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Six Municipalities, One Watershed: A Collaborative Approach to Remove Phosphorus in the Assabet River Watershed

Wachusett Aqueduct spanning the Assabet River at Northborough, Massachusetts
Photographer: Gemma Kite

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Four wastewater treatment facilities (WWTFs) in Hudson, Marlborough, Maynard, and Westborough and the six Massachusetts communities they serve (Figure 1) partnered to develop and implement phosphorus removal strategies. Their goal was to improve water quality in the Assabet River by reducing phosphorus loads on a watershed scale. After years of joint planning and collaboration with state and federal agencies, each facility analyzed the most important factors (such as operational concerns, footprint and flexibility) influencing the decision about which technology would work best for its particular site characteristics. Each WWTF selected a different phosphorus removal technology, which was implemented with other facility improvements. The portion of the upgrade costs due to phosphorus removal improvements is difficult to separate from the total cost and can vary significantly based on how the costs are allocated. Three of the four facilities estimated the phosphorus removal upgrade to cost from 4 to 25 million dollars. After the upgrades, all WWTFs have been meeting effluent limits of 0.1 milligrams per liter (mg/L) on a 60-day rolling average, representing over 90% reduction in total phosphorus loads to the river from April through October. The facilities are also meeting effluent limits of 1 mg/L the rest of the year. This case study describes the joint efforts of the WWTFs and key elements of each WWTF's improvements, and provides a summary of lessons learned for use by other watersheds and communities seeking to work together to improve water quality. It also provides a summary of the significant water quality improvements measured in the Assabet River from 1995 through 2013.

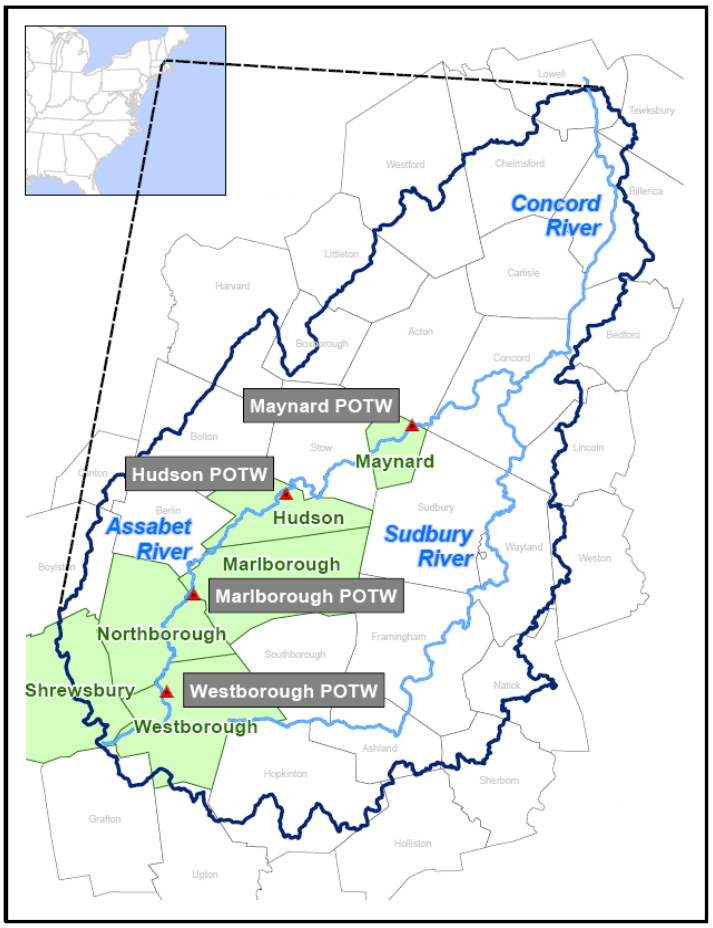

Figure 1. Assabet River Watershed, Major WWTFs, and the Municipalities They Serve

ASSABET RIVER CONSORTIUM AND PHOSPHORUS REMOVAL

The Assabet River is an effluent-dominated river located in central Massachusetts. It receives treated wastewater discharges from four major municipal WWTFs that serve portions of six communities, as well as three minor wastewater treatment facilities. During the low-flow periods of the summer months, the discharges from the four main WWTFs provide approximately 80%

of the stream flow. During the 1999 and 2000 summer-time conditions, field investigations showed that 95 to 97% of the phosphorus loading to the river came from these four WWTFs. In addition, impoundments by nine dams along the 32-mile river have contributed to the accumulation of phosphorus in the sediments with the potential for future release.

