Application to the Representative Policy Board For Approval of a Project to Complete the Branford Hill Service Area Improvements

South Central Connecticut Regional Water Authority
February 20, 2020

Application to the Representative Policy Board
For Approval of a Project to Complete the
Branford Hill Area Improvements

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1. Statement of Application

This is an application of the South Central Connecticut Regional Water Authority (SCCRWA) to the Representative Policy Board (RPB) of the South Central Connecticut Regional Water District for approval of the Branford Hill Service Area Improvements, located in Branford, Connecticut. Section 19 of Special Act 77-98, as amended, requires the approval of the Representative Policy Board before the Authority commences any capital project costing more than $2 million. The project described in this application is estimated to cost $2,400,000.

The Branford Hill Area Improvements project includes the construction of approximately 5,200 linear feet (lf) of water transmission main located on West Main Street (Route 1) and continuing within the Montoya Drive right-of-way, all in the Town of Branford. The original project, as approved in the Fiscal Year (FY) 2020 Capital Improvements Plan, was proposed as a multi-year project spanning FY 2020-2021 at a total estimated cost of $1,750,000. Based on paving work proposed by State of Connecticut Department of Transportation (CTDOT), this project was expedited and the schedule condensed, with design and materials purchase commencing in FY 2019 and construction work scheduled for completion in FY 2020. As actual project costs accrued, it became evident that the project would exceed the $2 million threshold requiring RPB approval. The project is now nearing completion and due to unforeseen circumstances as described below, actual final project costs are estimated to be approximately $2,400,000. Section 33-B of Part III of the RPB's Rules of Practice requires approval of the RPB of any project whose original estimate was less than $2 million but where subsequent estimates exceed $2 million.

In January 2019, SCCRWA was notified by the CTDOT of a proposed roadway improvements project in the Branford Hill Service Area Improvements project area, which included full-width paving of Route 1, scheduled to commence in June 2019. Through discussions with the CTDOT staff, this date was shifted back to September 2019 to allow time for RWA to install our water main prior to the state's work. As a result, and in order to capture savings related to pavement restoration costs, RWA staff worked diligently to accelerate the project schedule to complete design work for the project in late winter and spring of 2019. Commencement of Phases I and II of the construction work soon followed by SCCRWA's on-call capital pipe contractor, John J. Brennan Construction (Brennan), in order to be complete the work on Route 1 by September and capitalize on the financial benefits associated with minimal paving requirements. Phases 1 and 2, whose extents are shown on the drawing in Appendix B, included the installation of the 12-inch and 16-inch main along Route 1. Additionally, the project timeframe was condensed from two years to nine months.

During the water transmission main installation, an issue was discovered with the proposed location of the new 16-inch water main on West Main Street (Phase 2). A conflict with the field markings of existing underground high-voltage electrical transmission lines resulted in the need to alter the proposed path of our water main. The only viable corridor available for the water transmission main in this highly utility-congested area of Route 1 was adjacent to an existing 8-inch water main installed in 1912. The decision was made to abandon the 108 year-old 8-inch main and transfer its services and hydrants. Significant additional costs, totaling approximately $400,000, were incurred as a result of this unanticipated work.

Additionally, after SCCRWA's project timeline was accelerated and shortened in an effort to complete the water main installation prior to the CTDOT's proposed roadway improvements project, we were notified that CTDOT's project was postponed due to budgetary constraints. This notification came in August 2019, two months into construction of the water main. Initially, the partnership with the CTDOT would have relieved SCCRWA from performing milling and overlay of our trenches which would have resulted in a estimated savings of approximately $175,000. With CTDOT's project postponed, we were also notified that instead of saving the cost of paving, we would now be responsible for these additional costs. Furthermore, SCCRWA expects to expend an additional $25,000 associated with final asphalt repair/restoration in the Spring, which will bring the total unanticipated costs related to paving to approximately $200,000.

There were also unanticipated additional costs associated with Phase III of the project, which consists of work in the Montoya right-of-way (ROW), the location of which is shown in Appendix B. Land surveying, and significant clearing, grubbing and tree removal was necessary for access and egress from the right of way. These additional costs, as well as restoration costs are estimated at $70,000, and considered minor relative to the overall project costs.

This project, which is nearing completion, was originally estimated to cost $1.75 million, well under the $2.0 million threshold where RPB approval is required. SCCRWA was anticipating significant cost savings by accelerating the project to meet the CTDOT's schedule. Unfortunately, the savings have not been realized and the additional paving cost, along with significant additional costs related to a conflict with the high-voltage electrical lines caused the project costs to exceed $2.0 million, therefore requiring this application submittal for RPB approval. A Lessons Learned (See Appendix C) was held with staff to determine if anything could have been done differently and how to avoid situations such as this in the future.

2. Description of Action Taken

The Branford Hill Area Improvements project was previously identified as part of a long-range plan to improve service and pumping costs in the central area of the transmission and distribution system, while providing redundancies and reducing costs at water treatment plants; as well as to address a historic area of low service pressure and fire flows. With the development of Brushy Plains Improvements project, which incorporated the Cherry Hill Service Area (Cherry Hill SA) into North Branford Service Area (North Branford SA), the future Branford Hill Area Improvements project was added to the 20-year Capital Improvements Plan in February 2016. In order to address the low pressures in the Branford Hill area, the initial phase of work associated the Brushy Plains Water System Improvements project needed to be completed first. The work associated with Brushy Plains included the installation of approximately 12,000 lf of new 12- and 16-inch water main to connect the North Branford SA to the Cherry Hill SA. With this service area connection in place, the project to address the historic low pressures in the Branford Hill area could now be executed.

The project was first included in the FY 2017 Capital Improvements Plan as a multi-year project spanning two fiscal years, with commencement in FY 2020 and completion of the project planned for FY 2021. It was accelerated in January of 2019 to align with planned CTDOT improvements, and scheduled and carried out in FY 2019 and FY 2020.

