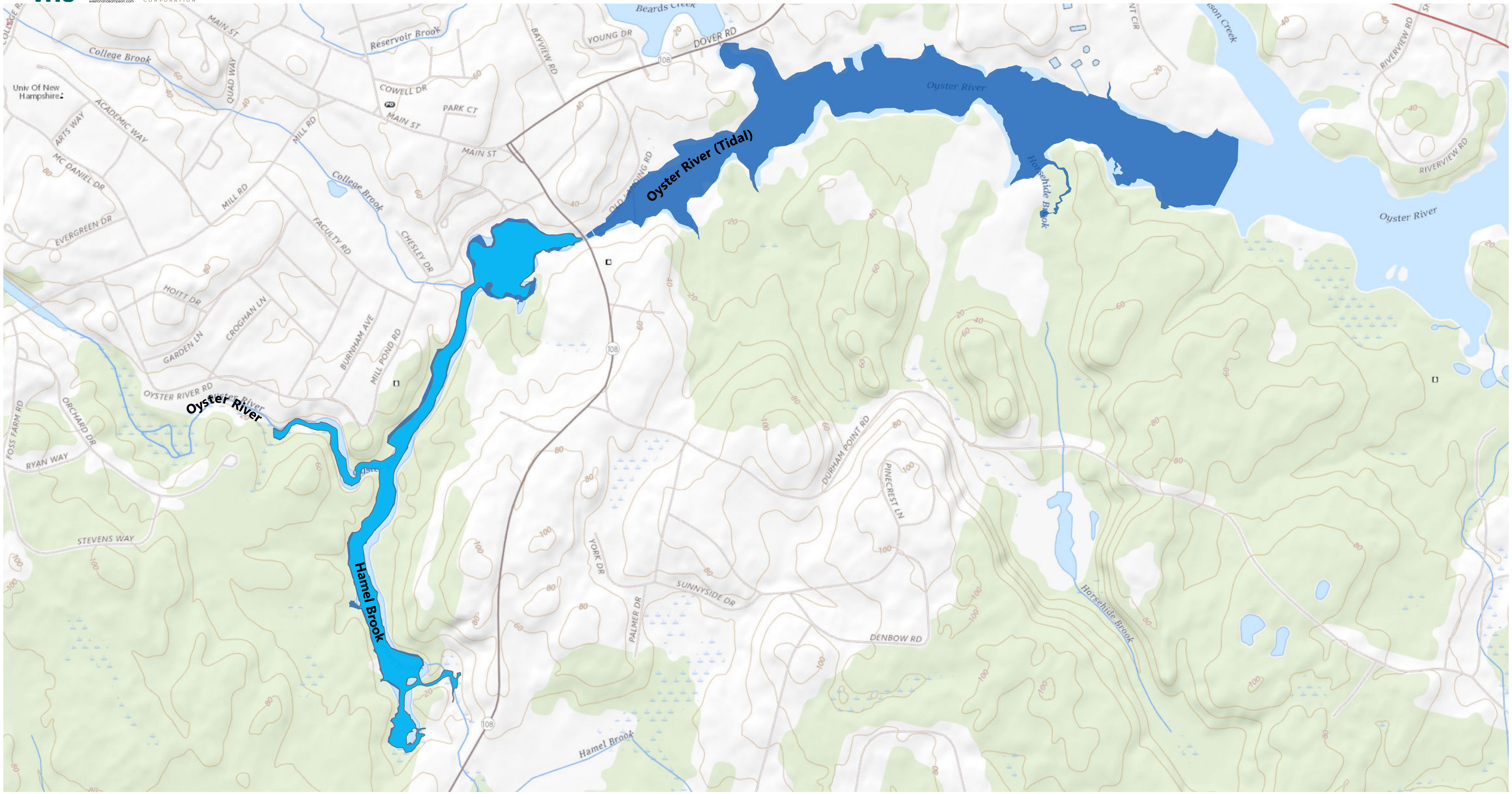
Existing Condition, Alternative 1 - Dam in Place

