

DRAFT

Resource Management Plan for Monponsett Pond

July 2021



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Section 1

Introduction

1.1 Project Scope

Humans impact freshwater systems, particularly when water sources serve multiple uses. Monponsett Pond, located in Halifax and Hanson, MA, is one such water source, as it serves as a drinking water supply for the City of Brockton, cranberry bog irrigation source, aquatic life habitat, and community and recreational asset.

This report addresses the Resource Management Plan (RMP) requirements of the May 21, 2019 amendment to the Administrative Consent Order (ACO), Enforcement Document No. 0001010. The ACO defines the RMP as recommending “metrics and procedures for Silver Lake diversions and Stump Brook Dam operations intended to improve Monponsett Pond’s water quality and ecosystem while maintaining Brockton’s drinking water supply reliability.”

The amendment to the ACO requires the RMP include the elements listed below, along with the report section(s) where the requirements are addressed.

- a. Establishment of monthly Monponsett Pond elevation goals or some other metric on which to base Stump Brook Dam operating procedures to balance the needs to providing:
 - Stump Brook flow
 - Better flood control, including reduced need of flood control diversions to Silver Lake
 - Improved flushing of West Monponsett Pond
 - Fish passage
 - Adequate water depth for bathing, fishing, and cranberry cultivation
 - Impoundment to provide adequate water for Silver Lake diversions
- b. Research compilation to provide historical pond elevation information, using available data from the US Geological Survey (USGS) and other agencies, for comparison to more recent pond elevation trends
- c. Collection of flow data to correlate Silver Lake diversion rates with flow rates from West Monponsett Pond (WMP) to East Monponsett Pond (EMP) during diversions to Silver Lake
- d. Performance of an evaluation to determine feasibility and effectiveness of seasonally adjusting flow out of Monponsett Pond to Stump Brook to increase spring flushing rates in WMP enough to reduce summertime nutrient levels and stagnation in WMP and potentially reduce the frequency of warm weather cyanobacteria

- e. Development of a Stump Brook Dam operating procedures manual based on the information and findings from completion of above requirements
- f. Develop of a Silver Lake Diversion operating procedures manual based on information and findings from completion of the above requirements (a-d).
- g. Compilation of a recommended actions list and prepare a preliminary feasibility assessment of additional measures that could be performed by others, including but not limited to, the Towns of Halifax and Hanson, area cranberry growers and residents to improve water quality in Monponsett Pond, such as: programs to upgrade septic systems; improved stormwater management, installation of a control structure between EMP and WMP, and utilization of alternative procedures and/or technologies, and chemical treatment. Implementation of recommended actions list prepared herein is not the responsibility of the City.

The scope of work to address the ACO/RMP requirements were developed with review by MassDEP and the public, with the draft scope of work having been presented at a public hearing. The final RMP scope of work dated July 19, 2018 is provided in **Appendix A**. The final RMP scope of work was made to be available to the public on the City of Brockton website, and paper copies of the document were available at Brockton City Hall, and the Halifax and Hanson Town Hall. The final scope of work includes the following main tasks:

- Task 1 – Project Scoping and Regulatory Coordination
- Task 2 – Document Historical Practices and Existing Pond Uses and Conditions, and Develop Monthly Pond Water Level Targets (ACO Item 33a)
- Task 3 – Research Historical Pond Elevations (ACO Item 33b)
- Task 4 – Collect Flow Data at Route 58 Culvert (ACO Item 33c)
- Task 5 - Estimate Seasonal Releases to Stump Brook (ACO Item 33d)
- Task 6 - Operating Procedures for Silver Lake Diversion and Stump Brook Dam (ACO Items 33e and 33f)
- Task 7 – Recommend Action Items and Preliminary Feasibility Assessment (ACO Item 33g)
- Task 8 – Draft Report Preparation and Public Comment (ACO Item 36)

1.2 Monponsett Pond

The Monponsett Pond complex is located in Halifax and Hanson, MA. **Figure 1-1** is a map of the pond and its watershed; the watershed boundary was taken from MassGIS. The pond is comprised of two basins, East Monponsett Pond (EMP) and West Monponsett Pond (WMP), connected by an eight-foot wide by 5 foot, 2-inch-high box culvert. This culvert is located at the southern end of the ponds under Route 58. The ponds are classified as public water supplies by MassDEP. Characteristics of the ponds are listed in **Table 1-1**.

Table-1-1. Monponsett Pond Characteristics

	EMP	WMP
Watershed Area ¹	2,212 acres	3,845 acres
Pond Area	246 acres	282 acres
Elevation (NGVD29)	52 ft	52 ft
Maximum Depth	13 ft	13 ft
Average Depth	7 ft	7 ft

¹Watershed delineated using USGS StreamStats

The ponds are part of the Taunton River watershed. The natural routing of water is from Stetson Brook to EMP, through the culvert to WMP, and out to Stump Brook, which flows into the Satucket River, a tributary of the Taunton River. As authorized through 1964 and 1981 Acts of the Legislature, Brockton operates a water supply diversion in EMP, which transfers some of this water to Silver Lake, which is in the Jones River watershed.

Pond levels are controlled by natural hydrology, a dam on Stump Brook and diversions to Silver Lake. The diversion inlet is in the southeast corner of EMP, while Stump Brook originates in the northwest corner of WMP. Historically, the spillway elevation of the Stump Brook dam, which is the crest of the dam, was reported to be 53 ft NGVD; a recent survey (GHD Group 2015) noted a spillway elevation of 52.74 ft. For this RMP, a spillway elevation of 53 ft is used as it is unknown where the GHD survey point was collected.

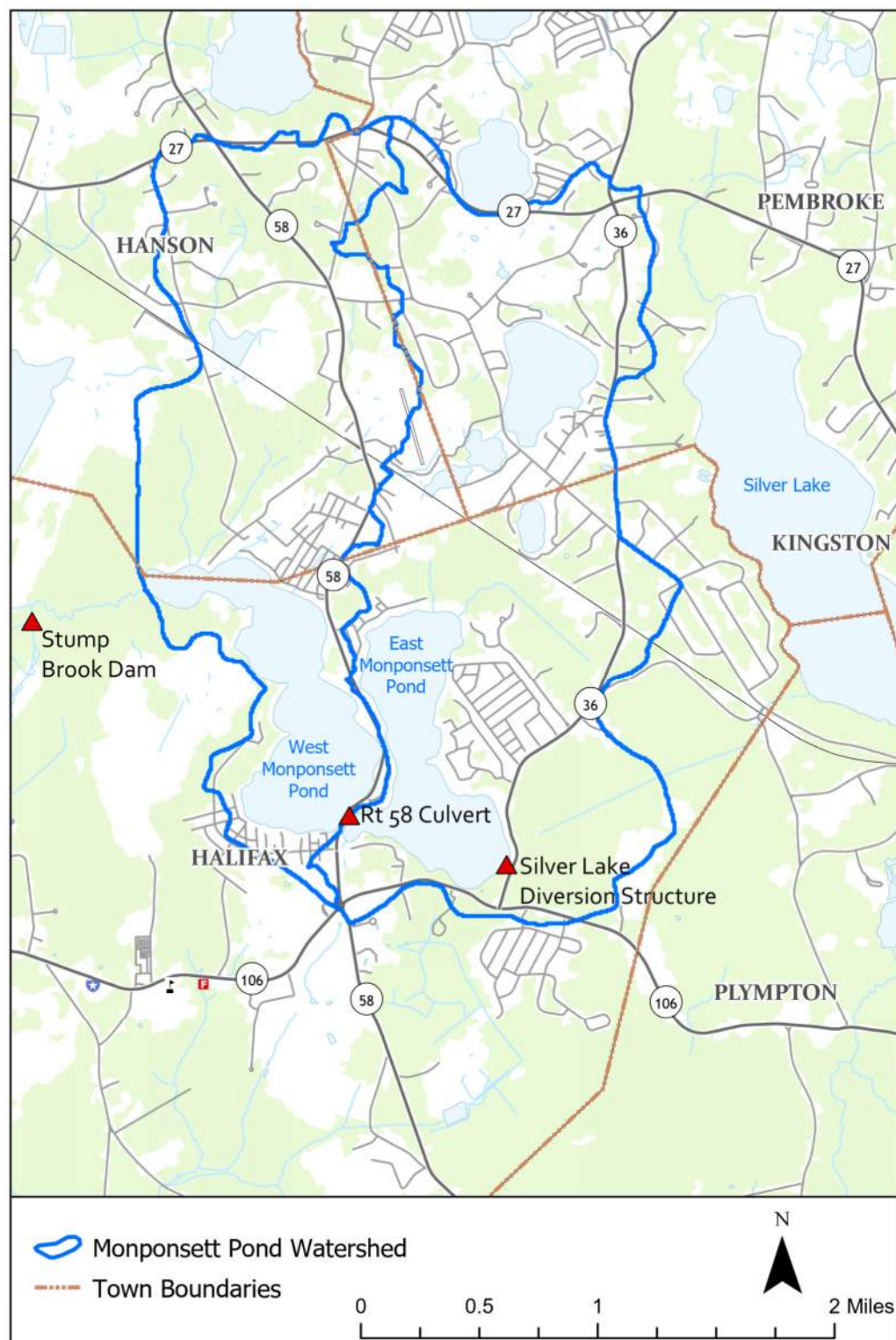


Figure-1-1. Monponsett Pond Watershed and Management Structures

1.3 History of Monponsett Pond Management

Silver Lake has served as a water supply source to the City of Brockton since the implementation of Act 356 in 1899. The lake was the city's primary water source until a regional drought in the 1960s required additional water sources. This led to the establishment of Monponsett Pond as part of the City of Brockton water supply system, by means of diversion to Silver Lake, through the Chapter 371 Act of 1964. Until this time, a Chapter 91 license, issued in 1923, gave primary water management authority of Monponsett Pond to the Hanson Cedar Company in support of their cranberry bogs. This license permitted the building of a dam or dyke and flumes on Stump Brook, to be operated for cranberry production needs. This dam replaced an earthen dam in the brook. This license was updated in 1965, shortly after Monponsett Pond was designated to serve water supply purposes.

Chapter 91 License No. 4987 authorizes Brockton to divert excess overflow water from Monponsett Pond to Silver Lake with a restriction of a minimum elevation below which a diversion cannot occur; the original elevation of below 52.5 ft in Chapter 371 of the Acts of 1964 was amended to below 52.0 ft by Chapter 237 of the Acts of 1981.

In 1995, the first Administrative Consent Order (ACO) for Monponsett Pond was enacted, requiring a series of water management tasks and developments, including the establishment of a Board of Water Commissioners and a Comprehensive Water Management Plan, including the development of new sources of water supply. A revised ACO, accepted in 2017, supports the continuation of these efforts. Changes to water supply management due to the 2017 ACO include not diverting water when cyanobacteria concentrations are higher than the Massachusetts Department of Public Health (MDPH) advisory level of 70,000 cells/mL and reducing the historical 25 mgd diversion to by 50 percent, 12-14 mgd. The full timeline of key events is displayed in **Figure 1-2**.

The information in **Figure 1-2** was extracted from a collection of sources listed below. Elevation data was converted and is presented in NGVD29 datum. United States Geological Survey (USGS) topo quadrangle maps for the towns of Hanover, Hanson, and Provincetown provided historical pond elevations. Elevations were also gathered from bathymetry data, collected by BioBase on June 28th, 2017, and pond elevation data collected from 1996 through 2019 by Veolia North America. Primary policy documents, including Chapter 237, Chapter 371, the Hanson Cedar Company license of 1923, the 2017 Administrative Consent Order for the City of Brockton, and public responses to this project's scope of work provided qualitative and quantitative data. Lastly, various reports were referenced for data, including Princeton Hydro (2013), the Horsley Witten Group (2016), MA DEP (2021), and the Horsley Witten Group (2015).

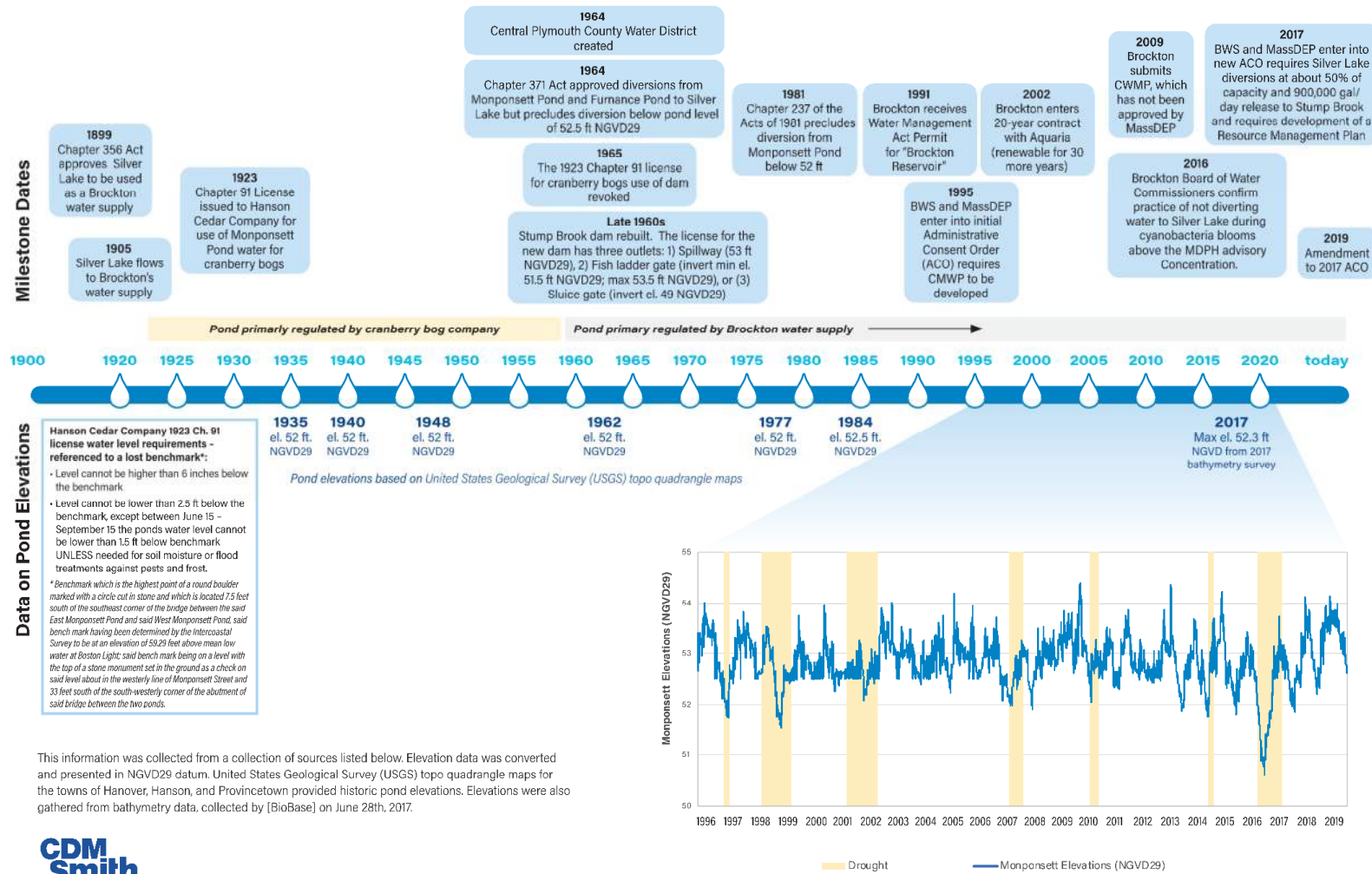


Figure 1-2 Milestone Dates in Use of Monponsett Pond for Water Supply and Documented Water Level Data

In summary, Brockton manages its active water supplies (Silver Lake, Monponsett Pond, Furnace Pond and Brockton Reservoir) within its legislative rights and in accordance with its Water Management Act Registrations and Permit. These Acts of the Legislature, and Water Management Act Registrations and Permit, limit Brockton's withdrawals from Monponsett Pond (and Furnace Brook), require releases to specific downstream watercourses, and provide for allowable withdrawals by compatible uses (e.g., cranberry bogs, etc.) and recreational use of the pond. Brockton water system operations meet these requirements. The City also works with the Towns of Halifax, Hanson (and Pembroke) and adjusts its operations to make periodic beneficial releases (e.g., flood control, herring migration, etc.) through an open dialogue with these communities.

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Section 2

Monponsett Pond Uses and Data

2.1 Elevation Considerations in Existing Pond Uses

The following sections outline the current uses of Monponsett Pond.

2.1.1 Water Supply

Throughout the history of Monponsett Pond as a water supply source, pond elevations have been a central part of its management. As shown in **Figure 1-2**, the Chapter 91 license of 1923 granted to the Hanson Cedar Company included water level constraints on operations. When primary water management authority of Monponsett Pond was passed to Brockton in 1964, Chapter 371 of the Acts continued that practice by establishing a minimum elevation requirement of 52.5 ft (NGVD29) below which diversions could not occur. In 1981, Chapter 237 of the Acts revised this requirement to 52 ft (NGVD29). Historical diversions over this time were about 25 mgd but has since been reduced to 12-14 mgd. Currently, Brockton's water supply is primarily dependent on Silver Lake and its diversions from both Furnace and Monponsett Ponds, but also can receive up to 0.83 mgd from the Brockton/Avon Reservoir and up to 4.07 mgd of supplemental supply from the Aquaria Desalination Plant in Dighton, MA.

The inlet to the 48-inch diversion conduit is located in the southeastern corner of EMP and is controlled by a 36-inch butterfly valve. The elevation of this Monponsett Pond inlet is 46 ft NGVD29. Diversions are permitted November through May, and they have historically exceeded or were comparable with the total withdrawals from Silver Lake. In order to divert water to Silver Lake, the elevation in Monponsett Pond must be above 52 ft (NGVD) and Silver Lake must be below 47.5 ft (NGVD29). In practice, Brockton often diverts water to Silver Lake when Monponsett Pond is above 52.5 ft (NGVD29). Diversions are prohibited June through October unless required for flood control.

2.1.2 Wildlife Habitat

Both EMP and WMP provide habitat to three state-listed rare species (Schlüter, 2020). Monponsett Pond is within *Priority Habitat 737* (PH 737) and *Estimated Habitat 611* (EH 611) as documented in the *Massachusetts Natural Heritage Atlas* (14th Edition). Listed species that are dependent on the pond are protected under the Massachusetts Endangered Species Act and the Massachusetts Wetlands Protection Act. Those species are listed in **Table 2-1**.

Table 2-1. Massachusetts State-listed Threatened Species and Species of Concern

Scientific Name	Common Name	Taxonomic Group	State Status	Reference
<i>Leptodea ochracea</i>	Tidewater Mucket	Mussel	Special Concern	MassWildlife 2015c
<i>Ligumia nasuta</i>	Eastern Pondmussel	Mussel	Special Concern	MassWildlife 2015b
<i>Emydoidea blandingii</i>	Blanding's Turtle	Reptile	Threatened	MassWildlife 2015a

The Tidewater Mucket inhabits freshwater environments and lives in water depths of 1 ft to over 25 ft under a range of flow conditions but tends to prefer depositional areas with slow currents

and ponds. These mussels are predominantly stationary so are vulnerable to changes in their environment, including degraded water quality, eutrophication, shoreline development, lake recreation, and altered flow regimes (MassWildlife, 2015c; Princeton Hydro, 2013). Additionally, sudden drops in water elevation can leave freshwater mussel populations stranded above water. This has been cited as a concern in Silver Lake primarily (Princeton Hydro, 2013). However, it is a consideration for policy regulating water elevation in Monponsett Pond.

The Eastern Pond mussel inhabits streams, rivers, ponds, and lakes, the latter two comprising the majority of the eastern Massachusetts populations. It can live under a variety of flow and environmental conditions and studies have not identified any distinct preference for habitat substrate or depth. However, they are subject to similar threats to the Tidewater Mucket (MassWildlife, 2015b).

The Blanding's Turtle inhabits seasonal pools, marshes, wetlands, and open uplands. In Massachusetts, the Blanding Turtle habitat changes throughout the year, with drier seasons spent in upland forests and cooler, wet seasons spent in permanent wetlands and vernal pools. The persistence of these lowland wet habitats is important for winter survival and reproduction (MassWildlife, 2015a). Water elevations in the pond are a consideration for maintaining wetland habitats.

In addition to supporting threatened species and species of concern, Monponsett Pond is inhabited by a variety of fish species. The fish population in EMP was sampled in 2001. Bluegill, white perch, yellow perch, pumpkinseed and largemouth bass were common, and smaller populations of chain pickerel and golden shiner were also present. Ten species in WMP were documented in 1990: white perch, yellow perch, pumpkinseed, bluegill, largemouth bass, black crappie, golden shiner, brown bullhead, chain pickerel and American eel. Largemouth bass are the primary gamefish in these ponds (MassWildlife, 2005). The MDPH currently has a fish consumption advisory over Monponsett Pond that advises against eating largemouth bass due to mercury levels (MDPH 2020).

2.1.3 Recreation

Monponsett Pond is used for a variety of recreational activities, including boating, fishing, swimming, and flying seaplanes. Seaplanes are managed by the Monponsett Pond Seaplane Base.

Boat access is available to town residents by two ramps, one located on WMP on Lingan Street and the other in the southeast corner of EMP on Holmes Street. A state boat ramp is also available for public use on Monponsett St./Rt 58 and provides access to WMP. In addition, a visual survey using aerial photography identified about 65 private docks in the Monponsett Pond complex.

Six active beaches are present on Monponsett Pond, with three on EMP and the remaining three on WMP. Five of them are private or open to residents. One beach is open to the public. All active beaches are located in Halifax. The beaches are listed in **Table 2-2**. These beaches are narrow and relatively flat, suggesting that elevated water levels could reduce bathing areas and access.

Table 2-2. Monponsett Pond Beaches

Beach Name	Town	Access
Annawon Drive Beach	Halifax, MA	Private
Halifax Beach Association Beach	Halifax, MA	Private
Holmes Street Beach	Halifax, MA	Public beach for Halifax residents
Lingan Street/ 4 th Avenue Beach	Halifax, MA	Public beach for Halifax residents
Twin Lakes Condominiums Beach	Halifax, MA	Private
Monponsett St. - Rt. 58	Halifax, MA	Public
Ocean Ave. Beach	Hanson, MA	Permanently closed

The Town of Halifax and Massachusetts agencies monitor the environmental health of the ponds for swimming and recreational purposes using concentrations of cyanobacteria, fecal bacteria (*E. coli*), and Secchi depth. Both ponds are regularly tested for cyanobacteria and fecal bacteria. The MDPH has set a advisory level of 70,000 cells/mL for cyanobacteria as the concentration at which swimming or contact with the affected body of water should be prohibited. The Towns of Halifax and Hanson have both historically closed its beaches to recreational activities when the samples have exceeded this standard.

Six beaches are also regularly tested for *E. coli*, which is used to assess whether the water is safe for primary contact recreation. Secchi depths have also been collected by MassDEP to measure water clarity. A Secchi depth of 4 ft (1.2 meters) indicates suitability for swimming. One beach in Hanson, called Ocean Ave. Beach, was another site for water quality testing, but was permanently closed due to cyanobacteria blooms. Historical water quality data are described in **Section 2.2**, including a comprehensive explanation of historical water quality data at beaches and boat ramps.

2.1.4 Shoreline Development, Septic Systems, and Stormwater Management

2.1.4.1 Shoreline Development

EMP and WMP have about 3.5 and 4 miles of shoreline, respectively (MassWildlife, 2005). The shoreline is largely developed by residential and commercial users. In the early 1900s many cottages were built around the ponds as seasonal homes, but many of these cottages were converted into year-round residences. Updated information on the percentage of seasonal housing was not evaluated as part of this study, but the 1987 Lycott study found that only 25 percent of the seasonal cottages remained seasonal.

2.1.4.2 Septic Systems

CDM Smith held discussions with town Boards of Health to describe current septic system management practices near Monponsett Pond. The Town of Halifax has an active septic system inspection and management program, requiring an annual Title 5 inspection if the septic system is within 100 ft of Monponsett Pond. Innovative/Alternative (I/A) systems are required to have an annual maintenance contract. Hanson does not currently monitor septic systems beyond the Title 5 inspections required when properties are sold and if an existing system fails.

2.1.4.3 Stormwater

Stormwater management is a critical component of Monponsett Pond management, as the ponds are an asset to both Halifax and Hanson, as well as a utility for Brockton. Both towns have Stormwater Management Plans in accordance with the Massachusetts National Pollutant Discharge Elimination System (NPDES) General Small Municipal Separate Stormwater System (MS4) Permits (Environmental Partners Group 2019; Town of Halifax 2019). Stormwater discharges can cause pollutant loading, including sediment, bacteria, and nutrients. Stormwater management programs are an active effort to implement Best Management Practices, eliminate illicit discharges, control construction site discharges, and minimize municipal stormwater sources. In Halifax, 54 outfalls discharge into Monponsett Pond. The town's Illicit Discharge Detection and Elimination (IDDE) Plan includes a priority ranking of outfalls for illicit discharges. The 2020 annual report identifies 40 outfalls as "High Priority." The locations of these outfalls are available on the Halifax MS4 Stormwater Infrastructure Web Viewer, a GIS-based platform that documents the town's outfall inventory (Town of Halifax, 2020). The Town of Hanson has one outfall that flows into Monponsett Pond and it is identified as being a source of phosphorus (Environmental Partners Group, 2019). The IDDE program also requires the indication of sanitary sewer overflows (SSOs) into drainage systems. From 2016 through 2020, septic system inspections found no evidence of SSOs in Halifax (Town of Halifax, 2020). As of 2018, the Town of Hanson had also reported no known SSO events (Environmental Partners Group, 2019).

2.1.5 Cranberry Agriculture

Cranberry growers often depend on lakes for summer and spring frost irrigation and flooding during the autumn harvest and winter seasons. Water access, often from adjacent water bodies, is critical to the success of cranberry operations in southeastern Massachusetts. Although annual water demands for bogs vary with spatial characteristics and environmental conditions, a study conducted in 2017 estimated an annual water requirement of about 1.5 - 3.2 meters per year, as much as two-thirds of which are used for flooding practices (Kennedy *et al.*, 2017).

Cranberry bogs located within a reasonable proximity to a surface drinking water source must comply with regulations depending on the zone in which they fall. Zone A protects the area between the water body and the upper bank and the area that falls within a 400-ft lateral distance from the upper bank of the water body. It also includes land within 200 ft of tributaries and other water bodies associated with the drinking water source. Zone B protected areas are within a half-mile buffer around the water body and Zone C protected areas are those that contribute to the water body from the greater watershed. Cranberry farming operations that fall within these zones are encouraged to develop Farm Conservation Plans to adequately protect the drinking water supply (DeMoranville and Sandler, 2000). Cranberry bogs are also regulated by the Water Management Act (WMA) of 1985 as a 'virtually non-consumptive' water use to both protect the use of water for cranberry bogs and incentivize more sustainable, water-conserving practices (Averill *et al.*, 2008). The WMA also governs the distribution of water permits for bogs with total areas using more than 34,523 cubic meters of water during a continuous 91-day period greater than a minimum defined area. These threshold areas are 4.66 acres for older bogs and 9.33 acres for new bogs that implement best management practices (Kennedy *et al.*, 2017).

Approximately 300 acres or 8 percent of the Monponsett Pond watershed is cranberry bogs, as shown in **Figure 2-1** (MassDEP, 2021). The Winebrook bog, southwest of WMP, withdraws

water from WMP for irrigation and flooding purposes. It only drains minimal agricultural return flows into Monponsett Pond, instead sending most of them toward Stump Brook (Horsley Witten Group, 2015). This was confirmed in a 2019 meeting held with MassDEP, the City of Brockton, and Morse Brothers, Inc.

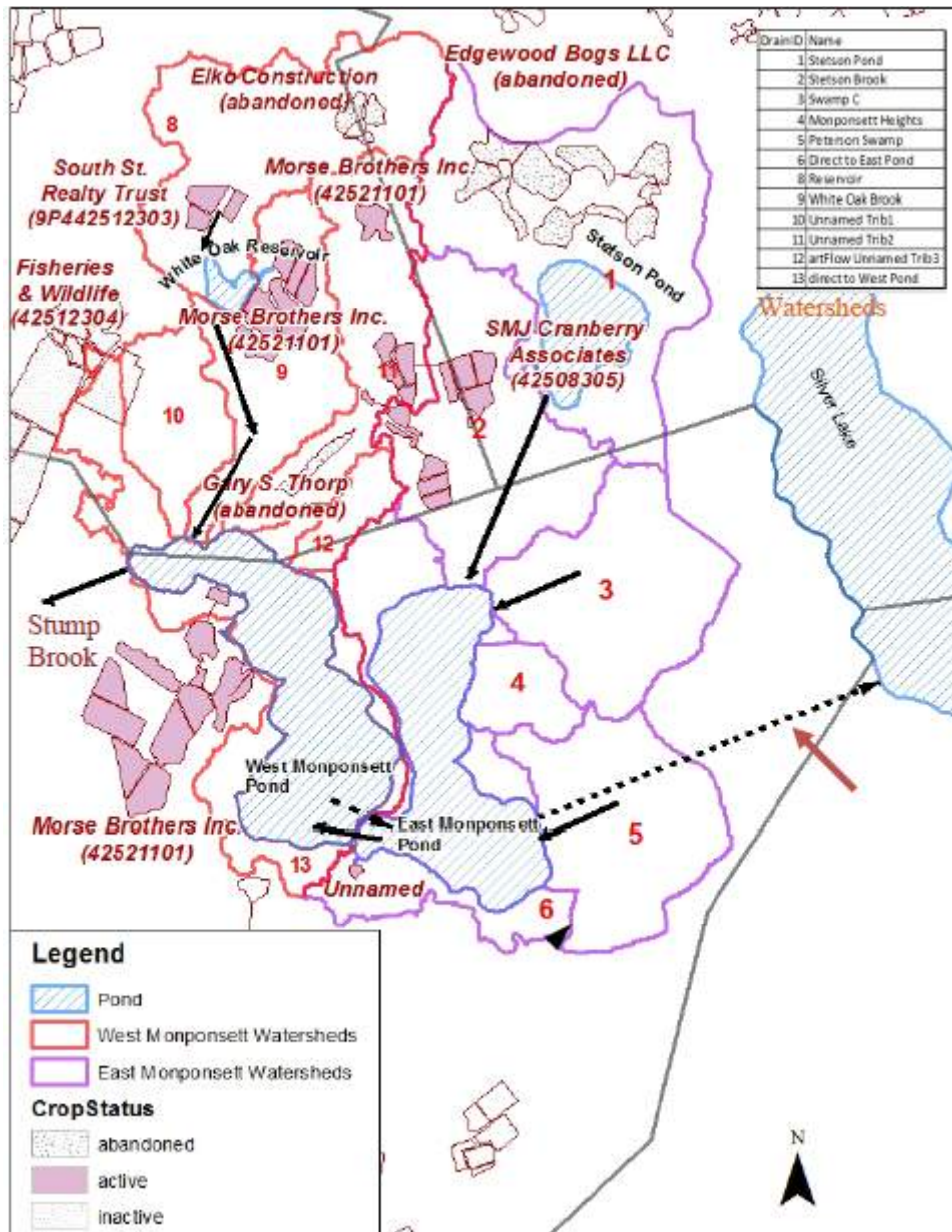


Figure 2-1. Map of Cranberry Bogs within Monponsett Watersheds. Retrieved from MassDEP (2021)

2.1.6 Stump Brook Flows and Silver Lake Diversions

Outflows from Monponsett Pond include those to Stump Brook, in the northwest corner of WMP, and diversions to Silver Lake through a 36-inch gravity-fed conduit, with a full diversion capacity

of approximately 25 mgd depending on the water level. Considerations for both are described below.

The Chapter 91 license associated with the 1960s-era dam reconstruction outlined the routes for water to flow into Stump Brook as: the spillway at 53 ft (NGVD29), the fish ladder, or a sluice opening. The 2017 ACO with MassDEP codifies the current instream releases of at least 0.9 mgd at all times of the year when available; if water is below the fish ladder gate then no water is available. A concern of the Silver Lake diversion is the possibility of it overcoming the flow route of the natural hydrology and pulling water from WMP to EMP. In the event of this switch in flow direction, Stump Brook flows are further reduced (MassDEP 2021).

Recently, studies have investigated possible alternative management approaches to improve Stump Brook flow. A water balance study conducted by Princeton Hydro (2013) found that the diversions from Monponsett Pond reduce the flow in Stump Brook to 1/3 of its natural potential capacity. Another study by the Horsley Witten Group (2015) evaluated the impacts of alternative management scenarios for the Stump Brook Dam on Stump Brook flows and Monponsett Pond levels. Using a water budget analysis with a United States Geological Survey (USGS) MODFLOW numerical groundwater flow model, the Horsley Witten Group simulated water diversions representing changes in dam operations. Their findings suggest that various diversion rules and dam operations can significantly change pond elevations and Stump Brook flows. Management practices showed potential for increasing Stump Brook flows, though correlated with lower pond elevations. Such studies were considered and integrated into the 2017 AOC. Additional analysis of Stump Brook flow for consideration in this RMP are detailed in **Section 5**.

2.1.6.1 Monponsett Pond to Silver Lake Diversions

Diversions from Monponsett Pond to Silver Lake can occur for two reasons:

- Water supply for the City of Brockton
- Flood control in Monponsett Pond for protection of private property and downstream tributaries.

As described in **Section 3.3**, water supply diversion from Monponsett Pond to Silver Lake can only occur between October 1 and May 31 when Monponsett Pond is above 52 ft NGVD and Silver Lake is below 47.5 ft NGVD. In addition to the water supply diversions, Brockton will operate the diversion upon the written request of the towns of Halifax or Hanson or the request of MassDEP for flood control purposes. Flood control diversions are authorized by Chapter 314 of the Acts of 1964; diversions made between June 1 and September 30 require MassDEP notification.

Flood control diversions from Monponsett Pond to Silver Lake were estimated using historical water levels in Silver Lake and Monponsett Pond. For this assessment, diversions that occurred when conditions for water supply diversion were met were assumed to be for water supply needs. All other diversions were assumed to be for flood control purposes. The flood control and water supply diversions for the study period (2004 through 2019) are described in **Table 2-3**. Over this period, the flood control diversions were variable year-over-year, ranging from 0 to 93 percent of the total diversion volume. On average, the flood control diversions were 1,004 MG/year and the water supply diversions 1,114 MG/year.

Table 2-3. Monponsett Pond to Silver Lake Diversion Volumes Reported by Veolia, 2008 through 2017

Year	Total Diversion (MG/year)	Flood Control Diversion (MG/year)	Water Supply Diversion (MG/year)	Percent Level Control
2004	2,445	1,390	1,055	57%
2005	3,690	3,047	643	83%
2006	2,818	1,830	988	65%
2007	2,006	1,126	880	56%
2008	3,089	764	2,325	25%
2009	2,890	2,682	208	93%
2010	2,532	1,770	761	70%
2011	2,241	1,963	278	88%
2012	1,665	1	1,665	0%
2013	1,970	982	988	50%
2014	1,794	0	1,794	0%
2015	635	90	545	14%
2016	1,391	0	1,391	0%
2017	1,856	0	1,856	0%
2018	1,802	195	1,608	11%
2019	1,065	224	840	21%
Average	2,118	1,004	1,114	39%

Flood control diversions for the 2004 through 2019 study period were identified for each year and evaluated in the context of modeled Stump Brook spills and releases (**Section 5.2.3**), and measured water levels in Silver Lake and Monponsett Pond, and groundwater elevations at a USGS well in Duxbury. For this assessment, a flood control diversion event was assumed to be a one day or longer period when a diversion from Monponsett Pond to Silver Lake occurred either outside of the allowable water supply diversion period or when Silver Lake is above 47.5 ft during the allowable water supply diversion period. There were 66 flood control diversion events that occurred during the study period, with an average diversion of 243 MG. Beginning in 2016, flood control operations changed significantly relative to historical practices, resulting in significantly lower flood control diversion rates to Silver Lake. The average flood control diversion from 2016 through 2019 was 105 MG/year, with several years with no recorded flood control diversion. Prior to 2013, nearly all of the flood control diversions occurred during the diversion season; after 2013 flood control diversions only occurred during the diversion season.

Figure 2-2 is an example analysis of diversion events in 2013. Annual plots for the remaining years (2004 through 2019) are in **Appendix B**. In 2013 there were two diversion events:

- A 30-day, 671 MG diversion starting on February 28. During this event the modeled Stump Brook release and spills totaled 205.7 MG. .

- A 14-day, 311 MG diversion starting on June 12. During this event the modeled Stump Brook release and spills totaled 158 MG.

In general, groundwater patterns at the Duxbury USGS well matched the pattern observed in the Monponsett Pond and Silver Lake levels, with higher groundwater elevations typically coinciding with higher pond and lake levels during flood control diversion events. The Duxbury well was used in the RMP model-calculated groundwater seepage rate, which represents impacts on the ponds from changes in local groundwater recharge and pumping, such as pumping from the Halifax groundwater supply wells. Higher groundwater elevations contributed more water to Monponsett Pond, and lower groundwater measurements created a slight negative flux out of the pond. Modeled Stump Brook spills and releases also were typically highest before or during the diversion events; higher Monponsett Pond levels allow greater volumes of spills and releases from Stump Brook. However, since the data on Stump Brook flows were lost, these data are modeled and are not observed.

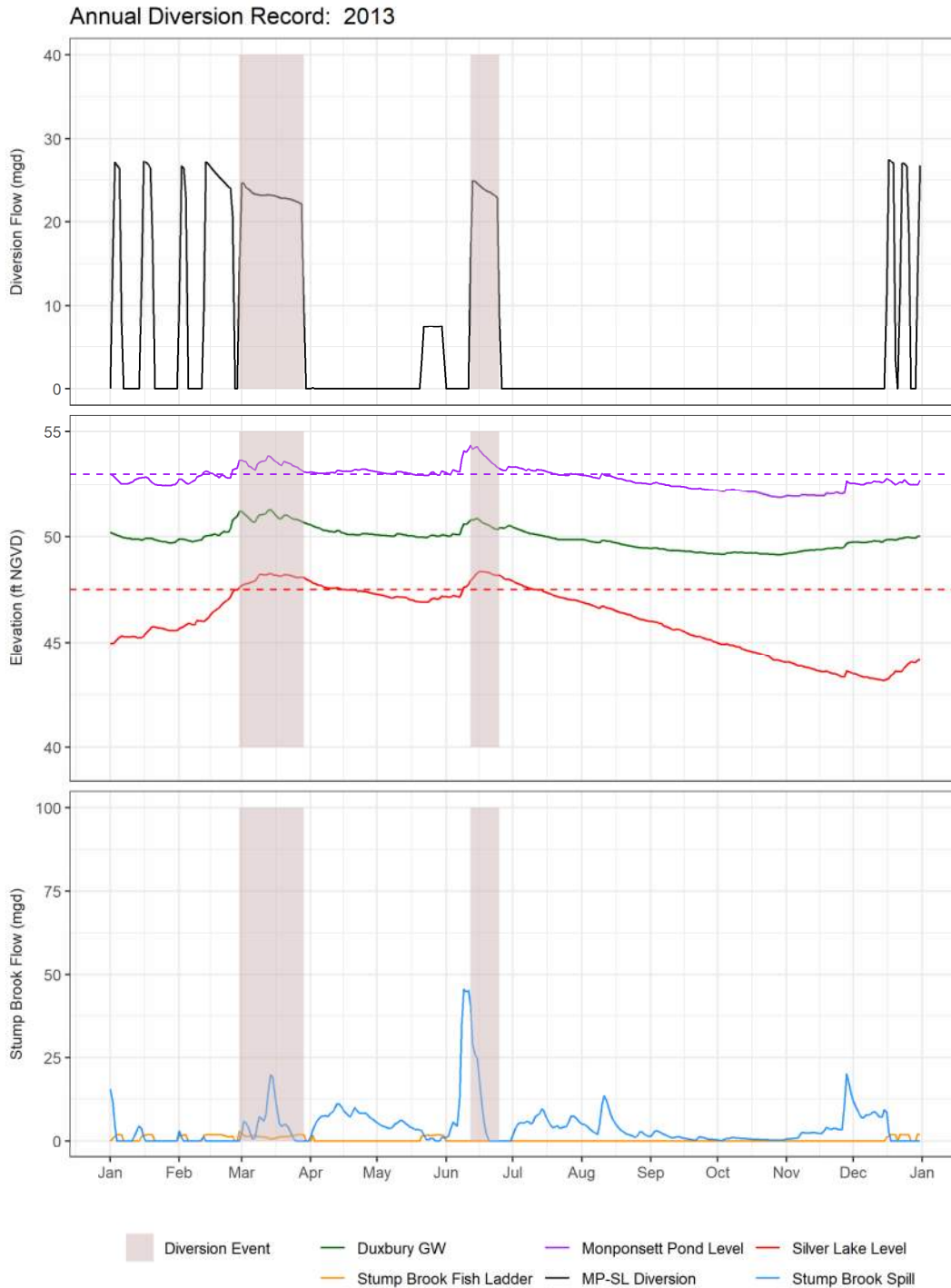


Figure 2-2. Annual Flood Control Diversion Analysis for 2013

2.2 Monponsett Pond Bathymetry

Four known bathymetric data collection and mapping efforts have been completed on Monponsett Pond. Data were collected and assessed by Lycott Environmental (1987), the

Massachusetts Department of Fish and Wildlife (date unknown), BioBase (EMP, June 2017), and the Massachusetts Department of Fish and Wildlife (WMP, 2018). Bathymetric mapping from each of these studies are presented in **Figures 2-3** through **2-5**.

The historical and current bathymetric data are difficult to compare due to the relatively low resolution in the historical bathymetry data and different techniques used to collect the bathymetric data. Given these uncertainties, the data generally show similar bathymetry in the historical and current datasets. The overall bathymetric profile in both ponds is fairly consistent among the surveys, with the deep and shallow sections matching. The maximum depth measured in the current WMP bathymetry is deeper than the two historical measurements (15.3 ft compared with 13 ft), but this is likely attributable to the higher density of depth measurements conducted in the 2018 WMP bathymetric survey. Conversely, the maximum depth in EMP is shallower in the current bathymetric survey when compared with the Massachusetts DWF dataset, although deeper than the 1987 Lycott Environmental survey (11.8 ft in the 2017 survey compared with 13 ft in the Massachusetts DFW dataset and 9.8 ft in the Lycott Environmental survey). However, it is not possible to evaluate whether this represents a significant change in bathymetry or is simply a product of different pond elevations during the surveys or the higher resolution data and different measurement techniques.