The project included three phases:

- Phase 1: the installation of approximately 1,400 feet of 12-inch main along West Main Street in the Branford Hill area
- Phase 2: the installation of 1,600 feet of 16-inch water main along the West Main Street corridor moving east
- Phase 3: an additional 2,200 feet of 16-inch main to be installed in the Montoya ROW

Additionally, existing gate valves were modified and new isolation gate valves installed to isolate the Branford Hill area from the Saltonstall SA, and provide a new connection to the expanded North Branford SA. Further details on the project limits and phasing of work are shown on the drawing in Appendix B.

During the work for Phase 2, the conflict with the planned location of the new 16-inch water main versus the location of the electric transmission lines required the pipe location to be changed. This resulted in the abandonment of an existing 8-inch main originally scheduled to remain in service. The services and connections from the 8-inch main were required to be transferred before the ongoing 16-inch main installation work could progress.

The Phase 3 main installation occurred in the Montoya ROW, consisting of an easement across privately owned land. The easement area was significantly overgrown, and survey and planning work with the landholder was coordinated during the project. Major tree and brush removal was required in order to facilitate construction equipment access and complete the pipe installation.

As the work was underway, the CTDOT paving project, which had dictated the project timing, was postponed. This resulted in additional paving restoration requirements, which were not anticipated during project planning and budgeting; increasing the overall cost of the project. The final restoration for the project is currently scheduled to occur in Spring 2020, pending weather conditions.

3. Need for Action Taken

This project was necessary to address long-standing low-pressure and fire flow issues in the Branford Hill area. The service provided by SCCRWA to the Branford Hill customers at this time is not reflective of the SCCRWA mission to provide high quality water and services, with the water pressure in this area below 30 psi on high demand days. Additionally, the available fire flow in the area on maximum demand days is less than desired, given the development of the area with businesses and multi-story office buildings. This analysis can be found in hydraulic modeling entitled *Proposed Connection of North Branford Service Area and Branford Hill area to Cherry Hill Service Area – Water Quality and Hydraulics Impacts, July 21, 2014 and revised on September 2, 2014*, prepared by Tighe & Bond and included as Appendix D for reference.

4. Analysis of the Alternatives to the Action Taken

4.1 Description of Alternatives

In determining the best course of action to address the issues in the Branford Hill area of the distribution system, SCCRWA considered the following alternatives. They included maintaining the status quo, the installation of a booster pumping station, and installation of a piping connection to the Branford Hill area to the North Branford SAs. Descriptions of the proposed alternatives are as follows:

1. **Alternative 1 – Status Quo:** The status quo alternative takes into account maintaining the existing level of service and fire flow availability in the Branford Hill area. This alternative was dismissed because it would not improve the long-standing low-pressure and fire flow issues. Taking no action does not allow for future improvements which advance towards SCCRWA's long-term goal to optimize our distribution system and reduce long-term operational expenses, as supported by hydraulic evaluations conducted in recent years, including the analysis in Appendix D.

2. **Alternative 2 – Booster Pump Station:** This alternative would involve the installation of a booster pumping station in the Branford Hill area, in order to improve water pressure and available fire flow. The station would consist of a larger fire pump and two smaller pumps for daily service. It

would pump water from the Saltonstall SA into the newly created Branford Hill SA. Property acquisition or a long-term easement and lease would be required to construct the facility. SCCRWA asset management practices for pump stations are to perform preventative maintenance and inspections on a monthly basis, and in addition, there would be maintenance for the driveway, and landscaping of the area. Piping improvements along the West Main Street corridor, which would allow the area to be separated from the existing SA, would be required in order to connect all affected customers. The capital investment for this alternative is estimated to be $2.0 to 3.0 million.

This alternative was dismissed due to the overall capital investment, and the ongoing operation and maintenance costs, estimated at $20,000 annually, which would be incurred over the life of the facility.

3. **Alternative 3 – Branford Hill to North Branford SA Piping Connection:** This alternative, which is the subject of this application, consists of the construction of approximately 5,200 linear feet (lf) of water transmission main located on West Main Street (Route 1) and continuing within the Montoya ROW, all in the Town of Branford.

   The modifications to Cherry Hill Pump Station that were completed as part of the Brushy Plains Improvements project included forethought to address the needs of Branford Hill, as included in the Brushy Plains Water System Improvements application approved by the RPB in July, 2016. As referenced in that application, it would be hydraulically possible to address the Branford Hill area following the completion of that work. That future plan included serving this location with Lake Gaillard WTP source water and the higher pressure of the North Branford SA through the installation of new main along Route 1 and the Montoya ROW. Hydraulic modeling entitled *Proposed Connection of North Branford Service Area and Branford Hill area to Cherry Hill Service Area – Water Quality and Hydraulics Impacts*, July 21, 2014 and revised on September 2, 2014, prepared by Tighe & Bond, supported this planning and was also included as part of the Brushy Plains project development. It is included in Appendix D for reference.

   This alternative includes the lowest life cycle operation and maintenance costs, and makes the improvements to service for the customers in Branford Hill, as identified in the project needs. Although initial capital costs for water mains are high, the reliability, long service life, and minimal operational and maintenance costs over the life cycle make them desirable when compared to the costs of operating and maintaining an additional pumping facility.

4.2 Alternatives Evaluation

The selected alternative, Alternative 3, was identified during development of the Brushy Plains Improvements project and planned for in the long-term Capital Improvements Plan in FY 2017, to be constructed in FY 2020-2021. It is the next step in SCCRWA's long-term plan to make improvements to the hydraulic grades in the distribution system, with the overall goal of providing redundancy and resiliency throughout the system. The project was expedited under the pretense that we could gain efficiencies and save significant costs in pavement restoration by partnering with the state on their roadway improvements project. Unfortunately, this was not the case.

5. Statement of the Cost Incurred

5.1 Capital Cost

This project will result in a capital expenditure of approximately $2.4 million. Table 1 illustrates the capital cost breakdown for this project below. John J. Brennan Construction, Inc., SCCRWA's on-call contractor, was the installation contractor on this project.