Oyster River Feasibility Study | Durham, New Hampshire

Source: NHDES, VHB, ArcGIS Online, Weston & Sampson

Limits of Inundation
Alternative 3 – Dam Stabilization
Median Annual Flow

Figure D-2



0 400 800 1600 Feet

Limit of Inundation

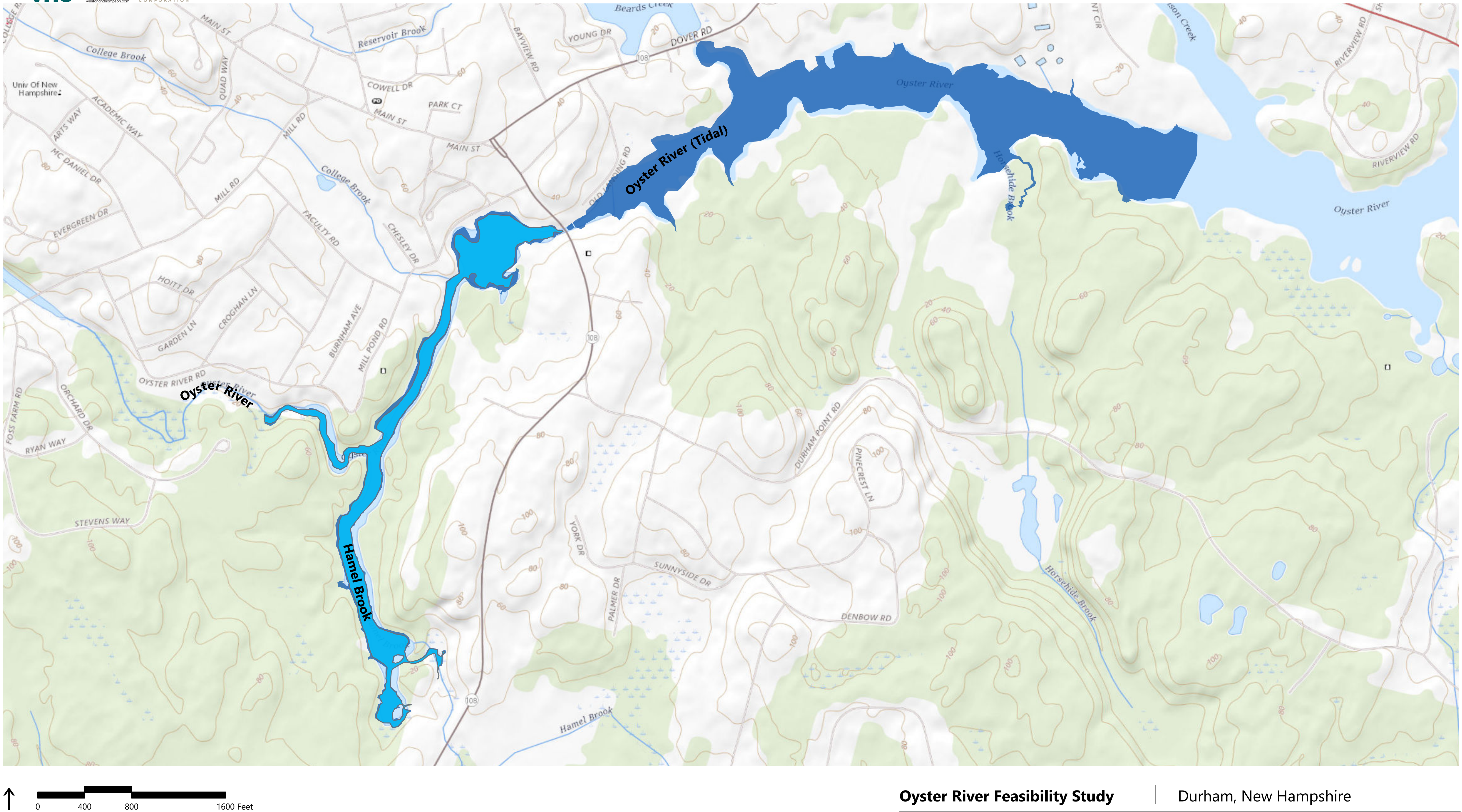
Existing Condition, Alternative 1 - Dam in Place