In Massachusetts' water quality standards, the Assabet River is designated as capable of providing and supporting habitat for fish and other aquatic wildlife, and for primary and secondary contact recreation (Class B). However, in 1998 the Massachusetts Department of Environmental Protection (DEP) listed the Assabet River as impaired, primarily for nutrients and organic enrichment/low dissolved oxygen. The federal Clean Water Act requires the restoration of impaired water bodies through the development of a "pollution budget," also referred to as a total maximum daily load (TMDL). The TMDL identifies the maximum amount of a pollutant that can be discharged to a water body while maintaining water quality standards for its designated uses.

After field investigations, a computer modeling effort, and stakeholder involvement, the DEP decided phosphorus was the cause of the impairment. Phosphorus is a nutrient and acts like a fertilizer. Its presence or absence controls the extent of plant and algae growth in the water. If too much phosphorus is present, it causes excess growth of nuisance plants and algae. The DEP issued a TMDL in 2004 for total phosphorus (TP) entering the Assabet River from direct, treated wastewater discharges and indirect discharges. The TMDL requires reduction of TP from WWTF effluent to concentrations of 0.1 mg/L from April through October, and a 90% reduction of sediment flux.

In 1999, the DEP invited the municipalities of Hudson, Marlborough, Maynard, Northborough, Shrewsbury, and Westborough to a meeting to discuss nutrient over-enrichment and TP issues in the Assabet River and to recommend that the towns work together to address the issue on a watershed-level. These towns contribute wastewater to the four WWTFs discharging to the Assabet River, and together formed the Assabet River Consortium as a working group of town managers and technical representatives. The goals of the Consortium were to quantify current and future wastewater needs, evaluate needs for TP removal, and identify alternatives for TP removal as needed. While each town and WWTF developed its own Comprehensive Wastewater Management Plan (CWMP), the Consortium also went through the process of developing a joint CWMP as a combination of the other plans. This joint plan enabled the Consortium to represent the towns as a single voice in discussions with the DEP and the U.S. Environmental Protection Agency. The Consortium CWMP was funded through Massachusetts' state revolving fund (SRF) program, developed in parallel with the TMDL, and completed in December 2007. Through the CWMP process, wastewater alternatives were evaluated for the four WWTFs, and each facility took a different approach to phosphorus removal, as described in this document.

WWTF UPGRADES FOR HUDSON, MA

In addition to TP reduction, the Hudson WWTF needed to replace and upgrade aging systems and equipment because no major upgrade had occurred since 1985. During the initial steps of the TMDL development, nobody knew what TP limit would be needed to restore the Assabet River. The Hudson WWTF Chief Operator optimized the existing treatment system to reduce effluent TP concentrations within the existing system, and was able to reduce them to approximately 0.2

mg/L by increasing chemical use and adjusting effluent pH. While the seasonal TMDL limit was subsequently set to 0.1 mg/L, the efforts by the WWTF Chief Operator allowed for flexibility in upgrade options.

The WWTF initially considered a number of technologies and developed a short list of those that could reliably meet a TP effluent concentration of 0.1 mg/L and other site-specific effluent limits (e.g., silica from industrial user), be tested onsite through a pilot system, and have low capital and operation and maintenance (O&M) costs.