Table 1
Estimated Project Capital Cost

Cost Description	Estimated Cost
Original Project Budget	$1,745,000
Costs Incurred to Date (as of January 2020)	$1,200,000
Costs Incurred Pending Payment:	
Pavement Restoration	$ 200,000
Abandonment of 8" Main	$ 400,000
Additional Right-of-Way Work	$ 70,000
Additional Estimated Costs to Complete the Project *	$ 530,000
TOTAL ESTIMATED PROJECT COST	**$2,400,000**

* This amount represents pipe installation completed but not yet invoiced for Phase 3, restoration requirements in the Montoya Drive ROW and additional paving work in the Spring, dependent on CTDOT requirements.

5.2 Operation and Maintenance Cost

There is not a significant change in operational and maintenance costs associated with the installation of this transmission main. There is, however, a small savings of approximately $140 per MG of water (associated with treatment costs), which equates to $1500 per year, to serve the Branford Hill area. The area will now be served from North Branford SA whose source water is the Lake Gaillard Water Treatment Plant (WTP), which is less expensive to treat, compared to the area as currently served through Saltonstall SA, with source water from Saltonstall WTP.

5.3 Bonds or Other Obligations the SCCRWA Intends to Issue

The capital cost of the project to construction this transmission main is approximately $2.4 million. This project has been primarily financed by SCCRWA Water System Revenue Bonds and may also be financed through internally generated funds. Assuming debt financing, the annual average debt service would be approximately $131,630. As a result, the annual cost of this project to a typical residential customer would be approximately $0.94, based on the overall project cost of $2.4 million.

6. Statement of the Facts on Which the Board Is Expected to Rely in Granting the Authorization Sought

- This project addresses the Branford Hill area, which is a known area of deficiency in RWA's distribution system. The improvements included in this project were part of SCCRWA's long-term distribution system plan and made hydraulically possible with the completion of the Brushy Plains Improvements project.

- This project addresses historic issues with low pressure and reduced fire flows in the Branford Hill area by providing a connection to the North Branford Service Area.
- Completion of this project will allow for future long-term improvements to the Saltonstall Service Area, and the potential for a reduction in pumping leaving the Lake Saltonstall WTP.
- The project was accelerated, and the project timeframe condensed from two years to nine months, in order to accommodate the State of Connecticut Department of Transportation's project to perform roadway improvements to West Main Street (Route 1) in Branford and save paving costs during the fall of 2019.
- The project will exceed the $2.0 million threshold for RPB approval, mainly for the following reasons:
  - Additional unanticipated paving costs, estimated at $200,000 due to CTDOT's change in schedule for work on Route 1; and
  - The abandonment of an existing 8-inch main with associated service transfers in order to allow for installation of the new 16-inch main in the very congested Route 1, following mismarked underground high-voltage electrical lines, resulting in additional costs of approximately $400,000.
  - The Montoya ROW was not well defined and required surveying, significant land clearing and tree removal, as well as additional restoration in the Spring. This additional work has resulted in approximately $70,000 of projected costs.
- The estimated final project cost is approximately $2.4 million.

7. Explanation of Unusual Circumstances Involved in the Application

As discussed previously, this project was planned for and included in the capital budget for fiscal years 2020-2021. This was based on the completion of the Brushy Plains Improvements project, which would incorporate the Cherry Hill SA into the North Branford SA, therefore providing the means for addressing this long-standing deficiency in our distribution system. While planned and budgeted for, the timing of the project became critical when SCCRWA was notified of CTDOT plans to pave Route 1. If the road were to be paved prior to the water main being installed, SCCRWA would likely not have been allowed to install the main for a period of five years, in accordance with CTDOT requirements.

This project was not expected to require RPB approval. SCCRWA was anticipating significant cost savings by accelerating the project to meet the CTDOT's schedule. Unfortunately, this was not the case and the additional paving cost, along with significant additional costs related to a conflict with a high-voltage electrical line caused SCCRWA staff to request approval from the RPB while the project is nearing completion. These circumstances are further described below.

The FY 2020 Capital Budget narrative for the project noted that the total multi-year expenditures were estimated at $1,745,000. The final costs of the project are now estimated to be approximately $2,400,000. The difference between the originally estimated and estimated final cost is attributed to the following:

1. Pipe corridor relocation:
   The planned corridor for the location of the transmission main became unavailable when it was determined in the field that there was a conflict with high-voltage electrical transmission lines . As a result, the only viable corridor available for the transmission main in this highly utility-congested area of Route 1 was adjacent to the corridor used by an existing 8-inch main installed in 1912. The decision was made to retire and abandon the 108 year-old 8-inch main and transfer its services and hydrants to a parallel 16-inch main. Associated pavement cutting and additional pavement restoration costs were incurred as a result of the location on a state road, where the average pavement thickness at the site was an extraordinary 16 to 24-inches. Additional pavement restoration will likely be required by CTDOT this spring. The final cost of this change and associated work is estimated at $400,000.

2. Pavement Restorations:
   The RWA project timeline was accelerated in an effort to complete the water main installation prior to the State Department of Transportation's (DOT) plan to mill and overlay the area in the fall of 2019. Completing our work before the DOT's work would have relieved SCCRWA from performing a costly mill and overlay of its trenches and required SCCRWA to only perform a typical trench repair, resulting in a savings of asphalt report costs projected at $175,000. Two months after starting the project DOT informed RWA that its mill and overlay project had been postponed and that RWA would now be required to perform the mill and overlay of its trenches. The final cost of this work is estimated at up to $200,000.

3. Montoya Right-of-Way:
   Phase 3 of the project currently under construction consists of installing the 16-inch transmission main within an existing right-of-way. The right-of-way is not well defined and is overcome with heavy brush and large diameter trees. Land surveying, clearing, grubbing and tree removal was necessary for access and egress from the right-of-way. These costs were not figured into the original estimate. Subcontractor change orders totaling $38,300.00 have been approved to address the additional expense associated with this work. Additionally, an estimated $30,000.00 will be needed in the spring of 2020 to address restoration work in the right-of- way. The final total cost of this work is estimated at $70,000.