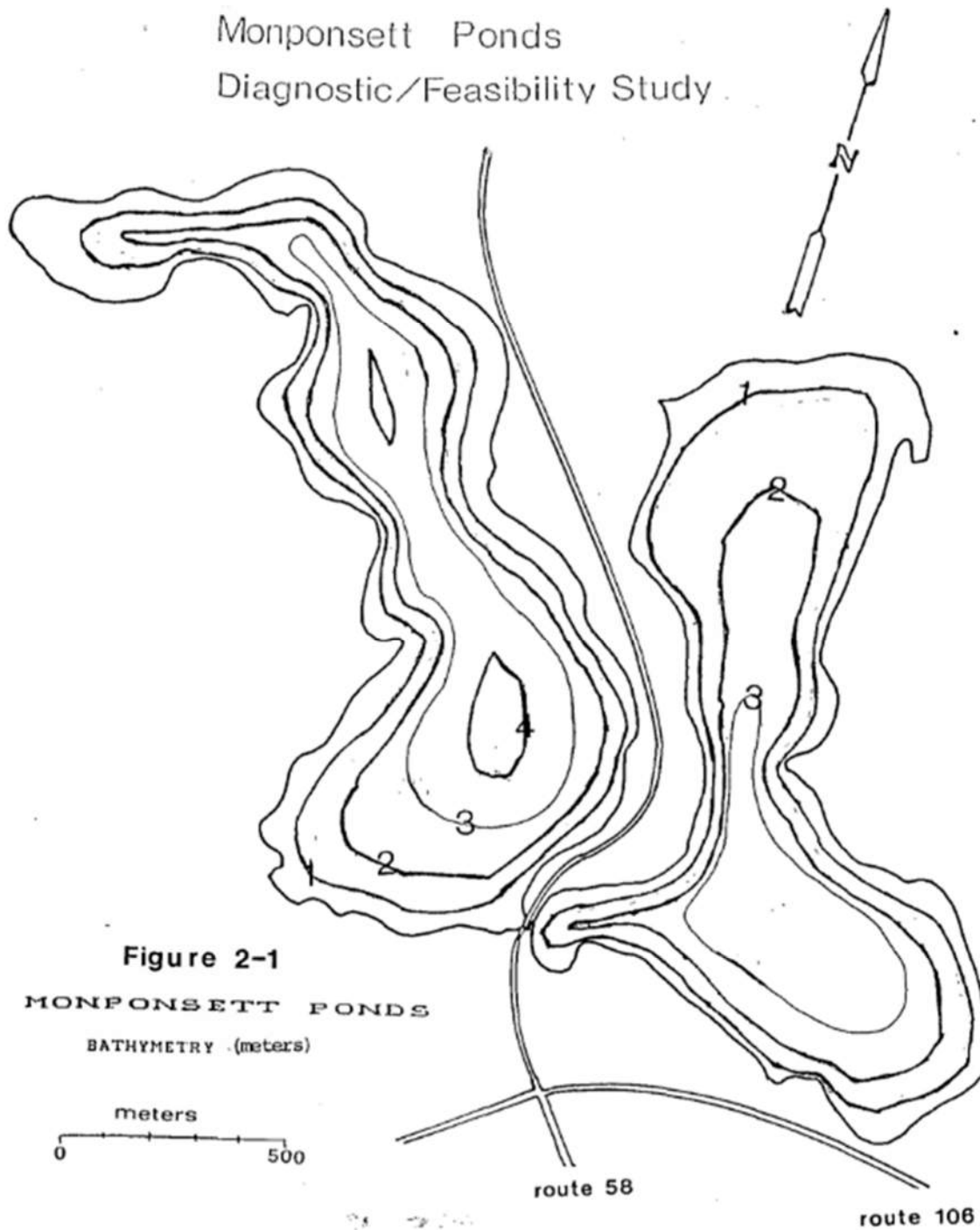


Figure 2-3. Bathymetric Mapping Conducted by Lycott Environmental (1987)

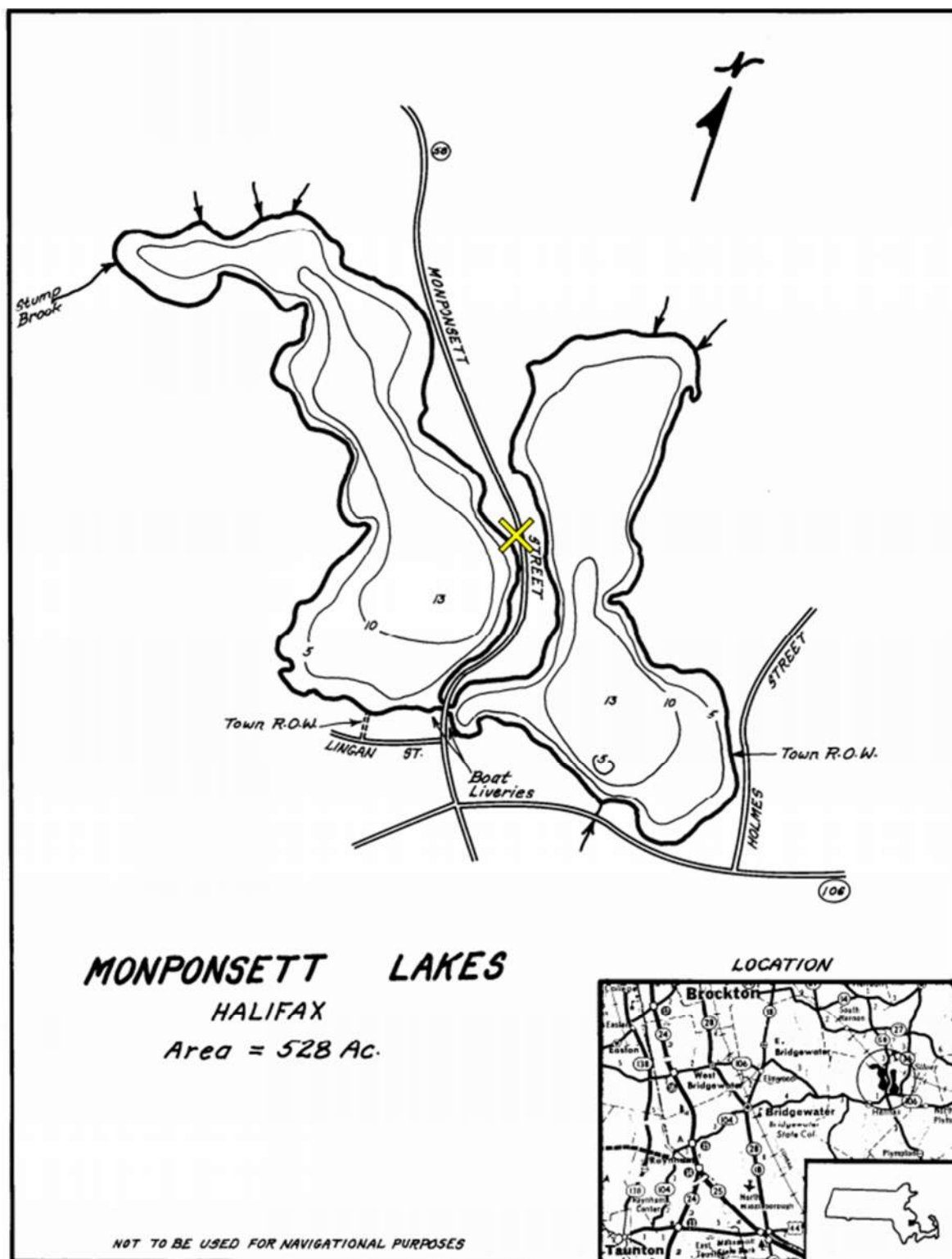


Figure 2-4. Bathymetric Mapping from the Massachusetts Department of Fish and Wildlife (Mass DFW, 2005)

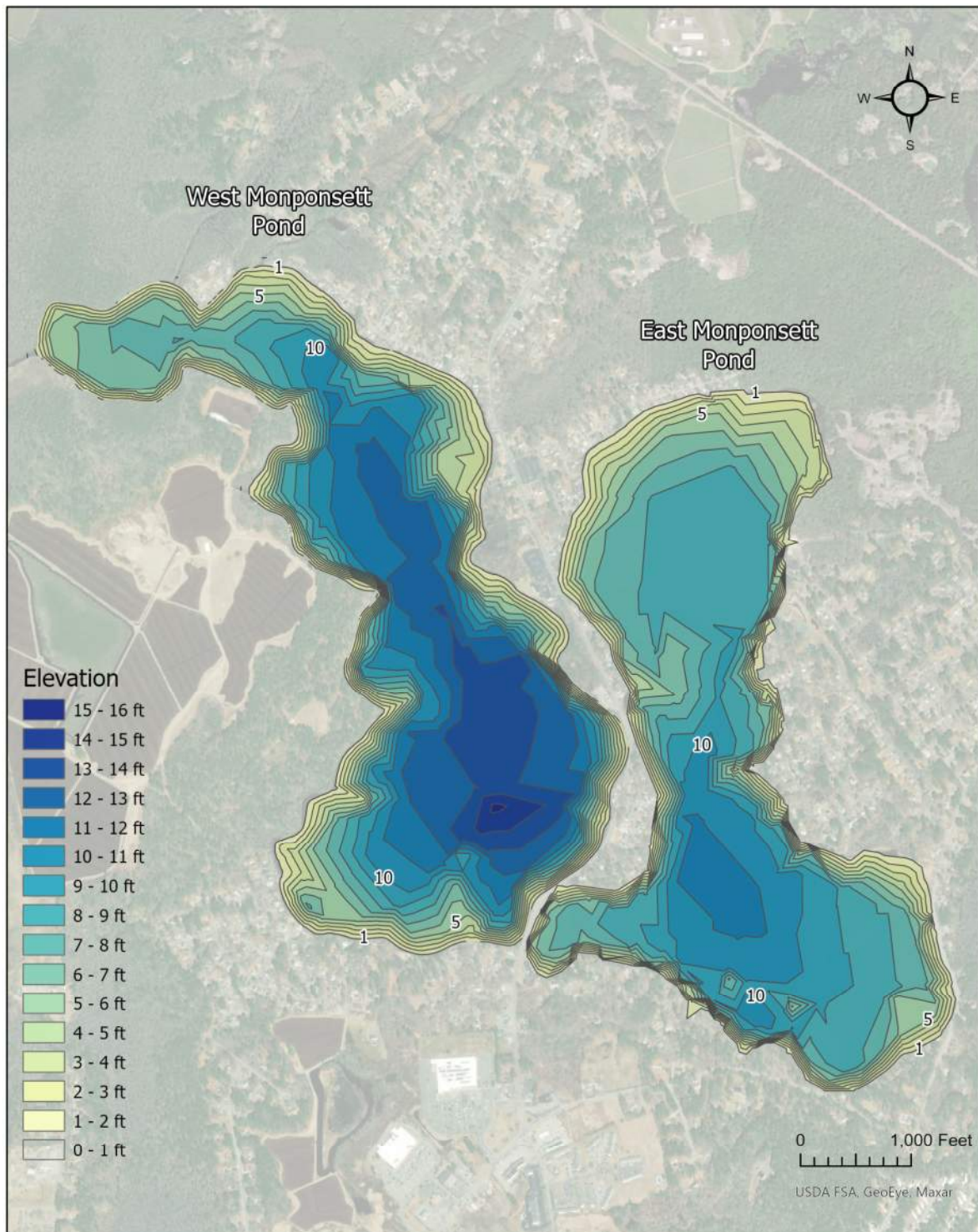


Figure 2-5. Bathymetric Data (ft) of Monponsett Pond from 2017 & 2018
EMP: BioBase 2017. WMP: Mass DWF 2018

2.3 Water Quality Data

Historical water quality data on Monponsett Pond have been collected by MassDEP and Lycott Environmental. In addition, several studies have used water quality models and analysis to evaluate water quality in the ponds relative to existing conditions and alternative analyses.

Poor water quality conditions have been known since at least 1982, based on unpublished data collected by the Technical Services Branch of the Massachusetts Division of Water Pollution Control. At the time, impairments included low visibility, high algal concentrations, and high concentrations of total phosphorus (Lycott Environmental, 1987). Both ponds are currently listed as Category 5 “Impaired” waterbodies on the 2016 Final Massachusetts Integrated List of Waters (303(d) list) (MassDEP, 2020). WMP impairment causes are chlorophyll *a*, cyanobacteria and harmful algal blooms, phosphorus, and water clarity. EMP impairment causes are chlorophyll *a*, cyanobacteria and harmful algal blooms, and mercury levels in fish. MassDEP issued a final draft TMDL for total phosphorus in EMP and WMP in 2021. The ponds are also impaired by the presence of invasive species, but these are not considered pollutants and a TMDL is not required.

Mercury pollution in Massachusetts water bodies is predominantly caused by atmospheric deposition of coal-fired power plant emissions. The pollution is widespread and must be treated at the emissions source (Randall, 2011). Like many Massachusetts lakes, mercury has been found in fish tissue in the Monponsett Ponds (MassDEP, 2021). The levels were evaluated in 2001, with EMP largemouth bass samples exceeding the regulatory standard of 0.5 mg/kg, set by MDPH (MassDEP, 2001). A TMDL was established in 2007 for mercury concentrations.

2.3.1 Previous Studies

Water quality in Monponsett Pond has been investigated in several previous studies conducted by Lycott Environmental (now SŌLitude Lake Management) (1987), Princeton Hydro (2013), the Horsley Witten Group (2015), and MassDEP (2021).

Water quality data were collected by Lycott Environmental and MassDEP. A study conducted by Lycott Environmental (1987) sampled Monponsett Pond on 18 dates across 1985 and 1986. Samples were collected at two in-lake locations, five tributary confluences into the ponds, the outlet, intensive storm locations, and shallow test well/seepage sampler sites. Data for eight parameters were collected, including phosphorus and chlorophyll *a* concentrations, and Secchi disk transparency. The Lycott study also included a detailed survey of aquatic vegetation. MassDEP collected water quality data in 2001 and 2009-2018 for both EMP and WMP. Samples were tested for total phosphorus (TP), chlorophyll *a*, and Secchi disk transparency (MassDEP 2021).

Cyanobacteria sampling is also routinely conducted by MassDEP in EMP and WMP typically from June through the end of the growing season. In addition to the water quality data collection, several studies have developed water quality models to evaluate the impact of water supply, stormwater, and wastewater management on water quality. The Princeton Hydro (2013) evaluation of current management approaches modeled phosphorus loading into Monponsett Pond under various scenarios using the US EPA Unit Area Load (UAL) model. The Horsley Witten Group study (2015) included a component addressing water quality in Monponsett Pond using the Lake Loading Response Model (LLRM).

2.3.1.1 Phosphorus

Monponsett Pond is listed as impaired for total phosphorus by MassDEP on the final 2016 303(d) list, and a draft final TMDL was issued in 2021. Excessive phosphorus loads can cause algal blooms, including high cyanobacteria concentrations, and is used by MassDEP as one of many indicators of potential impairment to aquatic life. Massachusetts uses a narrative water quality standard for nutrients and does not have a numeric criterion for phosphorus. MassDEP describes its interpretation of the narrative water quality standard in its Consolidated Assessment and Listing Methodology (CALM) guidance manual. Phosphorus is used as an indicator of potential impairment to aquatic life, with a screening threshold of 25 µg/L as an indicator of potential nutrient impairment in lakes or ponds. If a combination of phosphorous concentrations exceeding the screening guideline and other factors, such as chlorophyll *a* and Secchi depth, indicate impairment then MassDEP may list a pond or lake as impaired.

Addressing phosphorus loading in WMP is closely tied with reducing the risk of cyanobacteria blooms. Water quality analysis conducted by the MDPH suggested a correlation between total phosphorus and cyanobacteria cell count in summer months (SOLitude Lake Management, 2017). The recurring cyanobacteria blooms led to the Massachusetts Division of Ecological Restoration granting priority project status for funding to the pond (Town of Halifax, 2016). As a result, the Town of Halifax began applying aluminum sulfate (alum) to WMP in 2013 through 2019, with the exception of 2014 to inactivate sediment phosphorus and reduce sediment recycling of phosphorus to the water column during anoxic conditions. These applications have been successful, resulting in reduced concentrations of phosphorus in both the upper and bottom waters of the pond (**Figures 2-6 and 2-7**).

Historical monitoring conducted by MassDEP found that TP concentrations in WMP decreased significantly from 2009 through 2012, with a 12.2 µg/L decrease in mean summer TP and 23 percent decline in median TP from 2009 and 2010 to 2011 and 2012. **Figure 2-6**, reproduced from the MassDEP TMDL, illustrates the decline in WMP TP concentrations from 2001 through 2015. In this figure, the points represent the individual data points and the dashed red line the annual median concentration. These decreases in median phosphorus levels are attributed to significant reductions in fertilizer application at the surrounding cranberry bogs as well as the alum treatments that occurred in 2013 and 2015. Average phosphorus concentrations across 2001 and 2009-2014 were about 80 µg/L (Horsley Witten Group, 2015). Data collected in 2016, 2017, and 2018 by MassDEP suggest continued improvement to phosphorus levels in WMP, with average concentrations of 22 µg/L, 15 µg/L, and 15 µg/L, respectively. These more recent average concentrations are closer to the historical time weighted mean surface concentration of 19 µg/L, documented in 1987 (Lycott Environmental, 1987).

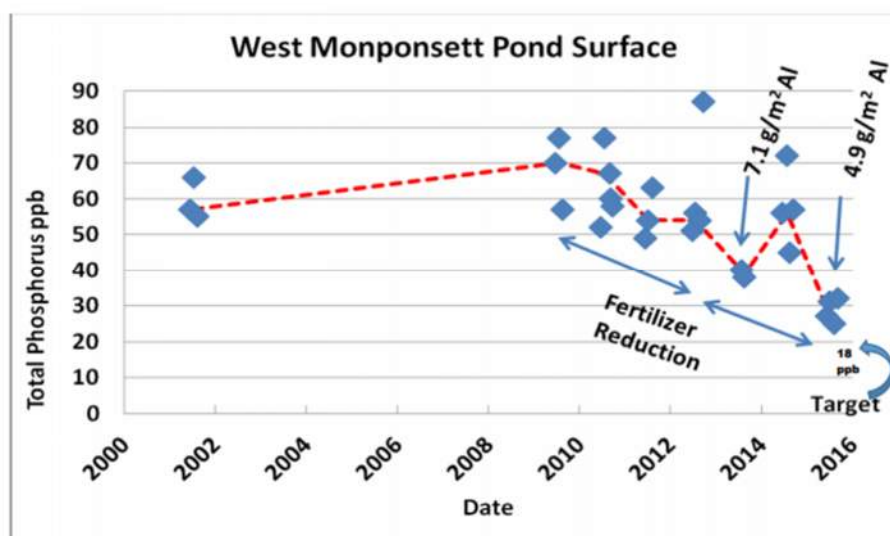


Figure 2-6. WMP Surface Total Phosphorus Concentrations, 2001 through 2015

Source: Figure 12, MassDEP 2021

In addition to the surface total phosphorus data cited by MassDEP in the TMDL, MassDEP has continued to collect water quality data in both ponds. **Figure 2-7** contains surface and bottom total phosphorus data from MassDEP for EMP and WMP between 2009 and 2018. These data indicate that the decline in WMP surface total phosphorus levels has been maintained. While there are limited bottom total phosphorus measurements, the 2018 WMP bottom concentrations were significantly lower than the historical concentrations, suggesting that the alum treatments may have reduced regeneration of phosphorus from the sediment. The total phosphorus concentrations in both the surface and bottom samples are approaching the TMDL target concentration of 18 µg/L.

In EMP, phosphorus concentrations in 1987, 2001, and 2009-2018 have largely stayed below 40 µg/L. EMP also exhibited a declining trend beginning in 2013 (Lycott Environmental, 1987; MassDEP, 2021). The Horsley Witten Group (2015) estimated average phosphorus concentrations across 2001 and 2009-2014 at 30 µg/L in EMP. Since then, MassDEP data suggest further reduction in annual average phosphorus concentrations, at 13 µg/L, 16 µg/L, and 21 µg/L in 2016, 2017, and 2018, respectively.

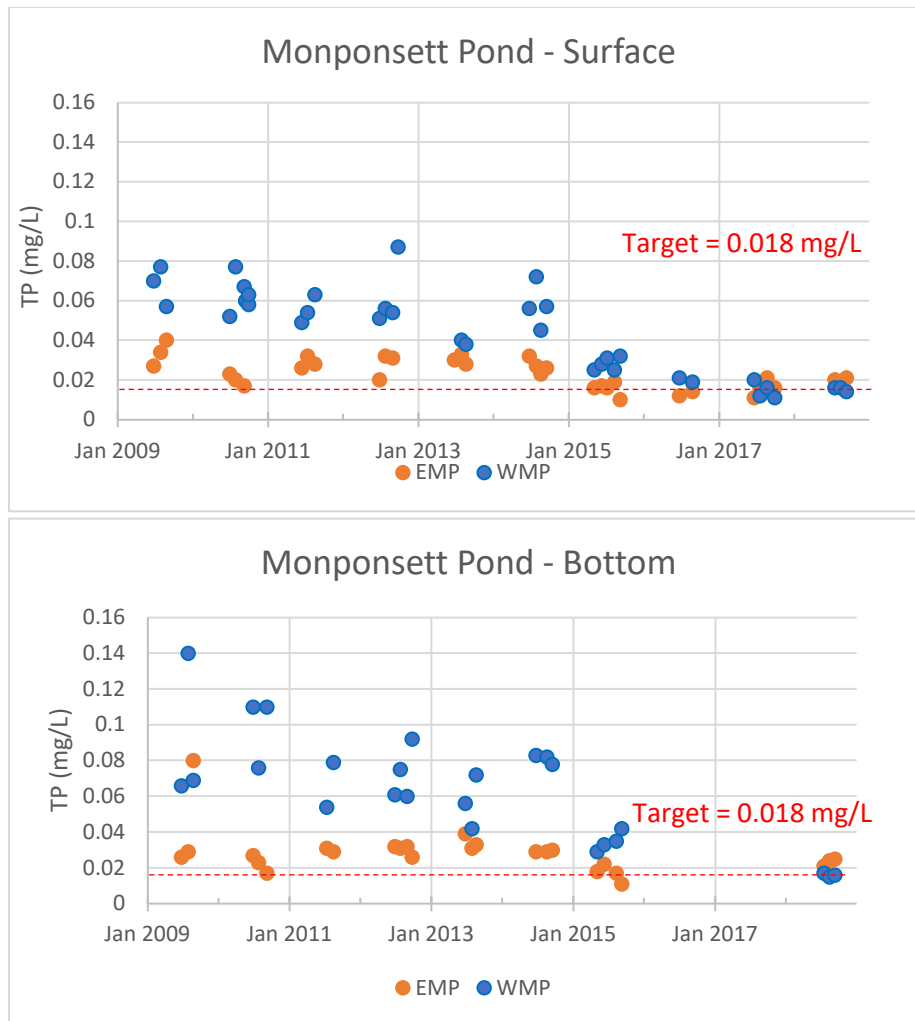


Figure 2-7. Historical Total Phosphorus Monitoring Data from MassDEP, 2009 through 2018

In 2021, TMDLs for phosphorus were established for EMP, WMP, Stetson Pond, and White Oak Reservoir. Both EMP and WMP were assigned a target concentration of 18 $\mu\text{g/L}$. Compliance with these TMDLs will require a 73 percent and 47 percent TP load reduction, respectively (MassDEP, 2021), relative to 2009 total phosphorus loads. However, since the baseline wasteload allocation was performed, significant water quality improvements have occurred, including the WMP alum treatments and fertilizer reductions at cranberry bogs, with annual concentrations in WMP and EMP approaching the TMDL's target concentration. While additional total phosphorus reductions are still needed to meet the TMDL wasteload allocation, the significant progress made to date is encouraging and has resulted in lower risk of harmful algal blooms and improved water quality.

2.3.1.2 Aquatic Vegetation

Lycott Environmental's survey of aquatic vegetation in 1985 found dense growth along the shoreline of both ponds except along the central eastern shore of WMP and the central western shore of EMP, where the steep shoreline was attributed to the change. The aquatic weed growth

was deemed “the most significant symptom of lake eutrophication” and were considered to detract from recreational uses of the lake. Shoreline residents were reported to use a variety of methods to control weeds, with raking being the most common.

More recently native aquatic vegetation has been recognized for the role it plays in maintaining/improving pond water quality. A healthy littoral submerged macrophyte community can contribute to sustaining a clearwater state around a lake by consuming nutrients that might otherwise be used to grow phytoplankton. In addition, they provide water quality benefits via habitat for zooplankton and small fish and stabilizing the bottom sediments from resuspension from waves.

2.3.1.3 Chlorophyll *a*

Nutrients from both point and nonpoint sources can contribute to increased algal growth, measured with chlorophyll *a*. As with phosphorus, Massachusetts does not have a numeric criterion for chlorophyll *a* but has a guidance value in the CALM of 16 µg/L that is used as a screening level to indicate the potential for nutrient-related impairments to the aquatic life designated use. Historical data collected in 1985 and 1986 (Lycott Environmental, 1987) were below this threshold. Concentrations of chlorophyll *a* collected by MassDEP in 2001 and 2009-2015 indicate periodic exceedances of the 16 µg/L guidance value. In EMP, the data suggest that chlorophyll *a* concentrations were both variable and high, exceeding 16 µg/L, in 2009-2014. In 2009, 2012, 2013, and 2014, the chlorophyll *a* concentration was as high as 30 µg/L, with a median over this time of 15-20 µg/L (MassDEP 2021). The data in 2015 exhibited improvements, with the mean concentration across five sampling events in May – September falling to 2.58 µg/L. The Horsley Witten Group’s (2015) data indicate an average concentration of 14 µg/L in 2001 and 2009-2014 in East Pond. MassDEP data from 2016–2018 indicate chlorophyll *a* concentrations of 2.6 µg/L, 8.3 µg/L, and 10 µg/L, respectively.

MassDEP (2021) reported that the WMP median chlorophyll *a* concentration increased from 2001 through 2013. Median concentrations remained above 20 µg/L and climbed to 70 µg/L in 2013. These concentrations began to trend negatively after 2013, but the median concentration did not fall below 20 µg/L until 2015. The Horsley Witten Group (2015) found an average chlorophyll *a* concentration in WMP to be much higher across 2001 and 2009-2014, at 172 µg/L. Data collected in 2016 by MassDEP records an average concentration of 40 µg/L, but shows significant improvement in 2017 and 2018, with average concentrations at 12 µg/L and 9 µg/L, respectively.

2.3.1.4 Cyanobacteria

Cyanobacteria blooms can be toxic to humans and animals living and can prevent recreational use of the ponds. MassDEP conducts routine testing of the ponds for cyanobacteria to evaluate whether the ponds exceed the MDPH advisory level of 70,000 cells/mL. Cyanobacteria blooms have been detected from this monitoring program each year from 2011 through 2020 (early data from 2021 do not show bloom levels), affecting recreation for the summer and fall months, particularly in 2013 and 2014 (MassDEP, 2021). However, cyanobacteria blooms have been an ongoing issue since 2008 (Town of Halifax, 2016). **Figure 2-8** shows the available data on cyanobacteria.

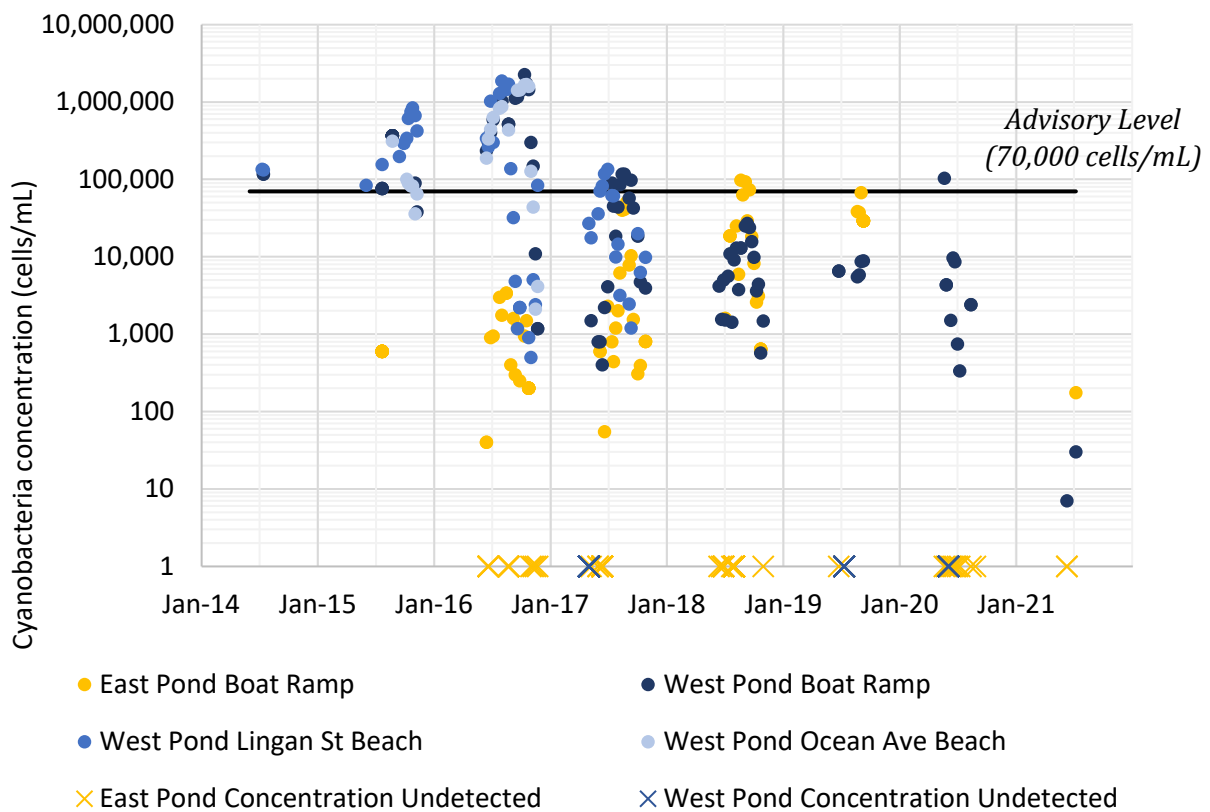


Figure 2-8. Records of MassDEP Cyanobacteria Testing at Four Sites from 2014-2021, as available on the Halifax Town website and provided by MassDEP

As with the phosphorus levels, the cyanobacteria levels have dropped with the addition of alum to WMP in 2013 and annually in 2015-2019. Results of more recent testing, from 2018-2020, suggest a reduction in cyanobacteria concentrations in the pond, with only occasional exceedances of the 70,000 cells/mL level: one exceedance at the EMP boat ramp in 2018 and one exceedance at the WMP boat ramp in 2020. On average there has been a three order of magnitude drop in peak seasonal cyanobacteria levels.

2.3.1.5 Water Clarity and Transparency

Secchi depth measures water clarity, with low Secchi depths indicating lower water clarity due to algae, sediment, or other sources of turbidity. The MassDEP CALM uses a screening guideline of 1.2 m (4 ft) for Secchi depth in lakes and ponds as an indicator of whether the aquatic life, aesthetic, and primary contact recreation uses are supported. If Secchi depth is less than 1.2 m combined with elevated total phosphorus ($\geq 25 \mu\text{g/L}$), elevated pH, and elevated chlorophyll *a* then MassDEP considers the waterbody to be impaired for aquatic life. In addition, if the Secchi depth is less than 1.2 m at least twice during a season then MassDEP may consider the waterbody to be impaired for aesthetics and/or primary contact recreation.

Historical Secchi disk data collected in 1985 and 1986 ranged between 1.1 meters (3.6 ft) to 2.7 meters (8.8 ft). At this time, the ponds generally met the Massachusetts threshold. Across 12 data

collection events, each pond fell below 1.2 meters only once. The average documented Secchi depths for EMP and WMP were 2.1 meters and 1.7 meters, respectively (Lycott Environmental, 1987).

Samples collected by MassDEP in 2001 and 2009-2015 suggest that the EMP transparency hovers at about the 1.2-meter guideline, with the exception of a sample in 2010, which was associated with a dry summer. Notable improvements in 2015 were observed in EMP with an increase in Secchi depth to 3 meters (9.8 ft). During this time in WMP, the Secchi depths had consistently been lower than the 1.2-meter target. However, the comparatively greater Secchi depths in 2013 and 2015 suggest potential improvements with additional alum treatments (MassDEP, 2021). More recent data collected by MassDEP in 2016, 2017, and 2018 were consistently greater than 1.2 m, with average Secchi depths in EMP of 2.6 meters, 2 meters, and 1.9 meters, respectively. Average WMP Secchi depths in 2016, 2017, 2018 were 0.6 meters, 1.8 meters, and 2.2 meters, respectively.

2.3.1.6 *E. Coli*

Massachusetts uses *E. coli* as an indicator bacteria for assessing whether primary contact recreation is safe at freshwater beaches. The bacteria standard is defined in terms of a single sample maximum concentration and geometric mean of the five most recent samples collected during a single bathing season. The single sample maximum concentration criterion is 235 cfu/100 mL and the geometric mean criterion is 126 cfu/100 mL.

The Massachusetts Environmental Public Health Tracking tool shares data on *E. coli* testing at Massachusetts beaches from 2002-2018. Six sites have been sampled in Monponsett Pond over this time, with a total of 22 documented exceedances of *E. coli* concentrations over 235 cfu/100 mL. Over half (13) of these exceedances occur at the Ocean Avenue beach in Hanson. Most years on record have no or one exceedance, except for 2005 and 2006, which had three and four exceedances, respectively (MA EOHHS, 2020). **Table 2-4** documents the exceedances, the geometric mean for *E. Coli* concentrations at the site, and the minimum and maximum documented concentrations over the data collection period.

Table 2-4. Data for *E. Coli* Sampling on Monponsett Pond
(Data made available by the Massachusetts Executive Office of Health and Human Services.)

Site	Years	Total Violations	Geometric mean cfu/100mL	Maximum cfu/100mL	Minimum cfu/100mL
Anawon Drive Beach, Halifax	2003-2018	1	8	292	2
Halifax Beach Association Beach, Halifax	2003-2018	2	12	440	5
Holmes Street Beach, Halifax	2003-2018	2	10	480	5
Lingan Street Beach, Halifax	2003-2018	3	10	700	5
Twin Lakes Condominiums Beach, Halifax	2003-2018	1	8	460	5
Ocean Ave. Beach, Hanson	2012-2017	13	21	5,600	1

Section 3

Historical Water Depth, Releases, and Diversions

3.1 Historical Water Depth

Figure 1-2 shows the available information on Monponsett Pond water levels for nearly the last 100 years. Little information is available prior to Brockton water level records, which begin in 1996. Data on historical pond levels were sought from the following sources:

- The 1923 Chapter 91 license, noting that this document refers to a reference point that most likely has been disturbed/lost. Information will be gleaned from this document, to the extent practicable.
- Discussions with Massachusetts Historical Commission, and town engineers and/or historical commissions in Halifax and Hanson on available historical mapping of Monponsett Pond.
- Historical mapping provided by the Jones River Watershed Association during the public comment period.
- Information from United States Geologic Survey (USGS) maps

The available data that could be referenced to the NGVD elevation datum all indicate pond water levels at either 52 or 52.5 ft. These data correspond to typical elevations found in Monponsett Pond today. This is not an unexpected finding as the outlet from Monponsett Pond has been controlled by flumes and a dam operated by cranberry bog growers starting as early as mapping with elevations was found.

3.2 Releases to Stump Brook

Water can flow from Monponsett Pond to Stump Brook in three ways: downstream releases can be made through a gate on the fish ladder or through a sluice gate on the dam or flow can spill over the dam's spillway. In practice, the sluice gate is not used. Water can also reach Stump Brook indirectly via the Winebrook cranberry bog operations where the bog withdraws water from the pond and discharges it overland to the brook.

Field reconnaissance was conducted on May 20, 2020 to attempt to determine if Monponsett Pond has a natural sill that might control pond elevations in addition to the controls at Stump Brook Dam. The dam is the first man-made control structure downstream from Monponsett Pond and is located about 0.8 mi downstream from the pond outlet. Beginning about 150 ft from the mouth of the pond water depths ranged between 3 and 5 ft deep. Water depths decreased and became relatively constant once the brook narrowed about 300 ft from the pond. Sediment probing showed a shallow layer of soft mud, of variable thickness (1.9 in – 20 in) underlain by fine sand. There was no indication that a sill existed beneath brook. The channel contained numerous stumps, snags and clumps of vegetation so the survey stopped about 1,000 ft from the pond outlet.

3.2.1 Downstream Releases to Stump Brook

Downstream releases to Stump Brook are made to meet release requirements of the Acts and the ACO. The Acts of 1964 required Brockton to release a minimum flow of 0.9 mgd from October through May whenever there was a diversion from Monponsett Pond to Silver Lake. This was codified in the Brockton Code of Ordinances (1964). Brockton voluntarily changed the release practice in November 2015 to always release a minimum of 0.9 mgd. This practice was codified in the 2017 ACO with MassDEP, which requires instream releases of at least 0.9 mgd at all times, unless the pond elevation cannot support the 0.9 mgd release with fish ladder gate placed at its lowest possible elevation (51.8 ft NGVD29). When the gate on the fish ladder is set 4 inches below the pond level, the release equals the required 0.9 mgd.

The instream flow releases were historically made by operating the gate of a fish ladder manually. To prepare for a diversion, operators would set the gate to release more than the minimum instream flow requirement, targeting about 7 inches below the current water surface, equivalent to a 1.9 mgd release. After pond levels fluctuated about 2 inches, the gate would be adjusted up or down a few inches to restore the 7 inches below water surface level. This process was repeated until the diversion was complete, when the gate would be re-set to its fully closed position of 53 ft NGVD. At some unknown date (but up to 2017), flow releases were also made during the summer months when there were no diversions to Silver Lake. While operating practices varied from year to year, this was accomplished by lowering the gate on the fish ladder (typically between 4 and 7 inches below the water level in early June) and allowing the pond to fluctuate naturally until the diversion season approached. After the 2017 ACO required a year-round instream release, the gate operations changed to release at least 0.9 mgd at all times.

In January 2018, the operation of the fish ladder gate was mechanized. The installation of an actuator and sensors allows for more frequent gate adjustments and produces a record of the operational gate settings. The actuator was modified in August 2019. This has resulted in improved accuracy in meeting 0.9 mgd release requirement in the past few years.

In addition to the fish ladder gate, there is a sluice gate at Stump Brook Dam. This sluice gate has historically remained in the closed position, but it has been opened periodically for to allow nominal additional flood control flow. All controlled releases from Stump Brook are typically managed by operating only the fish ladder gate.

3.2.2 Spills over Stump Brook Dam

Spills over the Stump Brook Dam occur when the water level of WMP exceeds the spillway elevation of 53 ft NGVD. Stoplogs can be added to the spillway to increase the maximum pond elevation to 53.5 ft NGVD29 but are not part of normal current operations. Based on conversations with Veolia staff, a maximum water level of 53.25 ft NGVD29 can be held without causing flooding to neighboring properties.

3.3 Water System Operating Procedures

The purpose of this section is to provide information on the historical and current operating procedures implemented by the Brockton Water Division (i.e., existing controls, inter-municipal and established withdrawals, and responses to droughts and emergencies) and to provide an understanding of the system so that insightful decisions can be made when managing the City of Brockton's water supplies.

3.3.1 Historical Operating Procedures at Monponsett Pond

The historical operating procedures at Monponsett Pond were structured to comply with the 1964 and 1981 Acts of the Legislature.

3.3.1.1 Diversions to Silver Lake

Diversions from Monponsett Pond to Silver Lake took place between October 1st and May 31st when:

- Water level in Silver Lake is below full (47.5 ft NGVD); and
- Water levels in Monponsett Pond are above the minimum water level (52.0 ft NGVD).

Until 2017, the practice was to operate with the diversion valve generally operated as either fully open or fully closed. Typically, when the diversion was being used, the valve was fully open all day, so the daily diversion volumes were similar from day to day.

To prevent flooding, diversions from Monponsett Pond to Silver Lake occurred throughout the year and by written request of the Town of Halifax or Hanson. It was the practice to monitor Monponsett Pond levels as the water approached the Stump Brook spillway elevation (53 ft NGVD) and begin flood (level-control) diversions at elevation 53.25 ft. Until about 2017, flood diversions were typically made to Silver Lake.

3.3.1.2 Downstream Releases to Stump Brook

Monponsett Pond levels are controlled by a dam on Stump Brook. The control structure contains a spillway, a 2-ft-wide weir gate controlling flow to a downstream fish ladder, and a sluice gate. The dam spillway elevation of 53.0 ft NGVD sets the maximum elevation of the pond. The fish ladder gate controls pond levels and releases. The sluice gate can make releases between elevations 51.0 and 53.0 ft NGVD but is not typically operated.

Releases to the fish ladder were made when the diversion to Silver Lake is in use, when herring are running, or when requested by the towns of Halifax and Hanson. When the diversion was in use, 0.9 mgd of flow over the fish ladder was maintained by the 1964 Acts of the Legislature. At some unknown time in the past but prior to 2017, it became the practice to attempt to allow flow out the fish ladder gate during summer months, when no water is being diverted, to keep a flow in Stump Brook. This was reported to be done by setting the weir between 4 and 7 inches below the water level in early June and allowing the natural hydrology to determine the releases throughout the summer.

3.3.1.3 Other Authorized Withdrawals

Water is also withdrawn from Monponsett Pond for consumptive and return uses at cranberry bogs in the area. Cranberry bog uses include water withdrawn during the spring and fall, which are used for frost protection, while summer withdrawal is used for irrigation. Return use includes winter withdrawals which are used for flooding operations, though not all water withdrawn for cranberry purposes is returned to the water supply system. These withdrawals are not under the control of Brockton.

3.3.2 Current Operating Procedures

The current operating procedures at Monponsett Pond were structured to comply with the 1964 Acts of the Legislature and the 2017 ACO. In general, the operating procedures are the same as listed above, with exception to the following changes made to comply with the ACO:

3.3.2.1 Diversions to Silver Lake

The diversion valve is now operated at less than a 50 percent valve position rather than fully open or fully closed. This results in a reduced diversion of about 12-15 mgd rather than about 25 mgd.

Diversions from Monponsett Pond to Silver Lake to prevent flooding have been greatly reduced. This is only done with written request of the Town of Halifax or Hanson or when requested by DEP.

3.3.2.2 Downstream Releases to Stump Brook

Minimum releases of 0.9 mgd over the fish ladder are maintained year-round as codified in the 2017 ACO with MassDEP. The 0.9 mgd release occurs any time the Monponsett Pond level supports such a release from the fish ladder (with lowest gate position at 51.8 ft NGVD29).

Section 4

Field Investigations

4.1 Introduction

Two field investigations were conducted as part of the RMP:

- Velocity measurements through the culvert connecting EMP and WMP under various Silver Lake diversion and Stump Brook release conditions, and
- Water quality monitoring in EMP and WMP under a range of Silver Lake diversions.

The objective of this study was to develop scoping level information to assess the potential adverse water quality impacts of nutrient loads conveyed from WMP to EMP under various City of Brockton water supply system operating conditions allowable under the ACO.

4.2 Velocity and Flow through Culvert

ACO Item 33c requires “collection of flow data to correlate Silver Lake diversion rates with flow rates from West Monponsett Pond to East Monponsett Pond during diversions to Silver Lake.”

The natural flow path is from EMP to WMP and Stump Brook. The intent of this requirement is to assess the potential for the flow of degraded water from WMP to pass through the culvert to EMP, given that the City of Brockton’s diversions are from the EMP.

To meet the ACO requirements, the City developed and implemented a flow measurement protocol to measure flow through the culvert at Route 58 for different Silver Lake diversion rates and releases to Stump Brook across a representative range of conditions of Silver Lake diversions and releases over the Stump Brook dam (see overview map, **Figure 4-1**). The flow monitoring program was conducted intermittently by Veolia staff between November 2019 and January 2021.

The monitoring program was designed to evaluate the velocity and flow rate between EMP and WMP for Silver Lake diversion rates of 0, 25, 50, 75, and 100 percent of the full diversion rate and releases over the Stump Brook dam of 0 mgd, 0.3 mgd, 0.6 mgd, and 0.9 mgd. For this study, the percentages represent the setting on the butterfly valve that controls the diversion from Monponsett Pond to Silver Lake. The relationship between flow and valve setting is nonlinear and depends on the pond elevation. The approximate flow rates associated with the 25, 50, 75, and 100 percent diversion rates are 6, 18, 22, and 24 mgd, respectively.

Velocity monitoring was conducted by estimating the surface velocity through the culvert by floating an orange to measure the travel time between East and West Monponsett Pond. An orange was used because its buoyancy characteristics reduce the influence of wind on the travel time through the culvert. The standard operating procedures followed for each trial are described in **Appendix C**.



Figure 4-1
Flow Monitoring and Water Quality Sampling Locations

4.2.1 Culvert Characteristics and Measurement and Analysis Protocol

On the first monitoring event (November 21, 2019), the culvert was measured to calculate the cross-sectional area and distance. In addition, a staff gage was fixed to the side of the culvert to monitor the water surface elevation at the culvert on each monitoring date. The culvert cross section is illustrated in **Figure 4-2**. While the culvert narrows the top, the water surface elevation during this monitoring program did not approach the top of the culvert, so a rectangular cross section was used to calculate the cross-sectional area for each monitoring event. The channel bottom through the culvert has sediment and debris buildup, so the depth was measured on each side of the culvert on each trial and averaged to calculate the average cross-sectional area for each monitoring date. The culvert length between East and West Monponsett Ponds is 49 ft.

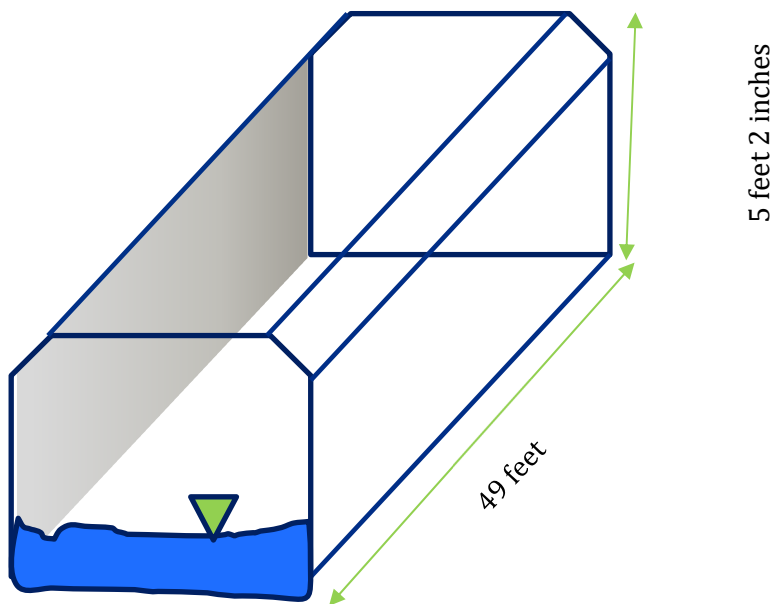


Figure 4-2. Culvert Dimensions Measured by CDM Smith and Veolia

On each monitoring date the flow direction was first evaluated (either East to West or West to East), the staff gage read, and the channel depth at the centerline measured on each side of the culvert. Then, an orange was gently placed in the water at the centerline of the culvert and timed to determine an estimated surface velocity through the culvert (**Figure 4-3**). A minimum of three trials were completed on each sampling date and averaged to calculate the surface velocity. In some cases during the monitoring program the water direction shifted mid-trial and the orange did not completely travel through the culvert. The flow for these trials was assumed to be 0 mgd.



Figure 4-3. Estimating Surface Velocity Using an Orange

Velocity in an open channel is not constant with depth and is influenced by friction from the channel bottom and sides. The mean channel velocity can be estimated using a logarithmic velocity profile where the velocity is highest at the surface and zero at the boundary layer at the bottom. Since this study is measuring the surface velocity an adjustment is needed to calculate the mean velocity through the culvert. For this study, the mean channel velocity was estimated using coefficients described in the United States Bureau of Reclamation's Water Management Manual (USBR, 2001). These coefficients are intended for use in canals and scale with channel depth accounting for the diminishing impact of channel bed friction on the mean channel velocity as the water depth increases. The coefficients reported by the USBR are described in **Table 4-1**. The surface velocity in each trial was multiplied by the coefficient to estimate the mean channel velocity through the culvert. The coefficient for each flow was computed for the average depth on each monitoring date by linearly interpolating the USBR coefficients (the relationship between 1 and 6 ft is linear).

Table 4-1. Coefficients Used to Calculate Mean Velocity from Surface Velocity Measurements

Average Depth (ft)	Coefficient
1	0.66
2	0.68
3	0.7
4	0.72
5	0.74
6	0.76
9	0.77
12	0.78
15	0.79
>20	0.8

Note: Reproduced from Table 13-1 in USBR, 2001

4.2.2 Data and Analysis

Veolia staff conducted 19 flow measurements between November 2019 and January 2021 in accordance with the field monitoring program and standard operating procedures. The date of each monitoring event, the season, the Silver Lake diversion rate, the Stump Brook release rate, the observed flow direction, and the conditions are described in **Table 4-2**. The sampling program was designed to have the velocity measurements conducted during light wind conditions to minimize wind influence on the surface velocity measurements. Data collected during moderate to high wind conditions (as noted in **Table 4-2**) could be subject to additional uncertainty due to wind influence on the orange. In addition, the Stump Brook release rates reported represent nominal flows based on a gate position and will vary depending on the pond water surface elevation.