The WWTF pilot-tested three technologies: the Kruger ActiFlo®, Densadeg®, and IDI AquaDAF™. All three technologies proved capable of reducing TP to 0.1 mg/L, and lower if needed with additional sand filters. The Town of Hudson selected the AquaDAF™ dissolved air flotation system primarily for the following reasons:

- Lowest capital construction cost
- Reduced solids handling costs and ability to use smaller holding tanks due to the production of a more concentrated, "thick" sludge
- Ease of operation: limited operator adjustments and input required

Dissolved air flotation in general is a process for clarifying water with low-density solids that cannot be removed efficiently with sedimentation. The AquaDAF™ proprietary system adds enhancements to the generic process, such as an improved effluent collection system that allows for higher flow rates on a limited footprint. While the system does not claim to meet 0.1 mg/L TP effluent by itself, the Hudson WWTF's treatment process had been optimized to reduce the influent concentration entering the AquaDAF™ system to 0.4 to 0.5 mg/L TP. While the Chief Operator had achieved effluent concentrations as low as 0.2 mg/L prior to the upgrade, reducing influent concentrations to the AquaDAF™ to 0.2 mg/L is costly in chemicals and not necessary to meet final effluent concentrations of 0.1 mg/L. At the Hudson WWTF, the AquaDAF™ system is used as a polishing component to meet the required effluent concentrations.

Total construction costs for the Hudson WWTF upgrade were approximately $15 million. In addition to the AquaDAF™ system constructed below grade with two treatment trains, this cost included the construction of a new 4,400 square foot building, sludge pumping, and ferric chloride storage. The cost associated with phosphorus reduction alone is estimated at approximately $5 million, or a third of the total costs. Construction of all upgrades took approximately two years.

Because the Town of Hudson runs its own non-profit municipal electric utility, the Hudson Light and Power Department, increased electric use was less important to the Town in the selection process than other O&M costs such as chemicals and staffing. In addition, while the recycle pumps from AquaDAF™ system require additional energy, other upgrades have improved

overall energy efficiency, partially offsetting the added power needs. The overall upgrades to the plant required adding one operator and one laborer to the original staff of seven. Generally, the WWTF has been able to limit the number of required staff by using the department of public works (DPW) water crew for pipe inspections and repairs at the facility. By selecting the AquaDAF™ system, the WWTF has been able to optimize the treatment process after the upgrade to limit the need for additional chemicals such that the upgrades have not resulted in any significant increase in chemical use. In addition, the WWTF has been successfully reducing wastewater contributions from infiltration and inflow through the collection system, resulting in a significant reduction in average daily flow and a further reduction in the need for chemicals.

The upgrades have also improved the consistency of the treatment, enabled the WWTF to more easily meet its copper effluent limits, and reduced effluent concentrations of total suspended solids (TSS), biological oxygen demand (BOD), ammonia, and copper. Additional elements of the upgrade, such as the new supervisory control and data acquisition (SCADA) system, have improved overall operations at the WWTF.

The WWTF operates the TP removal process year-round because it enables the facility to meet its copper effluent limit. Since construction was completed, the Hudson WWTF has been successfully meeting effluent concentrations of 0.1 mg/L from April through October, for a reduction in its seasonal TP loads to the Assabet River of approximately 2,840 lbs, or 91%, since 1998.

WWTF UPGRADES FOR MARLBOROUGH, MA

The City of Marlborough operates two WWTFs, one of which, the Westerly WWTF, treats wastewater from the Cities of Marlborough and Northborough and discharges the effluent to the Assabet River. Constructed in 1973 as a secondary treatment facility for a design flow of 2.0 million gallons per day (MGD), the Westerly WWTF was expanded to 2.9 MGD and upgraded with single-stage seasonal nitrification in 1988. The 20-year flow projection estimated during the needs analysis identified a future flow of 4.4 MGD. Three scenarios were developed to compare groundwater and surface water discharges and evaluate the potential need for a separate Northborough WWTF.