The total of the unanticipated costs is up to $670,000, the majority of which resulted from the pipe corridor relocation and pavement restoration costs. The magnitude of the corridor relocation costs was uncertain when the work was initiated and a timely decision was required. When evaluating the situation, both at that time and now, SCCRWA staff feel strongly that the work done was a prudent, efficient use of our customer's dollars. Pavement restoration requirements are dictated by the CTDOT. The CTDOT project was delayed due to their budget constraints. At the time that became known, SCCRWA's work was fully underway, and therefore were required to absorb these costs.

8. Conclusion

The Branford Hill area has experienced historically low pressure and reduced fire flows. A project was identified in 2014 to address these issues by providing a connection to the North Branford SA. The Brushy Plains Water System Improvements Project, which includes upgrades to the Cherry Hill Pump Station, made this connection feasible. As a result, the Branford Hill Service Area Improvements project was planned and budgeted in SCCRWA's long term Capital Improvements Plan to complete this connection and address these issues. With notification of the schedule for CTDOT's proposed roadway improvements project on Route 1 (West Main Street) in Branford, this project was accelerated.

During project execution, unforeseen conditions were encountered with another utility and the postponement of the CTDOT's project resulted in significant additional project costs being incurred by

SCCRWA. These costs have caused the project to exceed the threshold $2.0 million RPB project approval limit, as established by Section 19 of Special Act 77-98, as amended. SCCRWA management is therefore requesting the RPB's approval to complete this project.

APPENDIX A

Project Location Map

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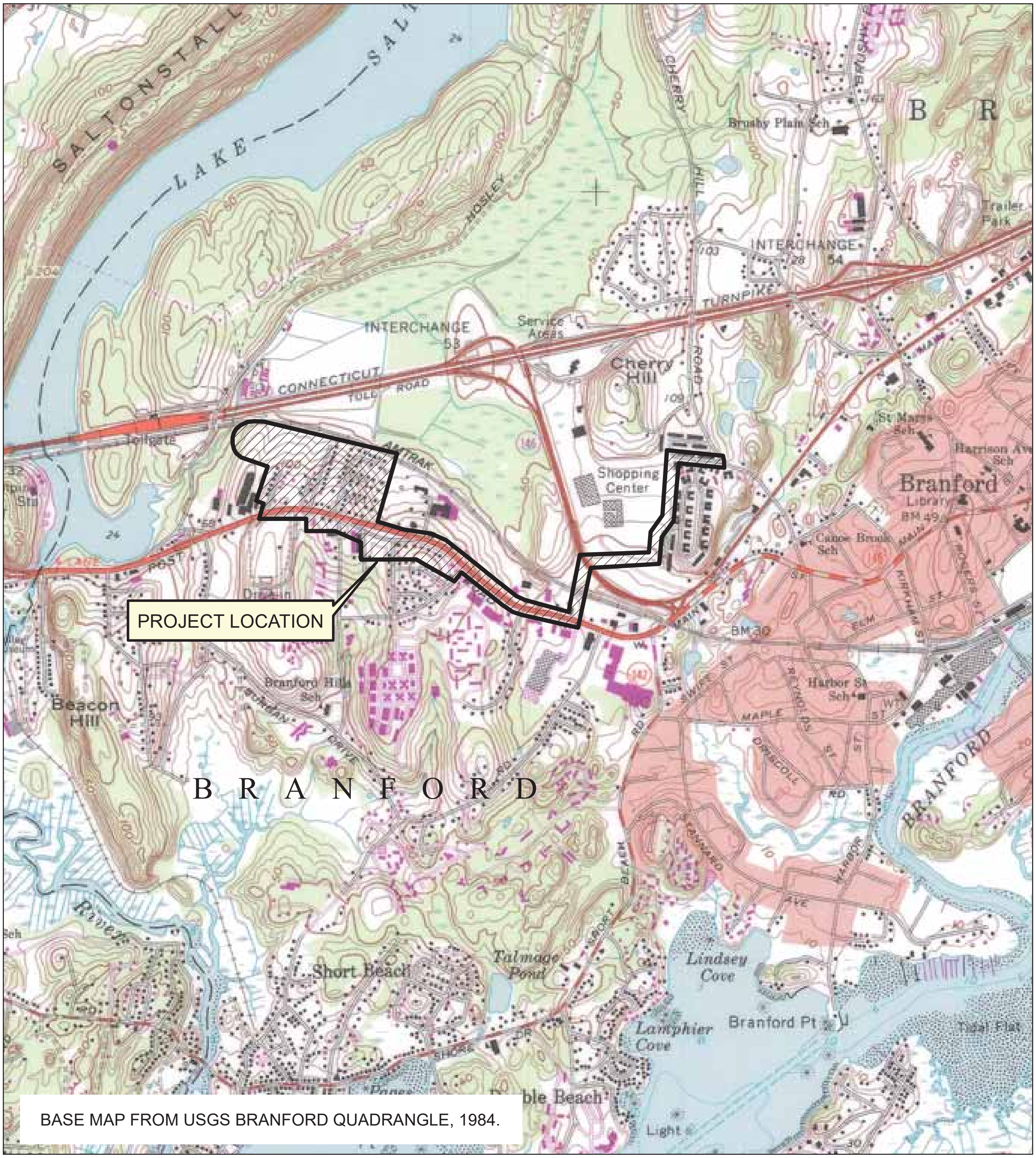