Table 4-2. Summary of Monponsett Pond Flow Measurement Dates with the Silver Lake Diversion and Stump Brook Release

Round	Date	Diversion to Silver Lake: Valve Setting (%) ¹	Silver Lake Diversion Rate (mgd)	Target Release to Stump Brook (mgd) ²	MP Level (ft NGVD) ³	Observed Flow Direction	Conditions ⁴
1 (fall)	11/21/2019	0	0	0.9	52.72	East to West	Sunny, light to no wind
	11/27/2019	25	6.2	0.9	53.02	West to East	Sunny, slight wind
	12/5/2019	50	17.9	0.9	53.25	West to East	Light wind, choppy
	12/9/2019	75	22.5	0.9	52.96	West to East	Light rain, very light wind
	12/11/2019	100	24.1	0.9	53.36	West to East	Clear
2 (winter)	1/28/2020	0	0	0.9	53.44	East to West	Cloudy, light wind
	1/31/2020	25	6.1	0.9	53.30	No Flow	Sunny, light wind
	2/3/2020	50	18	0.9	53.18	West to East	Cloudy, light to moderate wind
	2/5/2020	75	22.9	0.9	53.07	West to East	Cloudy, light wind
	2/7/2020	100	23	0.9	53.09	West to East	Light mist, no wind
3 (spring)	5/14/2020	0	0	0.9	53.26	East to West	Clear, light wind
	5/18/2020	25	6.3	0.9	53.22	Variable to no flow ⁵	Cloudy, calm
	5/20/2020	50	17.0	0.9	53.12	West to East	Clear, light wind
	5/22/2020	75	21.2	0.9	52.99	West to East	Clear, light wind
4 (winter)	1/11/2021	0	0	0	52.61	No Flow	Calm
	1/15/2021	0	0	0.3	52.55	Variable, dominant flow East to West ⁶	Partly cloudy, light wind
	1/19/2021	0	0	0.6	52.93	West to East	Sunny, steady east wind, choppy
	1/22/2021	0	0	0.6	52.91	East to West	Light wind
	1/25/2021	0	0	0.9	52.88	Variable, dominant flow West to East	Moderate east wind, choppy

Notes: 1. Diversion percentage represents the valve setting.

2. The Stump Brook release rates reported represent nominal flows through the fish ladder gate based on gage position and will vary depending on pond water level

3. When the Monponsett Pond water levels are higher than the spillway elevation (53 ft) the total release down Stump Brook is higher than the nominal value reported

4. Conditions are as reported by Veolia staff. Wind speeds and conditions are qualitative.

5. Flow was from east to west on the first trial, west to east on the second two trials, and then no flow (sampling crew waited 20 minutes for flow to change direction)

6. Tests were conducted over a period of 1 hour and 10 minutes. The flow was moving back and forth and was very low velocity. The orange passed through the culvert twice, West to East.

The flow monitoring results indicated that the flow through the culvert varies with changes to Silver Lake diversion, Stump Brook flow, and wind, and that a strong relationship exists between flow through the culvert and Silver Lake diversion rate. The data are summarized in **Table 4-3**. All data collected during this study are presented in **Appendix D**. For this assessment, positive values indicate flow from EMP to WMP, and negative values indicate flow from WMP to EMP.

4.2.2.1 Analysis when Silver Lake Diversion Varies and Stump Brook Dam Flow Only Varies with Pond Level

Flow measurements collected during the fall, winter, and spring monitoring periods where the Silver Lake diversion was varied at a constant Stump Brook discharge are shown graphically in **Figure 4-4**. The Silver Lake diversion is expressed as a percentage of the full diversion rate (25 mgd). These data indicate that flow between East and West Monponsett Pond is generally from EMP to WMP when the Silver Lake diversion was not active (0 percent). When the Silver Lake diversion is active (25 percent or greater), the flow is generally from WMP to EMP. As the diversion fraction increases the magnitude of the flow measured at the culvert increases. At the 25 percent diversion there is a weak flow that averages from West to EMP but flow occasionally was observed from East to West Monponsett Pond in during the spring monitoring season, and no flow was observed during the winter 2020 monitoring season. This condition is likely caused by wind effects on flow patterns between the two ponds in addition to the relatively low diversion rate to Silver Lake. Once the diversion was increased to 50 percent the flow was uniformly observed to be from West to EMP.

In addition, a seasonal pattern may be apparent in the data. The fall flows (observed during November and December 2019) are less variable and often higher, with the fall flows having the highest observed flow across all observed scenarios compared with the winter and fall monitoring periods. The winter data were still variable, especially for the 50 percent, 75 percent, and 100 percent diversion rates, but less variable than the spring monitoring periods. The spring data exhibited the most variability and were often the lowest observed flows. From the limited data there does not appear to be a strong relationship between mean depth and flow through the culvert. This suggests that the variability observed in the data is likely related to other sources of variability and does not have a significant seasonal component. However, since these data are limited to a single year of monitoring, additional data would be required to determine whether a clear seasonal pattern exists in the data or whether these differences are the result of different pond water levels, wind patterns, or other sources of variability on the observation dates.

Table 4-3. Summary of Monponsett Pond Flow Measurements Collected during the Monitoring Program

Season	Date	Diversion to Silver Lake (%) ¹	Diversion (mgd)	Stump Brook (mgd)	Mean Depth (inches)	Mean Flow (mgd)	Maximum Flow (mgd)	Minimum Flow (mgd)
Fall	11/21/2019	0	0	0.9	18.6	1.59	1.98	1.12
Fall	11/27/2019	25	6.2	0.9	22.8	-1.59	-1.40	-1.90
Fall	12/5/2019	50	17.9	0.9	22.5	-8.09	-6.47	-9.23
Fall	12/9/2019	75	22.5	0.9	21.5	-11.97	-11.53	-12.65
Fall	12/11/2019	100	24.1	0.9	24.1	-10.76	-10.23	-11.09
Winter	1/28/2020	0	0	0.9	28.9	2.94	3.13	2.62
Winter	1/31/2020	25	6.1	0.9	n/a	0.00	0.00	0.00
Winter	2/3/2020	50	18	0.9	25.8	-5.60	-4.64	-7.01
Winter	2/5/2020	75	22.9	0.9	22.6	-8.62	-7.71	-9.81
Winter	2/7/2020	100	23	0.9	22.3	-10.73	-9.47	-11.65
Spring	5/14/2020	0	0	0.9	24.7	3.10	4.08	2.45
Spring	5/18/2020	25	6.3	0.9	24.3	-0.27	1.88	-1.43
Spring	5/20/2020	50	17.0	0.9	23.4	-3.08	-1.43	-5.39
Spring	5/22/2020	75	21.2	0.9	20.5	-7.82	-6.61	-9.18
Winter	1/11/2021	0	0	0	16.8	0	0	0
Winter	1/15/2021	0	0	0.3	16.3	-0.21	0	-0.95
Winter	1/19/2021	0	0	0.6	21.1	-2.85	-1.69	-4.22
Winter	1/22/2021	0	0	0.9	21.1	0.89	1.06	0.59
Winter	1/25/2021	0	0	0.6	20.8	-1.16	-1.06	-1.26

Note: Negative flow indicates discharge from WMP to EMP. Zero flow indicates that no flow was observed during the sampling date.

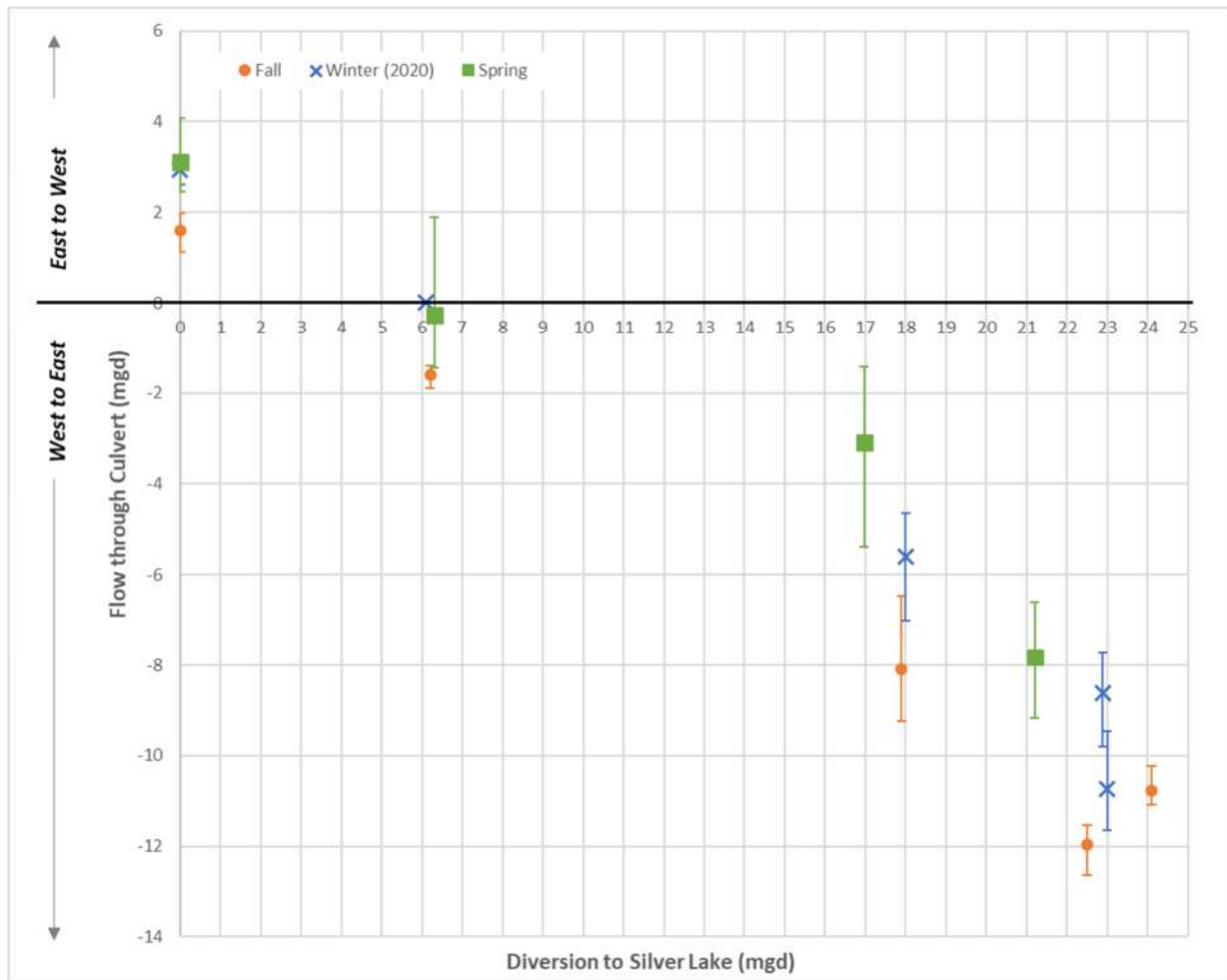


Figure 4-4. Summary of Culvert Flow Rates Measured During the 2019 – 2020 Monitoring Program at the Route 58 Culvert Between East and West Monponsett Pond

Note: Negative flow indicates discharge from WMP to EMP. Zero flow indicates that no flow was observed during the sampling date.

4.2.2.2 Analysis when No Diversion to Silver Lake and Stump Brook Flow Varies

The monitoring program consisted of variable Stump Brook releases during the Winter 2021 monitoring program, where the Stump Brook release ranged from 0 mgd to 0.9 mgd with no diversion to Silver Lake. The winter 2021 data are shown in **Figure 4-5**.

These data show no flow between the ponds when the Stump Brook gate was closed. When the Stump Brook gate was opened to release 0.3 and 0.6 mgd, the measured flow increased and was predominantly from West to East Monponsett Pond. The flow was estimated to be at an average rate of 0.9 mgd from East to West Monponsett Pond for the 0.9 mgd release rate scenario. The measurements at the 0.6 mgd Stump Brook release rate were likely heavily impacted by wind. Both 0.6 mgd measurements were conducted with a moderate to strong wind from west to east, with the higher flows (1/19/2021) described as “wind was ripping through the culvert in an easterly direction and the water was choppy.” The City was unable to maintain the zero diversion

to Silver Lake to complete additional tests due to operational constraints. Therefore, these data are inconclusive but indicate that when flow is being released that flow to Stump Brook can cause flow from EMP to WMP under low wind conditions, but that the flow dynamics between the two ponds can be heavily influenced by wind.

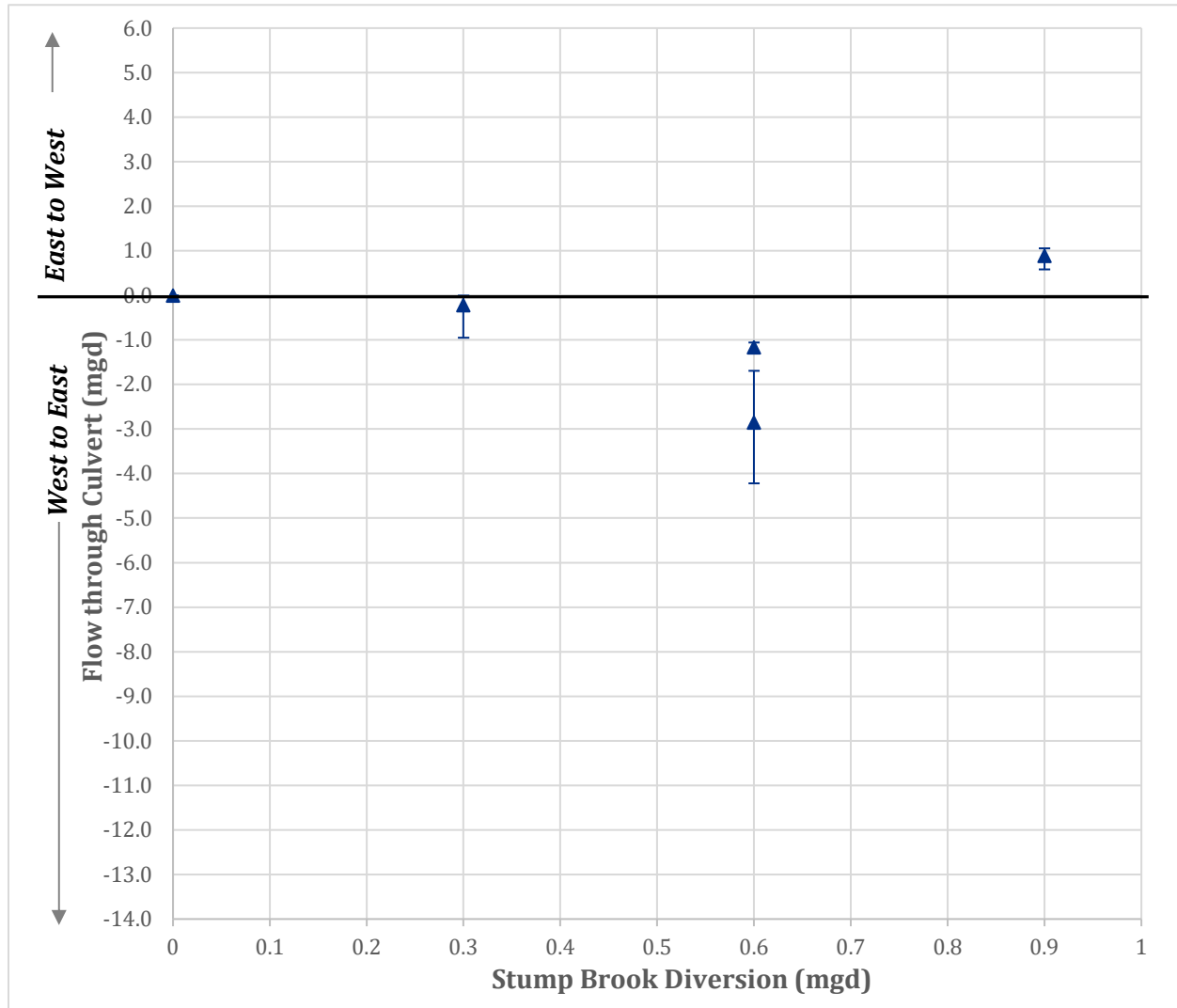


Figure 4-5. Winter 2021 Flow Measurements Conducted when the Silver Lake Diversion was 0 Percent for Variable Stump Brook Releases

Note: Negative flow indicates discharge from WMP to EMP. Zero flow indicates that no flow was observed during the sampling date.

4.2.3 Uncertainty Analysis

CDM Smith evaluated the relative uncertainty in the direction, velocity, and flow measurements collected during this study. Measurement of surface velocity and calculated flow through the culvert are subject to uncertainty due to several factors. These factors are listed below.

- Low velocity through the culvert is difficult to measure accurately.
- Wind can impact the surface velocity measurement by pushing the surface float through the culvert, impeding its progress, or causing wind-induced current through the culvert that is independent from flow induced by Silver Lake diversion or Stump Brook flow.
- Velocity through the culvert is not uniform through the cross section and varies both with depth and width.
- The surface velocity is scaled to an average channel velocity using existing empirical relationships developed for other channels. The average channel velocity scaling factor depends on channel width, channel roughness, and water depth.
- The channel bottom through the culvert is not uniform, so the cross-sectional area used to compute the flow is an approximation.

The relative uncertainty in the direction, velocity, and flow measurements based on these factors is described qualitatively below.

4.2.3.1 Flow Direction

The flow direction was recorded by Veolia staff for each trial and is therefore not subject to uncertainty. Even at very low velocity the dominant flow direction was consistent (either east to west or west to east).

4.2.3.2 Surface Velocity

Velocity measurements are subject to uncertainties related to the influence of wind, non-uniform streamlines across the channel, and the frictional losses that create a logarithmic velocity profile with depth through the culvert.

Variability due to wind is evident in at least a subset of the monitored events based on site descriptions from the Veolia field crews on each monitoring day. In addition, it is likely that streamlines through the culvert are non-uniform laterally which could cause variable velocity measurements through the culvert. **Figure 4-6** presents the range of surface velocity measurements collected during each trial illustrating the variability observed in the data. The variability in the velocity indicates that non-uniform conditions were present during each trial indicating uncertainty due to a likely combination of wind impacts and non-uniform lateral flow patterns through the culvert.

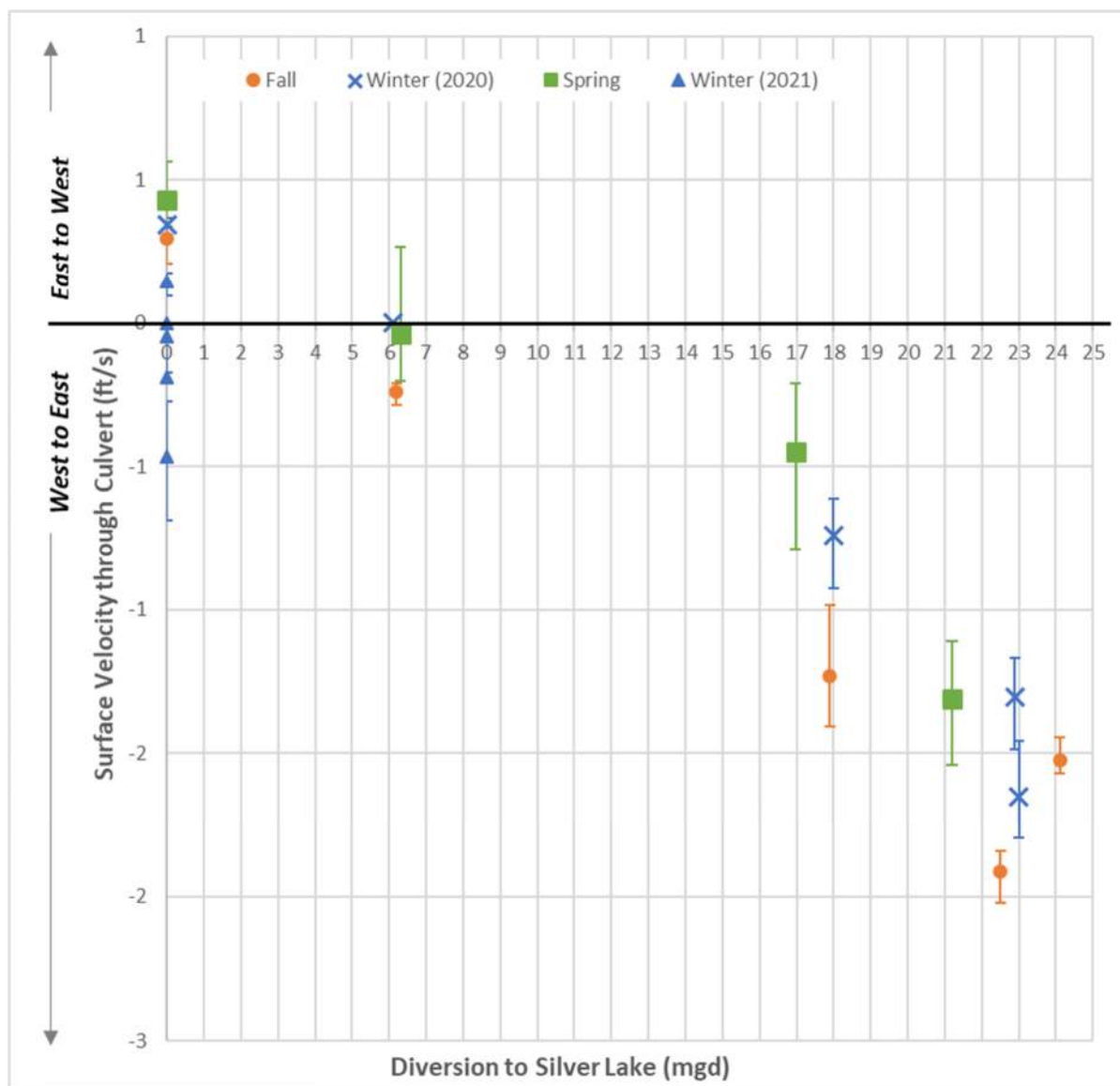


Figure 4-6. Variability in Surface Velocity Measured during the 2019-2021 Monitoring Program

Notes: Winter 2021 measurements were conducted with variable Stump Brook flow. Velocities are surface velocities and are not corrected to mean channel velocity.

In addition to the non-uniform velocity conditions through the culvert, the velocity varies logarithmically with depth, with zero velocity at the boundary layer on the bottom and the peak velocity at the surface. Therefore, the surface velocity must be scaled to calculate the average channel velocity. While the theoretical velocity profile will be logarithmic, the profile will be impacted profile will be affected by channel roughness and other frictional losses. Therefore, the scaling factor used to transform the surface velocity to an average channel velocity is based on empirical relationships developed by the USBR. The actual relationship between surface velocity and mean velocity is variable and site specific and can range from 0.5 to 0.9 (see, e.g., Fulton, 2019; Chiu, 1989). Field measurements are required to characterize the relationship between

surface velocity and channel velocity; these measurements would be difficult to accurately collect due to the low velocities observed through the Monponsett Pond culvert.

4.2.3.3 Culvert Cross Section and Estimated Flow

CDM Smith's field visits indicated that the channel bottom through the culvert is irregular, with significant sediment buildup through the culvert. For this study, the velocity measurements are used to calculate a flow by calculating the average cross section from a depth measurement at the centerline at the east and west ends of the culvert. This calculation assumes that the culvert bottom is uniform throughout the 49-ft length.

To evaluate the potential uncertainty in the depth measurements used to calculate the cross-sectional area, CDM Smith evaluated data from the permanent Monponsett Pond level sensor (0 = 52.5 ft NGVD), the temporary staff gage installed at the east end of the culvert (datum not established), and depth measurements collected at the centerline on the east and west culvert ends. A comparison of these data is presented in **Figure 4-7**. These data indicate:

- The depth is not constant through the culvert, and the depth on the east side of the culvert is always greater than on the west side of the culvert. This relationship is consistent (east is always deeper than west) and is therefore likely due to differential sediment buildup on either side of the culvert.
- The difference in measured depth on the east and west end is not consistent through the monitoring program. The difference between the two measurements ranges from 0.625 inches (1/25/2021) to 4.5 inches (11/21/2019, 11/27/2019, and 12/5/2019). The cause of this difference is not known but could include measurement error or shifting sediment through the culvert.
- The relationship between the permanent Monponsett Pond staff gage and the temporary staff gage and the two depth measurements is strong and linear but is not perfect (slope of 1). As with the deviation between the depth at the east and west culvert end, the cause of the scatter in this relationship are not known. Potential causes include different measurement times, wind effects, and measurement error.

The mean cross section was assumed to be the average of the east and west depths, representing a reasonable approximation for the mean channel cross section through the culvert. However, uncertainties in the cross-section geometry through the culvert could result in error in the estimated flow through the culvert.

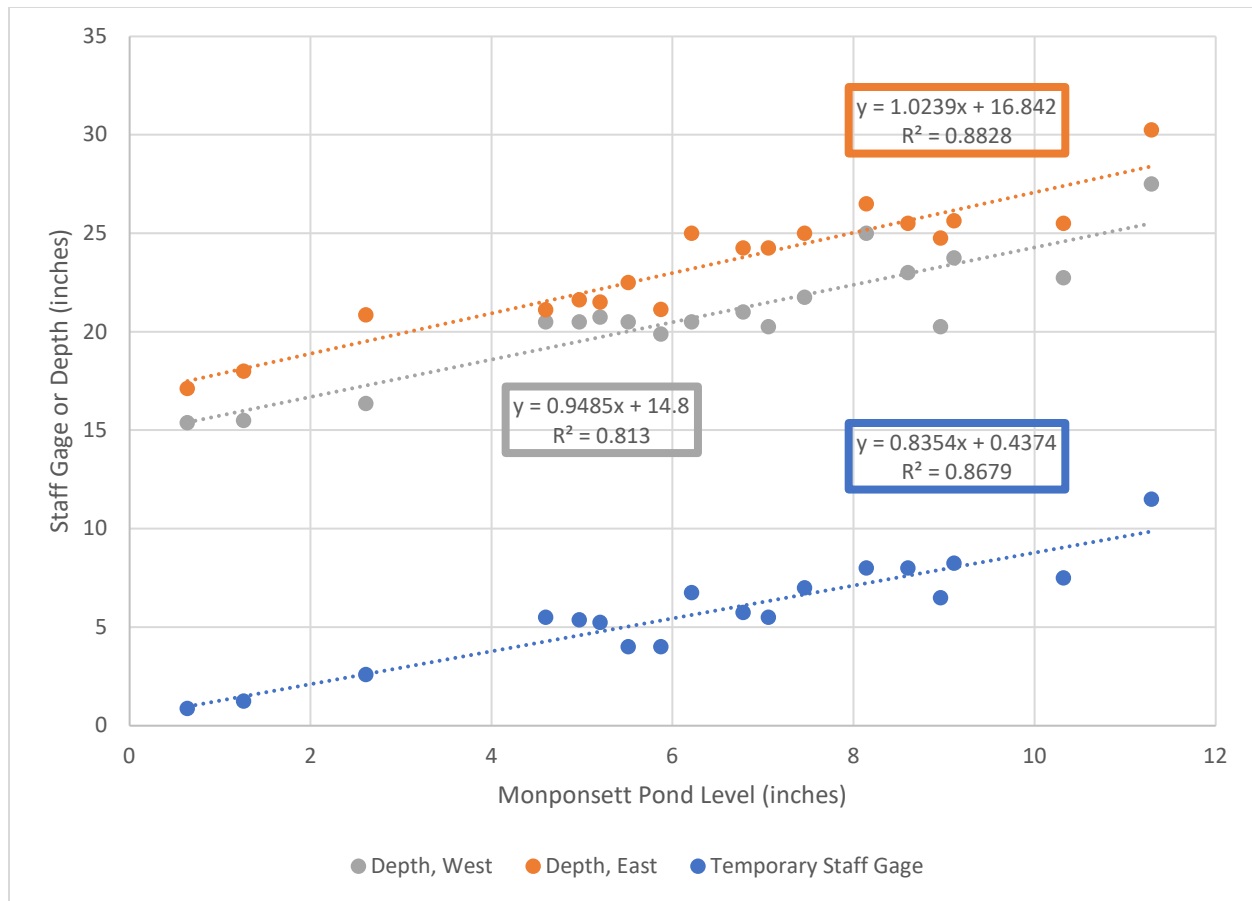


Figure 4-7. Relationship Between the Permanent Monponsett Pond Staff Gage, the Temporary Staff Gage, and the Measured Depth at the East and West Culvert Ends

4.2.3.4 Uncertainty Analysis Conclusions

The sources of uncertainty discussed in this section demonstrate the relative difficulties of measuring low velocities through an irregular culvert. The analysis presented here represents CDM Smith's estimate of the most likely mean channel velocity and flow measured through the culvert during the monitoring program. While the precise velocities and flows are subject to the uncertainties noted above, the data collected during this study indicate a strong, significant relationship between Silver Lake diversion and flow through the Monponsett Pond culvert.

4.3 Water Quality Sampling

During this study, the University of Massachusetts at Dartmouth School of Marine Science and Technology (SMAST) conducted a water quality study during four sampling rounds at five locations. Each of the four sampling rounds were conducted at diversion rates between Monponsett Pond and Silver Lake of 0, 25, 50, and 75 percent. Three samples were collected in EMP and two in WMP (**Figure 4-8**). Samples were analyzed for nutrients (ammonia, nitrate/nitrite, dissolved inorganic nitrogen, dissolved organic nitrogen, particulate organic nitrogen, orthophosphate, and total phosphorus), particulate organic carbon, chlorophyll *a*, pheophytin *a*, and field parameters (pH, temperature, conductivity, Secchi depth, and dissolved oxygen, color, and turbidity). **Table 4-4** describes the timing of tested diversion operation scenarios and reports the date when water quality samples were collected after 48 hours of continuous operation. As noted above, the diversion percentage corresponds to the opening percentage on the butterfly valve controlling the diversion and not the percentage of the full diversion rate. The diversion rate associated with each diversion trial is described in **Table 4-4**. Flow measurements in the culvert between WMP and EMP were also collected during sampling event, as described in **Section 4.2**.



Figure 4-8. Map of Water Quality Sampling Locations in the May 2020 Scoping Study

Table 4-4. Diversion Scenarios Tested in May 2020 Water Quality Impacts Scoping Study

Scenario	Diversion (mgd)	Start Date	End Date	Duration (Days)	Water Quality Sampling Date
No Diversion	0	5/13/2020	5/15/2020	2	5/14/2020
25 Percent Diversion	6	5/15/2020	5/18/2020	3	5/18/2020
50 Percent Diversion	17	5/18/2020	5/20/2020	2	5/20/2020
75 Percent Diversion	21	5/20/2020	5/22/2020	2	5/22/2020
100 Percent Diversion	No Testing				

4.3.1 Conditions During Sampling

Weather conditions during the May 2020 monitoring period were assessed based on the qualitative observations by the Veolia monitoring team (see **Table 4-2**) and precipitation records from the Taunton Airport. The 25, 50, and 75 percent diversion scenarios were sampled concurrently with the flow measurements. On each of these monitoring dates the wind was described as calm to light, suggesting a low relative impact of wind on transport through the culvert during the monitoring program. Precipitation records at the Taunton Airport (WBAN 54777) indicated one small precipitation event during the monitoring period with 0.5 inches on May 15-16 and 5/16 (between the 0 percent and 25 percent diversion scenarios).

As discussed in **Section 2.2.1**, MassDEP routinely monitors cyanobacteria concentrations in East and West Monponsett Ponds. During the May 2020 monitoring program a bloom of the cyanobacteria *Dolichospermum flosaquae* occurred in WMP, with a peak cyanobacteria concentration of 100,246 cells/mL, exceeding the 70,000 cells/mL cyanobacteria criterion. The presence of cyanobacteria was also noted by the UMass Dartmouth sampling team on the May 18th monitoring event.



Figure 4-9. Cyanobacteria Bloom at the West Monponsett Pond Boat Ramp on May 21, 2020

Image Credit: George Zoto, MassDEP

4.3.2 Results

This section describes summary statistics and for the water quality data collected during the May 2020 monitoring program. A complete table of validated data is presented in **Appendix D**. Total phosphorus, total nitrogen, and total pigment (chlorophyll *a* + pheophytin *a*) are summarized in **Table 4-5** and graphically in **Figures 4-10** and **4-11**. The nitrogen components are presented in **Figure 4-12** (including total nitrogen). Orthophosphate was at or below the detection limit during the monitoring program.

The total phosphorus, total nitrogen, and total pigment data recorded during this study exhibited different patterns in WMP versus EMP. On an average basis, the total phosphorus and chlorophyll *a* concentrations were slightly higher in WMP compared with EMP. Furthermore, while the total nitrogen concentrations were comparable between East and West Monponsett Ponds, the partition between dissolved inorganic nitrogen (nitrate + nitrite [NO_x] and ammonia [NH₄]) and organic nitrogen (dissolved organic nitrogen [DON] and particulate organic nitrogen [PON]) was significantly different. Dissolved inorganic nitrogen was near the detection limit in WMP and higher in EMP; conversely, the particulate organic nitrogen was higher in WMP. This difference may help explain differences in algae concentrations in East and West Monponsett Pond.

Table 4-5. Summary Statistics for TN, TP, and Total Pigment

Parameter	Station	Concentration (µg/L)			
		Mean	Median	Max	Min
TN	EMP1	549	546	570	533
	EMP2	561	562	565	554
	EMP3	559	556	586	539
	WMP1	575	579	655	489
	WMP2	538	545	606	455
	East	556	557	586	533
	West	556	545	655	455
TP	EMP1	21	21	25	15
	EMP2	22	21	25	20
	EMP3	21	21	24	17
	WMP1	25	25	30	20
	WMP2	26	25	32	21
	East	21	21	25	15
	West	25	25	32	20
Total Pigment	EMP1	8	7	13	5
	EMP2	8	8	10	5
	EMP3	7	7	8	5
	WMP1	14	15	18	7
	WMP2	16	15	21	12
	East	8	7	13	5
	West	15	15	21	7

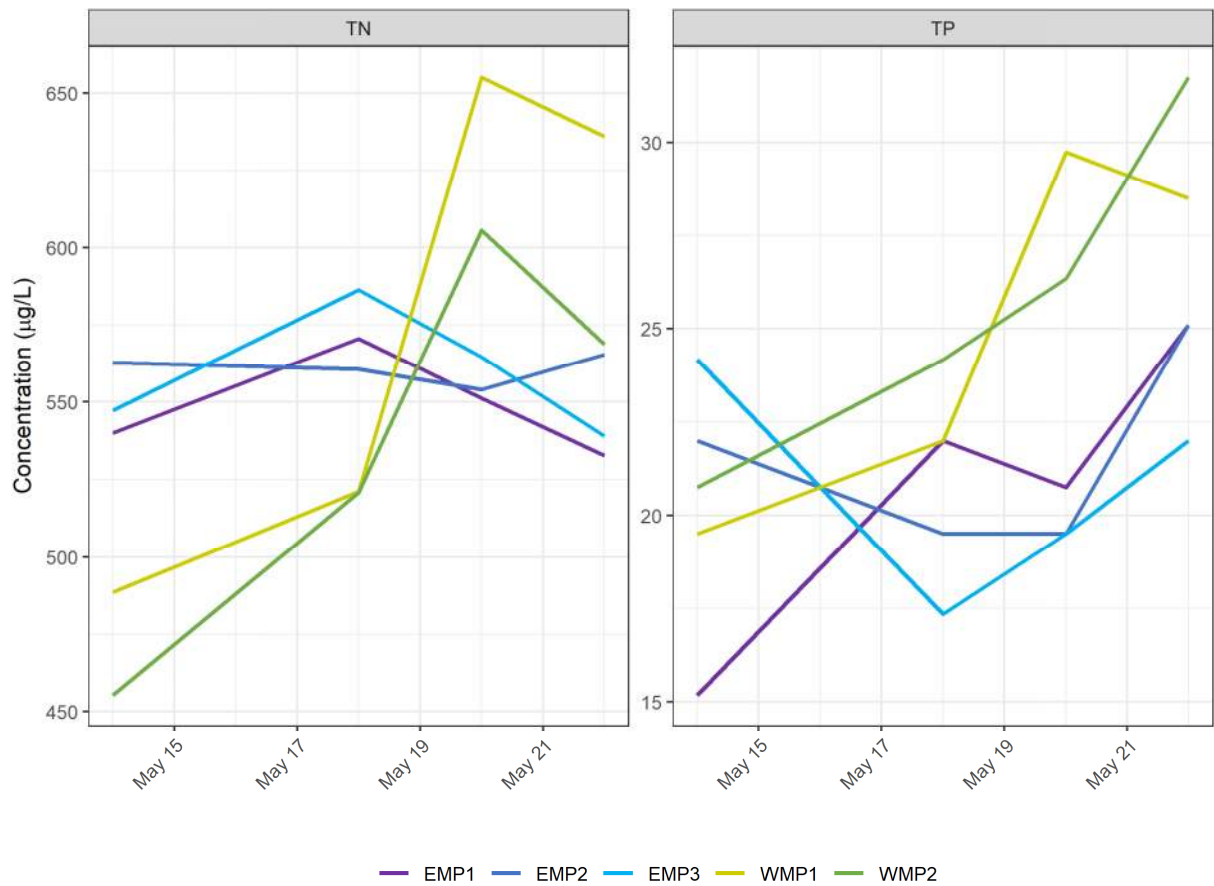


Figure 4-10. Total Nitrogen and Total Phosphorus Concentrations During the Monitoring Program

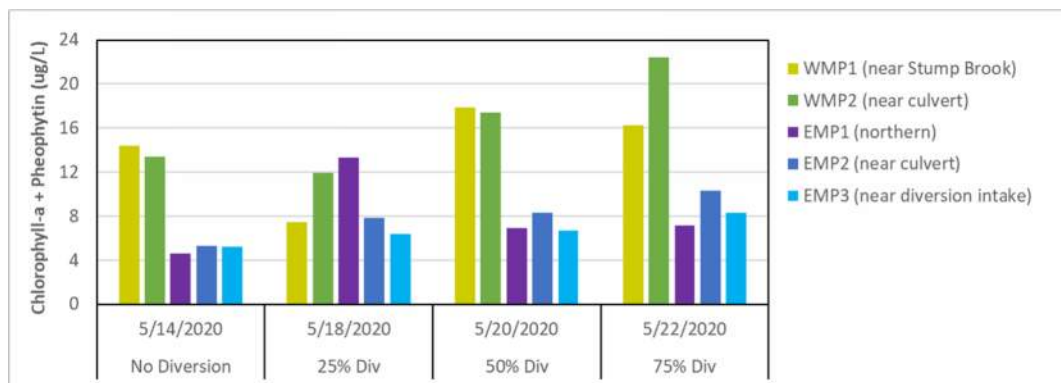


Figure 4-11. Algae in the Monponsett Ponds during May 2020 Silver Lake Diversion Impacts Scoping Study

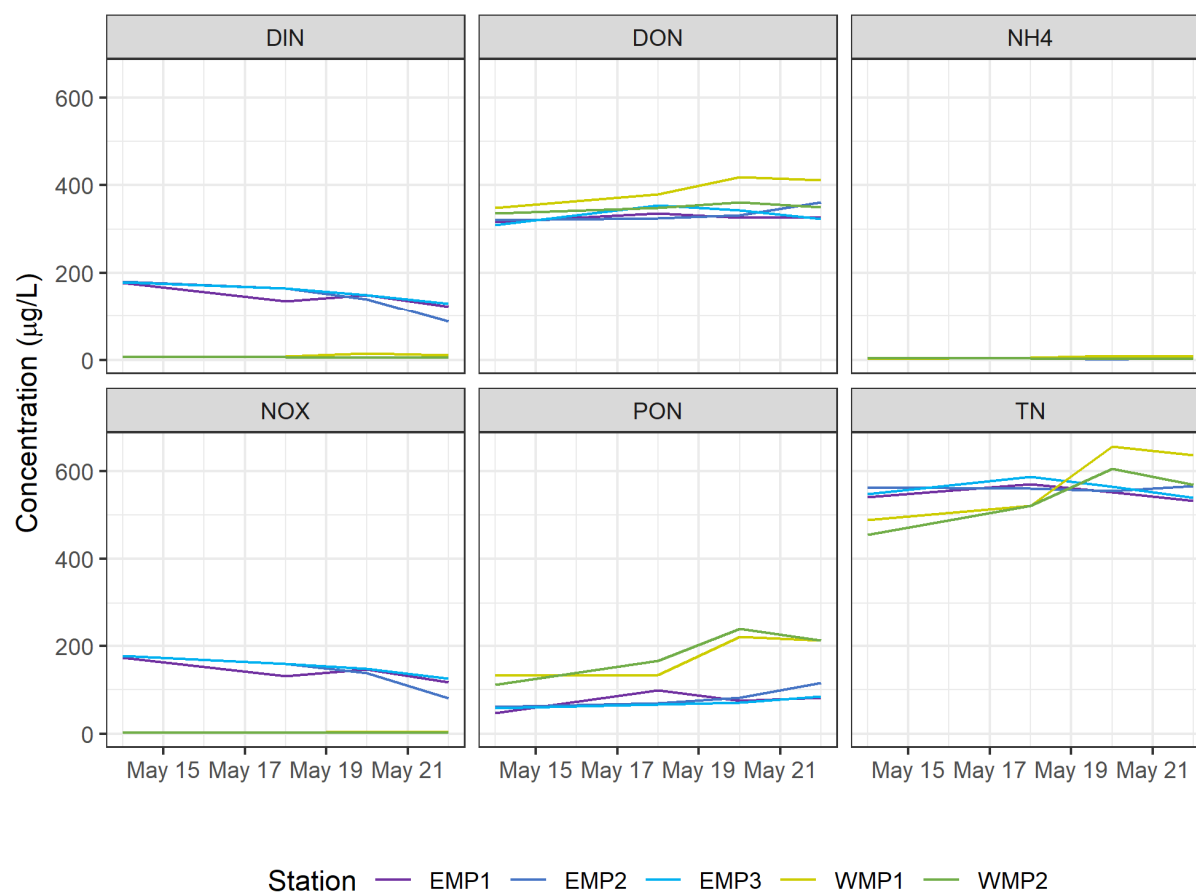


Figure 4-12. Nitrogen Components

During the monitoring program, there was a significant increase in WMP nutrients and total pigment from the first sample (5/14) to the last sample (5/22). Average WMP total nitrogen increases by 15 percent (550 µg/L on 5/14 to 630 µg/L on 5/18), total phosphorus increases by 50 percent (20.1 µg/L on 5/14 to 30.1 µg/L on 5/22), and chlorophyll *a* by 38 percent (13.6 µg/L on 5/14 to 18.7 µg/L on 5/22). The large increase in nutrient mass in WMP is likely attributable to a combination of stormwater inflow from the 0.5-inch precipitation event that occurred during the monitoring program and the algal bloom observed by the UMass Dartmouth sampling team and MassDEP on 5/18 through 5/21. The increase in particulate organic nitrogen in WMP suggests that the increase in total nitrogen can be at least partially attributed to the *Dolichospermum* bloom; similarly, the increase in total phosphorus is principally in the particulate form given the low orthophosphate concentrations and could also be explained by the algal bloom. *Dolichospermum* is able to fix nitrogen from the atmosphere as well as control its buoyancy (see, e.g., Wacklin *et al.*, 2009), so it is possible that the algal bloom brought phosphorus from deeper portions of WMP to the surface and nitrogen from the atmosphere, accounting for the observed increase in particulate phosphorus and particulate organic nitrogen throughout the monitoring period.

The pattern in the EMP nutrient concentrations is different with no significant change in total nitrogen concentrations and a slight increase in total phosphorus concentrations from the beginning of the program to the end of the program. Chlorophyll *a* in EMP increases slightly from May 14th-22nd but remains below the MassDEP 16 µg/L guidance value. MassDEP's cyanobacteria sampling found no cyanobacteria in EMP on 5/21, and found that the dominant algae were *Cryptomonas*, *Rhodomonas*, *Mallomonas* and *Synura*, which are typical for May conditions in Massachusetts.

While these results are consistent with historical water quality studies, the results may not be indicative of summertime conditions due to the seasonality of internal nutrient loads and algal blooms further into the summer growing season. Thus, conclusions from this scoping study conducted in May only apply to conditions in the late spring and should not be interpreted from standpoint of overall water quality in the Monponsett Ponds. For example, the draft TMDL and supporting scientific studies focus on summer season conditions, when there are no diversions to Silver Lake.

In addition to the nutrient and chlorophyll data, field parameters (pH, temperature, conductivity, Secchi depth, and dissolved oxygen, color, and turbidity) were measured at each sampling station. Measurements of pH, temperature, conductivity, and dissolved oxygen were collected at the surface and then in 1-ft intervals, turbidity was measured at the surface, mid-depth, and bottom, and color measured at the surface.

Temperature data at all five locations indicated that weak stratification was beginning to develop as of the first monitoring date (5/14). Both ponds exhibited fully mixed conditions on the three subsequent monitoring dates, with significant warming of the surface water temperature from 14° to 15° C on the first monitoring date to 17° - 18° C on the last monitoring date. Dissolved oxygen ranged between 8 and 11 mg/L, always above the state water quality standard (6 mg/L). As with the temperature data, little vertical variability was observed in the dissolved oxygen data. pH was variable throughout the monitoring program and ranged between 6.32 and 7.53 SU in

EMP and 6.74 and 8.28 SU in WMP; there were occasional exceedances of the state minimum pH criterion (6.5 SU) in EMP during the 5/20 monitoring date. Secchi depth measurements were slightly deeper in EMP compared with WMP, with a mean Secchi depth in EMP of 4.8 ft and in WMP of 4.7 ft. Secchi depth decreased over the course of the monitoring program concomitant with the increase in chlorophyll *a* and concentrations and the algal bloom. EMP Secchi depth ranged between 3.6 and 6.3 ft, and WMP Secchi depth ranged between 3.3 and 6.0 ft.