Oyster River Feasibility Study | Durham, New Hampshire

Source: NHDES, VHB, ArcGIS Online, Weston & Sampson

Limits of Inundation
Alternative 3 – Dam Stabilization
Typical Summer Low Flow

Figure D-3



Limit of Inundation

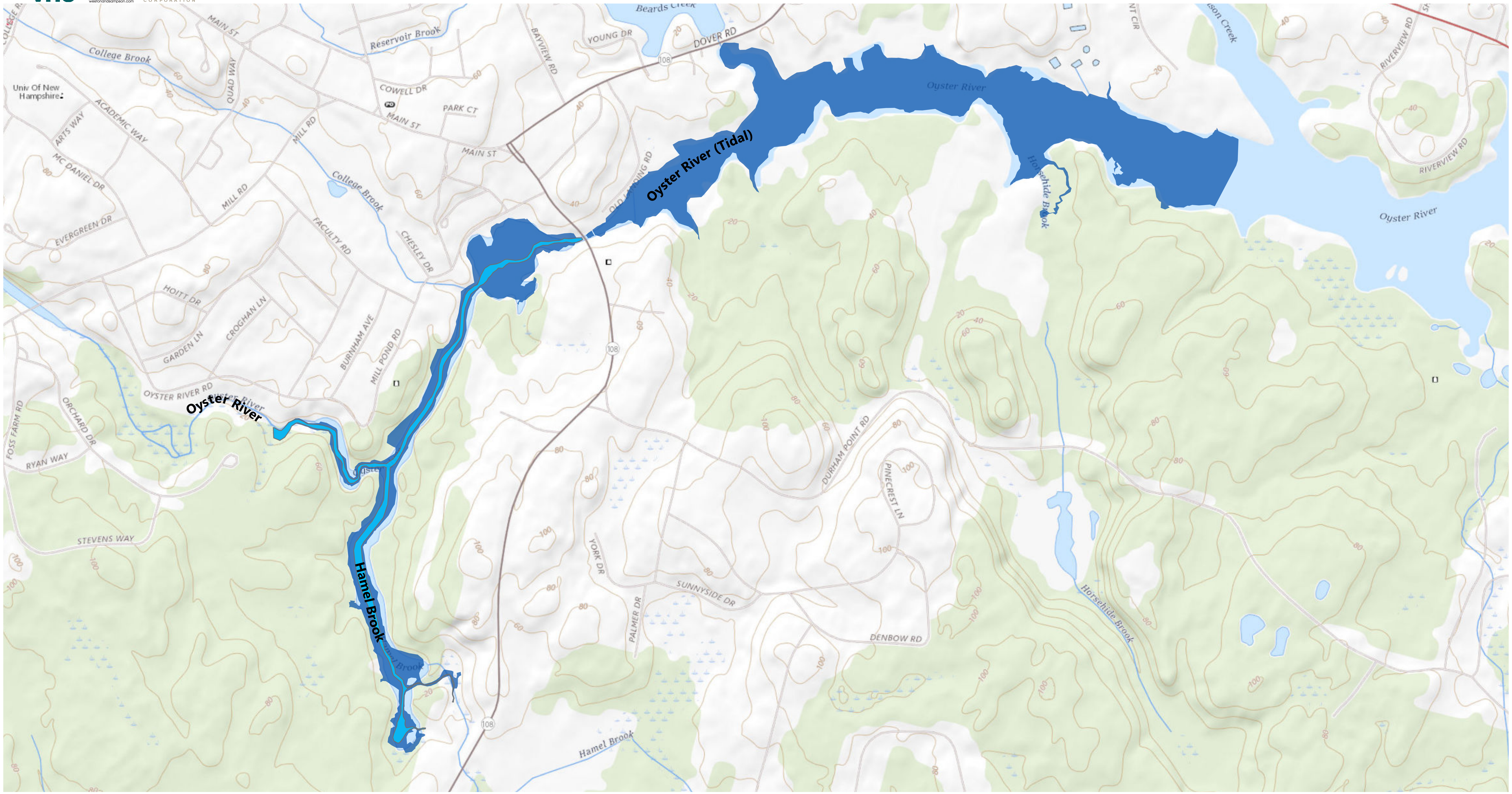
Existing Condition, Alternative 1 - Dam in Place