BRANFORD HILL SERVICE AREA IMPROVEMENTS

WEST MAIN STREET AND MONTOYA DRIVE
BRANFORD, CONNECTICUT

APPENDIX A

PROJECT LOCATION MAP

0 2,000 4,000 Feet

1 inch = 2,000 feet

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APPENDIX B

Work Summary Map

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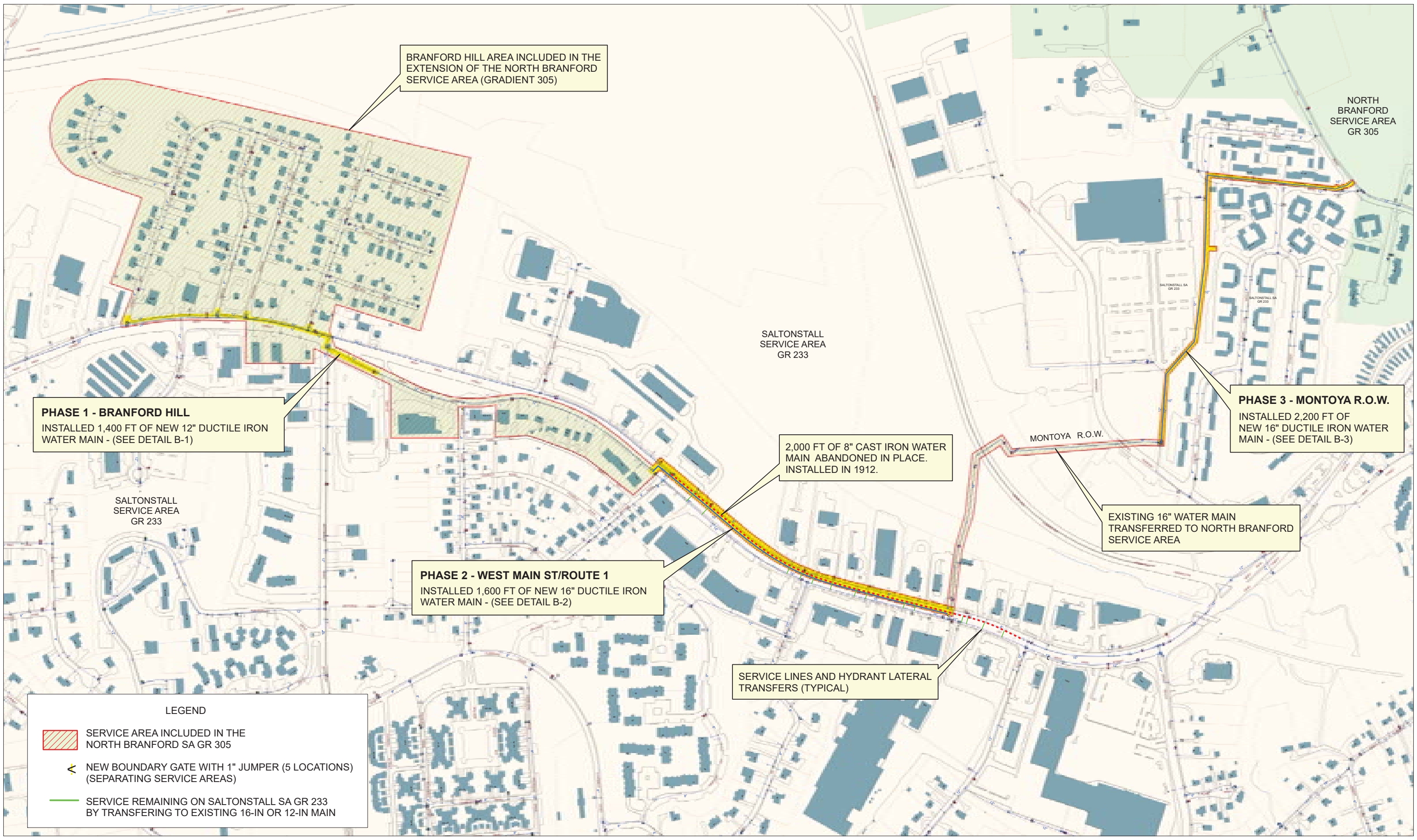

BRANFORD HILL SERVICE AREA IMPROVEMENTS

WEST MAIN STREET AND MONTOYA DRIVE
BRANFORD, CONNECTICUT

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APPENDIX B

WORK SUMMARY MAP

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BRANFORD HILL SERVICE AREA IMPROVEMENTS

WEST MAIN STREET AND MONTOYA DRIVE
BRANFORD, CONNECTICUT

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DETAIL B-1

WORK SUMMARY MAP

Regional Water Authority
Tapping the Possibilities

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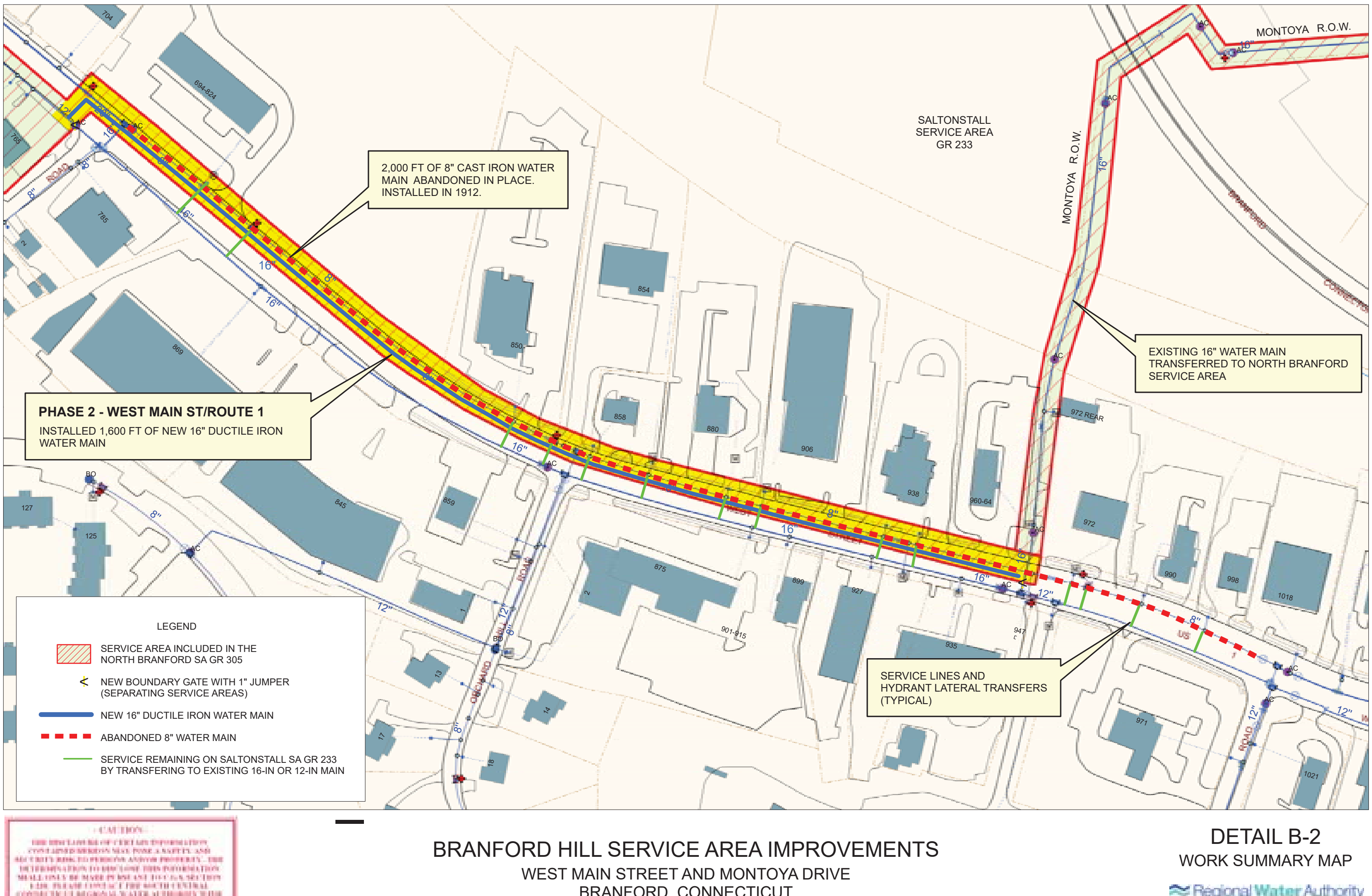