4.3.3 Risk to Brockton Supply and other Silver Lake Uses

Two key questions are addressed in the following analysis of results:

1. Does this loading translate to a significant rise in water column nutrients or algae in EMP at the beginning of the growing season?
2. What is the load of nutrients from WMP to EMP during different levels of diversion?

4.3.3.1 East Monponsett Pond Water Quality

One of the objectives of the study requires close interpretation of water quality conditions at monitoring site EMP3, near the intake for the City of Brockton water supply. Water quality at this location is important because the water is pumped to Silver Lake for municipal supply and also for releases to the Jones River. The study design involved increasing diversion rates over time to provide the greatest potential to transfer nutrients or algae from WMP as close to the growing season as is allowed under the ACO. Thus, results should be considered conservative about potential risk to Brockton's water supply because the monitoring program was conducted during May when algal growth and internal phosphorus release is expected to be lower than during the summer months.

Table 4-6 provides key water quality results at this site for each of the tested diversion scenarios. A small increase in algal productivity was observed with increasing diversion rate as the study progressed from early to late May, but concentrations remained well below thresholds in the CALM and no cyanobacteria was identified within EMP. There was no corresponding change in phosphorus or nitrogen levels.

Table 4-6. Water Quality Results for Site EMP3 Near the City of Brockton Water Intake

Scenario ¹	Chlorophyll-a + Pheophytin (µg/L) ¹	Total Phosphorus (µg/L)	Total Nitrogen (µg/L)
No Diversion ³	5.2	24.2	457
25 Percent Diversion	6.4	17.3	586
50 Percent Diversion	6.7	19.5	565
75 Percent Diversion ⁴	8.3	22.0	539

1) On average, pheophytin was less than 5 percent of the total pigment

4.3.3.2 Culvert Flows from WMP to EMP

The changes in nutrient concentrations at monitoring sites WMP2 and EMP2 were evaluated to determine whether a water quality impact from transfers of load from WMP to EMP at the varying diversion rates is evident. **Figure 4-13** shows the differences in nutrient concentrations at these sites over the course of the study at EMP2 and WMP2. TP concentrations increase in both ponds across the duration of the study, although the pattern of the increase differs between the two ponds. In WMP, the TP concentration increases uniformly across the duration of this study from 19.7 µg/L at WMP2 on 5/14 to 30.7 µg/L at WMP2 on 5/22. In contrast, a consistent pattern is not evident in the EMP data, with the TP concentration starting at 21.9 µg/L on 5/14, declining to 19.7 µg/L on 5/18 and 5/20, and then increasing to 25.2 µg/L. The TN response is similar at WMP2, with a relatively uniform increase in TN in from the first measurement (440 µg/L) to the last measurement (565 µg/L). TN concentrations at EMP2 remain relatively constant across the monitoring program.

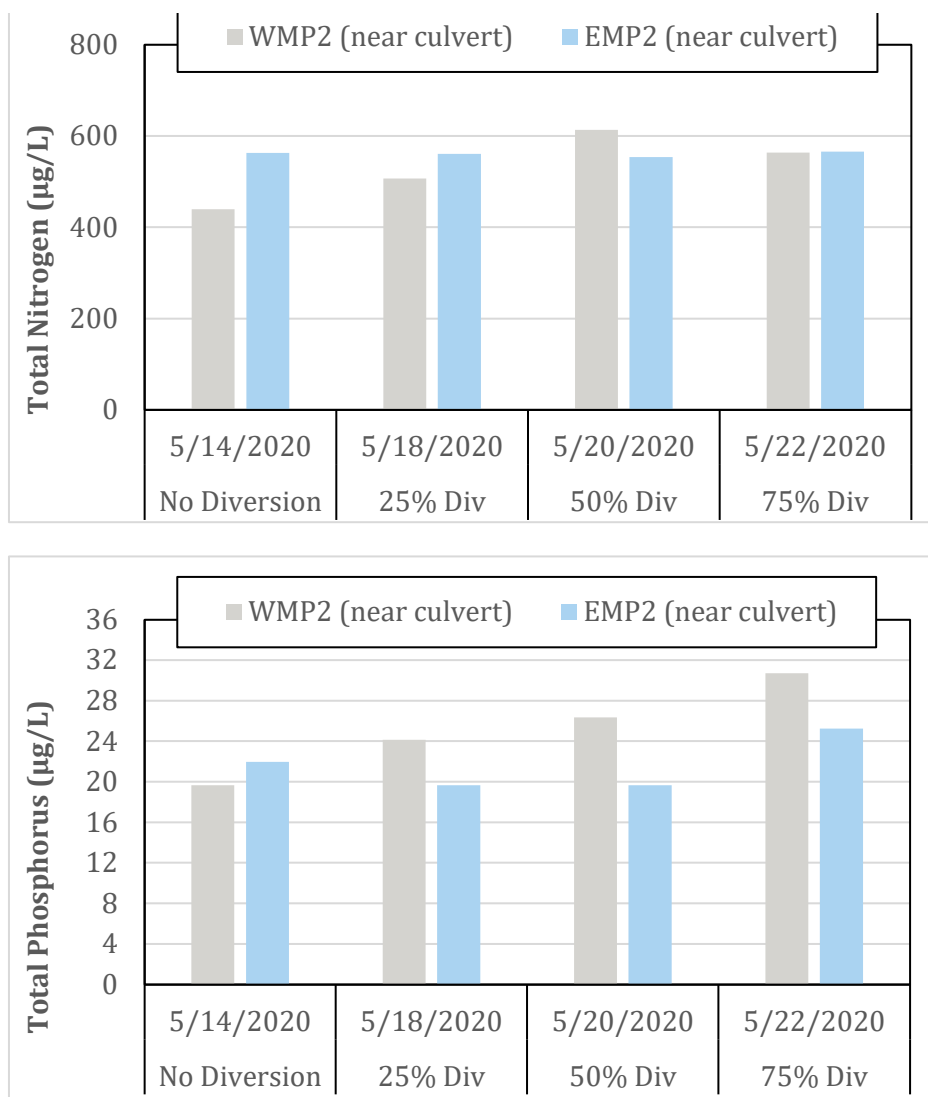


Figure 4-13. Comparison of Nutrient Concentrations at Sites WMP2 and EMP2 Closest to the Culvert Connecting the Monponsett Ponds

Samples collected at the start of the study showed nutrient concentrations were higher in EMP than WMP. Furthermore, samples collected during the 25 percent and 50 percent diversion tests on May 18 and May 20, respectively, showed a slight decline in TP in EMP near the culvert, with TP decreasing by 11 percent between the first event and the 25 percent diversion event. The difference in TN across these two monitoring events is negligible (less than 0.5 percent). The nutrient and chlorophyll *a* results suggest that nutrient transport from WMP to EMP during periods when a Silver Lake diversion is occurring may not be significant. However, the precipitation event and WMP algal bloom that occurred during the monitoring program may obscure some of the impacts from the Silver Lake transfer on pollutant transport between the two ponds through the culvert.

Flow measurements collected from the culvert connecting WMP to EMP were taken to support a concurrent water balance and system optimization analysis. This effort was designed to collect flow measurements on the dates of water quality sampling to provide the necessary data to approximate mass transfer from WMP to EMP. **Table 4-7** provides the flow measurements and approximate average daily transfer of nutrient loads through the culvert over the two-day operational scenarios with constant diversions from EMP to Silver Lake. The flow measurements show that transfers from WMP to EMP do increase with increasing diversions to Silver Lake.

Table 4-7. Flow Measurements and Approximated Nutrient Load Transfer from WMP to EMP in May 2020

Date	Diversion to Silver Lake (mgd)	Flow from EMP to WMP (mgd)	TP from EMP to WMP (kg/day) ¹	TP from EMP to Silver Lake (kg/day) ²
5/14/2020	0	3.10	0.23	0.00
5/18/2020	6	-0.27	-0.02	0.40
5/20/2020	17	-3.08	-0.31	1.41
5/22/2020	21	-7.82	-0.91	1.59

1) Computed based on concentrations of nutrients at site WMP2 – near the culvert

2) Computed based on concentrations of nutrients at site EMP3 – near Silver Lake intake

The nutrient load transferred with these flows is explored further via a simple mass balance analysis focusing on TP changes over the 2-day period between May 20 and May 22 (this period and TP only was selected because all other scenarios showed a reduction in nutrients over the course of the scoping study). Following two days of operation of the diversion at 21 mgd (75 percent valve setting), a rise in TP from 10.2 µg/L to 13.0 µg/L (28 percent) in EMP near the culvert was observed on May 22. Applying this to May 22 volume of EMP in the southern portion of the lake, it was estimated that a rise of 2.5 kg TP occurred.

Estimated outflow TP load via the diversion to Silver Lake during the 75 percent diversion scenario was greater than inflow TP load through the culvert (see **Table 4-7** above). Thus, the source of the increased load in the EMP water column is not likely to be solely associated with

inflows from WMP. Hypothetically, at an approximate TP concentration of 15 µg/L in WMP (May 20-22 average), transfer through the culvert would have had to be as high as ~80 MGD to cause a 2.1 µg/L rise in TP in just the southern segment of EMP (assuming no mixing between the northern and southern segments of EMP). Assuming that at least some longitudinal mixing occurs would require an even larger flow through the culvert to explain the TP increase through transfers from WMP to EMP alone.

Over the course of the two-day period, diversions from EMP to Silver Lake exceeded inflows from WMP to EMP. A loss in stored volume of approximately 4 MG was measured (~2 mgd), but an additional volume of approximately 15 MG (7.5 mgd) of other water (e.g., shallow groundwater) made up the water balance for EMP. This hydrologic scenario would certainly pull water from the northern part of EMP toward the south, along the natural flowpath of the system. On May 22, concentrations of TP at the northern site EMP1 also rose from 10.8 µg/L TP to 13.0 µg/L TP. It would be reasonable to conclude that water from the northern part of EMP gave way to a rise in TP in the southern part of EMP.

4.3.4 Summary of Key Findings

The water quality monitoring program found that average total phosphorus and chlorophyll *a* concentrations during the May 2020 monitoring period were comparable to conditions in the MassDEP TMDL after the alum treatments and fertilizer reductions began and are expected to improve more as the TMDL wasteload allocations are met. Algae as measured by chlorophyll-*a* increased over the course of the study remained below 16 µg/L in EMP, which is the recommended threshold in the CALM and draft TMDL numeric response target¹. Chlorophyll *a* in WMP was generally below the draft TMDL numeric response target until the cyanobacteria bloom occurred at the end of the monitoring program. TP exceeded the 18 µg/L proposed causal numeric target for both EMP and WMP in the draft TMDL in 80 percent of the samples in EMP and 100 percent of samples in WMP (**Figure 4-9**).

The water quality data were evaluated using the estimated flows from the surface velocity study to understand the potential impact of Silver Lake diversions on nutrient transport through the Route 58 culvert. Data collected during this study suggest that the impact on water quality from the diversion is relatively low given the low measured nutrient flux through the culvert and the lack of a strong relationship between nutrients and chlorophyll *a* at the paired WMP2 and EMP2 sites on either side of the culvert. However, any relationship between water quality at these locations and flux through the culvert may have been obscured by the impact of the precipitation event and the algal bloom that occurred during the monitoring event.

Despite improvements in water quality relative to historical conditions, algae blooms within WMP in late May were identified and could impact water quality in EMP if allowed to occur over prolonged period. The scoping study evaluated conditions than may be expected after two days of 75 percent diversion in late May when conditions in WMP were better than typical.

¹ <https://www.mass.gov/doc/draft-west-and-east-monponsett-pond-system-total-maximum-daily-loads-for-total-phosphorus/download>

If nutrient loads in the draft TMDL were to be achieved, then the same water quality would be expected in both WMP and EMP; summertime median TP of less than 18 µg/L and chlorophyll-a meeting target of 16 µg/L 96 percent of time based on application of the LLRM.

Section 5

Model Scenarios

5.1 Introduction

Scenarios related to both water quantity and water quality were developed to understand how operational changes could reduce the likelihood of algal blooms and impact flooding to Stump Brook while balancing Brockton's water supply needs. To understand the system with regard to water quantity, an RMP systems model was developed. To evaluate whether increased flushing could reduce the likelihood of algal blooms, CDM Smith used the Modified Vollenweider total phosphorus model (Rast and Lee 1978) and the empirical models in the Lake Loading Response Model, which relate the allowable total phosphorus load and concentration to flushing rate. This Section describes the scenarios evaluated by these models and their results.

5.2 Water Quantity Scenarios

To explore operational changes proposed in this Resource Management Plan, the RMP Model was developed by updating a Safe Yield model of the Brockton system. In February 2007, the City of Brockton used the program Stella to develop a simulation model of the Brockton Water Supply System, which included Brockton Reservoir and the interconnected system of Monponsett Pond, Furnace Pond, and Silver Lake (CDM Smith, 2007). This model evaluated the effects of storage, operation, and hydrologic inflow on the system yield and was used to define the Firm Yield of the Brockton Water Supply System.

The RMP Model is a systems model designed to track flow and storage in the Brockton supply system. It is not a rainfall-runoff model, hydraulic model, or a numerical groundwater model. The RMP model was updated and designed to focus on Monponsett Pond and Silver Lake, and not the other possible supply sources to be considered in the CWMP. The RMP model was calibrated to a longer, more recent time frame than the Safe Yield Model: January 2004 to December 2019. The selected time frame includes a severe drought in 2016, one of the single highest storms in the 100-year precipitation record in 2010 (March 30-April 5, 2010), but does not include the most extreme droughts, which should be considered when developing the CWMP. The calibrated historical simulation accurately represents many of Monponsett Pond's peaks and drawdowns over the selected time period. The modeled culvert is also replicating the field measurements described in **Section 4** very well. **Appendix E** details the how the Safe Yield model was updated and calibrated for use in this RMP, with additional information on the various water balance components incorporated into the model.

The objective of the model scenarios is to test a wide range of possible operations to better understand the potential advantages or disadvantages of each. Several scenarios were developed by varying release rules and diversion requirements. Each operational scenario was run from 2004 through 2019 to understand how operations perform under different flow regimes. The scenarios were evaluated against a variety of metrics including flow characteristics through the culvert, ability to meet the release requirement to Stump Brook, days that Monponsett Pond floods (elevation > 53.25' NGVD29), and quantity of water Silver Lake received.

The same hydrology, groundwater seepage, Silver Lake withdrawals, and Stump Brook spill calculation was used as the calibration run. For scenario runs, the diversions to Silver Lake were based on ACO rules outlining when diversions are allowed, rather than observed diversions used in the calibration. The scenarios imposed a variety of maximum diversion rates ranging from 4 to 20 mgd. Releases from the fish ladder were specified based on either ACO rules (year-round release) or Acts rules (release during diversions only) rather than trying to replicate historical manual operations. **Table 5-1** shows the list of RMP model scenarios that were used to evaluate pond dynamics response based on operational changes to pond management.

Table 5-1. RMP Water Quantity Model Scenarios

Base Runs

Silver Lake Max Diversion Rate (mgd)	Stump Brook Release Rules	
20	Year-round 0.9 mgd (ACO rules)	0.9 mgd release only during diversions (Acts rules)
15		
12.5		
10		
6		
4		

Stump Brook Release Scenarios

Silver Lake Max Diversion Rate (mgd)	Year-round Stump Brook Release Rules (ACO rules, mgd)		
15	0.7	1.1	2

5.2.1 Monponsett Pond Dynamics in Base Runs

Results from the scenarios are evaluated to show the relationship between diversions, releases, and flow characteristics/direction at the culvert between EMP and WMP. When compared to the historical calibration run, the future scenarios showed a notable decrease in flow from Monponsett Pond to Silver Lake (**Figure 5-1**) and an increase in flow being released and spilled from WMP to Stump Brook (**Figure 5-2**). In these figures, results labeled “ACO” utilize the ACO-based rule of a 0.9 mgd release to Stump Brook year round and the number accompanying the ACO label, “ACO 6” for example, indicates the Silver Lake diversion used in mgd. There is a set amount of inflow that comes into the pond over each simulation, and the two primary outflows are the diversion to Silver Lake and flows out to Stump Brook. Before 2016, the scenario runs do not have flood-control diversions which causes a big increase in flows to Stump Brook. The Historical run behaves more closely to the future scenarios from 2016-2019 because of a reduction of flood control diversions, which more closely align to the scenario operations.

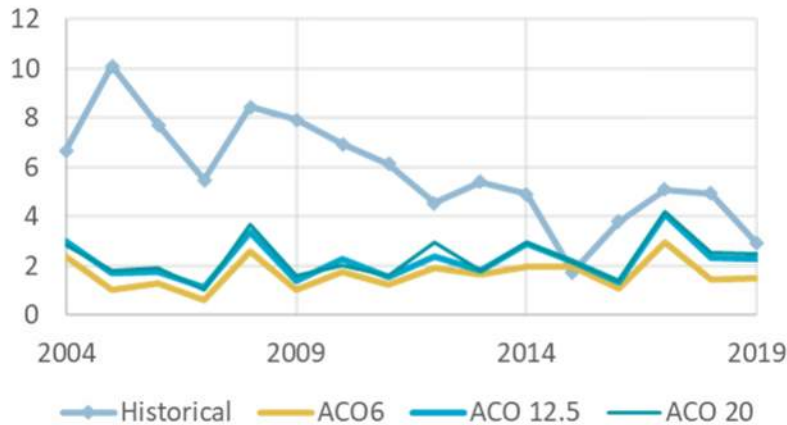


Figure 5-1. Average Daily Flow from Monponsett Pond to Silver Lake (mgd)

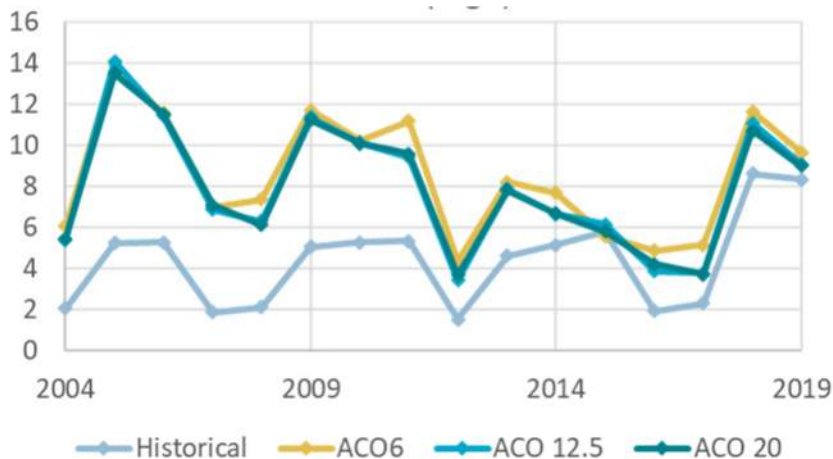


Figure 5-2. Average Daily Flow (Releases + Spill) from Monponsett Pond to Stump Brook (mgd)

Using ACO (year-round) and Acts (diversion only) release strategies does not significantly impact the amount of water that can be diverted to Silver Lake. As a result, other scenario variations were developed using only the year-round ACO flows. **Figure 5-3** shows the amount of water that can be diverted to Silver Lake based on the maximum allowed diversion flow and illustrates how the ACO and Acts results are very similar.

In the scenarios tested across the timeframe of 2004 to 2019, Silver Lake receives enough water, even as the maximum allowed diversion was reduced. Diversions occurring at lower rate will take place over a longer period of time, but all scenarios tested lead to enough water being transferred to Silver Lake. When considering water quantity operations, allowing diversions of more than 10 mgd is ideal.

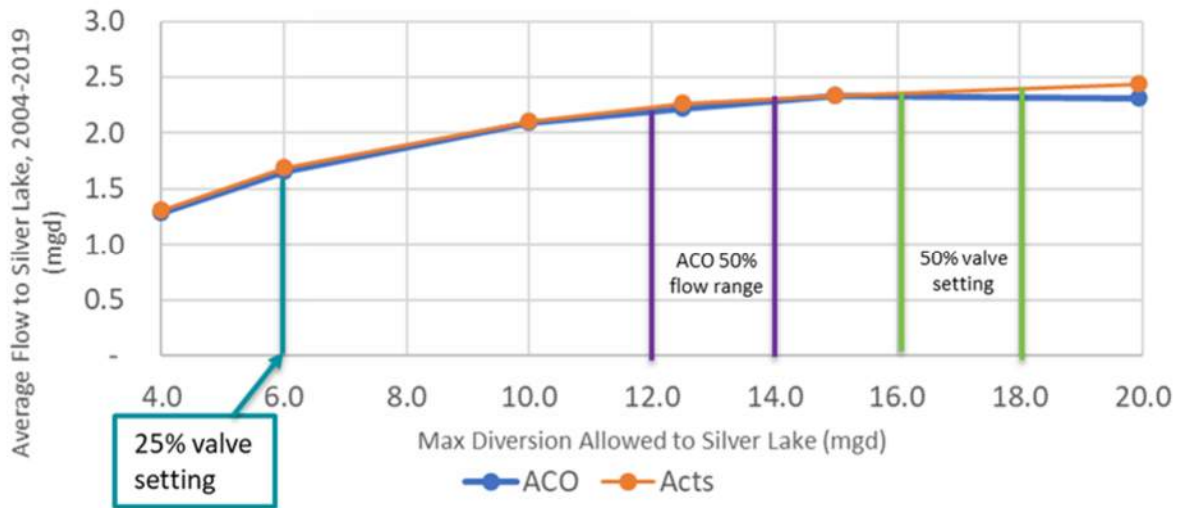


Figure 5-3. Average Silver Lake Diversion at Various Maximum Diversion Rates

The culvert behavior was also analyzed for each of these scenarios. **Figure 5-4** shows the impact that the maximum diversion to Silver Lake has on the amount of water that is transferred from WMP to EMP. The trend mirrors the results in **Figure 5-3**, where diversions about 10 mgd show little difference in the amount of water that moves eastward through the culvert. When considering water quality impacts, reducing eastward flow is preferable and the operating with maximum diversions of less than 6 mgd could better protect EMP and Silver lake until total phosphorus concentrations are reduced in WMP.

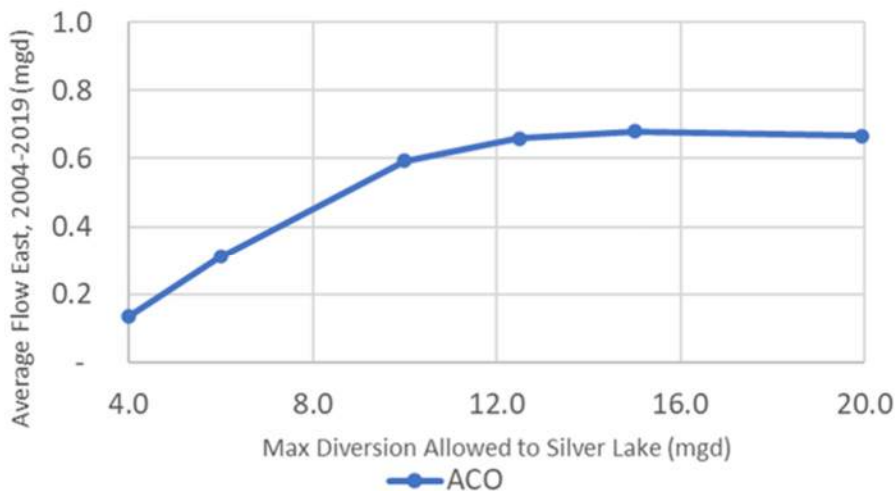


Figure 5-4. Flow through the Culvert from WMP to EMP

Varying the maximum diversion rate has a very slight impact on flooding frequency, which is defined as any time MP > 53.25 ft. Flooding occurs about 17 percent of the time in each of the ACO scenarios, which is about the same rate as the percent of days that flooded in the historical

calibration run (2004-2019). The number of flood days are similar across diversion rates, but the magnitude of the flooding is slightly higher when diversions are capped at 4 mgd or 6 mgd than at higher diversion rates.

5.2.2 Annual Residence Time

The annual residence time was calculated for each scenario and ranged from 50 to 190 days across all simulations. **Figure 5-5** shows the annual residence time calculated on Monponsett Pond and WMP for the ACO20 run and the ACO 6 run. Varying the diversion limit did not significantly impact the residence time. The annual variability of hydrology creates much more significant changes to residence time than the operational adjustments.

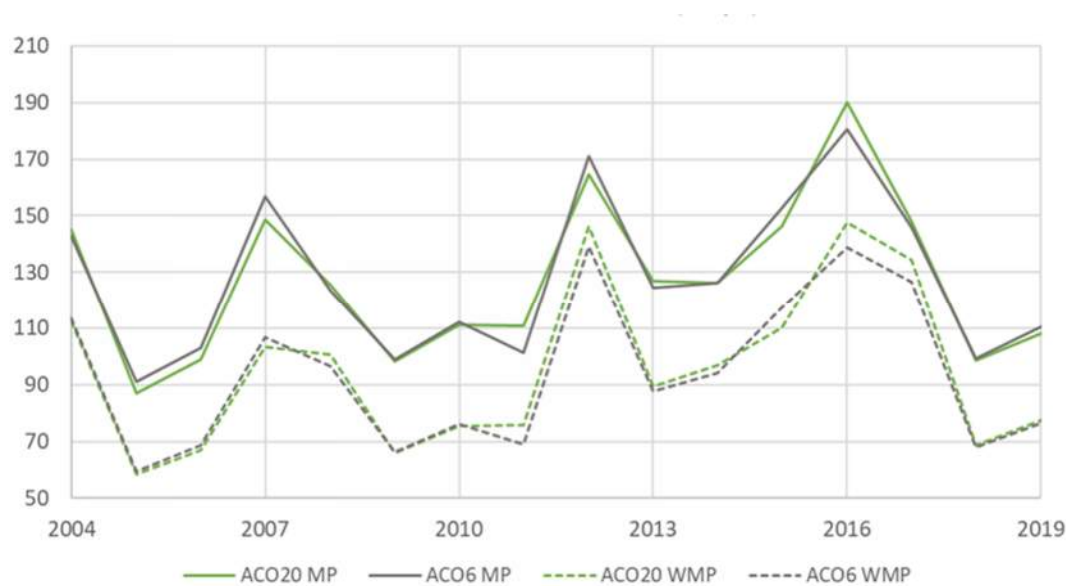


Figure 5-5. Annual Residence Time (days)

5.2.3 Stump Brook Release Scenario Results

The Stump Brook Scenario Runs were set up with a maximum 15 mgd diversion and varied the year-round releases: 0.7 mgd, 0.9 mgd, 1.1 mgd, and 2.0 mgd. The results of these simulations are shown in **Table 5-2**. Adjusting the current ACO required release of 0.9 mgd up or down by 20 percent was not found to change the simulation results significantly. When the year-round release was more than doubled to 2 mgd, the amount of water that was available for diversions to Silver Lake decreased, so the current target of 0.9 mgd should be maintained.

Table 5-2. Results of Stump Brook Scenario Simulations

	0.7 mgd release	0.9 mgd release	1.1 mgd release	2.0 mgd release
Annual Total Releases to SB when no Spill (MG)	90	120	152	305
Average Annual Flow East when no Spill (MG)	281	271	283	217
Total Annual Diversion to Silver Lake (MG)	843	852	844	782

5.3 Water Quality Scenarios

ACO Item 33d requires an evaluation of high-rate spring flushing to potentially reduce stagnation and algal blooms. To evaluate whether increased flushing could reduce the likelihood of algal blooms, CDM Smith used the Modified Vollenweider total phosphorus model (Rast and Lee, 1978), which relates the allowable total phosphorus load and concentration to flushing rate. The Modified Vollenweider curves were developed to relate mean lake depth, flushing rate, and phosphorus loading rate to lake trophic status. Input parameters were derived from the MassDEP TMDL and are described in **Table 5-3**. The loading rate is existing total phosphorus load estimated in TMDL Table 6 (EMP) and Table 8 (WMP), and includes atmospheric deposition, internal loads, septic system loads, watershed loads, and stormwater loads. The existing loads were set based on the 2009 water quality monitoring program because 2009 annual and summer precipitation were typical, and this year was prior to the WMP alum treatments. To account for the potential impact of the alum treatments on WMP water quality, a separate scenario was run assuming that the ongoing alum treatments in WMP effect a 95 percent reduction in internal load relative to baseline conditions based on the TMDL internal load wasteload allocation.

Table 5-3. Input Parameters for the Rast and Lee Modified Vollenweider Model

Parameter	EMP	WMP (No Alum)	WMP (95% Internal Load Reduction)
Mean Depth (m)	1.9	2.1	2.1
Flushing Rate (1/year)	3.1	2.1	2.1
Load (kg/year)	345	676	456
Pond Area (mi ²)	0.415	0.475	0.475
Area-normalized Load (mg/m ² -year)	321	549	

The Modified Vollenweider model was applied to the existing loads and flushing rate for EMP and WMP to evaluate the current trophic status and the required increase in flushing rate to cause a significant improvement in the trophic status. The results of the Modified Vollenweider model are shown in **Figure 5-6**. This analysis indicates that both EMP and WMP are currently classified as eutrophic ponds, characterized by excessive loading relative to the mean depth and flushing rate assumptions. This model can be used to predict the increase in flushing rate required to cause the existing total phosphorus loading to be in the permissible category. Based on this model, the flushing rate would need to increase by 3.75 times in EMP and 10.2 times in WMP on an annual basis.

This predicted required increase in flushing rate is not feasible. The MassDEP-estimated flushing rate is 3.1 times per year for EMP and 2.1 times per year in WMP. Increasing these flushing rates to transition the pond to the permissible loading rate would require new flushing rates of 11.6 and 21.4 times per year for EMP and WMP, respectively, equivalent to a residence time of 31 days in EMP and 17 days in WMP. The natural hydrology of Monponsett Pond does not support this frequent flushing rate.

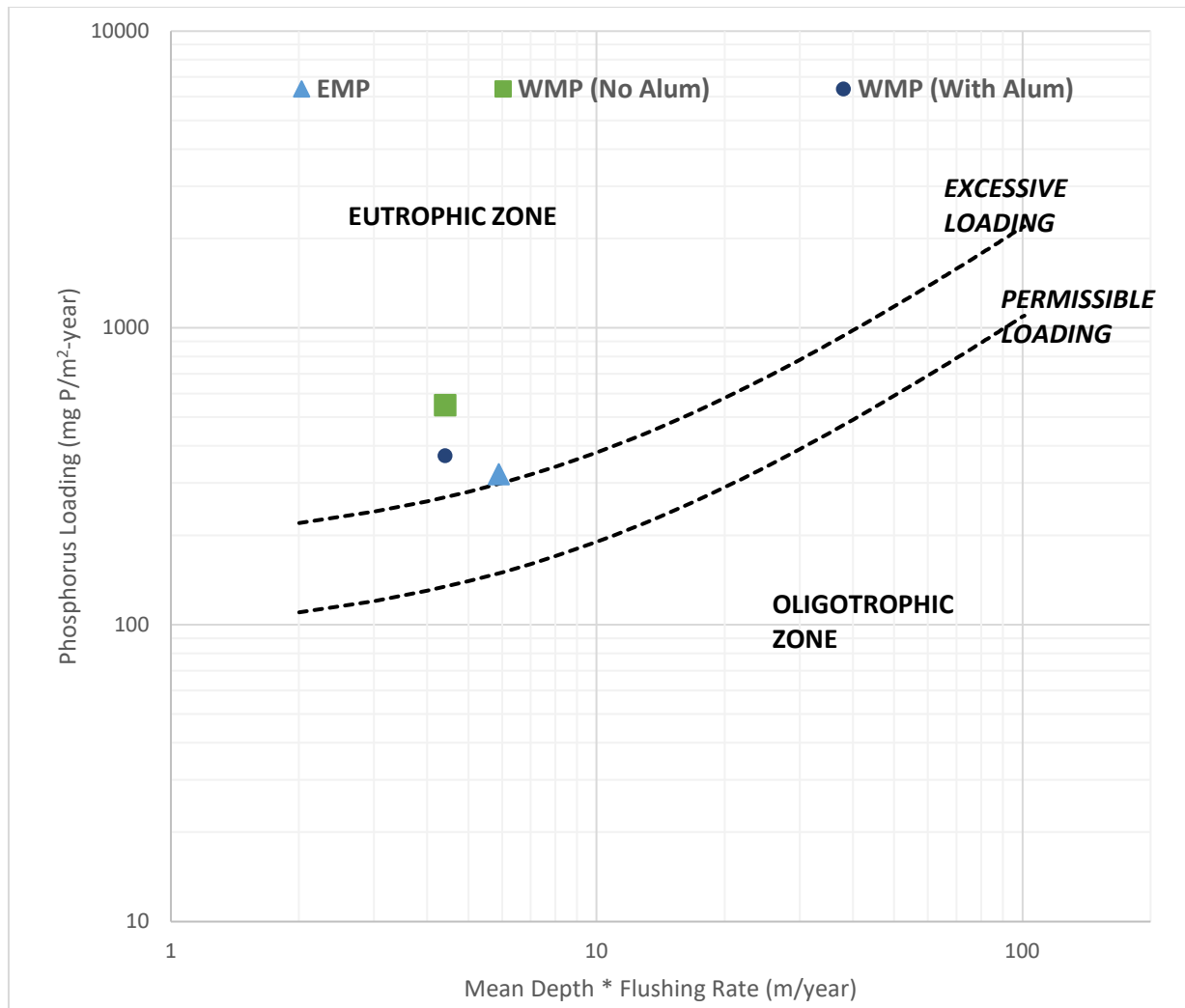


Figure 5-6. Modified Vollenweider Total Phosphorus Model Applied to EMP and WMP Total Phosphorus Loads as Described in the MassDEP TMDL

In addition to the Modified Vollenweider model, CDM Smith also applied a subset of the models incorporated into the Lake Loading Response Model (LLRM, AECOM, 2009)², parameterizing the model based on Appendix E of the Draft Final TMDL. The suspended fraction was not described in Appendix E but was estimated to be 0.25 to best match the LLRM results for the existing condition. The LLRM models were used to evaluate the predicted flushing rate increase necessary to meet the 18 µg/L TMDL target concentration. The range of flushing rate increases for these models is described in **Table 5-4**. The LLRM models also predicted significant flushing rate increases like with the Modified Vollenweider total phosphorus model results, albeit with

² Models applied were the mass balance model and the empirical models Vollenweider 1975, Larsen-Mercier 1976, Jones-Bachmann 1976, and Reckhow General 1977. The Kirchner-Dillon 1975 model was omitted from this analysis since the inflow rate and settling velocity used in the LLRM model runs for the TMDL were not reported. The average model predicted TP concentrations were 68 µg/L and 35 µg/L for WMP and EMP, respectively, compared with the TMDL reported 67 and 33 µg/L for WMP and EMP, respectively.

considerable variation due to the underlying empirical relationships that were used to develop the individual models in the LLRM.

Table 5-4. Range of Flushing Rate Increases and Residence Time Predicted by the LLRM Model for EMP and WMP

Pond and Scenario	Flushing Rate Increase		Residence Time (Days)	
	Average	Range	Average	Range
WMP, No Alum	5.2x	3.3x – 6.2x	33.2	28.1 – 52.1
WMP, 95% Reduction in Internal Load	3.3x	1.5x – 4.3x	52.1	40.6 – 118
EMP	3.6x	1.5x – 4.3x	33	27.5 – 79.8

The Modified Vollenweider model, like the empirical models used in the Lake Loading Response Model, predicts the impact of annual total phosphorus loads on lake or pond trophic status, and does not consider sub-annual variation in flushing rate or phosphorus loading. Water quality data post-alum treatment are limited, but the available data combined with typical New England limnology suggest increased flushing focused on the spring is not likely to yield significant water quality impacts. Available water quality data from EMP and WMP indicate that total phosphorus concentrations typically increase from spring through the summer, with the highest phosphorus concentrations occurring in the summer months prior to fall mixing. In both EMP and WMP, internal phosphorus load is a significant portion of the annual phosphorus budget. The internal phosphorus load rate increases with the extent of anoxic (low oxygen) conditions in the hypolimnion; stratification and anoxic hypolimnetic conditions are less likely to occur in the spring months. Therefore, the ability to remove significant total phosphorus mass from EMP and WMP through increased Stump Brook outflows during the spring is limited, and is not likely to significantly reduce the likelihood of harmful algal blooms in the summer and fall months, nor is it likely to cause the pond to transition to a less nutrient-enriched trophic state. Therefore, the best approach for reducing the total phosphorus loads and the risk of harmful algal blooms will be to implement the load reduction targets in the Draft TMDL.

5.3.1 RMP Water Quality Model Scenarios

In addition to the Scenarios described in **Section 5.2**, the RMP Model was used to evaluate two scenarios related to managing the water quality in MP which are listed in **Table 5-5**. This section describes these simulations and their results.

Table 5-5. RMP Water Quality Model Scenarios*Reduced May Diversion Scenario*

SL Max Diversion Rate (mgd)	Reduce SL Diversion in May
12.5	Diversion limited to 6 mgd
15	
20	

Spring Flushing Scenario

SL Max Diversion Rate (mgd)	Increase SB Release (Flushing in Spring)
12.5	Lower fish ladder gate to 51.5 ft (4/15-5/15), 0.9 mgd rest of the year

5.3.1.1 Reduced May Diversion Scenario

This scenario reduced the Silver Lake diversion to 6 mgd in the month of May while allowing higher diversion limits (12.5, 15, and 20 mgd) during the remainder of the diversion period (October through April). By reducing diversions in May, the amount of water transferring from WMP to EMP through the culvert would be minimized while balancing the need to fill Silver Lake by the end of the diversion period by allowing a more robust diversion for water supply during most of the diversion period.

Assessing the stage of Silver Lake on May 1 from 2004 to 2019, 2017 was the only year the reservoir did not start the month nearly full or spilling. This indicates that a stricter diversion limit in May would have a relatively small impact on the diversion potential in most years. The hydrology tends to be filling Silver Lake at this time of year, although streamflow and precipitation trends are increasingly variable. In a year where WMP is experiencing an algae bloom, this extra reduction in the amount of water diverted could help minimize the poor water quality spreading to EMP or Silver Lake and still allow for Brockton to draw some water for supply purposes.

5.3.1.2 Spring Flushing Scenario

The spring flushing scenario increases Stump Brook releases from April 15 through May 15 by fully opening the fish ladder gate completely (el. 51.8 ft) while releasing the minimum 0.9 mgd at all other times of the year. A maximum diversion to Silver Lake of 12.5 mgd was used in this scenario. By releasing more than the required amount in the spring, the summertime nutrient levels and stagnation would potentially be reduced, which could reduce the frequency of warm weather algae blooms.

This scenario resulted in a 9 percent increase to the average flow in Stump Brook (combination of spills and releases) in this timeframe, ranging from 0 to 42 percent. The increased flushing caused the WMP water level to drop an additional 0.3 inches at end of high flushing period (May 15) on average, with the decrease in pond level ranging from 0.6 to 3.4 inches. The simulation also

showed that there was minimal change to the Silver Lake diversion in most years from 2004 to 2019, because the WMP water levels were not greatly impacted. Under more extreme drought conditions, the impacts from this kind of operational change could more significantly impact the water available for Brockton's supply.

The spring flushing scenario model was used to complete a phosphorus mass balance to evaluate the potential water quality benefits of decreased residence time during the spring months. This mass balance was completed using the following assumptions:

- Inflows are culvert flow and seepage
- Outflows are Stump Brook (fish ladder and spillway)
- Other flows and loads assumed constant (atmospheric deposition, runoff, internal load)
- May total phosphorus concentrations were assumed from recent, available water quality data and other studies:
 - EMP: 20.1 µg/L from 2020 monitoring
 - WMP: 21.4 µg/L from 2020 monitoring
 - Groundwater: 0.1 µg/L from Horsley Witten (2015)

This mass balance found that the total phosphorus reduction averages 2.9 pounds (11 percent difference) relative to the baseline scenario April 15 – May 15 loads. The relative reduction in phosphorus mass varies from year to year, with some years having little to no reduction (e.g., 2006) and some years having a large reduction (e.g., 2013, a 6.5 pound, 35 percent difference in April 15 – May 15 phosphorus load). The monthly reduction in phosphorus mass from WMP to Stump Brook relative to the baseline model condition is presented in **Figure 5-7**. While this model scenario indicates that increased spring flushing can reduce WMP phosphorus mass, this represents a relatively small portion of the overall mass balance. Relative to the wasteload allocation of 409 pounds per year, the average reduction in phosphorus mass is less than 1 percent. Furthermore, any reduction in WMP total phosphorus concentration could be offset from an external phosphorus load from a spring rain event. Therefore, increased spring flushing is not recommended for water quality improvements in Monponsett Pond.

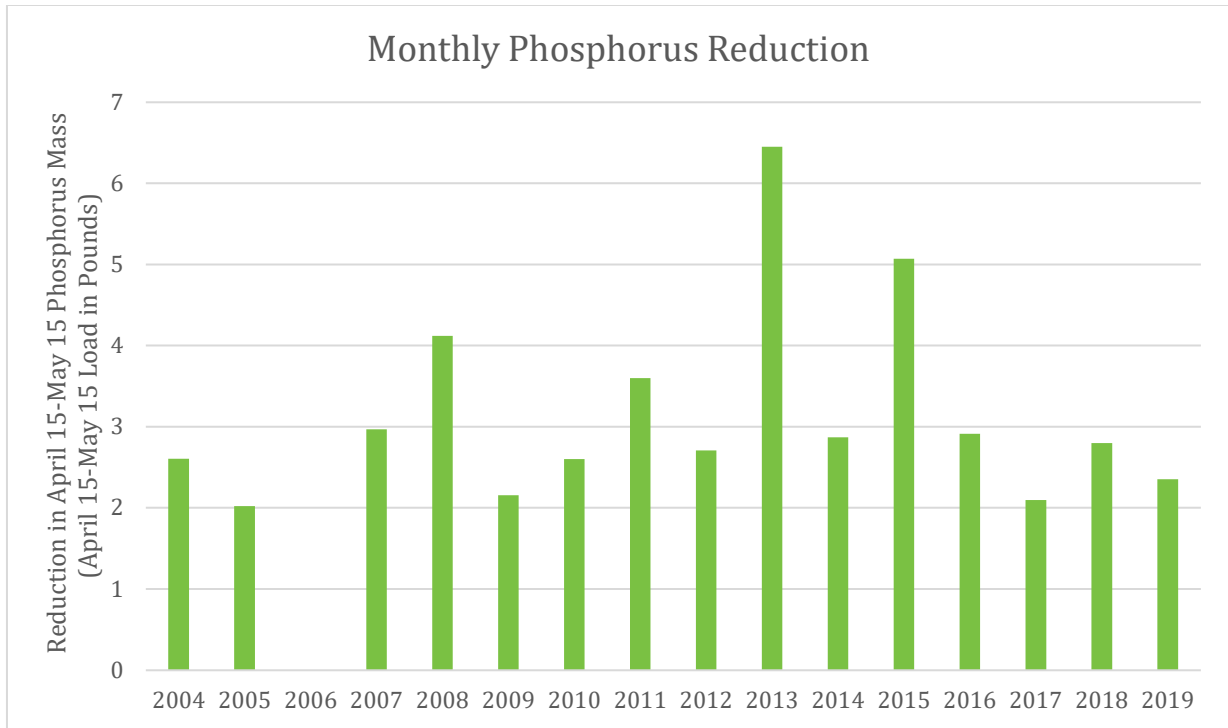


Figure 5-7. Modeled Reduction in April 15 – May 15 Phosphorus Load for the Spring Flushing Scenario

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Section 6

Recommendations

6.1 Recommended Water Level Targets

Water levels in Monponsett Pond are controlled by Stump Brook Dam and diversions to Silver Lake as specified by the Acts of 1964 and 1981. The Acts specify water levels targets below which diversions cannot occur (52 ft NGVD). The spillway at Stump Brook Dam is at 53 ft NGVD, establishing the normal high pond level that is not influenced by precipitation. Pond elevations that exceed 53 ft are due to high rainfall and/or snowmelt effects, where the uncontrolled spill over the Stump Brook Dam does not subside quickly.

These factors result in Monponsett Pond having a narrow operating range; the pond water levels are between 52.5 and 54 ft NGVD 95 percent of the time. This small range of variation in pond levels is more similar to the natural variation observed in unmanaged lakes, as opposed to larger elevation changes typical of a managed system.

Additional seasonal or monthly water level targets were considered but are not recommended as the pond levels are vary little except as controlled by its natural hydrology.

6.2 Recommended Operating Procedures

6.2.1 Diversions to Silver Lake

Diversions from Monponsett Pond to Silver Lake take place between October and May when:

- Water level in Silver Lake is below full (47.5 ft NGVD); and
- Water levels in Monponsett Pond are above the minimum water level (52.0 ft NGVD).

The diversion should be operated at a reduced valve position rather than fully open or fully closed that allows flow to be at about half of the maximum diversion. This results in a reduced diversion flow of about 12-15 mgd rather than about 25 mgd.

In May, if cyanobacteria is starting to bloom in WMP but not EMP (target: cyanobacteria count >5-10K cells/mL), the diversion should be reduced from 50 percent valve setting to the 25 percent valve setting, about 6 mgd for the duration of the bloom.

To prevent flooding, diversions from Monponsett Pond to Silver Lake should only occur throughout the year by written request of the Town of Halifax or Hanson or when requested by DEP. Flooding along the Monponsett Pond shoreline occurs when the water level in the pond is higher than 53.25 ft (slightly above the dam spillway elevation) when flow over the Stump Brook Dam cannot happen quickly enough.