Oyster River Feasibility Study | Durham, New Hampshire

Source: NHDES, VHB, ArcGIS Online, Weston & Sampson

Limits of Inundation
Alternative 3 – Dam Stabilization
Drought Flows

Figure D-4



0 400 800 1600 Feet

Limit of Inundation

Existing Condition, Alternative 1 - Dam in Place

Oyster River Feasibility Study | Durham, New Hampshire

Source: NHDES, VHB, ArcGIS Online, Weston & Sampson

Limits of Inundation
Alternative 5 – Dam Removal
Low Tide, Median Annual Flow

Figure D-5

0 400 800 1600 Feet

Limit of Inundation

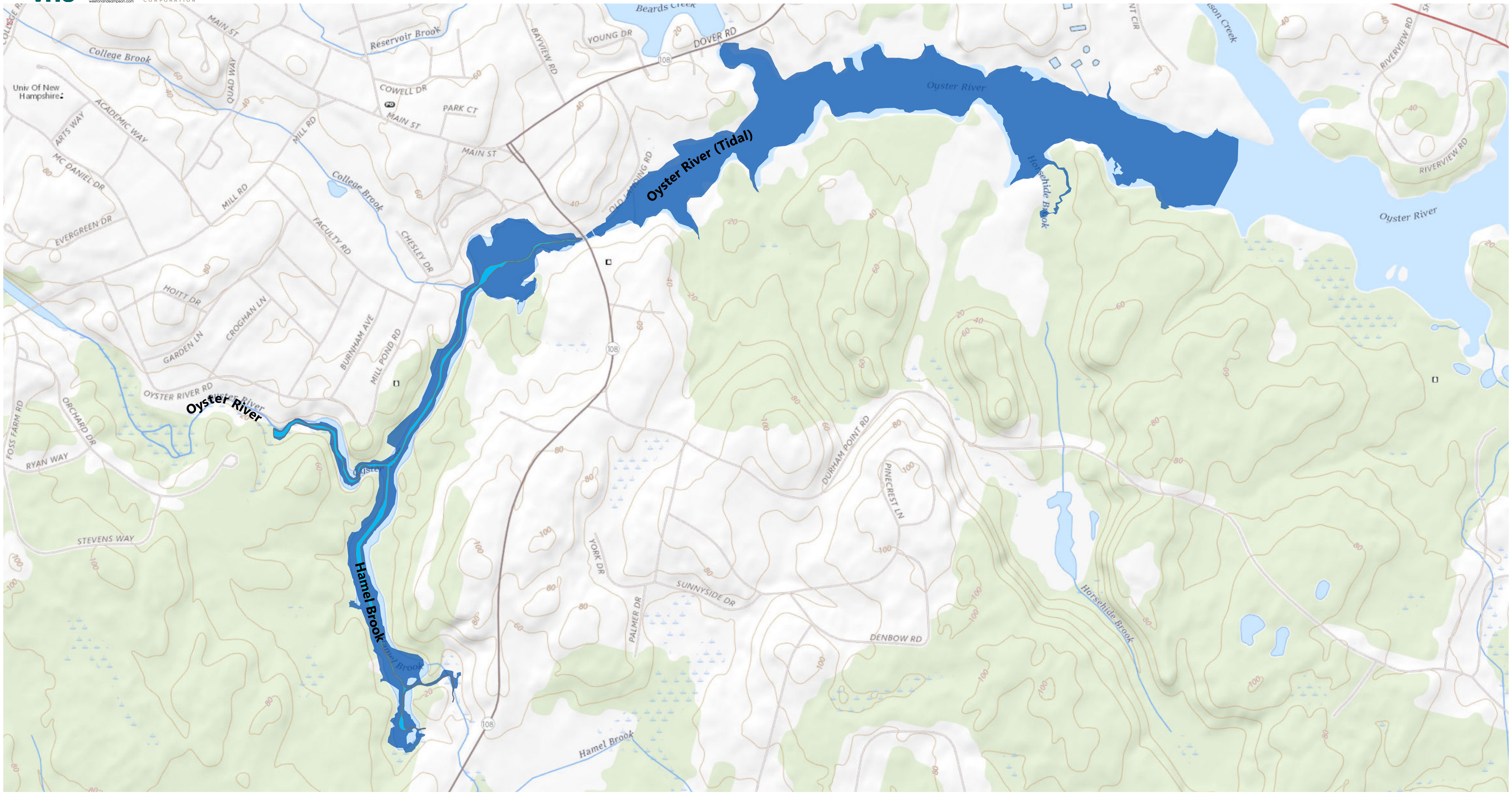
Existing Condition, Alternative 1 - Dam in Place