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BRANFORD HILL SERVICE AREA IMPROVEMENTS

WEST MAIN STREET AND MONTOYA DRIVE
BRANFORD, CONNECTICUT

DETAIL B-2
WORK SUMMARY MAP

Regional Water Authority
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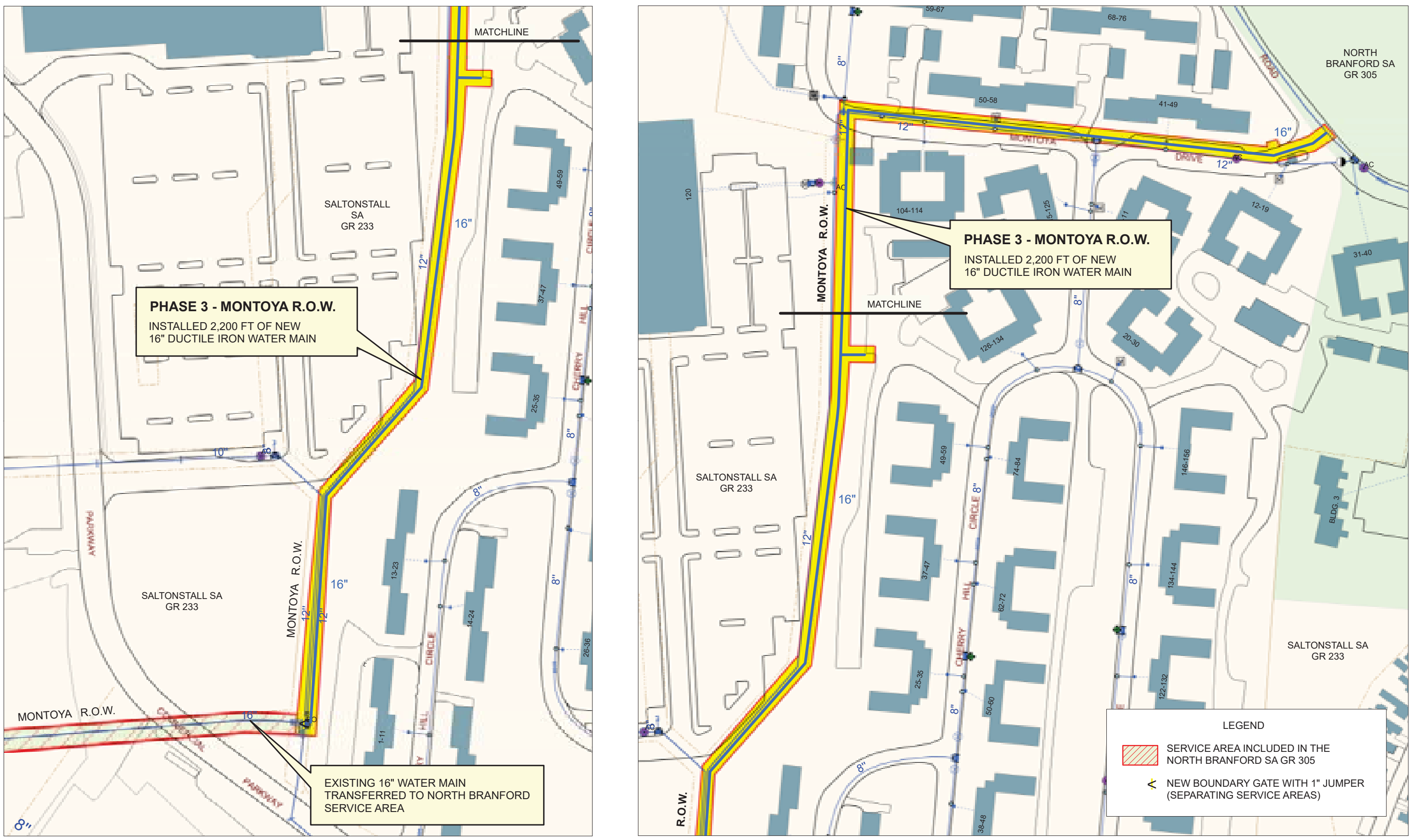

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BRANFORD HILL SERVICE AREA IMPROVEMENTS

WEST MAIN STREET AND MONTOYA DRIVE
BRANFORD, CONNECTICUT

DETAIL B-3

WORK SUMMARY MAP

Regional Water Authority
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APPENDIX C

Summary of Lessons Learned

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<u>Lessons Learned</u>

Project: Branford Hill Service Area Improvements

Summary of Lessons Learned Conducted February 11, 2020

Background:

This was a planned FY 2020 multi-year project, with an original project timeline encompassing FY 2020 and FY 2021. As a result of the CTDOT's intent to perform roadway improvements in our planned project area the project was accelerated for completion in FY 2020, condensing a two year project into nine months. CTDOT agreed to delay the start of their project to allow RWA to complete pipe installation work in Route 1. Because of this condensed timeline, the project was executed using the design/build philosophy. The highest goal of this extraordinarily complex project was the successful completion by the established deadline, which was attained.