6.2.2 Downstream Releases to Stump Brook

Monponsett Pond levels are controlled by a dam on Stump Brook. The control structure contains a spillway, a 2-ft-wide weir gate controlling flow to a downstream fish ladder, and a sluice gate.

The dam spillway elevation of 53.0 ft NGVD sets the maximum elevation of the pond. The fish ladder gate controls pond levels and releases. The sluice gate can enable releases between elevations 51.0 and 53.0 ft NGVD29 but is not typically operated. Releases of 0.9 mgd over the fish ladder are maintained year-round as codified in the 2017 ACO with MassDEP. The 0.9 mgd release occurs any time the Monponsett Pond level supports such a release from the fish ladder (with lowest gate position at 51.8 ft NGVD29).

6.2.3 Other Authorized Withdrawals

Water is also withdrawn from Monponsett Pond for consumptive and return uses at cranberry bogs in the area. Cranberry bog uses include water withdrawn during the spring and fall, which are used for frost protection, while summer withdrawal is used for irrigation. Return use includes winter withdrawals, which are used for flooding operations, though not all water withdrawn for cranberry purposes is returned to the water supply system. These withdrawals are not under the control of Brockton. Other authorized water supply withdrawals by users in the watershed include upstream cranberry bogs and Halifax water supply wells.

6.3 Feasibility Assessment

This section describes actions that should be taken to improve water quality in Monponsett Pond by first reviewing and assessing recommendations made by the authors of previous water evaluations for the pond, and then developing a set of RMP recommendations based on the previous work and the evaluations in this RMP. Finally, preliminary feasibility of the RMP recommendations is provided.

6.3.1 Recommendations from Previous Monponsett Pond Studies

Previous water quality and flow management studies conducted on the Monponsett Pond system applied data and modeling tools to develop management recommendations to improve water quality, increase flows to Stump Brook, and better manage Brockton's water supply needs in the future. **Table 6-1** presents a summary of recommendations from these previous studies.

Table 6-1. Summary of Recommendations from Previous Studies of Monponsett Pond

Recommendation	Status	Source
Acidification monitoring program due to low pH and alkalinity.	Not implemented, but pH monitoring conducted through periodic water quality sampling performed by MassDEP, Brockton, and others	Lycott Environmental, 1987
Community wastewater treatment plant with groundwater discharge	Not currently implemented	Lycott Environmental, 1987
Stormwater controls using sand filters	Not implemented, but see recommendations in MassDEP TMDL	Lycott Environmental, 1987
Aquatic weed raking	Not implemented as a program but in 1980s citizens reported raking weeds along their shorelines	Lycott Environmental, 1987
In-lake treatments, including alum, algaecide, and mixing/aeration	Alum implemented by Halifax starting in 2013 (see MassDEP TMDL discussion). Other options not implemented	Princeton Hydro 2013 ¹ , Geosyntec 2020
Watershed management, including riparian buffers, stormwater controls, fertilizer management, and stream bed and bank stabilization	Stormwater controls will be implemented in the context of MS4 permit requirements. Fertilizer management is in progress.	Princeton Hydro 2013 ¹
Limiting or eliminating Silver Lake diversion to improve WQ in Monponsett Pond and improve flow to Stump Brook	Limitations on Silver Lake diversion rate are incorporated into the MassDEP ACO	Princeton Hydro 2013 ¹
Lower Stump Brook dam to 51 ft	Not implemented	Princeton Hydro 2013 ¹
Increase water supply from alternative sources (Aquaria or horizontally-oriented groundwater wells) to offset up to 50 percent of Silver Lake supply	Not implemented	Princeton Hydro 2013 ¹
Directly pipe water from Monponsett or Furnace Pond to the Silver Lake WTP to preserve Silver Lake water quality	Not implemented	Princeton Hydro 2013 ¹
Reduce diversions to Silver Lake to increase water in Monponsett Pond and increase Stump Brook releases	Limitations on Silver Lake diversion rate are incorporated into the MassDEP ACO	Horsley Witten Group, Inc. 2015
Use the Stump Brook sluice gate to release more flow to Stump Brook	Not implemented	Horsley Witten Group, Inc. 2015
Aluminum sulfate treatment in West Monponsett Pond to realize 90 percent reduction in sediment P flux	In progress, with treatments completed 2013, 2015, 2016, 2017, 2018, 2019	MassDEP TMDL
Aluminum sulfate treatment in East Monponsett Pond if cyanobacteria blooms persist	Not currently implemented	MassDEP TMDL
Reduced fertilizer application rates at Morse Brothers Winebrook bogs and Bog #19	Implemented	MassDEP TMDL
Management of water usage at cranberry bogs	Not currently implemented	MassDEP TMDL
Management of Silver Lake diversion and Stump Brook dam	In progress (Resource Management Plan)	MassDEP TMDL

Recommendation	Status	Source
Septic system management, including an inspection program and bylaws to require Title 5 compliance	Implemented in Halifax	MassDEP TMDL
Sewering	Not currently implemented	MassDEP TMDL
Stormwater controls implemented in MS4 permits	To be implemented in latest Small MS4 Permit	MassDEP TMDL
Implementation of local bylaws to limit development	Not currently implemented	MassDEP TMDL
Routine monitoring, including cyanobacteria, total phosphorus, Secchi depth, and chlorophyll <i>a</i>	Cyanobacteria is routinely monitored and reported during the recreation season. Routine monitoring for other parameters (nutrients, field parameters) is not yet implemented.	MassDEP TMDL
Shore-based micro-floc aluminum injection pump to control watershed nutrient loads (if other recommendations do not achieve TMDL targets)	Not implemented, and pending implementation of other watershed and in-pond controls; also, discussions with NHESP indicate permitting would be difficult	MassDEP TMDL
Perform feasibility studies and construct 3 stormwater BMPs in the West Monponsett Pond watershed (preliminary design completed by GHD in 2017)	Preliminary design completed. Status of feasibility study for constructability unknown. Not yet constructed.	Geosyntec, 2020
Additional BMP planning and implementation	Planning anticipated in 2021, with 2-3 BMPs implemented each year in 2022, 2024, 2026	Geosyntec, 2020
Optimize and evaluate non-structural BMPs, including street sweeping, catch basin cleaning, and IDDE	In progress, being implemented through Halifax MS4 program	Geosyntec, 2020
Septic system inspections and improvements	Continue the Halifax septic system inspection, upgrade, and repair program.	Geosyntec, 2020
Public information and education	Ongoing	Geosyntec, 2020
Track BMP implementation	Ongoing	Geosyntec, 2020
Implement water quality monitoring program at the outlet, tributaries, and the deepest location	Unknown	Geosyntec, 2020
Re-evaluate long-term water quality goals every 3 years	Not yet started (will occur in 2023)	Geosyntec, 2020

Notes: 1. The alternatives discussed in the Princeton Hydro report were principally conceptual and may not be feasible to implement

6.3.2 RMP Recommendations

The investigations of this RMP have shown that water quality in Monponsett Pond has improved significantly since the 2009 baseline TMDL condition with reductions in fertilizer use, the alum treatments in WMP, and the change in handling of flood flows. The following actions are recommended to support further improvements in pond water quality.

Since the City of Brockton’s jurisdictional authority is limited to the diversion from Monponsett Pond to Silver Lake and operation of the fish ladder gate and sluice gate on the Stump Brook Dam, other possible responsible parties are being identified for some of these recommendations.

Recommendation #1: Develop TMDL Implementation Plan and Implement the WMP Watershed-based Plan

Possible Responsible Party: Towns of Halifax and Hanson with Oversight by MassDEP

This past year has seen the publication of two critical documents that began to lay a roadmap for the improvement of water quality in Monponsett Pond:

- MassDEP’s 2021 Final Draft West and East Monponsett Pond System Total Maximum Daily Loads for Total Phosphorus; and
- Watershed-based Plan: West Monponsett Pond Watershed. Prepared for the Town of Halifax by Geosyntec (2020).

These documents follow nearly a decade of actions by MassDEP and the Towns of Halifax and Hanson to improve the pond water quality through engagement with the cranberry bog owners to reduce fertilizer use and the application of alum to WMP. Brockton’s operational change in 2016 of the handling of flood flows in Monponsett Pond has also contributed to water quality improvements. By reducing the transfer of the flood flows to Silver Lake, and instead letting them discharge via Stump Brook, the residence time for WMP has likely been decreased, and flow through the culvert from WMP to EMP has also been decreased.

As noted in the TMDL and the Watershed-based Plan, however, more work is needed to improve the pond’s water quality. The TMDL study set the target and load allocations to achieve unimpaired pond water quality; a strong action plan (typically called TMDL implementation plan) is now needed to describe concrete steps that will be taken to realize these goals. Halifax’s Watershed-based Plan is an example of an action plan to meet the goals. The plan, however, focuses on actions that can be accomplished in Halifax’s portion of the watershed and more specifically, the WMP subwatershed. Review of recent data indicate that water quality in EMP has not improved to the degree that water quality has improved in WMP and that, by some measures, water quality in EMP is lower than in WMP. As the ponds have relatively similar water quality now, equal focus is needed to advance the TMDL goals. Since many of the actions needed will focus on controlling external (watershed-based) loads, these watershed actions need to be spread between both the Towns of Hanson and Halifax with oversight by MassDEP.

Recommendation #2: Updated Lake Diagnostic Study with Comprehensive Sampling to Evaluate Progress Toward TMDL Goals

Possible Responsible Party: Towns of Halifax and Hanson

While the draft final TMDL has just been published (2021), the study is based on a load assessment that is over a decade old, and thus, does not reflect the alum treatments that started in 2013 nor the change in handling of flood flows that started in 2016. The TMDL load assessment forms the basis for targeted phosphorus reductions and progress against those goals should be assessed so that future actions can be cultivated using an adaptive management approach. Water quality conditions in Monponsett Pond have improved markedly with the actions described above, and in recent years, total phosphorus concentrations periodically have been below the TMDL target concentration of 18 µg/L.

An updated lake diagnostic study should be completed by the Towns of Halifax and Hanson to benchmark progress and help refine the current internal and external loads of phosphorus and should include both EMP and WMP. Previous actions have targeted the larger, known sources of phosphorus. A lake diagnostic study would identify the pond's current health status and allow informed and judicious decisions to be made in the TMDL implementation process that is to come.

Both the TMDL and this RMP (recommendation #4) include alum treatment for EMP. It would be sensible to complete a diagnostic study within a couple of years after implementing that alum treatment.

Recommendation #3: More Regular Water Quality Monitoring

Possible Responsible Party: MassDEP or Towns of Halifax and Hanson

A key element of any implementation plan is to track progress. The lake diagnostic study discussed above would involve a short-term intensive sampling effort, while a regular water quality monitoring program takes a longer view. While current monitoring efforts provide useful monitoring data, a regular monitoring program by MassDEP or the Towns of Halifax and Hanson would allow for better tracking of the pond's water quality. Suggestions include:

- Continuing with MassDEP's cyanobacteria monitoring program, but starting the sampling earlier in the year (by early May) to catch the beginning of cyanobacteria blooms.
- Expanding field parameter measurements to include Secchi depth and a vertical profile in each pond for temperature, DO, pH, and if possible, fluorescence.
- Continuing to take nutrient samples for nitrogen and phosphorus but consistently collect a bottom sample. Also consider adding chlorophyll to the analyte list.

Recommendation #4: Plan for Additional Alum Treatments

Possible Responsible Party: Town of Halifax

The alum treatments conducted in WMP from 2013-2019 have been very successful in improving WMP's water quality. However, until the external loads of phosphorus are better controlled,

harmful periodic cyanobacteria blooms (CyanoHABs) may continue to occur (as has happened in 2019 and 2020). Further, there had been an increasing trend in cyanobacteria levels in EMP, excepting 2020 when few cyanobacteria were found in EMP.

The Town of Halifax should plan and seek funds for possible future alum treatments, including treatment for EMP. This was also a recommendation of the TMDL.

Recommendation #5: Reduce the Rate of Diversion in May if a Cyanobacteria Bloom is Starting to Occur in WMP but not in EMP

Possible Responsible Party: City of Brockton

The field work and modeling included in this RMP confirm that if the diversion value is set at about 25 percent or 6 mgd then the transfer of flow through the culvert from WMP to EMP is minimized. This reduction is only proposed for the month of May as this represents the only month where there is overlap between Brockton being authorized to divert flow and months in the when a CyanoHAB occurred recently (following the alum treatments and the fertilizer reductions).

It is proposed that the City of Brockton reduce the diversion rate if cyanobacteria levels are measured above 5,000 to 10,000 cells/mL (noting that 70,000 cells/mL is the threshold when recreation actions are stopped). The reduced diversion rate minimizes the transfer of poor water quality from WMP to EMP and would apply until the bloom subsides.

Recommendation #6: Additional Monitoring for Future Evaluations

Possible Responsible Party: City of Brockton

Two additional monitoring programs are recommended to assist with further understanding of the water balance of Monponsett Pond.

- **Upgrade the weather station at Silver Lake** – While completing the RMP analysis, precipitation records from gages across southeastern Massachusetts were reviewed for applicability. We found the gages varied over a wide range both in terms of total annual precipitation and the seasonal distribution of precipitation. Brockton has been collecting rainfall data manually at Silver Lake but this data is not currently being uploaded to an observer program where it could be easily accessed. The recommendation is for City of Brockton to upgrade the weather station at Silver Lake to one that automates the data collection process and then to have the data uploaded to the NOAA cooperative observer program.
- **Establish a sentinel well to monitor local groundwater levels** – Groundwater seepage into and out of Monponsett Pond can be a significant part of the ponds water balance. This study relied on the nearby Duxbury well to determine seepage direction and magnitude based on a comparison of the groundwater elevation and pond level. This relationship would be better refined if a well directly adjacent to Monponsett Pond was developed by the City of Brockton as it would capture any localized influence from groundwater extraction and recharge.

6.3.3 Preliminary Feasibility Assessment of Additional Recommendations

A preliminary feasibility assessment for the RMP recommendations was performed to evaluate each of the additional recommendations described in the previous section. The City of Brockton's jurisdictional authority is limited to diversion from Monponsett Pond to Silver Lake and operation of the fish ladder gate and sluice gate on the Stump Brook Dam. As many of these recommendations are beyond the City of Brockton's jurisdictional authority, the possible responsible parties are identified. Each recommendation was evaluated in terms of its relative impact on Monponsett Pond water quality and ecosystem benefits, water supply reliability, and a relative planning-level cost. **Table 6-2** presents the assessment of the RMP recommendations.

Table 6-2. Preliminary Feasibility Assessment

Recommendation	Water Quality and Ecosystem Benefits	Water Supply Reliability Impacts	Relative Planning-level Cost (\$: <\$50K; \$\$: \$50K-\$250K; \$\$\$: >\$250K)	Possible Responsible Party
Improved management of stormwater loads • Small MS4 permit implementation • BMP implementation per the WMP Watershed-based Plan • Develop TMDL Implementation Plan • Public education	High	None	\$	Towns of Hanson and Halifax, with oversight by MassDEP
Updated lake diagnostic study with one year of comprehensive monitoring following EMP alum treatment	Low	None	\$\$	Towns of Hanson and Halifax; if possible, with grant funding
Increased routine monitoring in WMP/EMP <i>Profiles, Secchi depth, top and bottom nutrients, chlorophyll; and continued algal ID but starting before May 1</i>	Low	None	\$ (as an annual cost)	MassDEP or Towns of Hanson and Halifax
Continue alum treatments WMP as needed; Plan for treatment at EMP and implement	High	None	\$\$	Town of Halifax; if possible, with grant funding
In May, reduce rate of diversion to Silver Lake to 25% if cyanobacteria is starting to bloom (>5-10K cells/mL) in WMP and not EMP	Moderate	Moderate – could impact Brockton's ability to fill Silver Lake in some years	\$	Brockton
Establish additional monitoring to support future evaluations • Update weather station at Silver Lake and add to publicly accessible site • Sentinel well to monitor local groundwater levels	Low	None	\$	Brockton

Section 7

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Appendix A

Final RMP Scope of Work

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City of Brockton, Massachusetts

Resource Management Plan Scope of Work

Task 1 – Project Scoping and Regulatory Coordination

Summary

This task includes preparation of the Resource Management Plan (RMP) scope of work, a public comment period including a public meeting, compilation of written public comments and response to written public comments. Included in this work are meetings between the City of Brockton and MassDEP (Massachusetts Department of Environmental Protection) intended to define project requirements and objectives, identify information sources, and specify any procedural/regulatory guidelines or requirements that must be satisfied. This task addresses the requirements of Administrative Consent Order (ACO) Item 34.

Detailed Scope of Work

- Meet with MassDEP representatives to review the requirements ACO for the Resource Management Plan (RMP) and discuss specific requirements of the draft RMP scope of work.
- Prepare a draft scope of work that addresses the RMP requirements of the ACO.
- Publish the draft RMP scope of work for public review and comment. The draft RMP scope of work will be available for public review on the City of Brockton website, and paper copies of the document will be available at Brockton City Hall, and the Halifax and Hanson Town Halls. Public comment period will be a minimum of 30 days. Written public comments will be accepted until February 26, 2018. Details are included in the public notification.
- Publish a notification of the availability of the RMP scope of work and solicit public comment in the Environmental Monitor, Brockton Enterprise and Patriot Ledger.
- Hold a public meeting to present the draft RMP scope of work and solicit public comment. The public meeting will be on February 6, 2018. Details are included in the public notification.
- Collate written public comments received on the draft RMP scope of work and prepare a response to comments.
- Meet with MassDEP to discuss the public comments received, the draft response to comments, and proposed modifications to the draft RMP scope of work.
- Finalize the proposed RMP scope of work, with modifications as warranted based on review of public comments received and MassDEP input.
- Submit the final RMP scope of work, public comments, and response to comments to MassDEP for review and approval.

- Publish the final RMP scope of work and response to comments on the City of Brockton website, and paper copies of the document will be available at Brockton City Hall, and the Halifax and Hanson Town Halls. Copies of the final RMP scope of work and response to comments will also be forwarded to each person/group who provided written public comments. Town of Halifax will also be requested to post these documents on the Town website with other Monponsett Pond documents.
- Meet with MassDEP to formally kick off the project.

Task 2 – Document Historical Practices and Existing Pond Uses and Conditions, and Develop Monthly Pond Water Level Targets

Summary

This task addresses ACO Item 33a by documenting the City of Brockton’s current and historic operating practices, and reviewing specific triggers, timing and respective water levels related to overall Monponsett Pond management, releases to Stump Brook, diversions to Silver Lake and flood control.

Possible changes to operating practices will also be examined that consider current pond uses water quality issues, water supply needs, flood control, and the corresponding water level requirements. Current pond uses include, in no particular order:

- Water supply
- Recreation (boating, fishing and bathing)
- Agricultural (cranberry cultivation)
- Residential (shoreline development)
- Stream flow to Stump Brook (future fish passage)
- Wildlife habitat

Input will be solicited from MassDEP, Massachusetts Department of Fish and Game (Division of Fisheries & Wildlife (MassWildlife), Massachusetts Division of Ecological Restoration (MassDER), Office of Fishing and Boating Access, and Marine Fisheries), Massachusetts Department of Public Health (MassDPH), local Boards of Health, Cape Cod Cranberry Growers Association (CCCCGA), and University of Massachusetts (UMass) Cranberry Station. This information and literature searches will be used to develop monthly target pond elevations to accommodate existing uses.

Detailed Scope of Work

- Brockton Water Department and Veolia (water treatment plant contract operator) staff will review up to five years of historical operations practices and issues and summarize historical average monthly Monponsett Pond water levels. Historical operations reviewed will include specific requirements of the Acts, water level management, diversions to Silver Lake, releases to Stump Brook, flood control measures, water quality restrictions, water supply requirements, recreational uses, habitat needs and agricultural requirements, as available.

Groundwater, stream flow and precipitation data will also be reviewed and compared with water level data. For groundwater and streamflow data, local United States Geologic Survey (USGS) data will be reviewed. For precipitation data, local Department of Conservation and Recreation (DCR) and/or National Weather Service (NWS) data will be reviewed.

- Solicit input from MassDEP, MassWildlife and Office of Fishing and Boating Access, CCCGA and UMass Cranberry Station, MassDPH, and various Halifax and Hanson town departments related to overall knowledge of the area, Monponsett Pond water quality data, cranberry growers' operations, stormwater discharges, and historical documents on file. Summarize findings.
- Solicit input from the MassWildlife and Office of Fishing and Boating Access, Mass DPH, and local Boards of Health regarding boating, fishing and bathing uses at Monponsett Pond, and required depths to support these uses. Summarize findings.
- Solicit input from the MassWildlife Natural Heritage & Endangered Species Program (NHESP) regarding habitat requirements for listed species present at Monponsett Pond. Summarize findings.
- Solicit input from the Halifax and Hanson Boards of Health regarding requirements and actions regarding septic systems near the Monponsett Pond shoreline. Summarize findings.
- Solicit input from the CCCGA and UMass Cranberry Station regarding cranberry agriculture management. Summarize findings.
- Review data on flood related diversions versus Stump Brook Dam releases. Data is expected to include elevations of Monponsett Pond, Silver Lake and local groundwater table for the week leading to and including the diversion/release event. The amount of the diversion/release will also be estimated. For groundwater data, local USGS data will be reviewed.
- Perform a literature search for reports and/or articles on Monponsett Pond, including documents prepared for/by MassDEP, MassDER, the towns of Halifax and Hanson, the Monponsett Pond Watershed Association, and the Jones River Watershed Association.
- Perform a cursory review of available recent and historic pond bathymetry by others, as available.
- Summarize available recent and historic pond water quality data obtained from MassDEP, MassDPH, recent studies, and other sources, as available. Summarize applicable regulations, Acts of the legislature granting water rights to Monponsett Pond, Water Management Act registrations, Chapter 91 license and other documents that apply to management of Monponsett Pond.
- Brockton Water Department and Veolia staff will explore possible changes to operating procedures that could:

- improved flushing in West Monponsett Pond to help control algal blooms/cyanobacteria impacts,
 - a flow path from East Monponsett Pond to West Monponsett Pond, during algal blooms, to minimize the potential for reversal of flow and degradation of East Monponsett Pond.
 - adequate water supply and water quality for diversion to Silver Lake,
 - better flood control (including timing, benefits and/or impacts of flood control diversions to Silver Lake and/or Stump Brook),
 - adequate water depth for bathing, boating, fishing and cranberry cultivation (agriculture),
 - suitable habitat for NHESP species of concern, and
 - future fish migration in Stump Brook.
- Develop monthly target pond elevations, or elevation ranges to accommodate existing uses noted above based on anticipated inflow and withdrawal patterns, suggested water depths for each use, and seasonality of each use.

Task 3 – Research Historical Pond Elevations

Summary

ACO Item 33b requires that the City “research historical pond elevation information using available data from United States Geological Survey (USGS) and other agencies....” In addition to the City’s historical Monponsett Pond level data, this task will include a cursory review of pond levels shown on historical mapping to compare pre-water supply and water supply pond elevations.

Detailed Scope of Work

- Review historical City of Brockton pond elevations and trends for Monponsett Pond for the last 20 years.
- Review historical USGS Hanover, MA Quadrangles that indicate Monponsett Pond elevation. Mapping sources include the University of New Hampshire and UMass Lowell.
- Review historical pond elevations in 1923 Chapter 91 license (ACO requirements for the RMP). It is understood that this document refers to a reference point that most likely has been disturbed/lost. Information will be gleaned from this document, to the extent practicable.
- Solicit historical mapping of Monponsett Pond from the Massachusetts Historical Commission, and town engineers and/or historical commissions in Halifax and Hanson. Investigate sources of historical mapping provided by the Jones River Watershed Association during the public comment period. An extensive document search is not included in this task.
- A search of the Registry of Deeds is not included in this task.

- Based on available historical (pre-water supply) mapping, compare pre-water supply pond elevations to historical water supply operating elevations.

Task 4 – Collect Flow Data at the Route 58 Box Culvert

Summary

ACO Item 33c requires “collection of flow data to correlate Silver Lake diversion rates with flow rates from West Monponsett Pond to East Monponsett Pond during diversions to Silver Lake.” The natural flow path is from East Monponsett Pond to West Monponsett Pond and Stump Brook. The intent of this requirement is to assess the potential for the flow of degraded water from West Monponsett Pond to pass through the culvert to East Monponsett Pond, given that the City of Brockton’s diversions are from the east pond. The City will collect data and estimate the flow patterns in the Route 58 box culvert between East and West Monponsett Ponds under varied conditions. Flow measurements will aid in understanding the hydraulic connection between the ponds. The flow measurement methodology is expected to be, by necessity, simplistic given that typical continuous flow metering devices are expected to have limited accuracy due to the culvert configuration and wind and kayak/canoe interference, and would be subject to tampering, vandalism and/or theft given this remote location.

Detailed Scope of Work

- Develop a protocol for City or Veolia staff use. Flow measurement methodology is envisioned to track the rate of travel of an orange or other object through the Route 58 box culvert. A round object, like an orange, will be less influenced by wind than a flat object floating at the water surface.
- Collect field measurements of the box culvert to define an average cross-sectional area and traverse length at different pond water levels. Install a staff gauge on the structure; the gauge will be tied via survey to a local benchmark that the local water elevation at the time of flow measurements.
- Flow measurement observations will be performed in a manner that does not conflict with the requirements of the Acts of 1964 and as amended by the Acts of 1981, such that at least 900,000 gallons per day (gpd) is released to Stump Brook during times of diversion to Silver Lake. It is understood that releases to Stump Brook can be temporarily reduced when there is no diversion to Silver Lake, with written approval of MassDEP. Allow two days for the ponds to stabilize under test conditions prior to data collection. Data will be collected for each flow condition specified below with the goal of obtaining several measurements during each season, when the condition is allowed per requirements of the Act. Data will be collected will target calm, dry weather and open water (at the culvert as minimum) conditions:
 - Full diversion rate to Silver Lake with at least 900,000 gpd release to Stump Brook (October to May)
 - 75 percent diversion rate to Silver Lake with at least 900,000 gpd release to Stump Brook (October to May)

- 50 percent diversion rate to Silver Lake with at least 900,000 gpd release to Stump Brook (October to May)
 - 25 percent diversion rate to Silver Lake with at least 900,000 gpd release to Stump Brook (October to May)
 - No diversion to Silver Lake with at least 900,000 gpd release to Stump Brook (year-round)
 - No diversion to Silver Lake with at least 600,000 gpd release to Stump Brook (June to September)
 - No diversion to Silver Lake with at least 300,000 gpd release to Stump Brook (June to September)
 - No diversion to Silver Lake and no release to Stump Brook (June to September)
 - Flood control and/or pond flushing scenarios, as negotiated in advance with MassDEP. The intent is to simulate flood conditions and/or a late spring flush period for water quality purposes. MassDEP has indicated that it may allow impounding of water (by temporarily waiving the ACO-required 900,000 gpd release to Stump Brook) when there is no diversion to Silver Lake.
- Correlate diversion rate and Stump Brook release rate with observed flow rates at the Route 58 culvert. Tabulate and graph findings.
 - Collect grab samples at four locations and perform water quality testing for total phosphorus, total nitrogen, ammonia, color and turbidity, dissolved oxygen, temperature, pH, and conductivity during up to four selected flow release/diversion scenarios above. Sampling locations are anticipated to be:
 - Northern East Monponsett Pond (near Stetson Brook)
 - Southern East Monponsett Pond (near the Silver Lake diversion structure/East Monponsett Ramp)
 - Southern West Monponsett Pond (downstream of the Route 58 culvert)
 - Stump Brook Dam or alternate shoreline access point on Northern West Monponsett Pond

Task 5 – Estimate Seasonal Releases to Stump Brook

Summary

ACO Item 33d requires an evaluation of high-rate spring flushing to potentially reduce stagnation and algal blooms. The analysis will define the maximum water level at which the Monponsett Pond can be held without causing flooding and possible pond flushing scenarios. It will consider the release constraints of the Stump Brook Dam, the natural sill of West Monponsett Pond and the

invert of the Route 58 box culvert dividing the ponds. The outcome sought is to estimate the water residence time for various scenarios and perform a qualitative assessment as to whether this might change water quality in West Monponsett Pond without creating downstream flooding of Stump Brook.

Detailed Scope of Work

- Define the maximum water level at which the pond can be held without causing flooding.
- Based on available drawings and data, assess flow relationships and constraints for flows released from the Stump Brook Dam structure, including sluice gate, fish ladder and spillway.
- Based on available drawings and measurements collected in Task 4, assess flow relationships and constraints for flows through the Route 58 box culvert connecting East and West Monponsett Pond
- Field reconnaissance will be conducted to identify the natural sill elevation of West Monponsett Pond.
- Assess stage/storage relationship for pond volumes considering vertical constraints of Stump Brook Dam release points, the natural sill of West Monponsett Pond, and the invert of the culvert dividing the ponds.
- Surface and groundwater inflow rates of East and West Monponsett will be approximated using readily available information including work done in previous studies. The estimates will be annual or seasonal, depending on their use in the subsequent analyses.
- Construct a spreadsheet and perform a high-level desktop analysis of potential seasonal pond operation changes to induce increased spring release rates to Stump Brook for pond flushing. The analysis will consider bounding scenarios where flow from East Monponsett Pond minimally and fully mixes with the waters of West Monponsett Pond, and additional scenarios where the East Monponsett Pond flow mixes with the upper waters (defined by the controlling vertical constraint and the typical summer epilimnion depth). A seasonally appropriate steady inflow from groundwater/surface water will be assumed based on previous studies of the pond by others. Water entering West Monponsett Pond from East Monponsett Pond and the groundwater are expected to contain less phosphorus, which is expected to reduce algal blooms.
- Based on the desktop analysis, consider the change in water residence time for various operations scenarios and make a qualitative assessment as to whether each scenario might change/improve water quality in West Monponsett Pond. Consider possible water supply impacts that may occur due to changes to Silver Lake diversion timeframe and minimum pond depth required to accommodate these scenarios.

Task 6 – Operating Procedures for Silver Lake Diversion & Stump Brook Dam

Summary

As required by ACO Items 33e and 33f, Monponsett Pond operating procedures manuals will be prepared for the Silver Lake diversion infrastructure and the Stump Brook dam. The results of Tasks 2 through 5 above will be used as the basis for developing separate operating guideline procedures manuals for Stump Brook dam and Silver Lake diversion structure.

Detailed Scope of Work

- Prepare separate operating procedures manuals for Stump Brook Dam and Silver Lake Diversion Structure. Based on the results of Tasks 2 through 5, modify and expand existing operations protocols to include goals, timeframes, and triggers for operations decisions regarding:
 - pond water elevations,
 - water supply diversions to Silver Lake, and
 - releases to Stump Brook.

Task 7 – Recommended Action Items and Preliminary Feasibility Assessment

Summary

In accordance with ACO Item 33g, the City will prepare a recommended actions list with a preliminary feasibility assessment. This actions list will largely include additional measures that are beyond the City's jurisdictional authority but could be performed by other stakeholders. These actions include, but are not limited to, septic system upgrades/improvements, improved stormwater management, improved land use management, in-pond treatment, and agricultural best management practices.

Detailed Scope of Work

- Compile a list of recommended actions from previous studies and MassDEP's *Draft West and East Monponsett Pond System Total Maximum Daily Loads for Phosphorus (CN 446.0)*.
- Recommend and list additional studies/actions based on the outcome of Tasks 1 through 6 above.
- Perform a cursory (preliminary) feasibility assessment and possible responsible parties for each action item listed.

Task 8 – Draft Report Preparation and Public Comment

Summary

In accordance with ACO Item 36, this task includes preparation of the draft RMP, a meeting between the City and MassDEP to present the findings prior to public review, a public comment period with a public meeting, compilation of public comments, a response to comments, and a meeting between the City and MassDEP to discuss the comments prior to finalizing the RMP.

Detailed Scope of Work

- Prepare the draft RMP based on the results of Tasks 2 through 6.
- Prepare for and attend a meeting between the City and MassDEP to present the draft RMP prior to its release for public review.
- Publish the draft RMP for public review and comment. The draft RMP will be available for public review online on the City of Brockton website, and copies of the document will be available at Brockton City Hall, and the Halifax and Hanson Town Halls. Written public comments shall be accepted for 30 days from the publish date.
- Publish a notification of the availability of the draft RMP to solicit public comment in the Environmental Monitor, Brockton Enterprise and Patriot Ledger.
- Hold a public meeting to present the draft RMP and solicit public comment.
- Collate public comments on the draft RMP and prepare a response to comments.
- Prepare for and attend a meeting with MassDEP to discuss the public comments and response prior to finalizing the RMP.
- Finalize the RMP and submit the document to MassDEP.

City of Brockton, Massachusetts
Resource Management Plan Scope of Work
Estimated Project Schedule

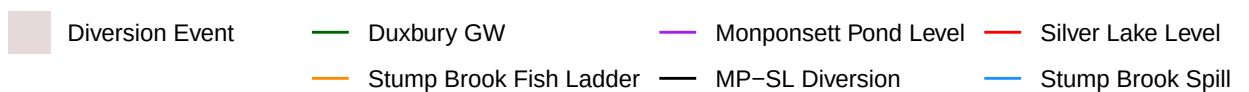
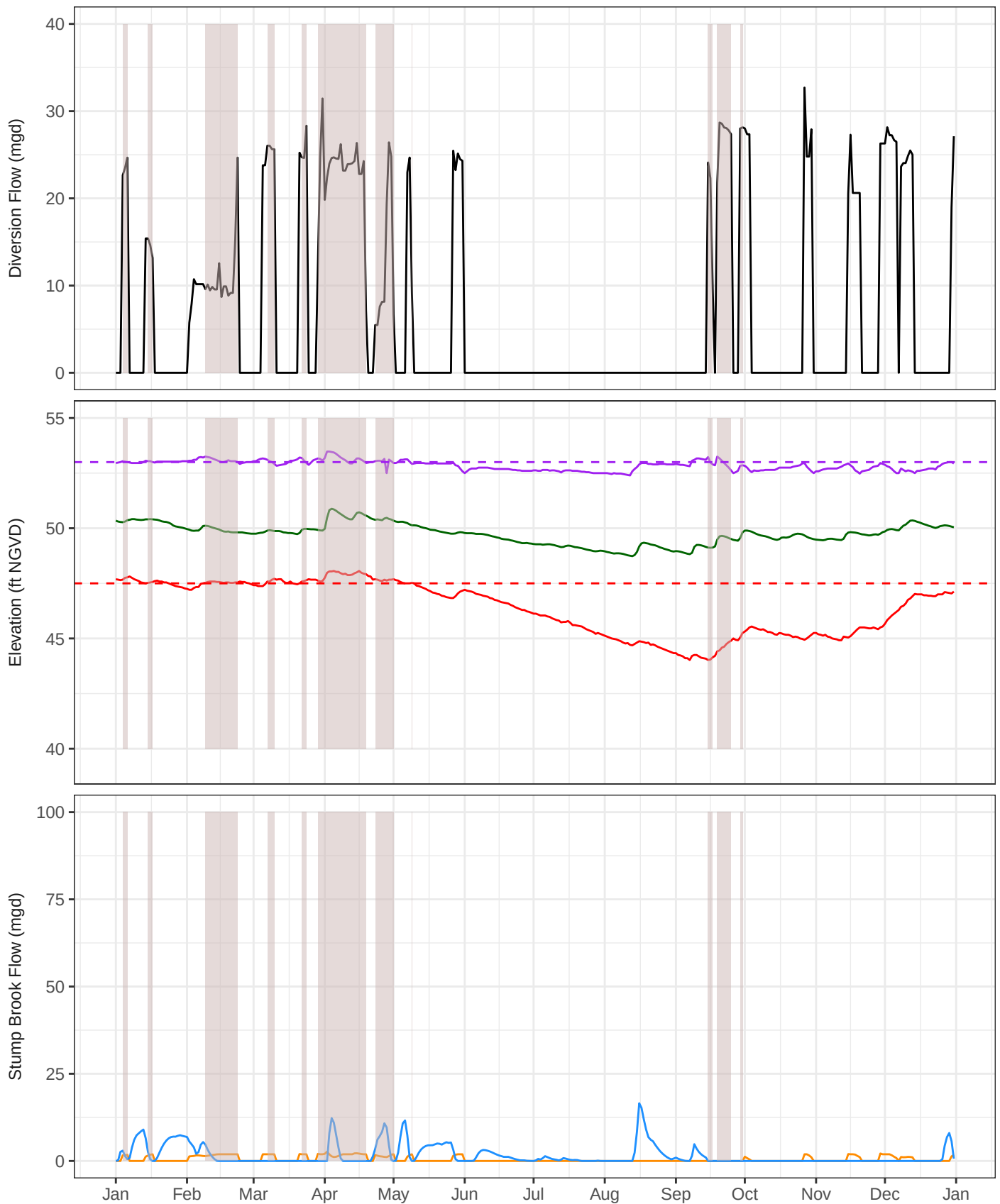
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Appendix B

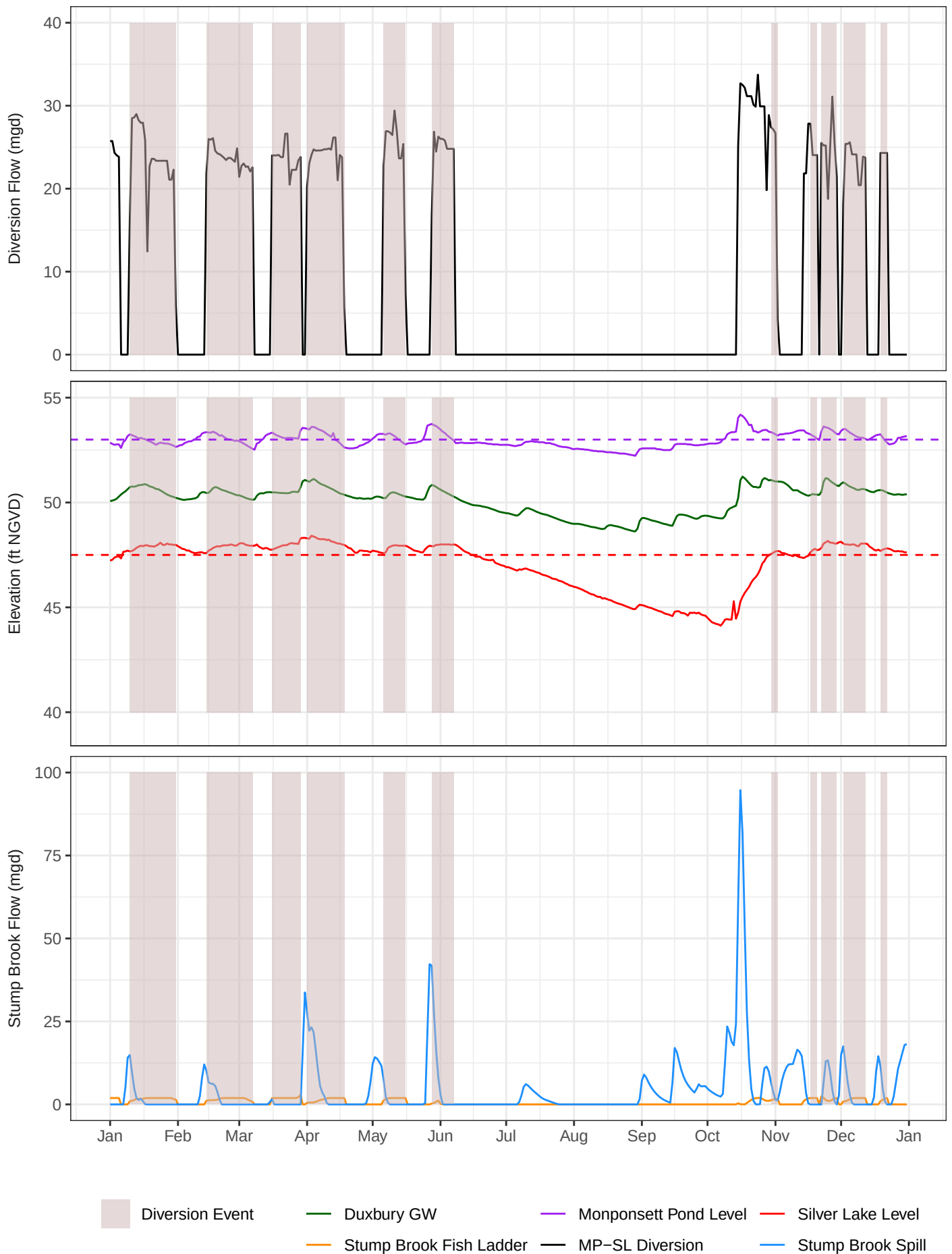
Diversion Plots (2004-2019)

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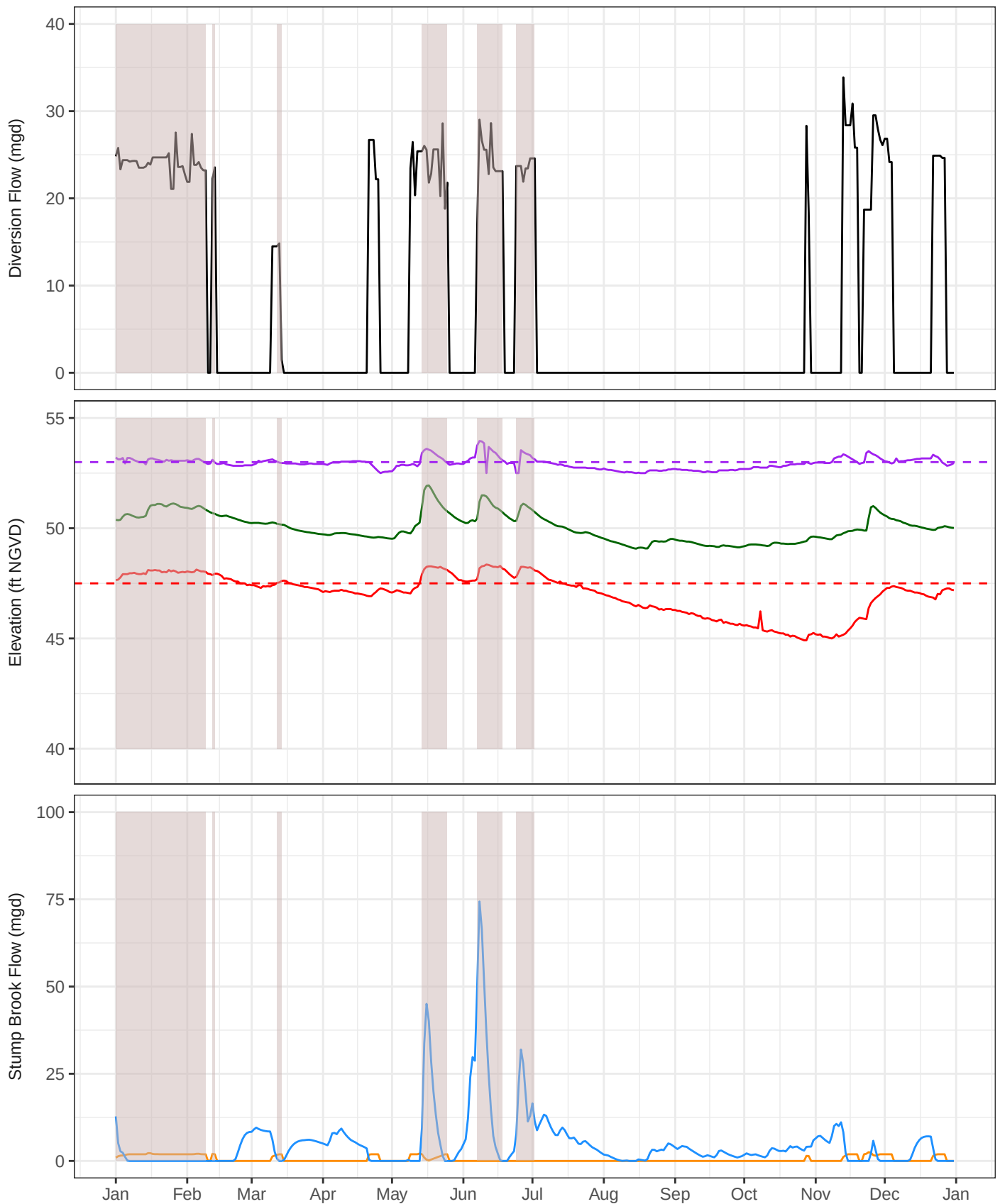
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Annual Diversion Record: 2005