Oyster River Feasibility Study | Durham, New Hampshire

Source: NHDES, VHB, ArcGIS Online, Weston & Sampson

Limits of Inundation
Alternative 5 – Dam Removal
Low Tide, Typical Summer Low Flow

Figure D-6



0 400 800 1600 Feet

Limit of Inundation

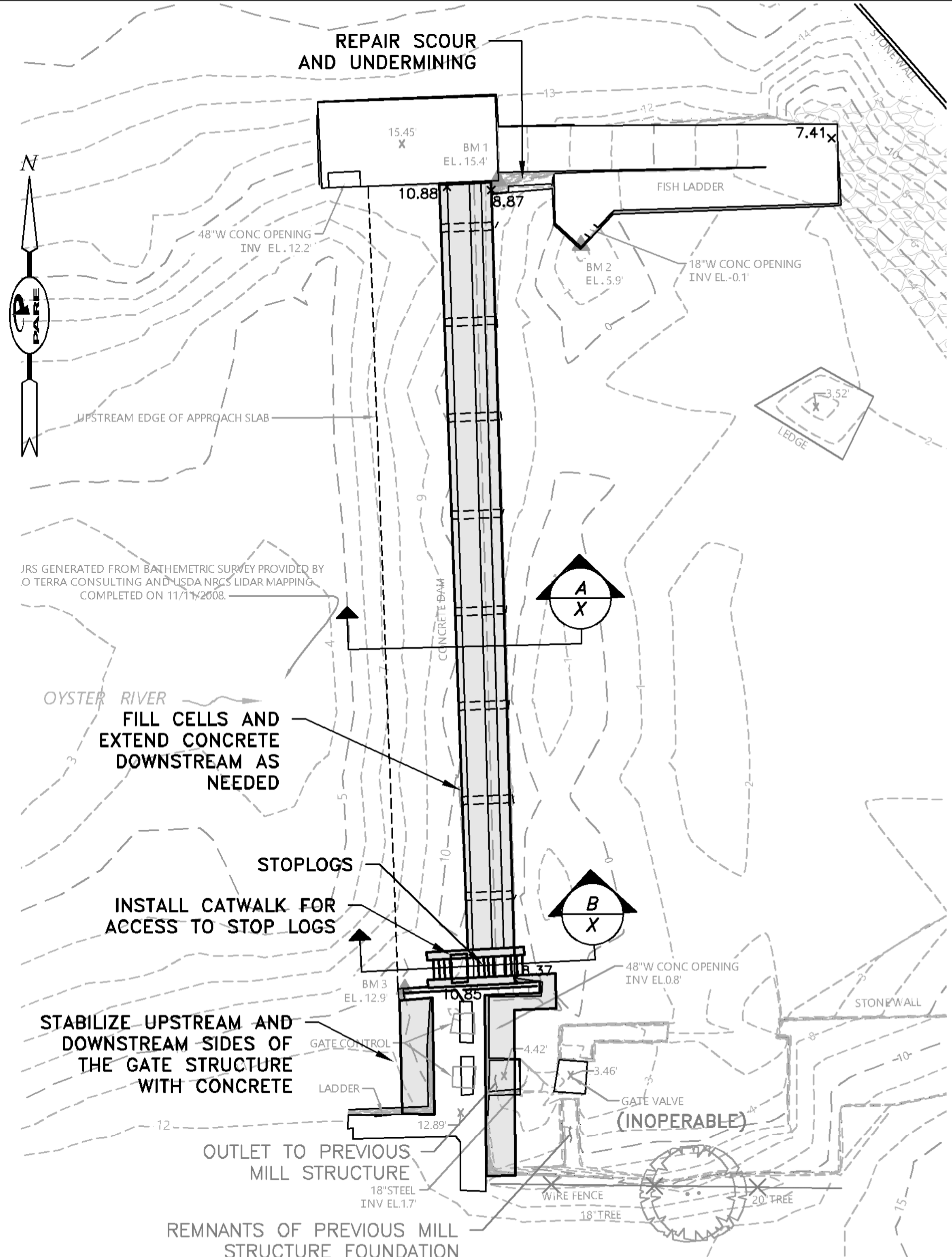
Existing Condition, Alternative 1 - Dam in Place