Issues affecting the project cost were the relocation of the proposed pipe corridor and the cancellation of the CTDOT's roadway improvements project.

Lessons learned questions and focus areas:

- Contract execution: Because of the timing of the project and the need to begin quickly, this project was awarded under our Capital Pipe Bid. That contract is more suited to work in residential roadways, which led to cost increases for items such as saw cutting as a result of increased pavement depth. To avoid this situation from reoccurring, the method by which large pipe projects are procured (bid individually versus utilizing the Capital Pipe Contract) will be evaluated to ensure that costs are better defined upfront.

- Project budgeting: Pipe installation projects, as with other capital improvement projects, are budgeted with a standard 5% contingency. Because of the inherent uncertainty of underground conditions, pipe project contingencies will be examined and increased, where necessary, to a level appropriate for the specific pipe installation project.

- Notification to the Authority: Staff was aware that project costs would be close to the $2 million threshold in late Fall of 2019. Due to the inherent lag of contractor invoicing and concurrent work with multiple pipe crews working on the project, it was difficult to estimate what the final costs would be. But those estimates should have been performed to the best of staff's abilities. Had this been the case, the Authority could have been notified that the project was likely going to exceed $2 million and staff could have begun preparation of an RPB application in December 2019. Staff recognizes that there should have not been a delay in notifying the Authority of this potential issue while more precise cost estimates were being determined. In the future, when a project is budgeted at an amount that is near, but not over the $2 million approval threshold, real-time cost increase estimates will be developed and the Authority will be advised as early as is possible of potential cost over runs.

Appendix D

Proposed Connection of North Branford Service Area and Branford Hill Area to Cherry Hill Service Area - Water Quality and Hydraulics Impacts
July 21, 2014 and revised on September 2, 2014,
Prepared by Tighe & Bond

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Proposed connection of North Branford Service Area and Branford Hill Area to Cherry Hill Service Area – Water Quality and Hydraulics Impacts

TO: Beth Nesteriak, P.E. - RWA

FROM: John McClellan, Ph.D., P.E. and Lesley Eckert

COPY: Peter Grabowski, P.E.

DATE: July 21, 2014

REVISED SEPTEMBER 2, 2014

1 Background

Due to the influence of the Brushy Plain Standpipe, the Regional Water Authority's (RWA's) Cherry Hill Service Area (CHSA) typically has high water age and associated water quality issues. The RWA has considered various alternatives for improving the water quality in the CHSA including installation of a new elevated storage tank, installation of an air-stripping system in the existing tank, adding blow-offs, pipe looping, and allowing flow from the CHSA back to the Lake Saltonstall Service Area via a pressure reducing valve (PRV). These alternatives were discussed in Tighe & Bond's *Cherry Hill Service Area Water Quality Modeling Analysis* dated November 26, 2012 (included in Appendix A).

Improvements to the Brushy Plain Standpipe, including a spray-aeration system for total trihalomethane (TTHM) removal and a rechlorination system, were designed and bid in May 2014. If the RWA decides to move forward with the spray-aeration system project, approval from the Representative Policy Board will be required, which will put the project off until 2015.

As an alternative to the Brushy Plain Standpipe Improvements project, RWA is considering supplying the CHSA from the North Branford Service Area (NBSA) via a new approximately 5,000 foot long water main from Queach Road in the NBSA to Laurel Hill Road in the CHSA. Under this alternative, the tank would be eliminated. The Cherry Hill Pump Station (CHPS) would remain. Preliminary modeling performed by Tighe & Bond indicated that this alternative would be hydraulically feasible.

Additionally, RWA is considering serving the Branford Hill area, which is currently part of the Lake Saltonstall Service Area (LSSA), from the CHSA. The Branford Hill area has relatively low pressure under existing conditions, and would have unacceptably low pressure if connected to the LSSA when the LSSA hydraulic grade is lowered in the future in accordance with RWA's long term plans. Connecting the Branford Hill area to the CHSA would address these issues.

The hydraulic model of the RWA distribution system developed by Tighe & Bond for previous studies was used to evaluate hydraulic and water quality effects of the aforementioned proposed distribution system modifications. The results of the evaluation are presented in this memorandum.

2 Results

For purposes of this evaluation, the following types of model simulations were prepared:

- General pressure analysis – performed assuming maximum day, peak hour demand conditions.
- Available Fire Flow (AFF) analysis – performed assuming maximum day demand conditions.
- Water age and source contribution analysis – performed assuming average day demand conditions.

The system-wide demand for the average day demand scenarios is 49 mgd, based on SCADA data from June 25, 2012. Water age and source contribution results are presented as averages over a 24-hour period under average day demand conditions. The system-wide demand for the AFF analysis is 89 mgd, representing max day demand. The max day demand is based on SCADA data from July 13, 2012. The system-wide demand for the general pressure analyses is 122 mgd, representing the peak hour demand during the max day, also based on July 13, 2012. Refer to Appendix B for additional description of the model.