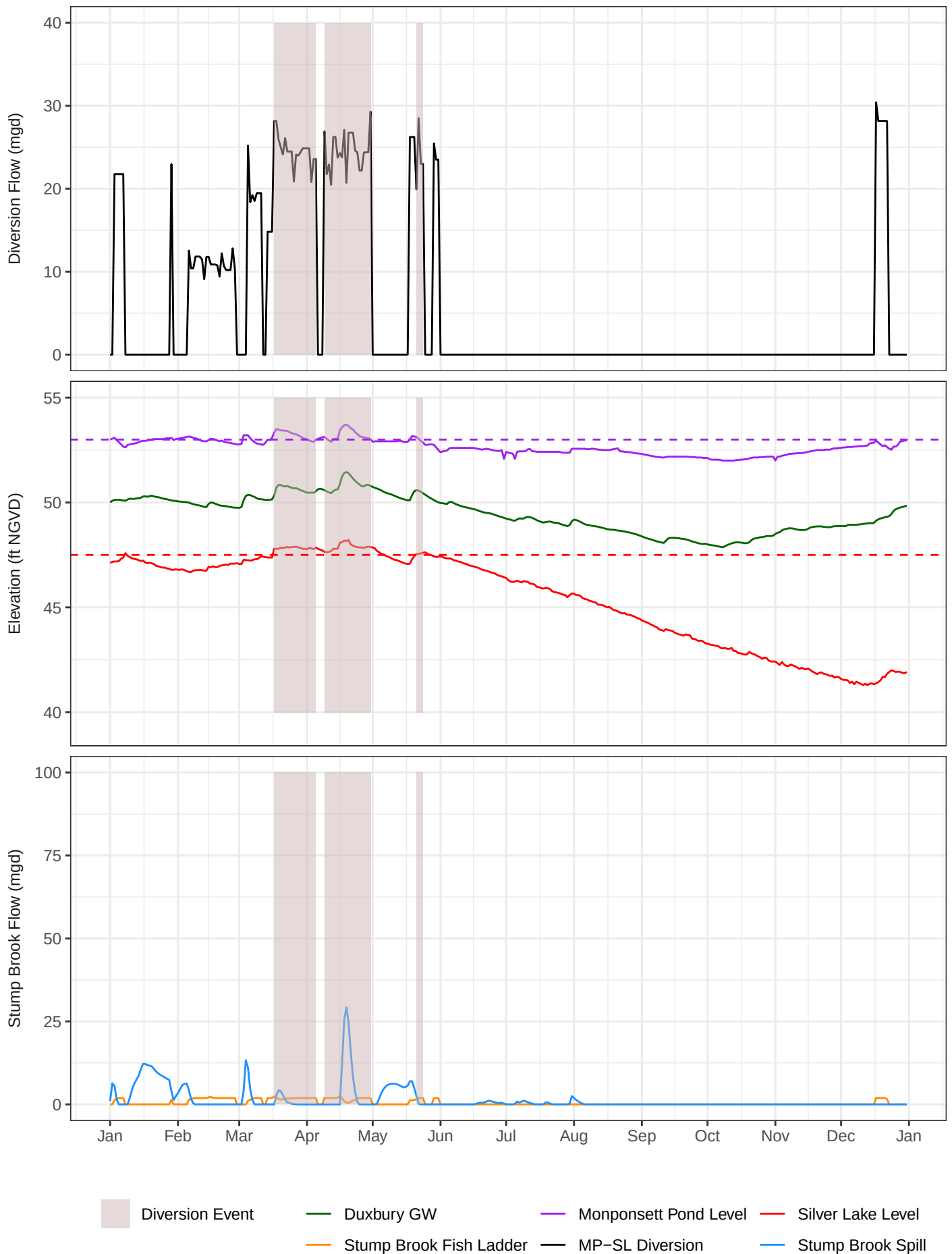


Annual Diversion Record: 2006

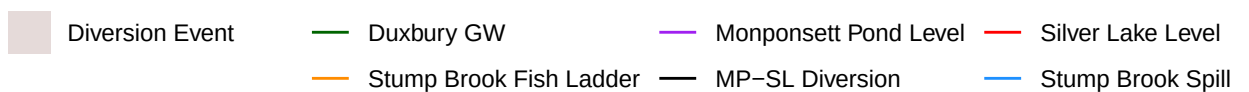
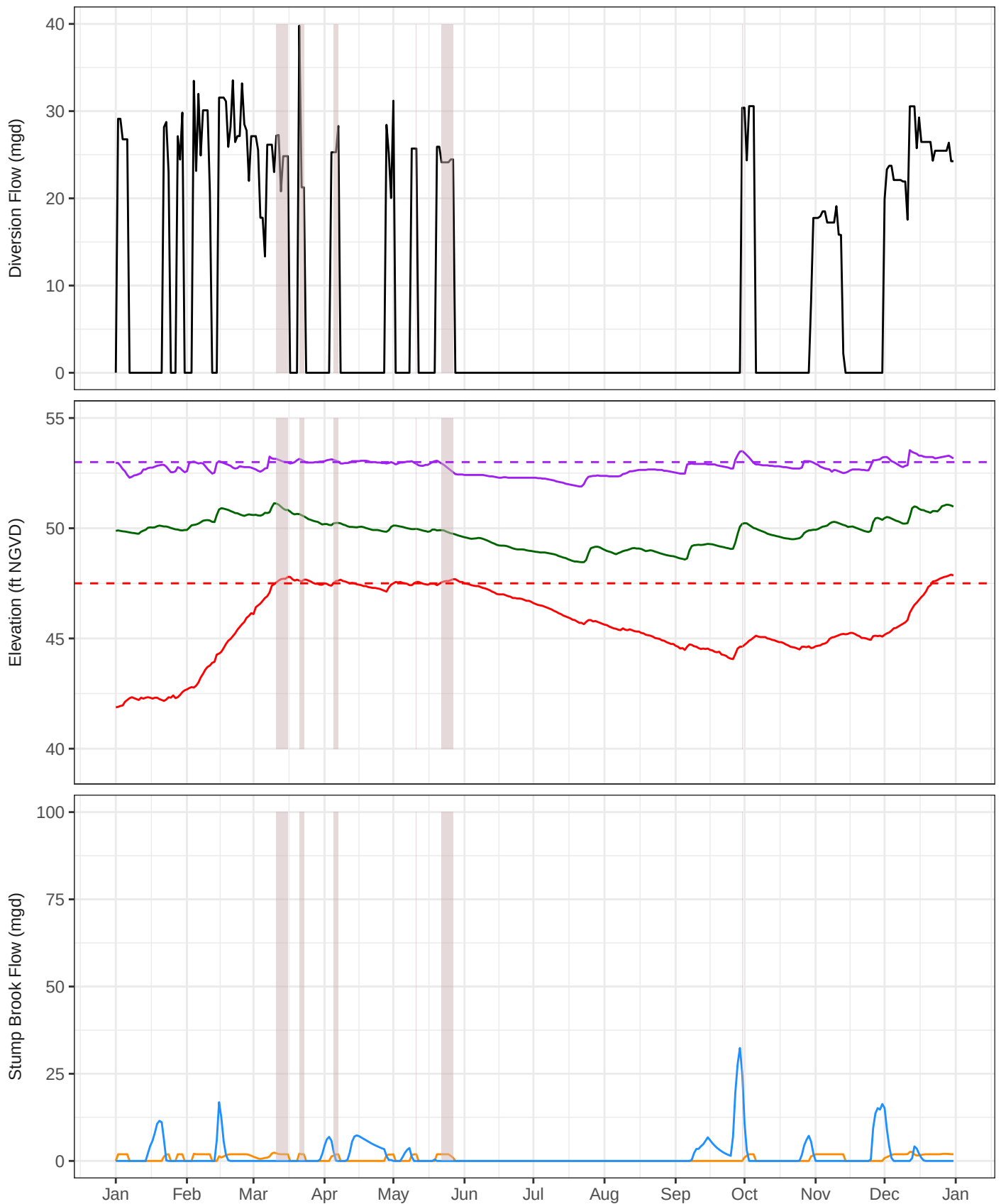


- Diversion Event
- Duxbury GW
- Monponsett Pond Level
- Silver Lake Level
- Stump Brook Fish Ladder
- MP-SL Diversion
- Stump Brook Spill

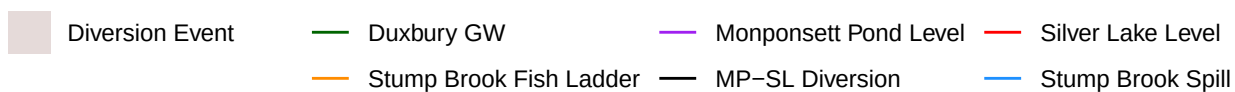
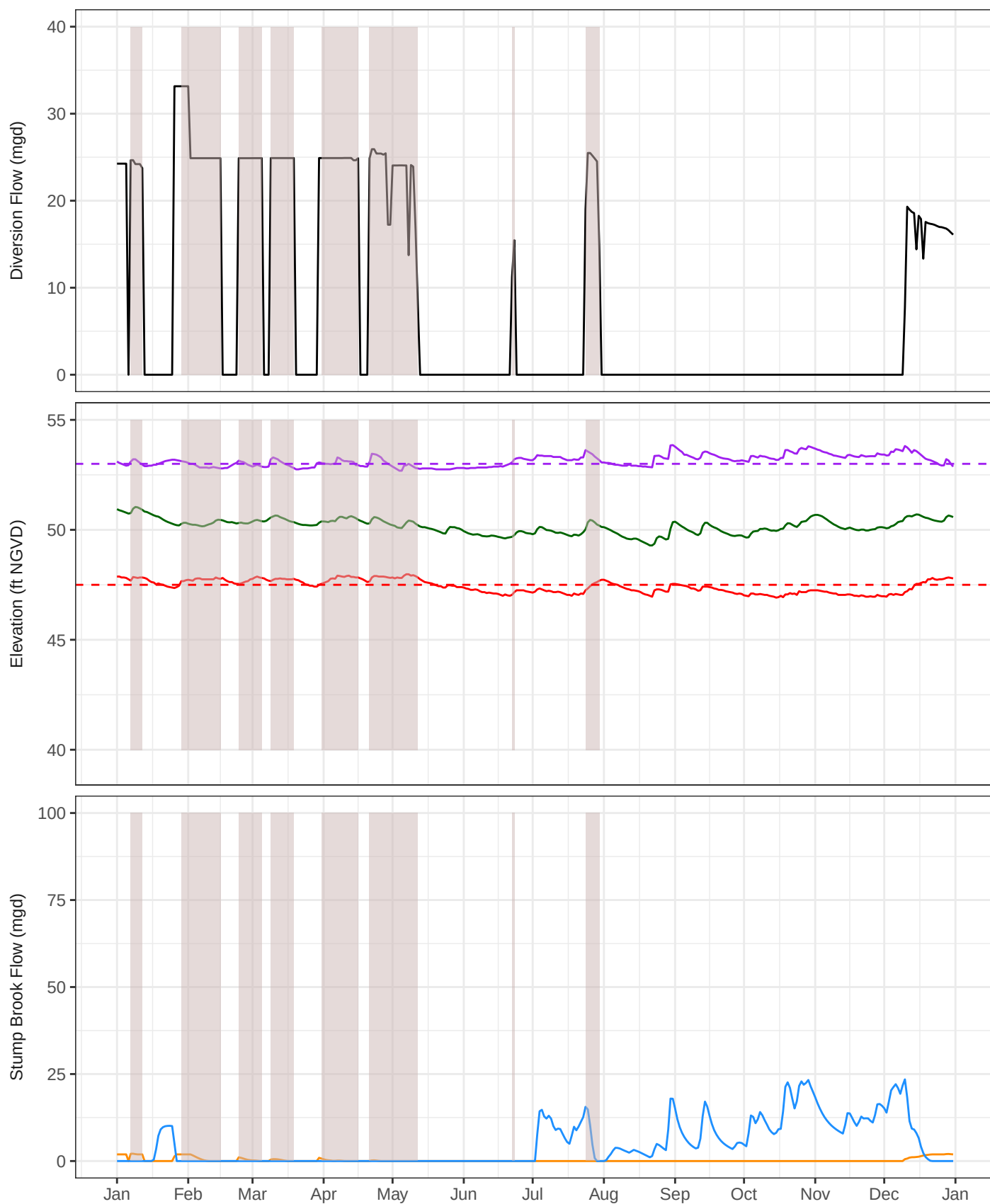
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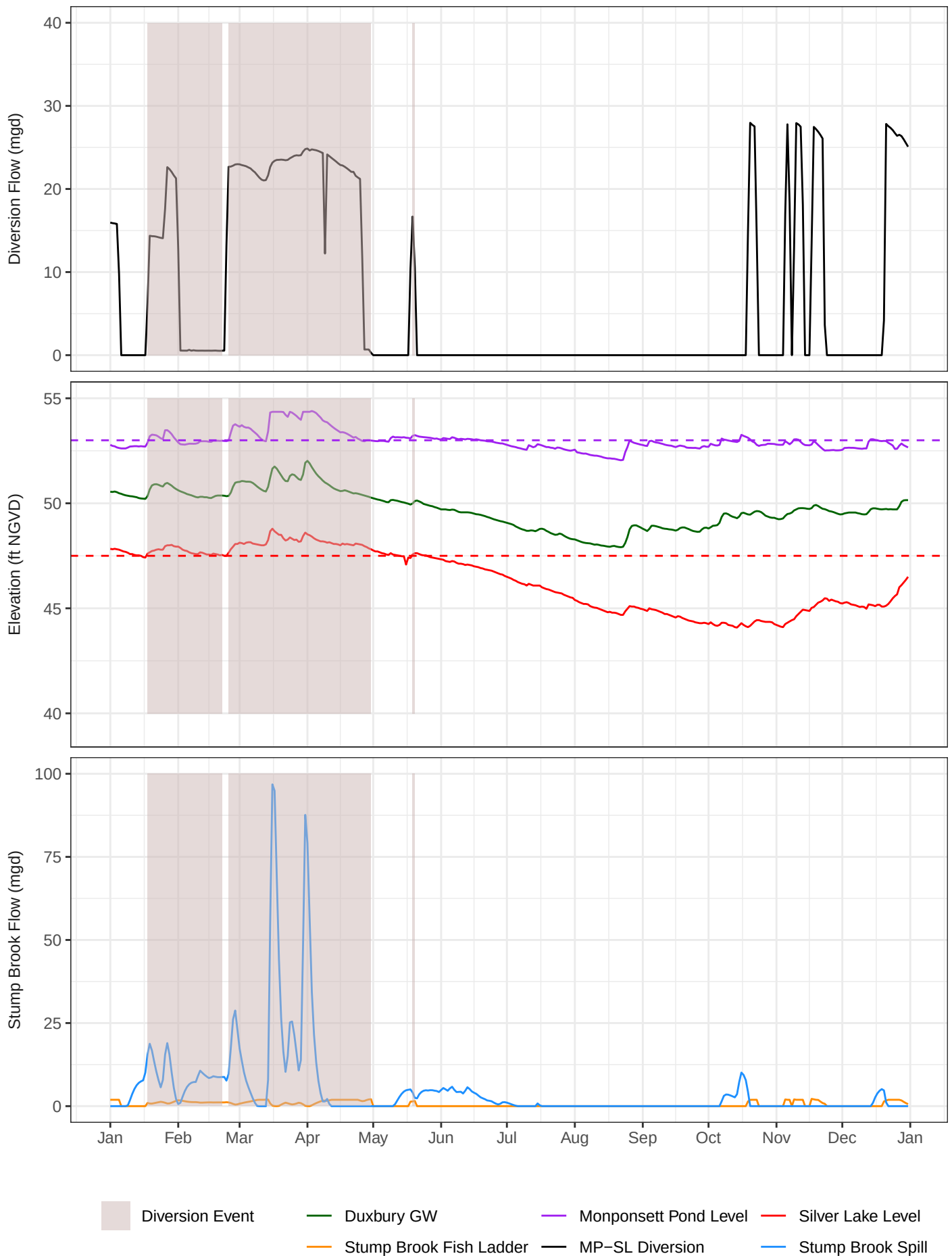
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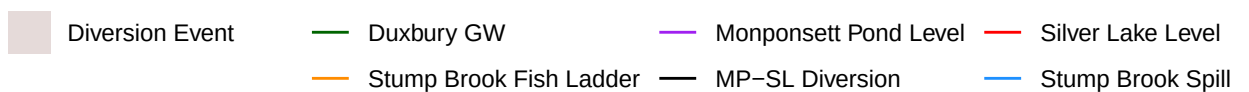
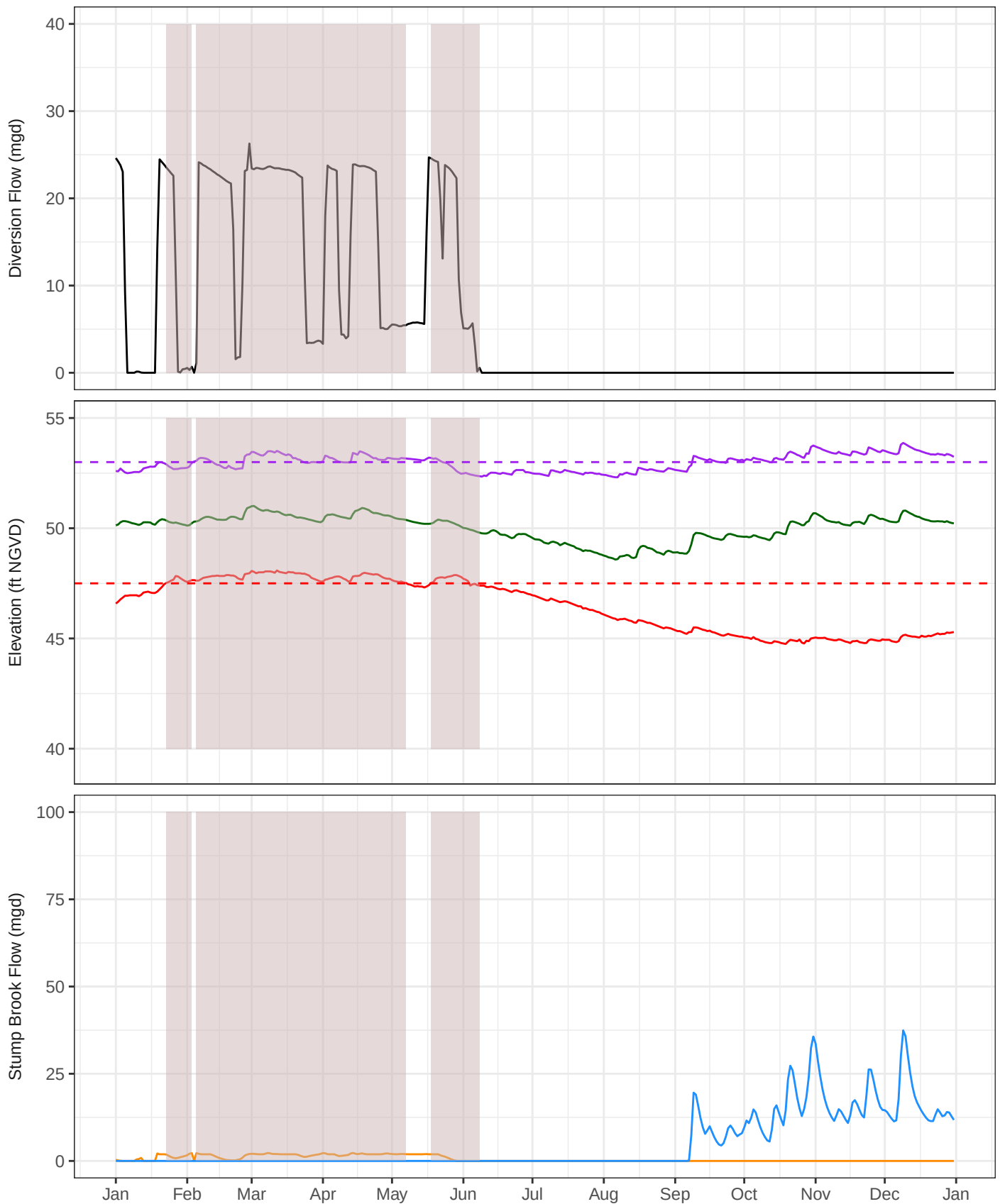
Annual Diversion Record: 2009



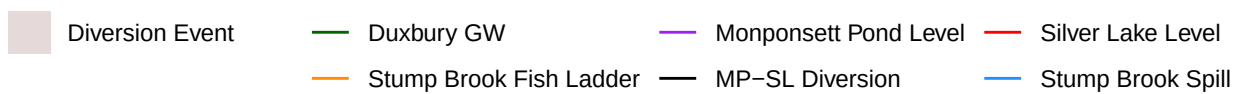
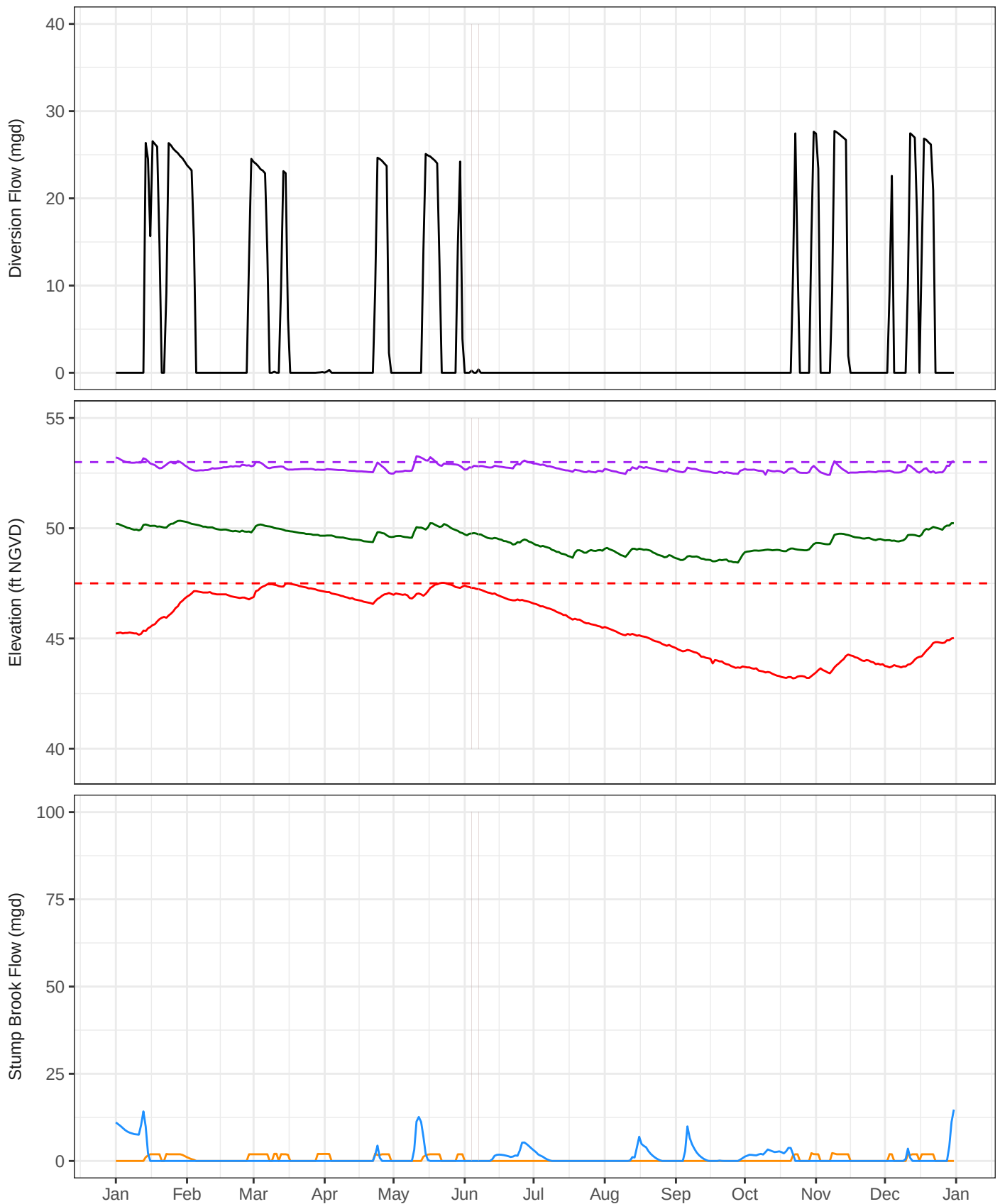
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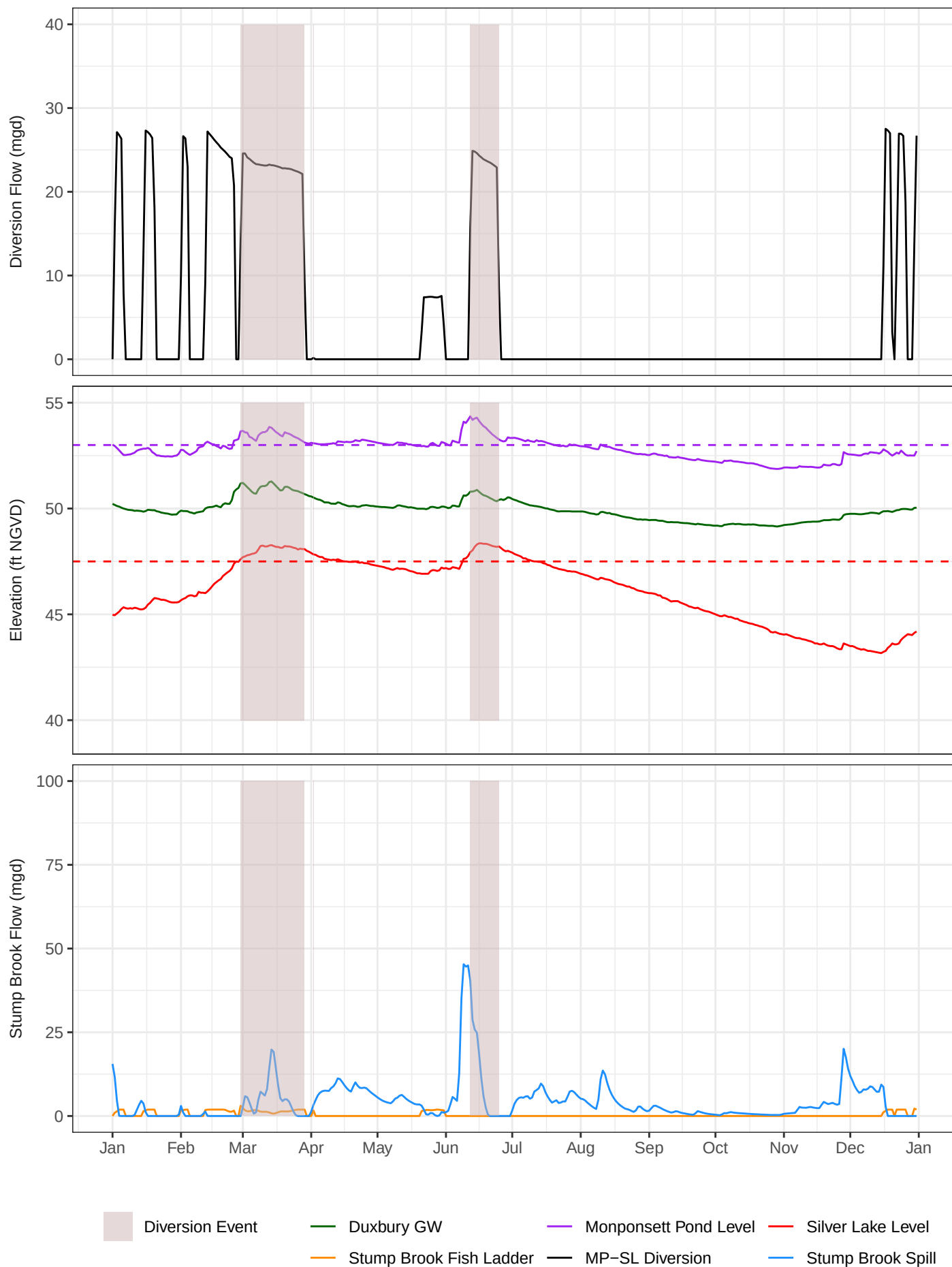
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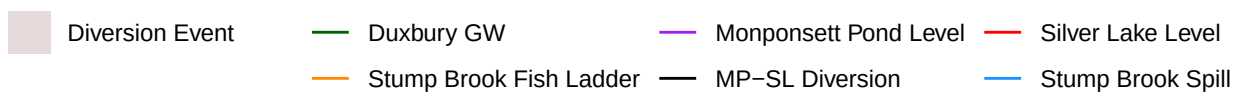
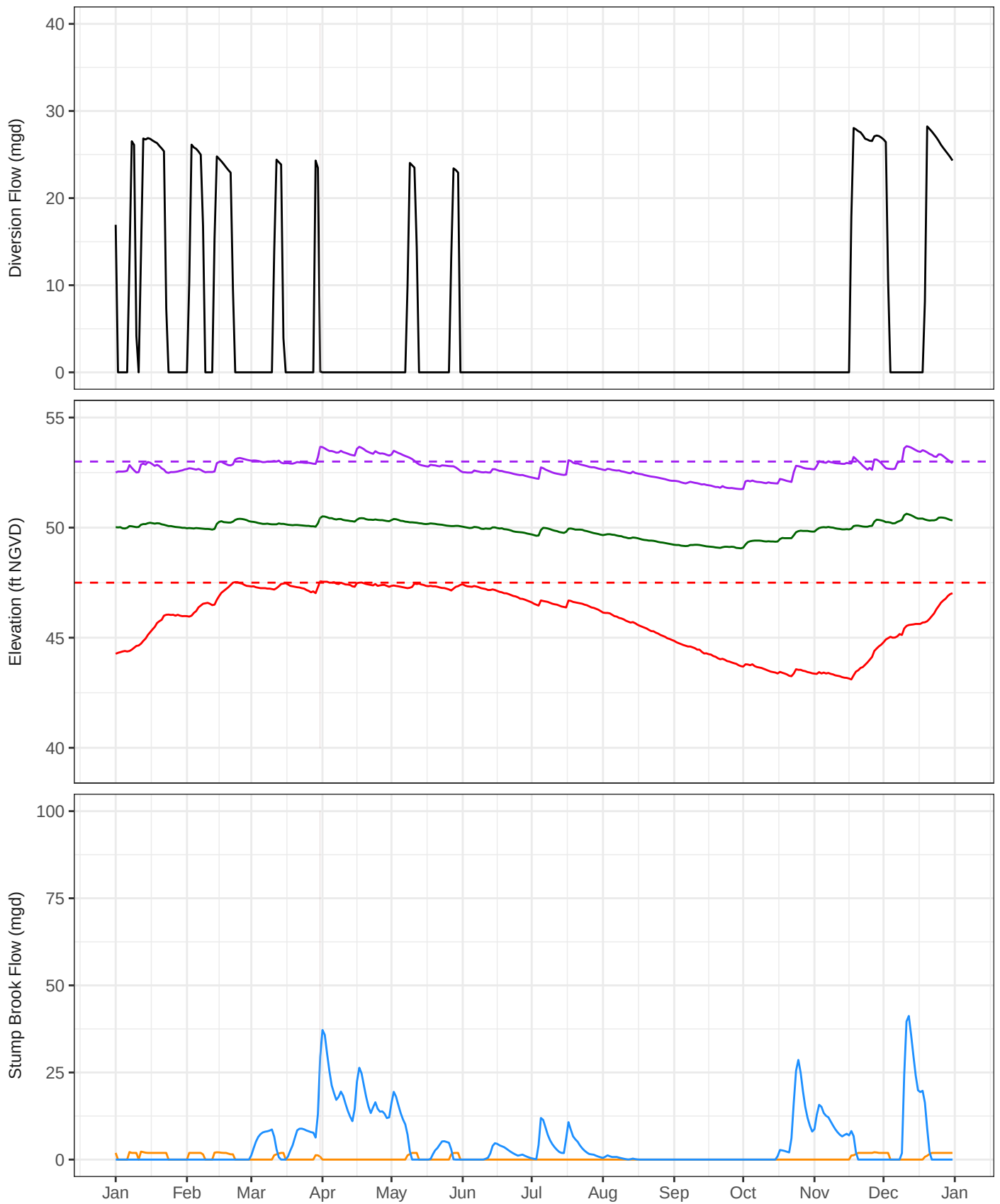
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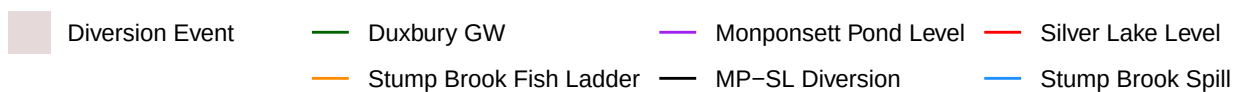
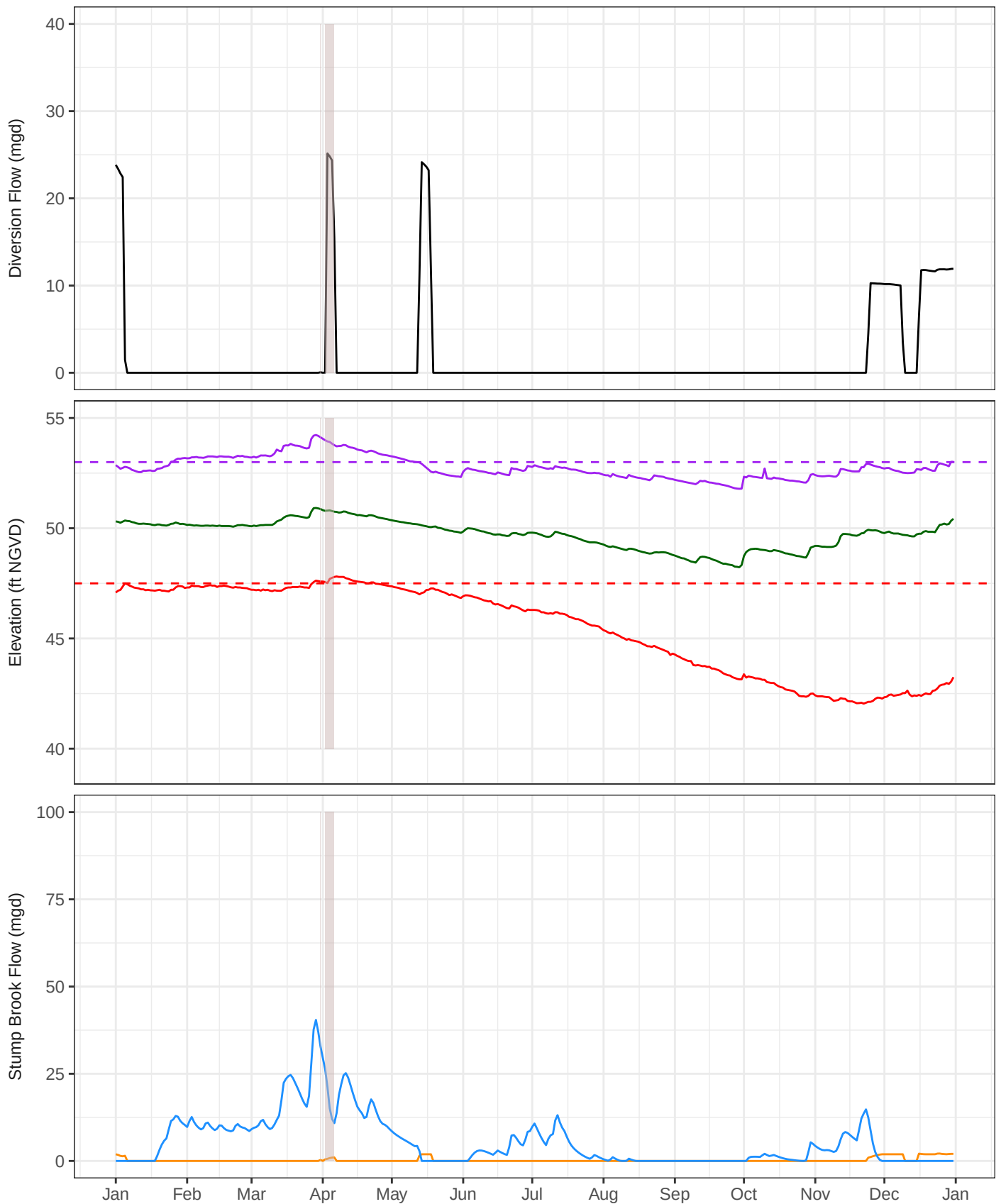
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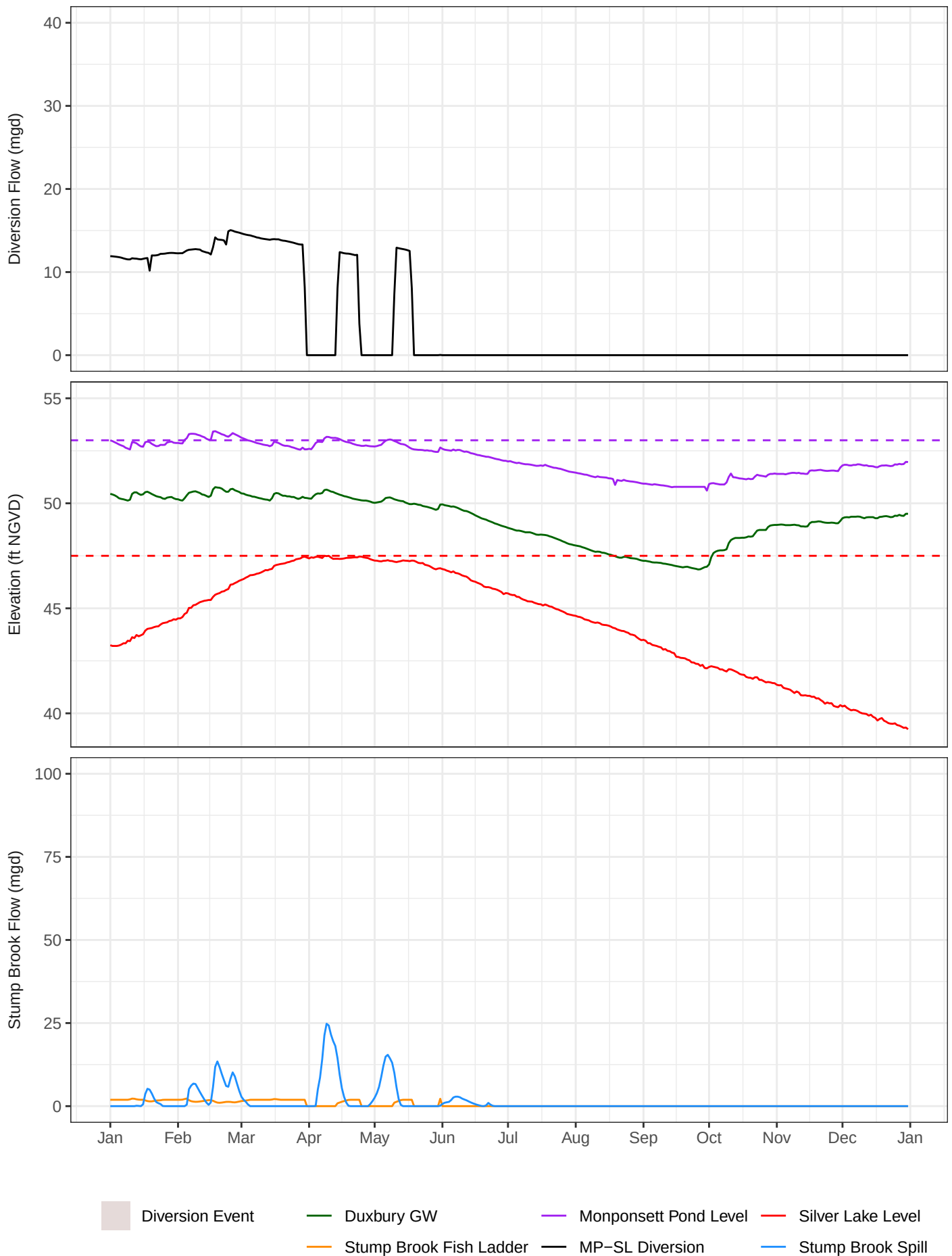
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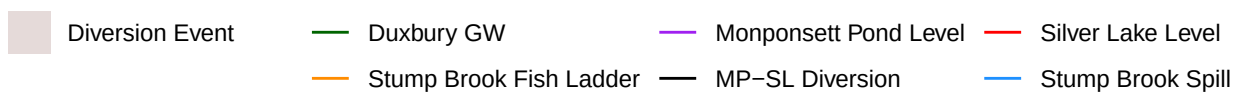
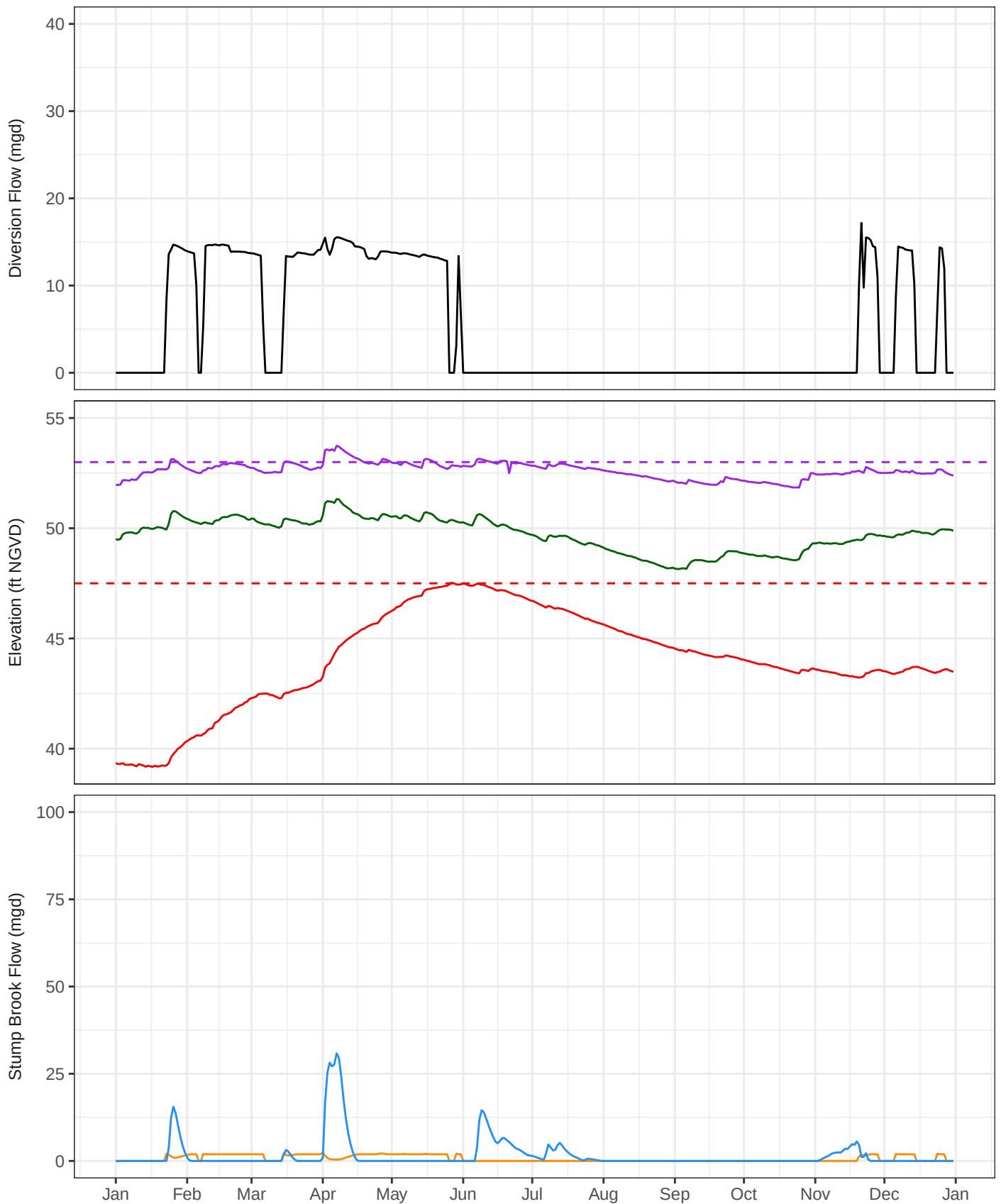
Annual Diversion Record: 2015



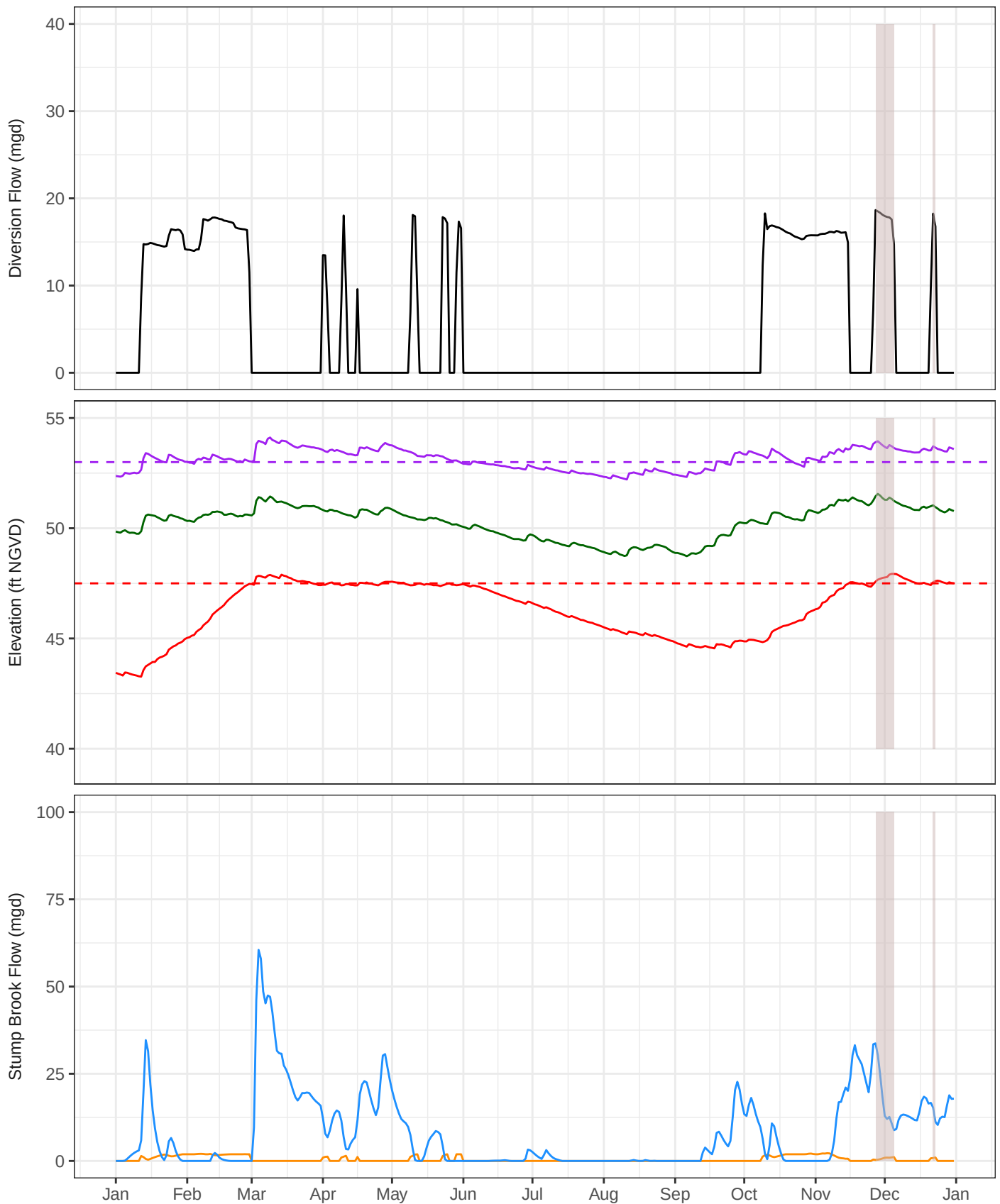
Annual Diversion Record: 2016



Annual Diversion Record: 2017

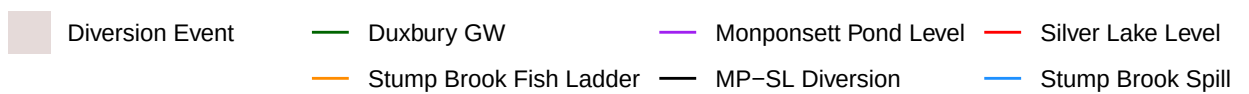
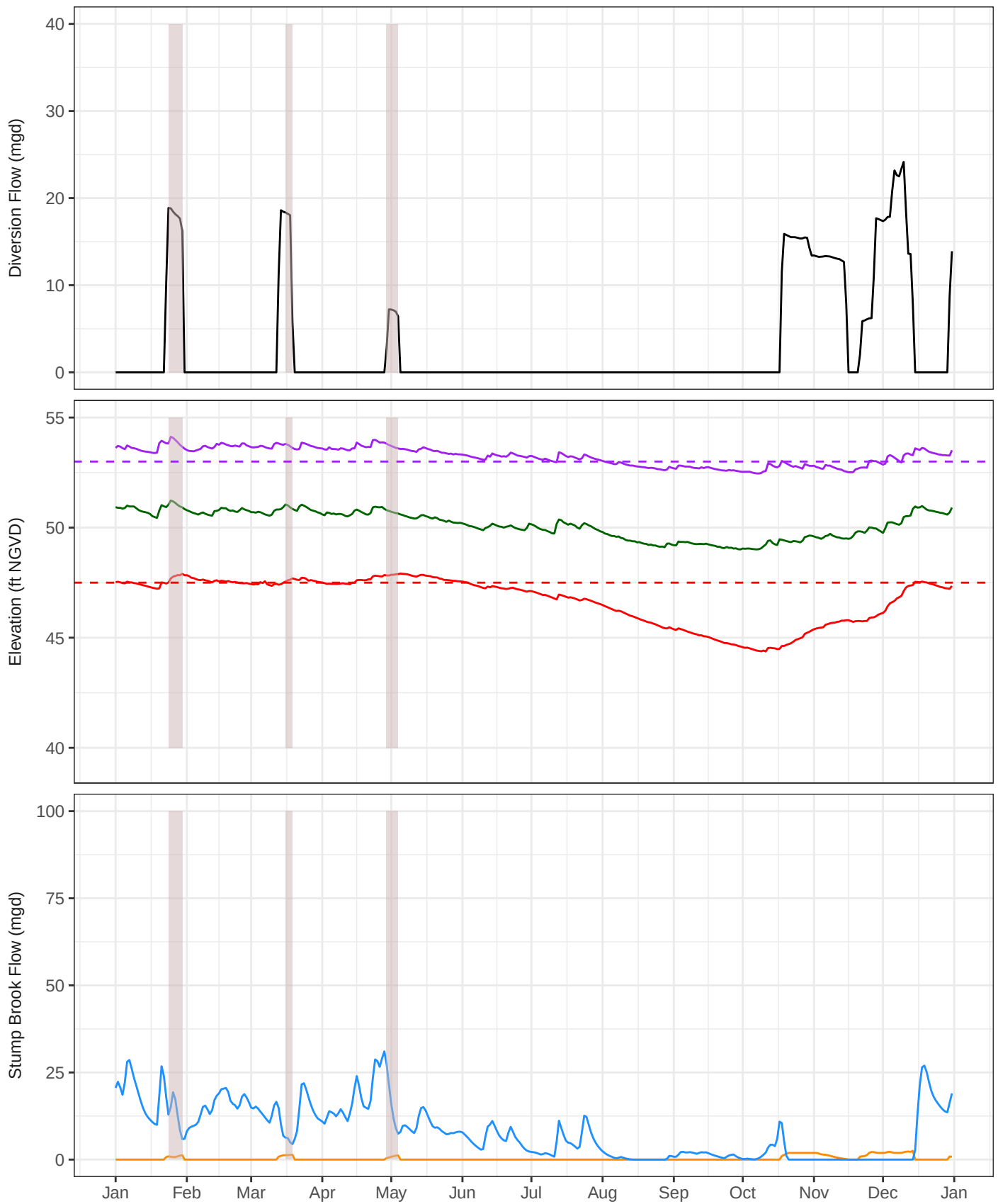


Annual Diversion Record: 2018



Diversion Event
 Duxbury GW
 Monponsett Pond Level
 Silver Lake Level
 Stump Brook Fish Ladder
 MP-SL Diversion
 Stump Brook Spill

Annual Diversion Record: 2019



Appendix C

Flow Measurement and Sampling Procedures for Conducting Task 4

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Memorandum

To: Larry Rowley, City of Brockton DPW Commissioner

*From: Buvana Ramaswamy
Nancy Beaton*

Date: October 22, 2019

*Subject: City of Brockton, Massachusetts
Resource Management Plan
Flow Measurement and Sampling Procedures for Conducting Task 4*

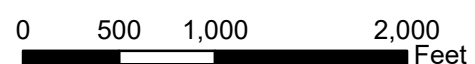
1.0 Background and Purpose

Task 4 of the approved Resource Management Plan Scope of Work (RMP SOW) is meant to address the Massachusetts Department of Environmental Protection (MassDEP) Administrative Consent Order (ACO) Item 33c which requires “collection of flow data to correlate Silver Lake diversion rates with flow rates from West Monponsett Pond to East Monponsett Pond during diversions to Silver Lake.” The natural flow path is from East Monponsett Pond to West Monponsett Pond and Stump Brook. The intent of this requirement is to assess the potential for the flow of water from West Monponsett Pond to pass through the culvert to East Monponsett Pond, given that the City of Brockton’s diversions are from the east pond. The purpose of this flow measurement task is to estimate the flow patterns in the Route 58 culvert between East and West Monponsett Ponds under varied conditions. Flow measurements will aid in understanding the hydraulic connection between the ponds.