Oyster River Feasibility Study | Durham, New Hampshire

Source: NHDES, VHB, ArcGIS Online, Weston & Sampson

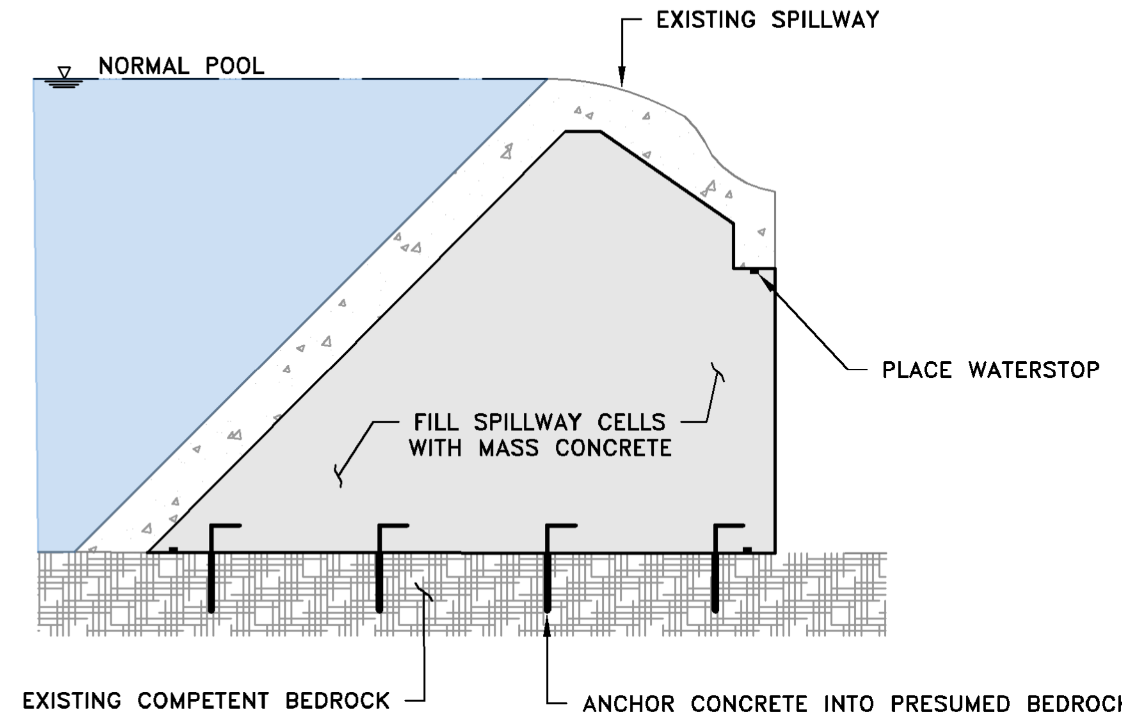
Limits of Inundation
Alternative 5 – Dam Removal
Low Tide, Very Low Flow