The City of Marlborough then reviewed and screened a variety of technologies capable of reducing TP concentrations to 0.1 mg/L or less, and short-listed three of the technologies for a two-week trailer-mounted pilot study: CoMag™, ActiFlo®, and BluePRO®. After issuing a

request for proposals (RFP) for the phosphorus removal system, the City of Marlborough selected the Blue Water BluePRO® system for the following reasons:

- Lowest capital and O&M costs
- Manufacturer's agreement to guarantees, warranties, and bonds
- Financial backing of the Shaw Group, a Fortune 500 company whose financial backing indicated some level of confidence in the long-term financial stability of the technology developers

The BluePRO® reactive filtration system combines co-precipitation and adsorption to a reactive filter media in an upflow sand filter. Phosphorus removal is achieved by adsorption followed by filtration.

Total construction costs for the Westerly WWTF upgrade were approximately $27.5 million, which included increasing the design flow by more than 40%, a number of baseline improvements to the WWTF, and the TP removal system. The baseline improvements involved modifications to primary and secondary clarifiers, conversion of the disinfection system from chlorine gas to ultraviolet (UV) disinfection, a new gravity thickener, new chemical feed systems, and new electrical distribution and SCADA systems. Many elements of the upgrade were needed, but not all contributed to improving TP removal; that portion was roughly estimated at 15% of the total cost, about $4 million. Only a rough estimate can be provided, because many of the upgraded elements are tied to the need to both increase design flow and remove TP. Construction of the upgrade occurred over a two-year period.

The upgrade resulted in increased power consumption (approximately 40% more than the original energy use), particularly because the Marlborough WWTF uses the BluePRO® system year-round. However, while ferric chloride is now dosed in multiple locations throughout the treatment process, the overall use of chemicals is approximately unchanged from use before the upgrade. The overall upgrades to the plant required one additional operator on staff and training for the existing operators, but a senior chemist position was eliminated, resulting in no overall staff increase.

The upgrades for advanced TP removal also resulted in reduced effluent concentrations for TSS, BOD, copper, and aluminum. Overall upgrades also resulted in easier facility management (through the SCADA system), improved screening and grit removal, and better sludge handling.

Since the upgrade was completed in summer 2012, the Marlborough WWTF has been successfully meeting effluent concentration limits of 0.1 mg/L from April through October, for a reduction in its seasonal TP loads to the Assabet River of approximately 13,050 lbs, or 97%, since 1998. The 2013 seasonal average TP concentration in Marlborough's effluent was approximately 0.094 mg/L, slightly below the seasonal TMDL requirement.

WWTF UPGRADES FOR MAYNARD, MA

The Town of Maynard WWTF dates back to the 1930s, and it was converted from an activated sludge to a rotating biological contactor system in 1986. The WWTF screened technologies for pilot testing to meet the following needs: a constrained budget, a site with no space for a new

tertiary treatment building, optimization of existing hydraulics, additional equipment, and upgraded and enhanced SCADA and control systems.

The WWTF piloted technologies to confirm their ability to achieve TP concentrations of 0.1 mg/L or less, verify their operational simplicity, and test their impacts on sludge handling and production. Sludge handling considerations were important for the Maynard WWTF because the limited available real estate at the facility made it challenging to manage additional sludge. The WWTF selected the Siemens CoMag™ system for the following main reasons:

- Partial re-use of existing aeration basins
- Ability to use a polishing filter to achieve 0.05 mg/L TP in the effluent
- Preferred O&M by existing operators

The CoMag™ process uses conventional coagulation and flocculation with the addition of finely ground magnetite as a ballasting agent. Magnetite is denser than suspended solids and sand, and generates heavy, dense flocs that settle rapidly, resulting in a high-rate sedimentation process. Once precipitated, the phosphorus and other pollutants are removed effectively. The footprint required to install CoMag™ clarifiers is small compared to other phosphorus removal processes, and the existing aeration basins were re-used to further minimize construction costs. The rectangular clarifiers for the CoMag™ technology optimized the use of the existing facility, allowed for a submerged inlet design to eliminate turbulence, and improved access to equipment.