Flow will be approximated by measuring the travel time of an orange or other suitable partially submerged floating object through the culvert multiple times. This simpler methodology is being used because typical continuous flow or velocity metering devices are expected to have limited accuracy due to the culvert configuration and wind and kayak/canoe interference, and would be subject to tampering, vandalism and/or theft given this remote location.

In addition to flow monitoring, grab samples will be collected from five sampling locations (shown in **Figure 1**) in East and West Monponsett Ponds during four varying flow scenarios (20 samples total) in spring 2020 to assess the impact various flows have on nutrient levels in the ponds.

Unless otherwise noted, it is anticipated that the data collection outlined herein will be performed by Veolia (the City’s water treatment facility contract operator). Veolia will be responsible for providing the necessary staff and equipment, as well as properly planning and executing appropriate health and safety measures, to safely perform the work outlined herein. This memorandum provides procedures to be followed by the Veolia field team in order to obtain the necessary data to complete Task 4 of the RMP SOW.



2.0 Preparation Prior to Flow Data Collection and Water Quality Sampling

2.1 Preparation for Flow Data Collection

Prior to measuring flows at the Route 58 culvert (see Figure 1 for location and Figures 2A and 2B for photos of east and west side of culvert), CDM Smith, with assistance by Veolia, will measure the cross-sectional area and determine the invert of the culvert, and identify monitoring locations so that flow measurements are taken from the same location during each flow measurement event.



Figure 2A
Route 58 Culvert (West Monponsett Pond side)



Figure 2B
Route 58 Culvert (East Monponsett Pond side)

The following equipment will be required, at a minimum:

- Field notebook
- Survey rod or other rigid measuring tool
- Paint
- Measuring tape
- Safety vest
- Waders

The cross-sectional area of the Route 58 box culvert will be calculated based on measurements of the culvert opening. The invert will be determined based on the depth of the culvert bottom below a known reference elevation (to be provided by Veolia).

The follow steps will be used to take appropriate measurements of the culvert dimensions:

1. Measure the interior of the culvert across the span, rise, and the dimensions of the horizontal and vertical haunch. All four haunch dimensions should be measured to confirm that the culvert is symmetric. Elements to measure are circled in red in Figure 3, excerpted from the MassDOT LRFD Bridge Manual, Part II, Drawing Number 11.3.1. Confirm that the bottom span is flat; if not flat, measure the rise every one foot across the bottom of the culvert.

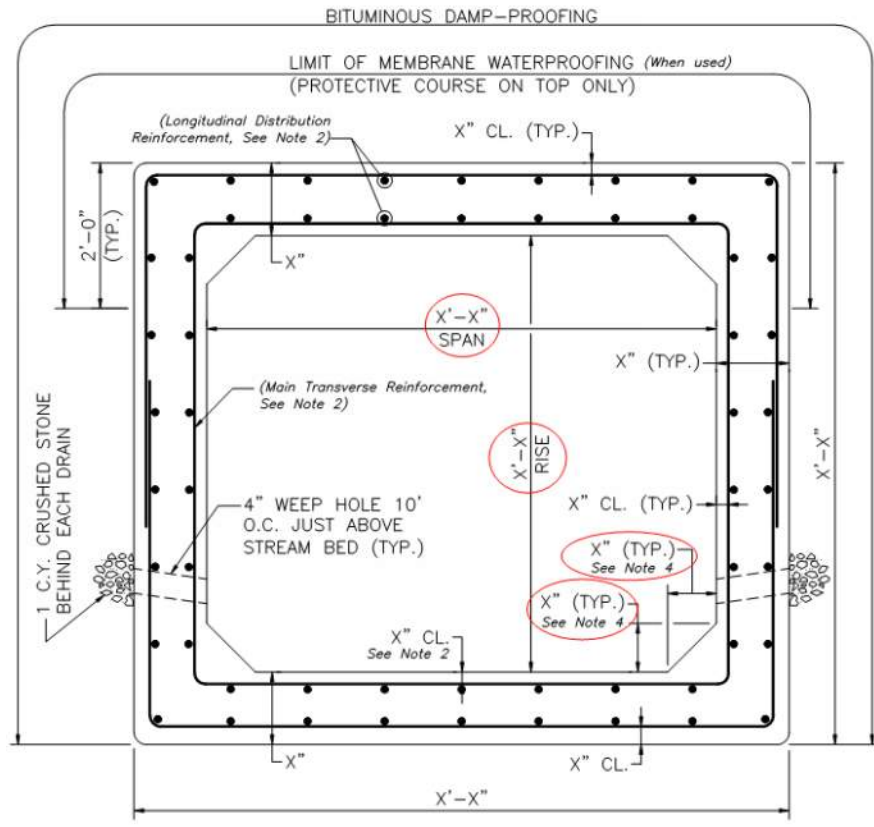


Figure 3 – Culvert dimensions to measure

2. Write the dimensions and a sketch of the culvert shape in the field notebook.
3. Document any obstructions or damage to the culvert in the field notebook.

To establish culvert monitoring locations from which to measure velocity and stage (water elevation), centerlines of the culvert will be measured and marked with paint on the east and west side of the Route 58 culvert.

2.2 Preparation for Water Quality Sampling

Water quality sampling is planned at the five locations shown on **Figure 1** and listed below:

- EMP-1: Northern East Monponsett Pond (near Stetson Brook)
- EMP -2: Southwestern East Monponsett Pond east of the Route 58 culvert
- EMP-3: Southeastern East Monponsett Pond (near the Silver Lake diversion structure/East Monponsett Ramp)
- WMP-1: Northern West Monponsett Pond (near Woodbine Avenue)
- WMP-2: Southern West Monponsett Pond west of the Route 58 culvert

Prior to water quality sampling reference coordinates will be established by CDM Smith for each location to support repeat sampling at the above-noted locations.

A boat will be required for the purpose of collecting water quality samples from both East and West Monponsett Ponds. Veolia will coordinate with the Town of Halifax and the City of Brockton to obtain permission to park at the boat launching location and to be on the ponds for the purpose of collecting samples.

Veolia will adhere to their existing Health and Safety plan for the purpose of conducting the field effort discussed below. This includes flow measurements taken at the Route 58 culvert which will be conducted from the side of the road as well as water quality monitoring and sampling from a boat on East and West Monponsett Ponds. Safety precautions should include, but are not limited to, safety vests, life jackets, gloves, appropriate footwear for the weather and terrain, mosquito repellent, and sunblock.

CDM Smith will initiate contact with the School for Marine Science and Technology (SMAST) Laboratory, affiliated with University of Massachusetts in Dartmouth, Massachusetts, to provide information on the sampling program, including sample parameters, detection limits, and projected schedule. All subsequent coordination with SMAST will be conducted by Veolia who will schedule drop-off of clean sample bottles and coolers and sample pick-up after each sampling event.

3.0 Schedule for Flow Data Measurement

Flow data will be collected at the Route 58 box culvert (location shown on Figure 1) during each season for the scenarios listed below. Flow will be monitored at least 7 days after diversion rate has been changed (longer if necessary due to inclement weather). This allows time after the specified operational changes have been made for the ponds to stabilize prior to taking measurements. Data collection should be conducted on a calm, dry weather day. The Veolia field team will coordinate with CDM Smith weekly during the seasonal flow data collection period to determine appropriate days for collecting flow data. Operational adjustments for subsequent scenarios can proceed as soon as scheduled flow measurement (and water quality sampling, if planned) have been completed.

The scenarios marked with an asterisk (*) indicate scenarios which require approval from MassDEP per the May 17, 2019 Amendment to the ACO to divert more than 50 percent diversion rate (more than 12 to 14 mgd) to Silver Lake. The scenarios marked with two asterisks (**) indicate scenarios which require approval from MassDEP per the May 17, 2019 Amendment to the ACO to release less than 900,000 gallons per day (gpd) to Stump Brook. The City of Brockton will submit a request to MassDEP for permission to perform these scenarios.

All scenarios will be dependent on water levels in the ponds during the proposed flow monitoring periods. If pond levels do not allow for diversions stated in the RMP SOW, Veolia will coordinate with CDM Smith and the City to determine appropriate diversion in order to obtain useful data. Similarly, if winter monitoring is limited by icing at the culvert, Veolia will coordinate with CDM Smith and the City to determine appropriate measures to obtain useful data. Procedures for flow data measurement are provided in the following section (Section 4.0).

Fall – October to early December 2019

- No diversion to Silver Lake with at least 900,000 gpd release to Stump Brook
- 25 percent diversion rate to Silver Lake with at least 900,000 gpd release to Stump Brook
- 50 percent diversion rate to Silver Lake with at least 900,000 gpd release to Stump Brook
- (*) 75 percent diversion rate to Silver Lake with at least 900,000 gpd release to Stump Brook
- (*) Full diversion rate to Silver Lake with at least 900,000 gpd release to Stump Brook

Winter – January to February 2020

- No diversion to Silver Lake with at least 900,000 gpd release to Stump Brook
- 25 percent diversion rate to Silver Lake with at least 900,000 gpd release to Stump Brook
- 50 percent diversion rate to Silver Lake with at least 900,000 gpd release to Stump Brook
- (*) 75 percent diversion rate to Silver Lake with at least 900,000 gpd release to Stump Brook
- (*) Full diversion rate to Silver Lake with at least 900,000 gpd release to Stump Brook

Spring – April to May 2020

- No diversion to Silver Lake with at least 900,000 gpd release to Stump Brook
- 25 percent diversion rate to Silver Lake with at least 900,000 gpd release to Stump Brook
- 50 percent diversion rate to Silver Lake with at least 900,000 gpd release to Stump Brook
- (*) 75 percent diversion rate to Silver Lake with at least 900,000 gpd release to Stump Brook
- (*) Full diversion rate to Silver Lake with at least 900,000 gpd release to Stump Brook
- (*) Flood control and/or pond flushing scenarios, as negotiated in advance with MassDEP, may also be conducted, as conditions allow. The intent of these scenarios is to simulate flood conditions and/or a late spring flush period for water quality purposes.

Summer – June to July 2020

- No diversion to Silver Lake with at least 900,000 gpd release to Stump Brook
- (**) No diversion to Silver Lake with at least 600,000 gpd release to Stump Brook
- (**) No diversion to Silver Lake with at least 300,000 gpd release to Stump Brook
- (**) No diversion to Silver Lake and no release to Stump Brook

4.0 Procedures for Flow Data Measurement

This section describes the procedures for measuring velocity at the culvert, which will be used to calculate the flow through the culvert on the day of sampling.

The following equipment is required, at a minimum:

- Several oranges of similar size and weight
- Field notebook
- Survey rod or other rigid measuring tool
- Stopwatch
- Rigid pole with basket to hold orange (e.g., telescoping dipper rod)
- Fishing net
- Safety vest

The following procedures should be followed to collect velocity readings:

1. Safely park vehicle near the Route 58 culvert (see **Figure 1**) and walk to the culvert.
2. Walk over the guardrail on the east side of Route 58 to access the culvert at the marked location.
3. Use the survey rod or other rigid measuring tool to measure the water depth and record the water depth in the field notebook.
4. Use a leaf or twig to determine the direction of flow through the culvert (e.g., east to west, west to east). If flow is east to west, continue to the next step. If flow is west to east, walk across the road and across the guardrail to access the west side of the culvert and proceed with the next step.
5. Use the rigid pole to gently place the orange in the water on the centerline of the culvert, just at the threshold. As the orange is placed in the water, make sure that the rigid pole is flat against the headwall.
6. Release the orange and start the stopwatch.
7. Walk across the road and across the guardrail to access the opposite side of the culvert at the marked location.
8. Watch for the orange to pass the threshold of the culvert. Stop the timer when this occurs, and retrieve the orange with the fishing net.
9. Write the time and location of the orange (e.g., along the center line, 1 foot to the right of center, etc.) in the field notebook.
10. Repeat two more times. If the time differs by more than 10 percent, repeat a third time.

5.0 Schedule for Water Quality Sampling

Water quality sampling will be conducted at the five locations shown on **Figure 1** during the spring scenarios listed below. Similar to the flow data collection, water quality sampling will be conducted at least 7 days after diversion rate has been changed (longer if necessary due to inclement weather). This will allow for adequate mixing in the ponds prior to collecting the water quality

sample. Sampling should be conducted on a calm, dry weather day after the flow data is collected. Sample dates will be coordinated with CDM Smith.

Spring – April to May 2020

- No diversion to Silver Lake with at least 900,000 gpd release to Stump Brook
- 25 percent diversion rate to Silver Lake with at least 900,000 gpd release to Stump Brook
- 50 percent diversion rate to Silver Lake with at least 900,000 gpd release to Stump Brook
- (*) 75 percent diversion rate to Silver Lake with at least 900,000 gpd release to Stump Brook
- If conditions present themselves, another sampling round will be conducted during a flood control and/or pond flushing scenario, as negotiated in advance with MassDEP. The intent is to simulate flood conditions and/or a late spring flush period for water quality purposes. MassDEP has indicated that it may allow impounding of water (by temporarily waiving the ACO-required 900,000 gpd release to Stump Brook) when there is no diversion to Silver Lake.

6.0 Procedures for Water Quality Sampling

Grab samples will be collected at the five locations shown on **Figure 1** and water quality analysis for total phosphorus, total nitrogen, ammonia, and color will be conducted by the SMAST Laboratory. Turbidity, dissolved oxygen, temperature, pH, and conductivity data will be collected in the field as described in Section 6.2.

The following subsections provides procedures for:

- 6.1 Navigating to sampling locations
- 6.2 Collecting vertical profiles
- 6.3 Secchi depth
- 6.4 Collection of discrete grab samples

6.1 Navigating to Sampling Locations

Navigating to each sampling location prior to beginning sampling is important to maintain consistency of observations across monitoring events. The location of the five monitoring points (shown on Figure 1) will be emailed or texted to the Veolia field team as “pins” which can be viewed and used for navigating to sample locations in the Google Maps phone app.

Once the sampling team has arrived at each site, an anchor will be used to maintain the boat at the monitoring location while sampling is being conducted. The boat is at the monitoring location when the coordinates are within approximately 100 feet of the monitoring location.

At a minimum, the following equipment will be required for this task:

- GPS unit, cell phone or other means of navigating to the sampling location coordinates
- Anchor
- Water level indicator with ability to measure at least 30 feet
- Field logbook

The following steps are procedures to navigate to the proper sampling locations:

1. Prior to sampling, determine the preferred order to visit monitoring locations. Elements to consider include, but are not limited to: water levels, current and forecast wind conditions, and travel time between monitoring locations on each pond.
2. Navigate to the monitoring location. Position the boat such that once the anchor is dropped the boat will be as close as possible to the GPS coordinates of the monitoring location.
3. Drop the anchor. Note landmarks (e.g., trees, rocks) on shore to confirm that the boat is not moving once anchored. Periodically check the boat's position against these landmarks to confirm that the boat is not moving relative to the anchored position.
4. Write down the sample location ID, total depth (on depth finder) and time of arrival on the field logbook.

6.2 Collection of Vertical Profiles for Temperature, Conductivity, DO, pH, and Turbidity

Vertical profiles will be collected from East and West Monponsett Pond to understand the vertical structure and how it impacts mixing within the water column and whether anoxic dissolved oxygen conditions develop in the deep water of the ponds. Profiles will be collected using a multiparameter probe at 1-foot increments at each location.

At a minimum, the following equipment will be required for this task:

- Calibrated multiparameter probe with adequate cable length to reach the bottom of the ponds at their deepest sample locations. If the instrument is not capable of measuring depth the cable should be marked in 1-foot increments prior to sampling.
- Calibration log sheets
- Extra battery, calibration solutions, and instruction manual for multiparameter probe
- Field logbook
- Depth finder, weighted tape or weighted rope with line calibrated to 0.5 ft intervals

Maintenance and Calibration

Prior to each sampling day, calibrate the multiparameter probe according to the manufacturer's instructions. Document the calibration in the calibration log sheet. Following each sampling day, rinse the sensors in tap water and then follow the manufacturer's instructions for short- or long-

term storage, as applicable. As needed, clean the sensor guard and sensors according to the manufacturer's instructions to prevent interference with the measurement.

Procedures

1. Note the weather conditions in the field notebook (temperature, wind, precipitation, sunny/cloudy etc.)
2. Navigate to the site following procedures in Section 6.1.
3. Secure the field probe to the boat so that if it is dropped it does not sink to the bottom of the pond.
4. Measure the total depth at the sampling location. Confirm that the total depth matches depth from prior measurements. If the total depth does not match, consider whether boat needs to be repositioned. Write the total depth on the sampling sheet as well as noting variations in pond level from expected depth.
5. Select the correct Site ID on the handheld sampling unit. Set up the sampling unit in the one sample logging mode. The probe will take a minute (+/-) to stabilize at each depth, so allow adequate time for probe to stabilize before moving probe down one foot to the next sample interval. Continuous logging will result in erroneous data. If equipment does not have the capability to save measurements and site IDs, this data will be collected manually by the field personnel manually by writing results manually in the field logbook.
6. Slowly lower the field probe over the edge of the boat until the depth reads 1 foot. Wait until the readings stabilize. Log the sample. If the dissolved oxygen concentration or saturation is low on the surface measurement (less than 5 mg/L or 75 percent) check the instrument calibration.
7. Repeat sampling every foot. Continue until just above the bottom of the pond. Care should be taken to avoid the meter hitting the bottom of the pond. If the probe inadvertently hits the pond bottom, move several feet away so that the disturbed sediments do not impact the measurement.
8. Once sampling is complete for the day, upload data from the multiparameter probe to a computer and import into the water quality database.

6.3 Secchi Depth

Secchi depth is a standard measurement of lake and pond transparency. The Secchi depth is measured by dropping a Secchi disk, a standardized 20 cm (8 in) diameter disk with alternate black and white quadrants, into the water until it is no longer visible. Secchi depth readings are inversely correlated with turbidity, and range between less than 3 feet in turbid or eutrophic lakes to over 30 feet in clear lakes.

The following equipment is required for collecting Secchi depth measurements:

- Secchi disk, weighted, with rope calibrated to 0.1-foot increments

- GPS unit, cell phone or other means of navigating to the sampling location coordinates
- Field logbook

Maintenance and Calibration

The Secchi disk should be inspected before each sampling day to check that the Secchi disk is intact, the disk is not unacceptably dull or scratched, and that the weight is still attached.

Once yearly the calibration of the rope should be checked against a measuring tape. If the calibration is off by more than 5 percent either recalibrate the rope (by remarking the depth lines) or replace the rope.

Procedures

When measuring the Secchi depth, do not wear sunglasses. If possible, measure the Secchi depth from the shady side of the boat.

1. Navigate to the site following the procedures in Section 6.1.
2. Secure the Secchi disk to the boat so that if it is dropped it does not sink to the bottom of the pond.
3. Position the boat such that the Secchi disk will be lowered on the shady side of the boat (if possible).
4. Slowly lower the Secchi disk into the water until it is no longer visible. Record the depth to the nearest tenth of a meter. If the Secchi disk is still visible on the bottom, record the Secchi depth as "bottom."
5. Lower the Secchi disk another 1 foot.
6. Slowly raise the Secchi disk until it is visible. Record the depth to the nearest tenth of a foot.
7. Average the two Secchi disk measurements. Record this depth on the field sampling sheet. Only the average Secchi disk depth measurement will be recorded in the water quality database.
8. Repeat the measurement at one sample location per day. If the repeated average Secchi disk measurement is not within 1.5 feet, repeat the measurement a third time. In addition, if Secchi measurements in a single pond on a sampling day differ by more than 1.5 feet, repeat the measurement at that location.

6.4 Collection of Discrete Grab Samples

The objective of this section is to guide the collection of grab samples.

Laboratory Coordination

1. Veolia will coordinate with SMAST Laboratory at least 2 – 3 days before the sampling to provide details regarding sample pick-up time. The point of contact for SMAST is provided in Section 7.

2. Sample results will be available to the City, Veolia and CDM Smith.

The following equipment will be required for this task:

- GPS unit, cell phone or other means of navigating to the sampling location coordinates
- Pre-labeled, clean sample bottles
- Cooler with ice
- Laboratory reagent water (e.g., distilled or deionized water)
- Chain of custody form
- Field logbook

Procedures

1. Navigate to the sample location (see Figure 1 for sample locations) following the procedures in Section 6.1. Confirm the boat is at the correct location using GPS or similar device.
2. Collect the surface sample directly into the sample container off the side of the boat, approximately 1 foot below the water surface. Note the sample collection time on the field logbook and on the sample bottle.
3. Take care not to not overfill the sample bottle. If a sample bottle with preservatives is overfilled, discard and fill a new bottle.
4. Immediately place the bottle in the cooler on ice after collecting the sample.
5. Collect a duplicate set of samples at WMP-2. This will be labeled as WMP-3 and submitted to the laboratory as a blind sample.
6. Complete the chain of custody form.

7.0 Points of Contact

The following points of contact are for the field team to use in case any questions or deviations from the above listed procedures are necessary.

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Dave Schlezinger (Lab Manager – SMAST secondary contact)

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Email - dschlezinger@umassd.edu

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cc: P. Hill, City of Brockton
D. Norton, City of Brockton
B. Creedon, City of Brockton
K. Feoderoff, Mead, Talerman & Costa, LLC
C. Kershaw, CDM Smith
M. Sessine, Veolia

Appendix D

May 2020 Water Quality Data

Raw water quality data are tabulated based on the data collected by UMass Dartmouth and Veolia. Data flags in Tables D-1, D-2, and D-3 are described below Table D-3.

Table D-1. C:N Ratio, Chlorophyll α , Pheophytin, and Total Pigment

Station	Date	C:N Ratio ¹	Chlorophyll α	Pheophytin	Total Pigment
EMP1	5/14/2020	9.26	4.2	0.36 MDL	4.56
EMP1	5/18/2020	7.99	13.26	0.03 MDL	13.29
EMP1	5/20/2020	8.37	5.78	1.11 RL	6.89
EMP1	5/22/2020	8.11	6.43	0.74 MDL	7.18
EMP2	5/14/2020	8.51	4.88	0.39 MDL	5.27
EMP2	5/18/2020	8.61	7.78	0.03 MDL	7.81
EMP2	5/20/2020	8.24	8.07	0.24 MDL	8.31
EMP2	5/22/2020	8.76	10.31	0.03 MDL	10.34
EMP3	5/14/2020	8.87	5.2	0.03 MDL	5.23
EMP3	5/18/2020	8.3	6.34	0.03 MDL	6.37
EMP3	5/20/2020	8.34	6.63	0.03 MDL	6.66
EMP3	5/22/2020	8.19	7.77	0.5 MDL	8.27
WMP1	5/14/2020	10.33	14.39	0.03 MDL	14.42
WMP1	5/18/2020	9.47	7.45	0.03 MDL	7.48
WMP1	5/20/2020	9.73	17.82	0.03 MDL	17.85
WMP1	5/22/2020	9.62	15.27	0.95 MDL	16.22
WMP2	5/14/2020	9.96	13.37	0.03 MDL	13.4
WMP2	5/18/2020	8.89	11.9	0.03 MDL	11.93
WMP2	5/20/2020	8.76	17.37	0.03 MDL	17.4
WMP2	5/22/2020	9.51	22.43	0.03 MDL	22.46
WMP2-dup	5/14/2020	10.16	12.01	0.03 MDL	12.04
WMP2-dup	5/18/2020	9.06	12.24	0.03 MDL	12.27
WMP2-dup	5/20/2020	8.87	17.82	0.03 MDL	17.85
WMP2-dup	5/22/2020	9.46	19.94	0.03 MDL	19.97
FIELD BLANK	5/14/2020	64.01	0.22 MDL	0.06 MDL	0.28 MDL
FIELD BLANK	5/18/2020	24.88	0.24 MDL	0.09 MDL	0.33 MDL
FIELD BLANK	5/20/2020	22.73	0.13 MDL	0.15 MDL	0.28 MDL
FIELD BLANK	5/22/2020	12.12	0.25 MDL	0.07 MDL	0.32 MDL

Notes: 1. Carbon to Nitrogen Ratio

Table D-2. Nitrogen

Station	Date	DIN ¹		DON ²		NH ₄ ³		NO _x ⁴		PON ⁵		TN ⁶	
EMP1	5/14/2020	177.04		316		3.64	RL	173	PB	46.78		540	
EMP1	5/18/2020	135.16		337		4.06		131	PB	98.88	PB	570	
EMP1	5/20/2020	149.16		327		2.1	RL	147	PB	75.21	PB	551	
EMP1	5/22/2020	123.39		327		6.16		117	PB	82.78	PB	533	
EMP2	5/14/2020	180.96		321		2.94	RL	178	PB	60.79		563	
EMP2	5/18/2020	165.69		325		5.74		160	PB	69.61	PB	561	
EMP2	5/20/2020	139.22		333		0.98	MDL	138	PB	82.36	PB	554	
EMP2	5/22/2020	88.52		361		7.42		81	PB	115.4	PB	565	
EMP3	5/14/2020	179.7		309		1.82	MDL	178	PB	58.12		547	
EMP3	5/18/2020	165.13		354		5.18		160	PB	67.09	PB	586	
EMP3	5/20/2020	150.14		343		2.1	RL	148	PB	71.29	PB	565	
EMP3	5/22/2020	130.54		324		5.04		125	PB	84.6	PB	539	
WMP1	5/14/2020	3.92		0.28		1.12	MDL	1.54	R	1.82	RL	4.1	MDL
WMP1	5/18/2020	2.66		4.9		0.56	MDL	1.54	R	4.06	R	7.6	MDL
WMP1	5/20/2020	4.9		2.52		1.26	MDL	2.1	R	4.48	R	3.1	MDL
WMP1	5/22/2020	7.84		0		1.54	MDL	1.26	R	5.88	R	4.5	MDL
WMP2	5/14/2020	6.3		349		2.94	RL	3.36	R	133.1		489	
WMP2	5/18/2020	7.84		379		5.18		2.66	R	134.5	PB	521	
WMP2	5/20/2020	14.85		419		9.66		5.04	R	221.6	PB	655	
WMP2	5/22/2020	10.78		412		7.42		3.36	R	213.2	PB	636	
WMP2-dup	5/14/2020	7.98		324		4.76		3.36	R	107.6		440	
WMP2-dup	5/18/2020	5.88		346		3.5	RL	2.38	R	155.2	PB	507	
WMP2-dup	5/20/2020	6.16		367		3.22	RL	2.94	R	239.9	PB	613	
WMP2-dup	5/22/2020	7.28		353		4.48		2.8	R	203.5	PB	564	
FIELD BLANK	5/14/2020	8.4		347		4.76		3.64	R	115.3		471	
FIELD BLANK	5/18/2020	6.72		352		4.06		2.66	R	176.2	PB	535	
FIELD BLANK	5/20/2020	5.04		355		2.1	RL	2.94	R	237.5	PB	598	
FIELD BLANK	5/22/2020	5.74		347		2.8	RL	2.94	R	220.9	PB	574	

Notes: 1. Dissolved inorganic nitrogen
 2. Dissolved organic nitrogen
 3. Ammonia
 4. Nitrate + nitrite
 5. Particulate organic nitrogen
 6. Total nitrogen

Table D-3. Phosphorus and Carbon

Station	Date	PO ₄ ¹		POC ²		TP ³	
EMP1	5/14/2020	0	MDL	371.6	R	15.18	
EMP1	5/18/2020	3.1		677.1	PB	21.99	
EMP1	5/20/2020	0	MDL	539.8	PB	20.75	
EMP1	5/22/2020	3.1		576.1	PB	25.09	
EMP2	5/14/2020	0	MDL	443.7	R	21.99	
EMP2	5/18/2020	3.1		513.4	PB	19.51	
EMP2	5/20/2020	0	MDL	582.1	PB	19.51	
EMP2	5/22/2020	3.1		866.8	PB	25.09	
EMP3	5/14/2020	3.1		442.5	R	24.16	
EMP3	5/18/2020	3.1		477	PB	17.35	
EMP3	5/20/2020	0	MDL	509.9	PB	19.51	
EMP3	5/22/2020	3.1		594.1	PB	21.99	
WMP1	5/14/2020	0	MDL	99.19	R	0	MDL
WMP1	5/18/2020	0	MDL	86.1	R	0	MDL
WMP1	5/20/2020	0	MDL	88.51	R	1.55	RL
WMP1	5/22/2020	0	MDL	61.25	R	1.55	RL
WMP2	5/14/2020	0	MDL	1179	PB	19.51	
WMP2	5/18/2020	3.1		1091	PB	21.99	
WMP2	5/20/2020	0	MDL	1849	PB	29.74	
WMP2	5/22/2020	3.1		1759	PB	28.5	
WMP2-dup	5/14/2020	0	MDL	918.6	PB	19.51	
WMP2-dup	5/18/2020	3.1		1183	PB	24.16	
WMP2-dup	5/20/2020	3.1		1802	PB	26.33	
WMP2-dup	5/22/2020	3.1		1659	PB	30.66	
FIELD BLANK	5/14/2020	0	MDL	1004	PB	21.99	
FIELD BLANK	5/18/2020	3.1		1369	PB	24.16	
FIELD BLANK	5/20/2020	3.1		1807	PB	26.33	
FIELD BLANK	5/22/2020	3.1		1792	PB	32.83	

Notes: 1. Orthophosphate
 2. Particulate organic carbon
 3. Total phosphorus

Flags: MDL = sample below method detection limit
 RL = sample below reporting limit
 PB = positive field blank for parameter/date combination with sample concentration greater than 5 times the field blank concentration
 R = positive field blank for parameter/date combination with sample concentration less than 5 times the field blank concentration

Table D-4. Color and Turbidity

Date	Station	Depth	Turbidity (NTU)	Color (CU)
5/18/2020	EMP1	S	1.2	84
5/18/2020	EMP1	M	1.04	
5/18/2020	EMP1	B	0.98	
5/18/2020	EMP2	S	0.86	74
5/18/2020	EMP2	M	0.81	
5/18/2020	EMP2	B	0.9	
5/18/2020	EMP3	S	0.92	79
5/18/2020	EMP3	M	0.89	
5/18/2020	EMP3	B	0.75	
5/18/2020	WMP1	S	1.43	63
5/18/2020	WMP1	M	1.82	
5/18/2020	WMP1	B	5.93	
5/18/2020	WMP2	S	1.68	56
5/18/2020	WMP2	M	1.74	
5/18/2020	WMP2	B	1.61	
5/18/2020	WMP3	S	2.11	57
5/18/2020	WMP3	M	1.52	
5/18/2020	WMP3	B	2.13	
5/20/2020	EMP1	S	1.71	74
5/20/2020	EMP1	M	1.8	
5/20/2020	EMP1	B	2.04	
5/20/2020	EMP2	S	1.85	73
5/20/2020	EMP2	M	1.79	
5/20/2020	EMP2	B	1.72	
5/20/2020	EMP3	S	1.86	74
5/20/2020	EMP3	M	1.91	
5/20/2020	EMP3	B	1.78	
5/20/2020	WMP1	S	1.02	77
5/20/2020	WMP1	M	1.33	
5/20/2020	WMP1	B	1.17	
5/20/2020	WMP2	S	0.99	77
5/20/2020	WMP2	M	0.99	
5/20/2020	WMP2	B	1.93	
5/20/2020	WMP3	S	0.99	60
5/20/2020	WMP3	M	0.91	
5/20/2020	WMP3	B	0.87	
5/22/2020	EMP1	S	1.29	83
5/22/2020	EMP1	M	1.2	
5/22/2020	EMP1	B	2.46	

Date	Station	Depth	Turbidity (NTU)	Color (CU)
5/22/2020	EMP2	S	1.57	76
5/22/2020	EMP2	M	1.41	
5/22/2020	EMP2	B	1.31	
5/22/2020	EMP3	S	1.26	82
5/22/2020	EMP3	M	1.23	
5/22/2020	EMP3	B	1.24	
5/22/2020	WMP1	S	2.5	80
5/22/2020	WMP1	M	2.76	
5/22/2020	WMP1	B	2.67	
5/22/2020	WMP2	S	2.28	71
5/22/2020	WMP2	M	2.44	
5/22/2020	WMP2	B	2.65	
5/22/2020	WMP3	S	2.57	73
5/22/2020	WMP3	M	2.54	
5/22/2020	WMP3	B	2.49	

Note: WMP3 is a field duplicate station for WMP2

Table D-5. Profiles and Secchi Depth

Station	Date	Start time	End time	Secchi Depth (ft)	Total Depth (ft)	Sample Depth (ft)	Dissolved Oxygen (mg/L)	Dissolved Oxygen Sat (%)	Temp °C	pH	Conductivity (µS)
WMP1	5/14/2020	11:10	11:30	4.3	7.1	0.15	10.7	104.2	13.96	8.28	219
WMP1	5/14/2020	11:10	11:30	4.3	7.1	1	10.6	102.5	13.93	8.21	219
WMP1	5/14/2020	11:10	11:30	4.3	7.1	2	10.71	103.3	13.76	8.1	218
WMP1	5/14/2020	11:10	11:30	4.3	7.1	3	10.77	103.1	13.4	8.01	218
WMP1	5/14/2020	11:10	11:30	4.3	7.1	4	10.74	102.2	13.06	7.93	218
WMP1	5/14/2020	11:10	11:30	4.3	7.1	5	10.56	99.2	12.54	7.84	216
WMP1	5/14/2020	11:10	11:30	4.3	7.1	6	10.44	98.4	12.51	7.77	218
WMP2	5/14/2020	11:47	11:59	6	8.4	0.15	10.65	104.3	14.36	7.72	217
WMP2	5/14/2020	11:47	11:59	6	8.4	1	10.63	103.7	14.34	7.76	217
WMP2	5/14/2020	11:47	11:59	6	8.4	2	10.67	104.7	14.38	7.77	216
WMP2	5/14/2020	11:47	11:59	6	8.4	3	10.71	104.6	14.31	7.76	215
WMP2	5/14/2020	11:47	11:59	6	8.4	4	10.72	104.4	14.21	7.76	215
WMP2	5/14/2020	11:47	11:59	6	8.4	5	10.72	104.3	14.09	7.77	216
WMP2	5/14/2020	11:47	11:59	6	8.4	6	10.7	103.8	13.87	7.75	215
WMP2	5/14/2020	11:47	11:59	6	8.4	7	10.97	103.6	12.77	7.72	211
WMP2	5/14/2020	11:47	11:59	6	8.4	8	10.28	97	12.65	7.68	207
EMP1	5/14/2020	13:27	13:40	3.6	5.4	0.15	9.72	96.3	14.96	7.11	179
EMP1	5/14/2020	13:27	13:40	3.6	5.4	1	9.7	96.1	14.93	7.12	179
EMP1	5/14/2020	13:27	13:40	3.6	5.4	2	9.73	96	14.93	7.09	180
EMP1	5/14/2020	13:27	13:40	3.6	5.4	3	9.69	95.5	14.84	7.11	180
EMP1	5/14/2020	13:27	13:40	3.6	5.4	4	9.8	96.6	14.53	7.1	180
EMP1	5/14/2020	13:27	13:40	3.6	5.4	5	10.16	98	13.73	6.99	180
EMP2	5/14/2020	12:17	12:32	6.3	8.5	0.15	9.59	93.8	14.3	7.53	181
EMP2	5/14/2020	12:17	12:32	6.3	8.5	1	9.59	93.8	14.19	7.44	181
EMP2	5/14/2020	12:17	12:32	6.3	8.5	2	9.71	91.3	12.89	7.36	180
EMP2	5/14/2020	12:17	12:32	6.3	8.5	3	9.49	89.3	12.66	7.3	181
EMP2	5/14/2020	12:17	12:32	6.3	8.5	4	9.46	88.9	12.57	7.28	180
EMP2	5/14/2020	12:17	12:32	6.3	8.5	5	9.39	87.9	12.44	7.22	180
EMP2	5/14/2020	12:17	12:32	6.3	8.5	6	9.42	88.2	12.27	7.2	179
EMP2	5/14/2020	12:17	12:32	6.3	8.5	7	9.47	88.4	12.2	7.17	181
EMP2	5/14/2020	12:17	12:32	6.3	8.5	8	9.51	88.6	12.17	7.15	181
EMP3	5/14/2020	12:47	13:10	6.1	9.3	0.15	9.52	92.9	14.15	7.07	181
EMP3	5/14/2020	12:47	13:10	6.1	9.3	1	9.53	93	14.11	7.09	181
EMP3	5/14/2020	12:47	13:10	6.1	9.3	2	9.62	93.4	14.05	7.08	180
EMP3	5/14/2020	12:47	13:10	6.1	9.3	3	9.53	92.9	14.08	7.08	180
EMP3	5/14/2020	12:47	13:10	6.1	9.3	4	9.59	92.9	13.94	7.07	179
EMP3	5/14/2020	12:47	13:10	6.1	9.3	5	9.58	92.7	13.92	7.04	180
EMP3	5/14/2020	12:47	13:10	6.1	9.3	6	9.58	92.7	13.85	7.03	179

Station	Date	Start time	End time	Secchi Depth (ft)	Total Depth (ft)	Sample Depth (ft)	Dissolved Oxygen (mg/L)	Dissolved Oxygen Sat (%)	Temp °C	pH	Conductivity (µS)
EMP3	5/14/2020	12:47	13:10	6.1	9.3	7	9.55	92.3	13.87	7.04	179
EMP3	5/14/2020	12:47	13:10	6.1	9.3	8	9.52	92	13.83	7.03	180
EMP3	5/14/2020	12:47	13:10	6.1	9.3	9	9.26	87.2	12.74	7.02	177
WMP1	5/18/2020	9:32	9:46	4.43	6.76	0.15	9.4	98.3	17.41	7.9	219
WMP1	5/18/2020	9:32	9:46	4.43	6.76	1	9.28	97.8	17.44	7.79	219
WMP1	5/18/2020	9:32	9:46	4.43	6.76	2	9.25	97.8	17.44	7.7	219
WMP1	5/18/2020	9:32	9:46	4.43	6.76	3	9.22	96.2	17.41	7.55	219
WMP1	5/18/2020	9:32	9:46	4.43	6.76	4	9.14	94.8	17.27	7.47	219
WMP1	5/18/2020	9:32	9:46	4.43	6.76	5	9.24	95.7	17.02	7.37	219
WMP1	5/18/2020	9:32	9:46	4.43	6.76	6	8.08	83.7	16.7	7.27	218
WMP2	5/18/2020	9:58	10:12	4.75	5.09	0.15	9.28	95.1	16.75	7.07	217
WMP2	5/18/2020	9:58	10:12	4.75	5.09	1	9.21	95	16.76	7.03	217
WMP2	5/18/2020	9:58	10:12	4.75	5.09	2	9.36	96.2	16.74	6.98	217
WMP2	5/18/2020	9:58	10:12	4.75	5.09	3	9.31	95	16.77	6.98	217
WMP2	5/18/2020	9:58	10:12	4.75	5.09	4	9.29	96.1	16.76	6.97	217
WMP2	5/18/2020	9:58	10:12	4.75	5.09	5	9.26	95.6	16.67	6.95	218
WMP3	5/18/2020	9:58	10:12	4.75	5.09	0.15	9.28	95.1	16.75	7.07	217
WMP3	5/18/2020	9:58	10:12	4.75	5.09	1	9.21	95	16.76	7.03	217
WMP3	5/18/2020	9:58	10:12	4.75	5.09	2	9.36	96.2	16.74	6.98	217
WMP3	5/18/2020	9:58	10:12	4.75	5.09	3	9.31	95	16.77	6.98	217
WMP3	5/18/2020	9:58	10:12	4.75	5.09	4	9.29	96.1	16.76	6.97	217
WMP3	5/18/2020	9:58	10:12	4.75	5.09	5	9.26	95.6	16.67	6.95	218
EMP1	5/18/2020	10:02	10:14	4.37	5.54	0.15	8.83	91.2	16.83	6.74	182
EMP1	5/18/2020	10:02	10:14	4.37	5.54	1	8.77	90.6	16.84	6.73	182
EMP1	5/18/2020	10:02	10:14	4.37	5.54	2	8.76	90.2	16.84	6.71	183
EMP1	5/18/2020	10:02	10:14	4.37	5.54	3	8.75	90.3	16.81	6.66	183
EMP1	5/18/2020	10:02	10:14	4.37	5.54	4	8.63	89.3	16.76	6.64	182
EMP1	5/18/2020	10:02	10:14	4.37	5.54	5	8.39	86.2	16.71	6.57	183
EMP2	5/18/2020	10:21	10:28	5.3	8.3	0.15	9.02	93.1	16.92	7.38	182
EMP2	5/18/2020	10:21	10:28	5.3	8.3	1	8.95	92.6	16.94	7.19	182
EMP2	5/18/2020	10:21	10:28	5.3	8.3	2	8.97	92.8	16.94	7.11	182
EMP2	5/18/2020	10:21	10:28	5.3	8.3	3	9.03	92.8	16.87	7.08	181
EMP2	5/18/2020	10:21	10:28	5.3	8.3	4	8.88	90.8	16.33	6.98	181
EMP2	5/18/2020	10:21	10:28	5.3	8.3	5	8.72	88.7	16.26	6.94	181
EMP2	5/18/2020	10:21	10:28	5.3	8.3	6	8.78	89.1	16.21	6.92	184
EMP2	5/18/2020	10:21	10:28	5.3	8.3	7	8.9	90.6	16.17	6.88	183
EMP2	5/18/2020	10:21	10:28	5.3	8.3	8	8.11	82.7	15.98	6.81	184
EMP3	5/18/2020	10:38	10:48	4.72	9.25	0.15	9.2	94.6	16.7	6.83	182
EMP3	5/18/2020	10:38	10:48	4.72	9.25	1	9.12	93.7	16.71	6.81	181