Appendix E – Conceptual Dam Stabilization Plan with Notch



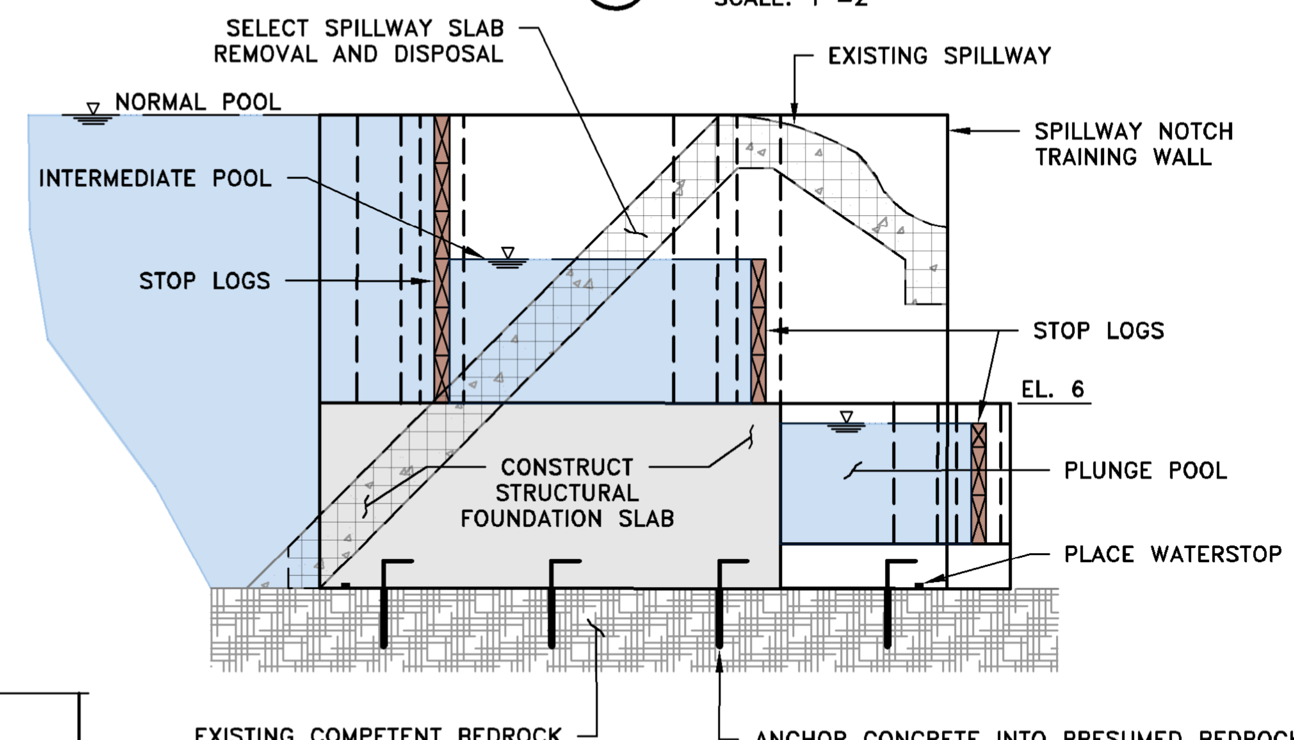
SITE SKETCH

SCALE: 1"=20'±



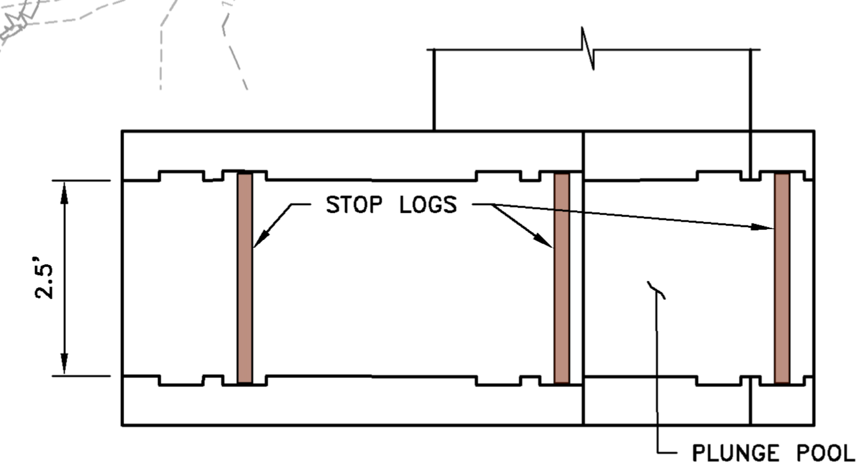
SECTION A

SCALE: 1"=2'



SECTION B

SCALE: 1"=2'



NOTCH PLAN

NOT TO SCALE

PARE CORPORATION
ENGINEERS • SCIENTISTS • PLANNERS
10 LINCOLN ROAD, SUITE 210
FOXBORO, MA 02035
508-543-1755

vhb

westonandsampson.com

MILL POND DAM
D71.03
DURHAM, NEW HAMPSHIRE
OWNER: TOWN OF DURHAM

SCALE ADJUSTMENT GUIDE
0" 1"
BAR IS ONE INCH ON ORIGINAL DRAWING.

REVISIONS:

PROJECT NO.:	19169.00
DATE:	APRIL 2021
SCALE:	AS NOTED
DESIGNED BY:	HMS
CHECKED BY:	ARO
DRAWN BY:	LMC
APPROVED BY:	ARO

CONCEPTUAL DAM STABILIZATION SKETCH

FIGURE NO.: X

Y:\JOBS\19 Jobs\19169.00 VHB-OysterRiver-Mill Pond Dam Feasibility-MA\dwgs\Conceptual Alternatives\FIG X ALT 3 STABILIZE WITH NOTCH.dwg