Construction costs for the Maynard WWTF upgrade totaled approximately $12 million, but as with other WWTFs, these costs were not limited to upgraded TP removal. The construction of the CoMag™ system was combined with additional streamlining of facilities for chemical management and sludge storage, the replacement of major mechanical equipment for which operational costs had recently significantly increased due to repeated failures, and a complete electrical and instrumentation upgrade (e.g., SCADA).

Due to the limited available real estate at the facility, pumps had to be incorporated into a compact footprint, and the upgrades resulted in increased electric use. The facility does not need to operate the CoMag™ system off-season because the TMDL waste load allocation of 1 mg/L from November through March for TP can be met without it. Bypassing the CoMag™ system reduces electric use during those months and limits the wear and tear of the system, but the Chief Operator noticed aluminum effluent concentrations increased significantly, so the facility might run the system during the off-season. While new chemicals were needed for the TP process, including poly-aluminum chloride (PAC) and polymers for flocculation, sodium hydroxide for pH adjustment, and magnetite, the total amount of chemicals used at the facility was reduced. PAC is still used in the off-season to meet TP and other effluent limits, so that chemical use is relatively consistent throughout the year. Following the upgrades, the DEP-mandated staffing

rose from 4 to 4.8 operators, including a sludge truck driver/operator position that can potentially be outsourced.

In addition to TP reduction, the upgrades resulted in reduced effluent concentrations for TSS, BOD, and copper, and the facility is more confident in meeting its secondary treatment requirements.

Since the new facility came online in 2011, the Maynard WWTF has been successfully meeting effluent concentration limits of 0.1 mg/L from April through October, for a reduction in its seasonal TP loads to the Assabet River of approximately 1,940 lbs, or 92%, since 1998. The 2013 seasonal average TP concentration in Maynard's effluent was approximately 0.093 mg/L, slightly below the seasonal TMDL requirement.

WWTF UPGRADES FOR WESTBOROUGH, MA

The original Westborough WWTF was built in 1899, upgraded in the early 1970s, and improved again in 1987. It receives the bulk of its 7.68 MGD wastewater design flow from the towns of Westborough (2.89 MGD allocation) and Shrewsbury (4.39 MGD), and only 5% of its flow from the Town of Hopkinton (0.4 MGD). During the design of the upgrades, the WWTF initially considered a number of technologies and developed a short list that could reliably, and with limited power use, meet a TP effluent limit of 0.1 mg/L (with the option to meet 0.05 mg/L with added polishing), operate with different coagulants, handle extreme loading conditions, and remove metals.

The WWTF pilot-tested four technologies: BluePRO®, AquaDAF™, ActiFLO®, and CoMag™. Evaluation criteria for the technologies focused on performance, costs and O&M, environmental and aesthetic impacts, footprint, and responsiveness of the manufacturer. The Town of Westborough selected the ActiFLO® system by Kruger, Inc. for the following reasons:

- Lowest 20-year life cycle cost
- Track record and full-scale operations for TP removal in the US
- Ability to use multiple chemicals to achieve low TP levels
- Ability to fit the system within the existing hydraulics of the WWTF

ActiFLO® is a high-rate compact chemical and physical water clarification process in which water is flocculated with polymer and micro-sand prior to settling. The micro-sand enhances flocculation and acts as ballast, increasing the flocs' settling velocity. The properties of the resulting micro-sand ballasted flocs allow for clarifier design with short retention times, high rise rates, and a compact system footprint.

Construction costs for the upgraded WWTF totaled $54 million, which included significant baseline facility upgrades in addition to the 100% redundant ActiFLO® system, upgraded sludge processing, and other elements implemented for TP removal. Most elements of the WWTF were either upgraded or replaced, including the pavement and roofs of existing buildings. The WWTF also replaced aerators, enhanced odor control capture and capacity, rehabilitated primary and secondary clarifiers, replaced chemical disinfection with UV, converted the chlorine contact tanks to post aeration tanks, upgraded the entire electrical and process control system, added a SCADA system, and implemented green infrastructure. Many elements of the upgrade were needed but not all contributed to improving TP removal; that portion was roughly estimated at 47% of the total cost, or about $25 million. The Westborough WWTF now takes advantage of solar power to reduce its energy costs; solar energy accounts for approximately 5% of the facility's current energy use. Funding for construction on this project was secured through a combination of federal stimulus funds (American Recovery and Reinvestment Act – ARRA), SRF funds with a 0% interest rate, and an energy rebate. In addition, the WWTF receives an alternative energy credit rebate on an annual basis that helps to cover O&M costs. Construction activities occurred over a 30-month period.