Station	Date	Start time	End time	Secchi Depth (ft)	Total Depth (ft)	Sample Depth (ft)	Dissolved Oxygen (mg/L)	Dissolved Oxygen Sat (%)	Temp °C	pH	Conductivity (µS)
EMP3	5/18/2020	10:38	10:48	4.72	9.25	2	9.15	94.1	16.71	6.8	181
EMP3	5/18/2020	10:38	10:48	4.72	9.25	3	9.12	93.7	16.7	6.8	180
EMP3	5/18/2020	10:38	10:48	4.72	9.25	4	9.07	93.6	16.68	6.79	181
EMP3	5/18/2020	10:38	10:48	4.72	9.25	5	9.07	93	16.65	6.78	180
EMP3	5/18/2020	10:38	10:48	4.72	9.25	6	9	92.3	16.52	6.78	181
EMP3	5/18/2020	10:38	10:48	4.72	9.25	7	9	92	16.41	6.76	180
EMP3	5/18/2020	10:38	10:48	4.72	9.25	8	8.92	91.1	16.3	6.75	181
EMP3	5/18/2020	10:38	10:48	4.72	9.25	9	8.26	83.6	15.87	6.67	181
WMP1	5/20/2020	9:44	9:57	3.33	6.8	0.15	9.47	97.7	16.87	7.12	220
WMP1	5/20/2020	9:44	9:57	3.33	6.8	1	9.32	96.2	16.86	7.09	219
WMP1	5/20/2020	9:44	9:57	3.33	6.8	2	9.22	95.1	16.75	7.03	222
WMP1	5/20/2020	9:44	9:57	3.33	6.8	3	9.1	93.6	16.74	6.98	221
WMP1	5/20/2020	9:44	9:57	3.33	6.8	4	9.1	93.6	16.68	6.94	222
WMP1	5/20/2020	9:44	9:57	3.33	6.8	5	8.97	91.9	16.43	6.91	221
WMP1	5/20/2020	9:44	9:57	3.33	6.8	6	9.22	93.9	16.18	6.87	227
WMP2	5/20/2020	10:11	10:20	4.3	8	0.15	9.89	101.7	16.62	6.74	217
WMP2	5/20/2020	10:11	10:20	4.3	8	1	9.93	102.3	16.61	6.77	217
WMP2	5/20/2020	10:11	10:20	4.3	8	2	9.88	101.5	16.59	6.77	216
WMP2	5/20/2020	10:11	10:20	4.3	8	3	9.97	102.3	16.62	6.75	217
WMP2	5/20/2020	10:11	10:20	4.3	8	4	9.95	102.4	16.59	6.77	217
WMP2	5/20/2020	10:11	10:20	4.3	8	5	9.98	102	16.59	6.77	217
WMP2	5/20/2020	10:11	10:20	4.3	8	6	9.93	102.1	16.59	6.78	217
WMP2	5/20/2020	10:11	10:20	4.3	8	7	9.93	102	16.57	6.78	217
EMP1	5/20/2020	11:12	11:19	4.3	5.5	0.15	9.14	94	16.69	6.56	183
EMP1	5/20/2020	11:12	11:19	4.3	5.5	1	9.09	93.6	16.76	6.53	183
EMP1	5/20/2020	11:12	11:19	4.3	5.5	2	9.32	95.4	16.71	6.51	183
EMP1	5/20/2020	11:12	11:19	4.3	5.5	3	9.21	94.5	16.34	6.49	182
EMP1	5/20/2020	11:12	11:19	4.3	5.5	4	9.09	91.9	15.88	6.42	183
EMP1	5/20/2020	11:12	11:19	4.3	5.5	5	8.74	87.7	15.57	6.32	186
EMP2	5/20/2020	10:29	10:40	4.8	8.25	0.15	9.55	98.4	16.88	6.69	184
EMP2	5/20/2020	10:29	10:40	4.8	8.25	1	9.51	98.3	16.9	6.67	183
EMP2	5/20/2020	10:29	10:40	4.8	8.25	2	9.61	99.2	16.86	6.65	184
EMP2	5/20/2020	10:29	10:40	4.8	8.25	3	9.61	99.2	16.82	6.65	184
EMP2	5/20/2020	10:29	10:40	4.8	8.25	4	9.55	98.7	16.81	6.64	184
EMP2	5/20/2020	10:29	10:40	4.8	8.25	5	9.61	98.6	16.72	6.62	184
EMP2	5/20/2020	10:29	10:40	4.8	8.25	6	9.61	98.9	16.69	6.61	185
EMP2	5/20/2020	10:29	10:40	4.8	8.25	7	9.66	99.2	16.55	6.59	187
EMP2	5/20/2020	10:29	10:40	4.8	8.25	8	9.65	98.5	16.41	6.59	192
EMP3	5/20/2020	10:48	11:00	4.25	9.2	0.15	9.25	95.3	16.79	6.57	181

Station	Date	Start time	End time	Secchi Depth (ft)	Total Depth (ft)	Sample Depth (ft)	Dissolved Oxygen (mg/L)	Dissolved Oxygen Sat (%)	Temp °C	pH	Conductivity (µS)
EMP3	5/20/2020	10:48	11:00	4.25	9.2	1	9.29	95.4	16.81	6.56	182
EMP3	5/20/2020	10:48	11:00	4.25	9.2	2	9.28	95.4	16.74	6.55	181
EMP3	5/20/2020	10:48	11:00	4.25	9.2	3	9.21	94.5	16.66	6.55	181
EMP3	5/20/2020	10:48	11:00	4.25	9.2	4	9.21	94.6	16.65	6.54	181
EMP3	5/20/2020	10:48	11:00	4.25	9.2	5	9.19	94.2	16.58	6.54	181
EMP3	5/20/2020	10:48	11:00	4.25	9.2	6	9.17	93.7	16.49	6.53	181
EMP3	5/20/2020	10:48	11:00	4.25	9.2	7	9.16	93.9	16.43	6.51	181
EMP3	5/20/2020	10:48	11:00	4.25	9.2	8	9.01	91.4	16.29	6.5	182
WMP1	5/22/2020	9:45	9:57	5.7	7.7	0.15	9.78	104.1	18.2	7.44	221
WMP1	5/22/2020	9:45	9:57	5.7	7.7	1	9.68	102.4	18.21	7.58	220
WMP1	5/22/2020	9:45	9:57	5.7	7.7	2	9.66	102.6	18.16	7.32	221
WMP1	5/22/2020	9:45	9:57	5.7	7.7	3	9.66	102.1	18.03	7.27	220
WMP1	5/22/2020	9:45	9:57	5.7	7.7	4	9.6	101.3	17.84	7.2	219
WMP1	5/22/2020	9:45	9:57	5.7	7.7	5	9.59	101.6	17.8	7.09	219
WMP1	5/22/2020	9:45	9:57	5.7	7.7	6	9.49	99.3	17.48	7.04	219
WMP2	5/22/2020	10:22	10:31	4.1	7.2	0.15	9.62	100.4	17.41	6.86	217
WMP2	5/22/2020	10:22	10:31	4.1	7.2	1	9.72	101.6	17.41	6.87	216
WMP2	5/22/2020	10:22	10:31	4.1	7.2	2	9.73	101.4	17.4	6.88	218
WMP2	5/22/2020	10:22	10:31	4.1	7.2	3	9.8	102.4	17.38	6.91	217
WMP2	5/22/2020	10:22	10:31	4.1	7.2	4	9.77	101.8	17.34	6.93	218
WMP2	5/22/2020	10:22	10:31	4.1	7.2	5	9.76	101.8	17.31	6.93	216
WMP2	5/22/2020	10:22	10:31	4.1	7.2	6	9.72	101.1	17.25	6.94	217
EMP1	5/22/2020	11:19	11:34	4	5	0.15	9.56	101.7	18.36	6.74	183
EMP1	5/22/2020	11:19	11:34	4	5	1	9.65	102.4	18.38	6.76	184
EMP1	5/22/2020	11:19	11:34	4	5	2	9.64	102.5	18.36	6.78	183
EMP1	5/22/2020	11:19	11:34	4	5	3	9.7	103.1	18.27	6.77	184
EMP1	5/22/2020	11:19	11:34	4	5	4	9.58	101.5	17.86	6.78	184
EMP2	5/22/2020	10:38	10:49	4.5	8.1	0.15	9.31	96.9	17.21	6.76	195
EMP2	5/22/2020	10:38	10:49	4.5	8.1	1	9.23	96.3	17.25	6.75	196
EMP2	5/22/2020	10:38	10:49	4.5	8.1	2	9.37	96.7	17.22	6.76	194
EMP2	5/22/2020	10:38	10:49	4.5	8.1	3	9.29	96.5	17.21	6.78	194
EMP2	5/22/2020	10:38	10:49	4.5	8.1	4	9.38	97.5	17.05	6.78	193
EMP2	5/22/2020	10:38	10:49	4.5	8.1	5	9.28	96	17	6.79	189
EMP2	5/22/2020	10:38	10:49	4.5	8.1	6	9.22	95.2	16.91	6.77	185
EMP2	5/22/2020	10:38	10:49	4.5	8.1	7	9.16	93.8	16.5	6.75	184
EMP3	5/22/2020	10:52	11:06	4.5	9	0.15	9.66	101.2	17.69	6.7	183
EMP3	5/22/2020	10:52	11:06	4.5	9	1	9.68	101.8	17.69	6.65	183
EMP3	5/22/2020	10:52	11:06	4.5	9	2	9.79	102.7	17.66	6.68	183
EMP3	5/22/2020	10:52	11:06	4.5	9	3	9.69	101.8	17.64	6.68	183

Station	Date	Start time	End time	Secchi Depth (ft)	Total Depth (ft)	Sample Depth (ft)	Dissolved Oxygen (mg/L)	Dissolved Oxygen Sat (%)	Temp °C	pH	Conductivity (µS)
EMP3	5/22/2020	10:52	11:06	4.5	9	4	9.67	101.4	17.63	6.7	183
EMP3	5/22/2020	10:52	11:06	4.5	9	5	9.67	101.4	17.58	6.71	182
EMP3	5/22/2020	10:52	11:06	4.5	9	6	9.65	100.9	17.58	6.73	183
EMP3	5/22/2020	10:52	11:06	4.5	9	7	9.71	101.1	17.45	6.72	183
EMP3	5/22/2020	10:52	11:06	4.5	9	8	9.65	100.7	17.28	6.72	182

Appendix E

Updates to STELLA Model

In February 2007, the City of Brockton defined the Firm Yield of the Brockton Water Supply System which included Brockton Reservoir and the interconnected system of Monponsett Pond, Furnace Pond, and Silver Lake (CDM Smith, 2007). A simulation model of the Brockton water supply system was developed using the program Stella to evaluate the effects of storage, operation, and hydrologic inflow on the system yield. This Stella model of the Brockton system was used at the basis of an updated model to explore potential operational changes at Monponsett Pond for this Resource Management Plan.

Model Updates and Assumptions

This section describes the updates that were made to the 2007 Safe Yield Model for use in the RMP. This RMP Model is a system model designed to track flow and storage in the Brockton supply system. It is designed to focus on the Monponsett Pond and Silver Lake systems and not the other parts supply to be considered in the CWMP.

Time Period of Interest

The Safe Yield model was developed to understand and characterize drought conditions. The model was set up to run 4-year periods that captured the two worst droughts on record as of 2007: the 1960s drought (January 1964 to December 1967) and the 1980s drought (January 1980 to December 1983). For this RMP, a longer, more recent time window was selected to capture a larger range of hydrologic variability: January 2004 to December 2019.

The selected time frame has most operational data needed to calibrate the model, good quality data for all hydrologic parameters used as inputs to the model, and large hydrologic variability over the 16-year time frame. This variability includes a severe drought in 2016, one of the single highest storms in the 100-year precipitation record in 2010 (March 30-April 5, 2010), and a range of annual flow conditions.

Annual and monthly precipitation statistics in Taunton were used to characterize the variability of the RMP model period compared against the long-term precipitation record. The Taunton precipitation record was developed from two precipitation gages, representing a complete record from 1893 through 2019. Data between 1893 and 1999 are from the Taunton COOP station (ID USC00198367), and data between 2000 and 2019 are from the Taunton Municipal Airport (ID USW00054777). **Figure E-1** is a cumulative distribution function plot showing the distribution of annual precipitation between 1893 and 2019. In this plot, the labeled points represent the annual precipitation in each year of the RMP study period. This indicates that, on an annual basis, the precipitation for the RMP study period spans the range of precipitation observed across the period of record, including low precipitation in 2016 and higher than normal precipitation in 2011, 2005, and 2018. However, the annual precipitation record in the RMP study period is missing precipitation totals near the median (see the gap between 2004 and 2014 on the CDF

plot), suggesting that the RMP model period may miss some of the variability that occurs in a normal to slightly above normal year.

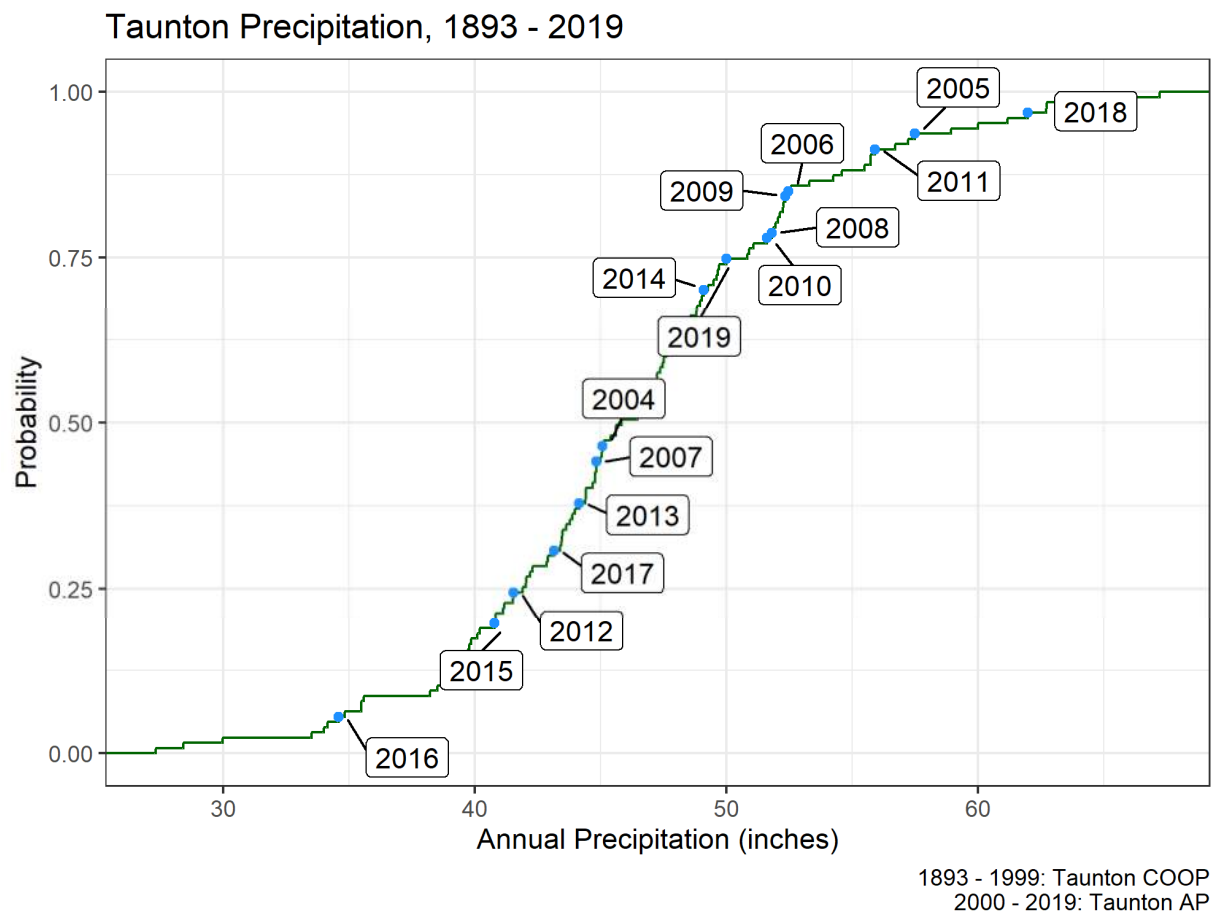


Figure E-1. Annual Precipitation Statistics in Taunton, Massachusetts Compared Against the RMP Study Period

In addition to the annual statistics, monthly precipitation statistics were also used to characterize the variability captured in the RMP study period relative to the full historical period of record.

Figure E-2 is a plot of the monthly variability in the full historical record compared against the monthly variability in the RMP study period. The color bands represent the range of precipitation in the historical record, separated by percentile. The green band represents the inter-quartile range, between the 25th percentile and 75th percentile, and is analogous to the box portion of a box-and-whisker plot. The box-and-whisker plots show the variability in the RMP study period data. This indicates that the inter-quartile range for the historical data generally match the inter-quartile range of the study period data, suggesting that the RMP study period captures most of the variation seen in the historical record. In addition, the monthly high and low values generally capture the extreme values in the record, including the historical maximum monthly precipitation in March, June, October, and November and historical minimum precipitation in August.

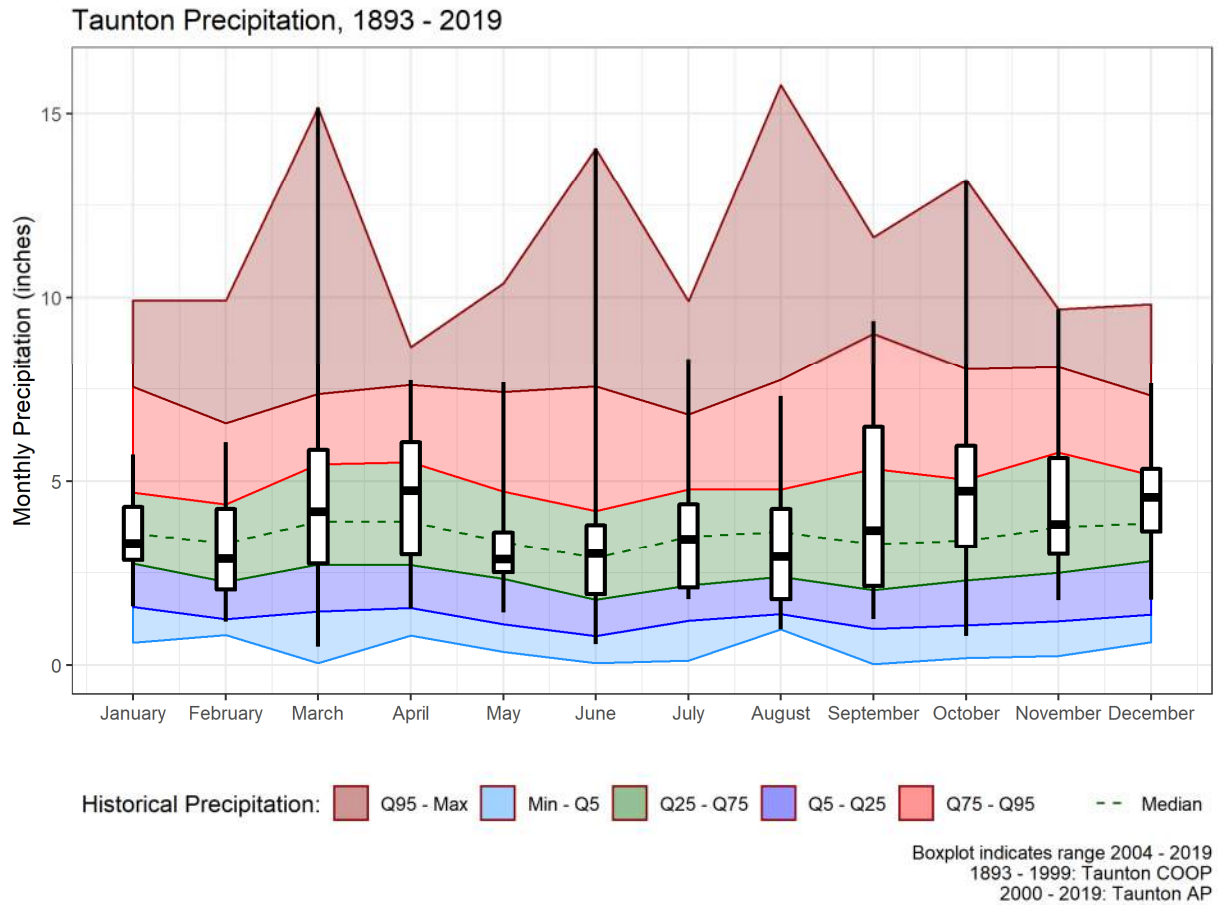


Figure E-2. Monthly Precipitation Variation in the RMP Study Period Relative to the Historical Record, Taunton, Massachusetts

Monponsett Pond Separation

Monponsett Pond was represented as one storage component in the Safe Yield model. The RMP seeks to understand the interaction of flow between WMP and EMP, and how the exchange of water between these ponds can affect water supply and water quality. The model was updated to represent the EMP and WMP as two separate storage volumes connected by a culvert.

The Route 58 culvert was represented as a box culvert with dimensions 8 foot wide, 5 foot, 2-inch-high, and 49 foot long. The culvert bottom was assumed to have no slope and an invert elevation of 51 ft NGVD29. This invert was back-calculated using recorded water levels and measurements taken during the field monitoring program. Manning's Equation was used to calculate the flow through the culvert using the head difference between the ponds to calculate slope in each time step. Flow could occur in both the eastward and westward direction.

Bathymetry

Updated bathymetry data was used to develop new stage – surface area – volume relationships for the EMP and WMP because the Safe Yield model had defined these relationships for the combined Monponsett Pond. The EMP bathymetry data originated from MassDEP and was

collected by Biobase on 6/28/2017. EMP has a maximum depth of 11 ft. The WMP data was collected by the Massachusetts Division of Fisheries & Wildlife in 2018 and had a maximum depth of 15 ft. This data was processed in ArcMap to develop updated stage-volume and stage-surface area relationships.

The Safe Yield model included stage-volume relationship from stages 48 to 53.5 ft for Monponsett Pond. This was appropriate at the time, as this model was developed to understand and characterize drought conditions. To characterize all possible flow conditions for the RMP, the upper end of the stage-storage curve was extrapolated to 54.5 ft to capture the highest measured pond elevation in the record from 2004-2019 within the upper end of the stage volume.

The updated stage-volume relationship is shown in **Table E-1** for EMP and in **Table E-2** for WMP. When aggregated together, the combined pond updated bathymetry resulted in an increase in total Monponsett Pond storage by about 28 MG at elevation 53.5 ft, which is about a 3 percent increase. The updated surface area calculation matched measurements using recent UGSG maps and orthoimagery and resulted in an increase of 15 percent at elevation 53.5 ft when compared to the Safe Yield model. The surface-area relationship is used to dynamically calculate direct precipitation, evaporation, and seepage.

Table E-1. East Monponsett Pond Stage – Volume – Surface Area Relationship

Stage (elevation)	Volume (MG)	Surface Area (sq mi)
43.0	0.0	0.000
44.0	8.9	0.068
45.0	27.7	0.122
46.0	64.4	0.224
47.0	117.3	0.277
48.0	178.8	0.311
48.5	212.0	0.325
49.0	246.5	0.337
49.5	282.3	0.349
50.0	319.3	0.361
50.5	357.6	0.375
51.0	397.5	0.389
51.5	438.6	0.400
52.0	480.6	0.408
52.5	523.6	0.415
53.0	567.3	0.423
53.5	611.8	0.432
54.0	658.2	0.446
54.5	704.5	0.447

Table E-2. West Monponsett Pond Stage – Volume – Surface Area Relationship

Stage (elevation)	Volume (MG)	Surface Area (sq mi)
40.0	0.0	0.000
43.0	71.8	0.194
44.0	115.7	0.226
45.0	165.4	0.252
46.0	221.3	0.288
47.0	285.2	0.323
48.0	356.4	0.358
48.5	394.5	0.372
49.0	434.1	0.388
49.5	475.4	0.404
50.0	518.2	0.418
50.5	562.4	0.430
51.0	607.9	0.442
51.5	654.5	0.452
52.0	702.3	0.463
52.5	751.1	0.475
53.0	801.1	0.482
53.5	851.4	0.483
54.0	901.4	0.484
54.5	951.4	0.485

The stage – surface area – volume relationship was also updated for Silver Lake. Silver Lake Storage Capacity data was provided by Veolia that differed slightly from the relationship that was in the Safe Yield model and improved the resolution of the relationships. The updated Silver Lake relationship is shown in **Table E-3**.

Table E-3. Silver Lake Stage – Volume – Surface Area Relationship

Stage (elevation)	Volume (MG)	Surface Area (sq mi)
-2.6	198	0.100
7.5	606	0.188
17.5	1353	0.372
22.5	1801	0.447
23.5	1903	0.463
24.5	2006	0.478
25.5	2108	0.495
26.5	2210	0.511
27.5	2312	0.527
28.5	2430	0.538
29.5	2548	0.548
30.5	2666	0.559
31.5	2784	0.570
32.5	2902	0.581
33.5	3035	0.594
34.5	3167	0.608
35.5	3299	0.620
36.5	3431	0.634
37.5	3563	0.647
38.5	3724	0.686
39.5	3886	0.725
40.5	4047	0.763
41.5	4299	0.802
42.5	4370	0.841
43.5	4579	0.873
44.5	4780	0.906
45.5	4970	0.941
46.5	5171	0.973
47.5	5371	1.006

Runoff

The inflows to Monponsett Pond were updated to reflect inflow to EMP and WMP separately. An area ratio was used to calculate flow into EMP and WMP. The total watershed area of Monponsett Pond is 6.01 square miles. EMP has a drainage area of 3.46 square miles into and WMP has a drainage area of 2.55 square miles, which result in area ratio of 0.58 and 0.42 respectively.

None of the inflowing streams to the Monponsett Pond area have current or historical gage data. The Safe Yield model used a Massachusetts Department of Environmental Protection (MassDEP)

statistical regression methodology to estimate streamflow into Monponsett Pond. This methodology was specifically developed to estimate the firm yield of a system, so it worked well for lower flow years, but was less appropriate for average and high flow years. Specifically, this streamflow methodology does not capture the peaks from larger precipitation events.

For the RMP update, several nearby stream flow gages were normalized by drainage area, compared and found to be fairly consistent. Daily flows from USGS #01105730 Indian Head River at Hanover, MA were selected and scaled to the Monponsett watershed area. The Indian Head River gage was selected because it had a smaller drainage area compared to others in the area (30.3 sq mi), was not affected dramatically by upstream regulation, and was located closer to the Monponsett study area than other possible reference gages.

Direct Precipitation

The precipitation gages used to calculate direct precipitation on the lakes were updated. The Safe Yield Model applied the Taunton precipitation gage to Brockton Reservoir and the Pembroke precipitation gage to Monponsett Pond and Silver Lake. The RMP model continues to use the Taunton gage record for Brockton Reservoir inputs, and also applies the Taunton gage for Monponsett Pond and Silver Lake precipitation because the Pembroke gage went out of service after the 1980s drought.

Evaporation

The Safe Yield model collected pan evaporation data from a National Weather Service (NWS) gage and used a factor of 0.7 to convert to free air evaporation. The RMP Model updated the evaporation calculation method for all ponds. The Hargreaves method was used to calculate daily evaporation using the Taunton temperature record as an input. The Hargreaves method is more accurate and reliable than pan evaporation data and allows for more daily variation.

Groundwater Seepage

In the Safe Yield model, seepage rates used a long-term average specific to each pond/reservoir for the entire simulation that was determined during model calibration. A negative net flux was used at Brockton Reservoir and Furnace Pond and a positive net flux was used at Silver Lake. The seepage rates from the Safe Yield model were maintained for these reservoirs.

The Safe Yield study had calibrated a slightly negative seepage out of Monponsett Pond in the droughts that were part of that study. The RMP calibration required an update of the seepage of Monponsett Pond. This updated seepage rate represents impacts on the ponds from changes in local recharge and pumping, such as pumping from the nearby Halifax groundwater supply wells, on the groundwater aquifer surrounding the ponds. A groundwater gage was employed to dynamically represent the exchange between the pond and groundwater. Records from USGS groundwater wells in Duxbury (USGS #420316070433501 and USGS #420321070433502) were evaluated because of the proximity to the Monponsett Pond site and the long records of data that were available. The groundwater record was used to vary the seepage rate based on the daily measured groundwater elevation. Higher groundwater elevations contributing more water to Monponsett Pond, and lower groundwater measurements created a slight negative flux out of the pond. This relationship was general across the years in the calibration period, so it could be applied to time periods outside of 2004 to 2019. The Duxbury well may not adequately capture

the local pumping that happens in the immediate vicinity of Monponsett Pond, so the understanding of how groundwater impacts Monponsett Pond could greatly benefit from a more local groundwater well to monitor groundwater levels.

Transfers

The rule-based transfer logic was revised when updating the Safe Yield model for use in the RMP. Transfers occur from Monponsett Pond to Silver Lake between October and May when a) water level in Silver Lake is below full (47.5 ft NGVD29) and b) water levels in Monponsett Pond are above the minimum water level (52.0 ft NGVD29); the latter was previously erroneously included at 52.5 ft NGVD29. The transfers are gravity-driven and vary daily based on the surface water levels of each body of water, time of year, and demand.

Cranberry Irrigation Withdrawals

Several cranberry farms adjacent to Monponsett Pond use water from the pond to supplement irrigation. The assumptions related to the cranberry withdrawal in the Safe Yield model were maintained for this RMP model update, with withdrawals and losses assumed to be equally divided between the two ponds. Cranberry producers (Morse Brothers) draw water from the WMP and directly discharge to the Stump Brook. This confirms the Safe Yield model assumption that return flows to the Pond are negligible. Smaller producers to the north could discharge back to Monponsett Pond or streams that feed it, but the quantity of withdrawals and returns are unknown.

Flows to Stump Brook

Two types of releases from Stump Brook Dam occur: (1) downstream releases to meet the required release of 0.9 mgd and (2) flows (spills) over the dam's spillway. These were updated in the RMP model.

Downstream Release to Stump Brook

Downstream releases to Stump Brook are made to meet release requirements of the Acts and the ACO. The Acts of 1964 required Brockton to release a minimum flow of 0.9 mgd from October through May whenever there is a diversion from Monponsett Pond to Silver Lake. This was codified in the Brockton Code of Ordinances (1964). Brockton voluntarily changed the release practice in November 2015 to always release 0.9 mgd. This practice was codified in the 2017 ACO with MassDEP. Several model scenarios discussed in **Section 5** reflect this updated guidance which requires releases of at least 0.9 mgd year-round.

The historical operation of the fish ladder gate was a manual process that has evolved over time. As a result, operators would tend to release more than the minimum instream flow requirement and adjust the gate up or down as needed every few days. **Section 3.2** describes the historical operations at Stump Brook Dam in more detail.

For the model calibration, a weir equation was used to dynamically simulate the fish ladder release based on the gate position and the stage of WMP. To replicate the manual fish ladder gate operations, a position of 7 inches below the water surface was selected at the beginning of the calibration run. Each time step, the model evaluates if the gate should be raised or lowered based on water level fluctuations, allowing a maximum gate opening of 15 inches. There is a one-day lag

before the gate can change its position, to simulate the ad hoc manual adjustments made in response to daily fluctuations. Releases were not included outside of the diversion period from October through May in the calibration run. These rules simulating manual releases to Stump Brook were applied for the entire simulation, so the operating principles required by the ACO were not fully captured in the last few years of the calibration run.

All scenario runs use a rules-based approach to release the required 0.9 mgd rather than the weir equation when the WMP elevation is above the 51.8' lowest weir placement. After January 2018, the operation of the fish ladder gate was mechanized, and an actuator was installed to allow for more frequent gate adjustments and more precision in releasing 0.9 mgd. A rules-based release more accurately represents the current capability to control releases to be at or just above the minimum requirement.

Stump Brook Spills

The spills from Monponsett Pond were reconfigured during the RMP update. The Safe Yield model set flood elevations for each reservoir, and any volume exceeding those levels was lost from the system. This release logic is maintained from the Safe Yield model for all reservoirs other than Monponsett Pond. After Monponsett Pond was separated into the EMP and WMP, it was assumed that spills only happened out of WMP via Stump Brook because there is no spillway structure on EMP. The concrete dam on WMP was represented using a broad-crested weir equation with a spillway length of 70 ft and invert height of elevation 53 ft. The weir discharge coefficient was varied based on the head over the weir (NHI 2013).

Model Calibration

Reservoir system models are typically verified by comparing simulated water surface elevations to records of water level data. To simulate drawdowns, the observed diversions from Monponsett Pond to Silver Lake were used as direct inputs to the model rather than using rules-based operations. The objective of this test was to assess the accuracy of the simulated response of the system to known inflows and withdrawals.

The results of the calibration simulations are shown in **Figure E-3**. In general, many of the major observed water level fluctuations are replicated in the model calibration with reasonable accuracy. The timing and magnitude of drawdowns was replicated fairly well in 2007, 2008, 2010, and 2016. The difference in water level elevation between EMP and WMP was typically very small. This was expected because of the large flow area provided by the Route 58 culvert and anecdotal evidence that the ponds tend to rise and fall at the same time.

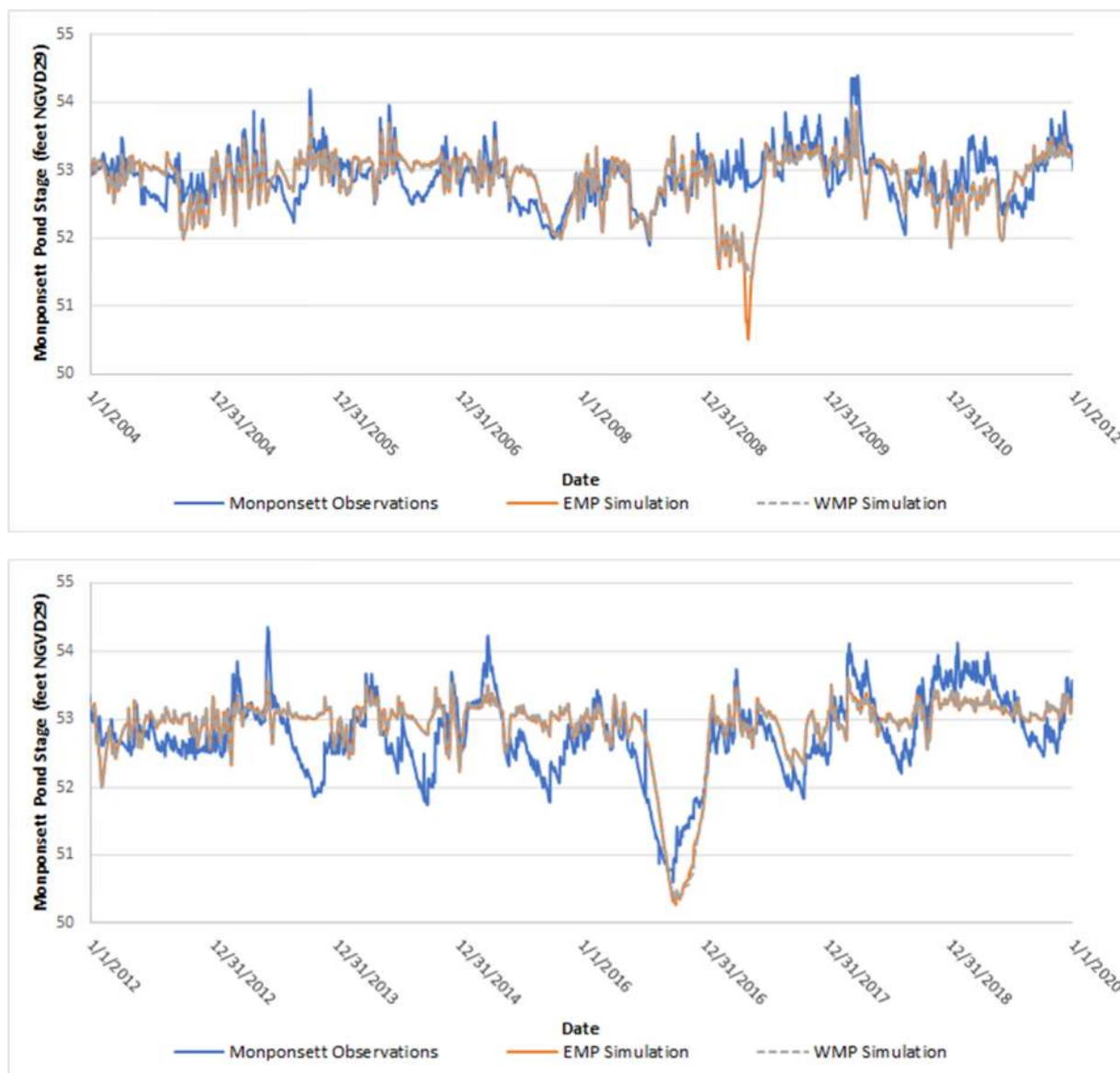


Figure E-3. Calibration of Monponsett Pond Water Levels (2004-2019)

The peaks caused by wet weather events were replicated fairly well across the record. When the pond elevation is above 53 ft NGVD29 and spilling, the model tends to slightly underpredict the pond elevation. The months around December 2018 are a good example of this model behavior. There is limited observed data on the amount of water released and spilled from Stump Brook. These data, collected between May 2018 and April 2021, showed occasional spills as high as 68 mgd. The weir equation spills water at comparable rates during these time periods. When the observed record peaks above 54 ft NGVD29, the simulated pond elevation replicates higher pond levels, but does not build up above the 53 ft NGVD29 spillway as high as the observed data.

Some of the variations between the calibrated model run and the observed data could be due to inaccurate diversion data recorded by a stuck pressure meter. Consistent records were not kept when the meter was broken and possibly recording flow when the diversion was closed. One year

that was not accurately captured in the calibration run was 2009. The observed water levels in Monponsett Pond show flooding conditions, and as a result the recorded diversions from Monponsett Pond to Silver Lake are very high during that period. There were likely diversions made for flood control in addition to water supply, but there are also several periods of time where these large diversions happen for several weeks in a row. The diversion data in early 2009 matches the description for possibly being high due to a stuck meter. The modeled hydrology inflows (runoff, direct precipitation, and seepage) do not support the high level of observed diversions and cause the simulated pond elevations to drop much lower than observed elevations.

Without a consistent record of when the meter was stuck and records showing where the record may have already been retroactively corrected, it is not possible to develop a consistent method to correct the observed diversion record. Despite the calibration in 2009 not matching the observed pond levels well, this year was still considered as valid and was used in the analysis of scenario results. The 2010 year similarly had some large wet weather events that required flood diversions, and the model inflow hydrology and calibration matched well during that time-period.

The model results do not match drop in observed water level in the fall of 2013, 2014, and 2015. Groundwater levels recede during these periods, so there could be groundwater losses that are not represented in the model. As described in the Model Updates Section, general groundwater trends were used to calibrate the model, but there is no groundwater well data local to the Monponsett Pond area. There could be losses and contributions to Monponsett Pond that cannot be captured in the existing calibration without more local information.

Another objective in calibration was verifying that the RMP model calculated flows through the culvert were reasonable. The culvert flows from the calibration run were comparing the results of the Flow Monitoring field tests (described in Section 4). The results of the calibration run show that the simulated culvert flow matches the field tests well. **Figure E-4** compares the modeled culvert flow from 2004 through 2019 (excluding 2009) to the analysis from the Flow Monitoring field test.

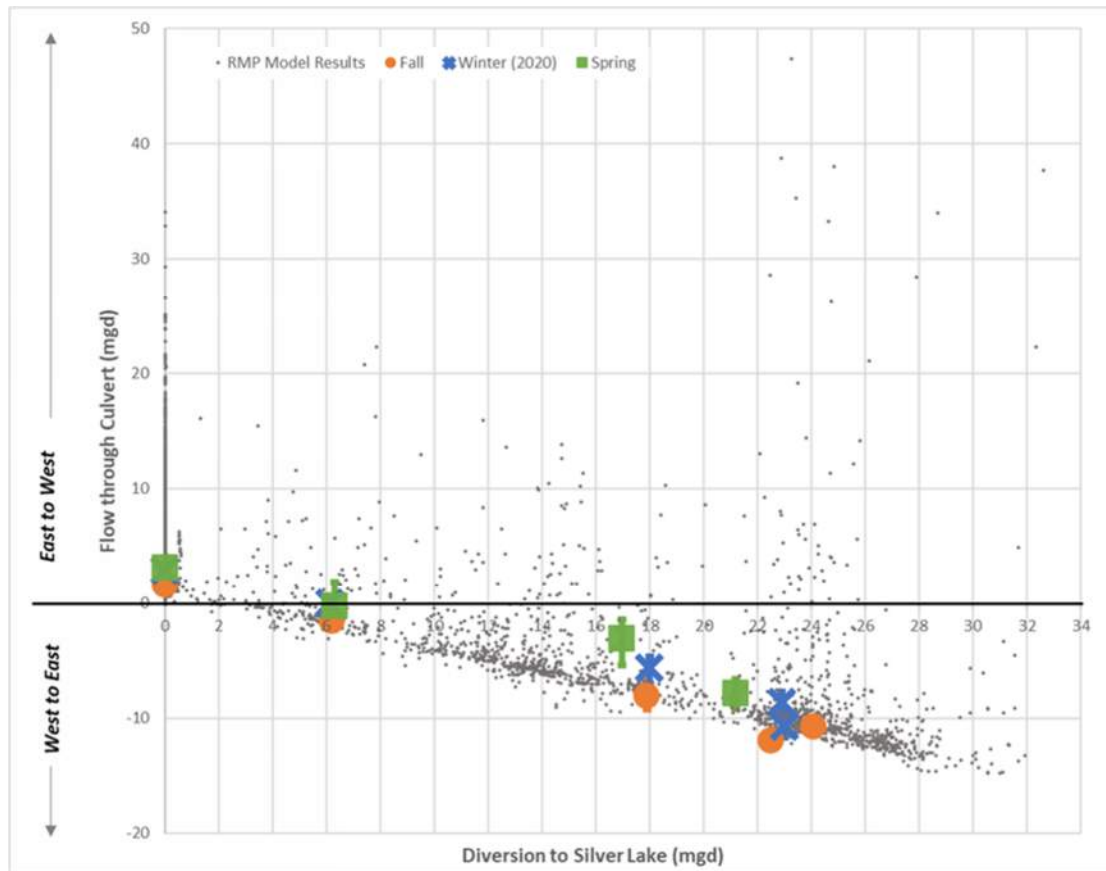


Figure E-4. Variability of Culvert Flow Calculated in RMP Calibration Run Compared to Variability in Measured Flow during the 2019-2021 Monitoring Program

When there is no diversion to Silver Lake, both the modeled and field data suggest that there is slight eastward flow. When the diversion to Silver Lake is at about 25 percent valve position, or about 6 mgd, the flow through the culvert is around 0, but can range to about 2 mgd in either the eastward or westward direction. As the diversion increases, the flow through the culvert tends to increase in magnitude and tends to flow to the west.

The data produced by the RMP model are fairly linear and match field data well. The scatter only trends in the westward direction and occurs during wet weather events when the pond elevation is above 53 ft NGVD29. In large flood events water will always be drawn west regardless of the level of diversion, because spills only happen over the Stump Brook Dam located on the WMP. Diversions were historically made to help reduce flooding down Stump Brook, so the large westward flows simulated by the RMP model can happen at any level of diversion.

The model logic seems to be functioning adequately since the calibrated historical simulation accurately represents many of Monponsett Pond's peaks and drawdowns. The modeled culvert is also replicating the field measurements very well. It is difficult to closely replicate historical conditions because of unknowns, incomplete record keeping, and changing operations. The

updates made to the Stella model for the RMP can be helpful in assessing the scenarios discussed in **Section 5**.