The upgrades for TP removal purposes resulted in increased chemical and energy use. The current energy use is approximately 10% higher than prior to the upgrades, and is expected to further increase when flows increase. The energy impact at full capacity was budgeted at approximately 30% of pre-upgrade energy use. However, that additional energy use is not solely due to TP removal, and has been mitigated by the upgrades to a number of systems throughout the facility to more energy-efficient systems. Total energy costs are also partially offset by the implementation of solar energy generation. The overall upgrades to the WWTF required one additional operator on staff, raising total staff from 10.5 full-time equivalent (FTE) staff to 11.5 FTEs.

The upgrades have reduced effluent concentrations of TSS and BOD. Additional elements of the upgrade, such as the new bio-selector for phosphorus control and the grease collection system, have improved overall operations at the WWTF.

The WWTF operates the TP removal process year-round with reduced chemical use during the off-season, except when the system is taken offline for maintenance and cleanout, enabling the facility to meet an effluent TP concentration of 0.5 to 0.6 mg/L, or half the off-season limit. Since the new facility was completed in 2012, the Westborough WWTF has been successfully meeting effluent concentration limits of 0.1 mg/L from April through October, for a reduction in its seasonal TP loads to the Assabet River of approximately 9,170 lbs, or 95%, since 1998. The 2013 seasonal average TP concentration in Westborough's effluent was approximately 0.05 mg/L, half the seasonal TMDL requirement.

ASSABET RIVER WATER QUALITY IMPROVEMENTS

The Organization for the Assabet River (OAR) started sampling the river at a number of sampling locations more than 20 years ago. OAR then expanded their efforts to the Sudbury and Concord Rivers, and changed its name to OARS, but continued sampling the Assabet River at the same locations. According to OARS data (Figure 2), water quality in the main stem of the

Assabet River has significantly improved since the mid-90s, as TP concentrations were reduced by almost two orders of magnitude following successive reductions in effluent TP concentrations at the four main WWTFs discharging to the river.

According to OARS, the following TP effluent reductions were achieved by the WWTFs through the years, which help explain the significant TP reductions in the river observed in Figure 2:

- Pre-1993: No phosphorus removal
- 1993: Westborough and Marlborough reduce summer TP effluent to 1.0 mg/L
- 2000: All four WWTFs reduce summer TP effluent to 0.75 mg/L (interim permit limit)
- 2004: DEP issues the Assabet River Nutrient TMDL
- 2005-6: Phosphorus limits with compliance schedules are put into permits for all four WWTFs
- 2007-8: All four WWTFs reduce winter TP effluent to 1.0 mg/L
- 2009: The Hudson WWTF reduces summer TP effluent to 0.1 mg/L
- 2011: The Maynard WWTF reduces summer TP effluent to 0.1 mg/L
- 2012: All four WWTFs are meeting summer TP effluent concentrations of 0.1 mg/L or less

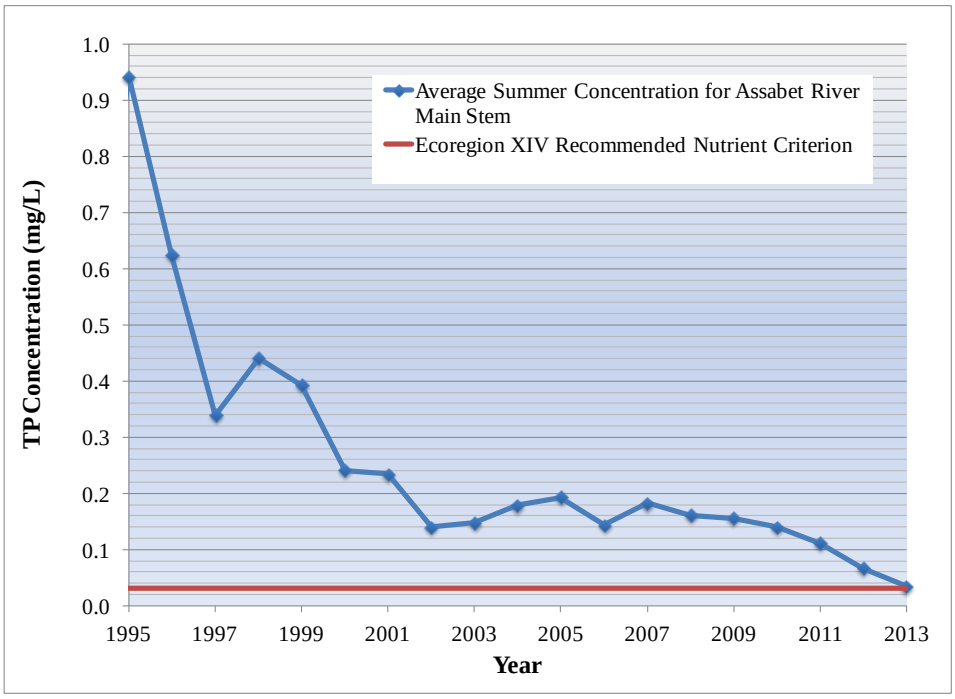

Figure 2. Average Summer TP Concentrations for the Main Stem of the Assabet River (OARS data)

Massachusetts does not have numeric phosphorus criteria for its rivers and streams in its water quality standards, and the TMDL for the Assabet River did not establish an in-stream target concentration; instead it used a weight-of-evidence approach for determining the desired load reductions. However, to give a frame of reference for how the river has improved, Figure 2 shows the average summer concentrations of phosphorus from 1995 to 2013 compared to the EPA's recommended nutrient criterion of 0.031 mg/L TP for rivers and streams in Ecoregion XIV (EPA, 2000), shown by the red line. After the most recent WWTF upgrades, summer TP concentrations in the Assabet River have dropped to levels close to the EPA's recommended value, indicating significant improvements in water quality.

SUMMARY

Although the Assabet River Consortium no longer meets regularly, it played a key role in uniting the WWTFs into a single voice during conversations with state and federal regulators, and demonstrated that a watershed-based approach to nutrient management can be implemented effectively through collaboration. Partnership between regulators and stakeholders can improve the permitting process through regular communication and result in a better understanding of cost implications for attaining certain environmental conditions.

This case study was developed from publicly available information and interviews with key people at the Consortium and the WWTFs. Each WWTF evaluated factors like capital and O&M costs, reuse of existing infrastructure, ease of operation, and land availability when choosing the treatment technology that would work best for its facility. The chief operators from the WWTFs all highly recommended conducting side-by-side pilot testing to confirm that a process works for a particular facility before investing in construction. Some of the operators also recommended asking for 20-year costs or life cycle costs in an RFP, because a technology with lower capital costs could incur significant O&M costs, resulting in higher long-term costs. For example, implementing a system where pumping is needed will require energy use that could be avoided with a gravity flow or feed system. An additional recommendation is to track chemical and energy use before and after the upgrade.

Table 1 provides a side-by-side comparison summary of the WWTF upgrades for each facility.

Table 1. Comparison of WWTF upgrades

WWTF Upgrade Characteristics	Hudson	Marlborough	Maynard	Westborough
Design flow (average daily in MGD)	2.65	4.15	1.45	7.68
Technology for advanced TP removal	AquaDAF™	BluePRO®	CoMag™	ActiFLO®
Effluent TP (mg/L)				
Seasonal (1998, source: TMDL)	0.64	3.44	0.64	0.79
Seasonal pre-upgrade (2004, DEP)	0.20	0.44	0.55	0.67
Seasonal post-upgrade (2013, DEP)	0.10	0.09	0.09	0.05
Reduction in seasonal TP loads since 1998	91%	97%	92%	95%
Construction cost (US$ million-M)				
Total cost	$15 M	$27.5 M	$12 M	$54 M
TP upgrade cost (approximate)	~$5 M	~$4 M	Unknown	~$25 M
O&M impacts				
Staffing increase (additional staff relative to existing staff)*	2 (+30%)	0 (0%)	0.8 (+20%)	1 (+9.5%)
Chemical use impact	Almost none	Almost none	Reduction	Increase
Electric use impact	Increase	Increase	Increase	Increase**

** Additional staff hired due to overall upgrades, not necessarily TP removal process.*
***Addition of solar power partially balanced the overall increase in energy demand at the Westborough WWTF.*

The bar graph in Figure 3 shows the seasonal TP loads for the four WWTFs from 1998 to 2013, and compares the loads to the TMDL allocations. The 1998 bar represents TP loads before discussions with the DEP. The 2000 bar represents an initial reduction achieved when all WWTFs started to adjust their existing systems to reduce TP loads. The 2004 bar represents the loads from the WWTFs following their commitment to reduce their seasonal effluent concentrations to 0.75 mg/L. This was achieved before the WWTFs were upgraded. The 2013 bar represents actual achievements in TP load reduction after the upgrades. Comparing the 2013 and TMDL bars shows that overall the facilities achieved greater load reductions than the TMDL requires.

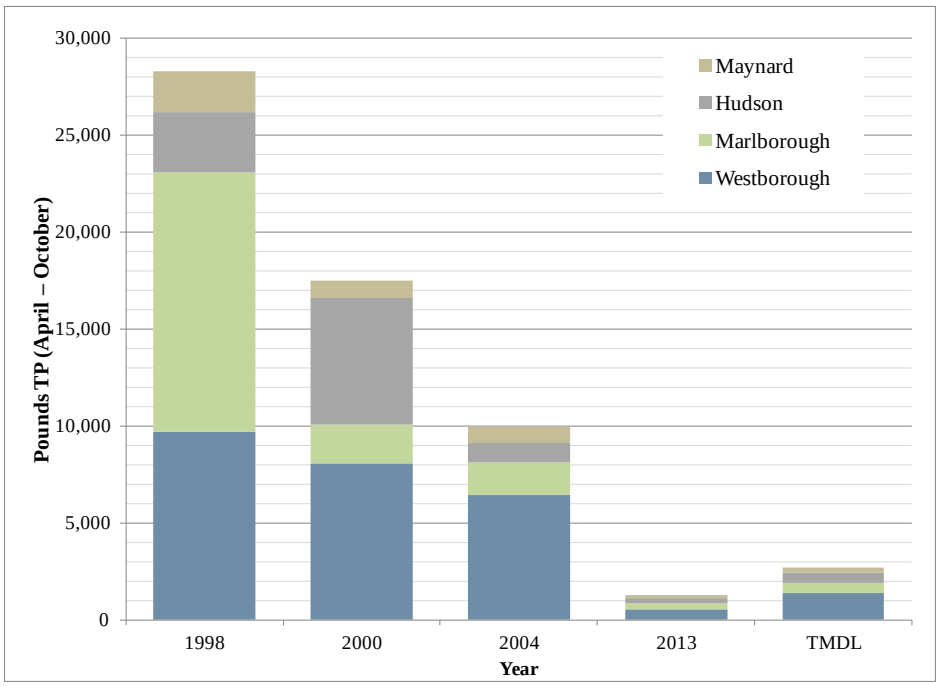

Figure 3. Cumulative Seasonal Loads for the WWTFs

The consecutive efforts of these four WWTFs over the past 20 years, culminating with the most recent infrastructure investments, have positively impacted water quality in the Assabet River. Summer TP concentrations in the river have been reduced by almost two orders of magnitude.

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