2.1 Proposed Connection of CHSA to NBSA

The CHSA and NBSA have nominal hydraulic grades (overflow elevation of the existing tanks) of 305 ft MSL. The proposed interconnection consists of a new water main running from Queach Road in the NBSA to Laurel Hill Road in the CHSA. The new main would intercept Laurel Hill Road to the north of the Rolling Hill Road intersection and continue in Laurel Hill Road to the existing 12-inch main near the intersection of Pineview Drive. Two water main improvements alternatives were considered. Alternative 1 consists of a 16-inch diameter Queach Road-Laurel Hill Road line and replacement of approximately 1,750 ft of existing 8-inch main in Brookhills Road with 16-inch main. The Brookhills Road line is a hydraulic bottleneck in the flow path between the two service areas and replacing it would reduce headloss during periods of high demand. Under Alternative 1, the existing CHPS pumping equipment would remain in service. Alternative 2 consists of a 12-inch diameter Queach Road-Laurel Hill line and does not include the Brookhill Road water main, but does include a pumping equipment upgrade at the CHPS. The additional pumping capacity would be necessary to provide adequate fire flow under Alternative 2 due to the additional headloss resulting from the smaller diameter water mains in the flow path from the NBSA to the CHSA. The Brushy Plain Tank would be decommissioned under both alternatives. The proposed water main improvements are presented in Figure 2-1.

2.2 Proposed Connection of Branford Hill Area to CHSA

The Branford Hill area and proposed water main improvements are shown in Figure 2-2. This area is currently connected to the LSSA, which has a nominal hydraulic grade of 233 ft MSL. Connection of this area to the CHSA, which has a nominal hydraulic grade of 305 ft MSL, is proposed. The proposed connection would require the following water main improvements:

- Approximately 2,200 feet of new 16-inch water main on Montoya Drive and Montoya Circle

- Approximately 1,600 feet of new 16-inch water main and 1,300 feet of new 12-inch water main on West Main Street (Route 1)

- Closing existing gate valves and/or installing new valves as necessary to isolate the Branford Hill Area from the LSSA

It is noted that new 16-inch diameter water mains on Montoya Drive, Montoya Circle, and West Main Street are proposed. In the 2014 *New Haven Service Area Improvements Study* prepared by Tata & Howard, 12-inch mains were proposed for these locations. The 16-inch mains are necessary to minimize headloss to provide adequate fireflow.

The 2014 *New Haven Service Area Improvements Study* shows the proposed new 12-inch water main on West Main Street from Kenyon Road to Gilbert Lane on the south side of the West Main Street, with crossings serving streets on the north side. It may be possible to cross West Main Street only once between Jefferson Road and Mona Avenue. The remainder of the new 12-inch main would run on the north side of West Main Street, connecting to Pompano Avenue, Gentile Place, and Gilbert Lane without crossing West Main Street.

2.3 Model Results - Hydraulics

2.3.1 Connection of CHSA to NBSA

Simulations were prepared to evaluate AFF and pressure under max day and peak hour demand conditions, respectively, assuming the CHSA and NBSA are connected as described in Section 2.1. It is noted that “max day demand” means the average of the hourly flow rates that occurred on the max day, while “peak hour demand” is the highest hourly flow rate on the max day.

The original proposed operational concept was to utilize the North Branford Pump Station as the primary source of supply for the combined CHSA/NBSA service area. We prepared several preliminary simulations attempting to serve the combined service area with the NBPS only. It was determined that the CHPS must operate some of the time in order to provide adequate pressure throughout the CHSA. The simulations indicated that the CHPS would need to be operated approximately 8 hours per day under average day demand conditions, and 16 hours per day under max day demand conditions in order to maintain pressure above 20 psi in an area in the vicinity of the Brushy Hill Standpipe. For purposes of this study, one CHPS pump is assumed to be operating during high demand periods of the day for the aforementioned durations for the water age, source contribution, and pressure simulations; and two pumps are assumed operating for AFF simulations. For the average day demand (water age and source contribution) simulations, the pressure reducing valve in the CHPS is assumed to be opened for 7 hours per day during the overnight period at a flow rate of 200 gpm, allowing Lake Gaillard WTP water to flow from the CHSA into the LSSA. For the Connection of CHSA to NBSA scenarios, the Alternative 1 water main improvements discussed in Section 2.1 are assumed.

Figure 2-3 shows model-predicted pressures under peak hour conditions, with the existing system configuration. For this baseline simulation, the Brushy Plain Tank is in service, one pump is running at the CHPS, and the system is experiencing peak hour demand. Figure 2-4 shows pressure for the proposed combined NBSA/CHSA, with the tank eliminated, the water main improvements discussed above in place, and one CHPS running. The model predicts a minimum pressure in the CHSA of 25 psi under existing conditions, and 26 psi under the proposed conditions.

Figure 2-5 shows model predicted AFF under the existing system configuration, max day demand, and two CHPS pumps running. Figure 2-6 shows model-predicted AFF for the proposed combined NBSA/CHSA with two CHPS pumps running. The model predicted AFF results for the two ISO sites within the CHSA under existing and proposed conditions are presented in Table 2-1.

TABLE 2-1
Available Fire Flow – CHSA and NBSA Connected

ISO Site	ISO Needed Fire Flow	Model Predicted AFF (gpm)	
		Existing System	CHSA-NBSA Connected
Brushy Plain Rd & Cedar St	2,500	4,016	2,539
Green Farm Rd & Hemlock Rd	2,000	3,061	2,325

As indicated in the table, the AFF would decrease under the proposed conditions; however, the AFF at the two ISO sites within the CHSA would remain above the ISO Needed Fire Flow at both locations. It is noted that the AFF determined in the ISO field tests is less than the model-predicted AFF for the existing system presented in Table 2-1. The model-predicted AFF of the existing system configuration is sensitive to the Brushy Plain tank level and to the number of pumps operating at the CHPS. The status of the pump station and the tank level at the time of the field tests is not known; however, with the CHPS off and the tank level set to match the static pressure observed during the field tests, the model predicted residual pressures were within 5 psi of the observed pressures.

2.3.2 Connection of CHSA, Branford Hill, and NBSA

Simulations were performed to evaluate AFF and pressure under max day and peak hour demand conditions, respectively, assuming the CHSA, NBSA, and Branford Hill area are connected as described in Section 2.1 and 2.2. For these simulations, the Alternative 2 water main improvements (12-inch diameter line connecting the NBSA and CHSA, no water main improvements in Brookhill Road, and CHPS pumping equipment upgrades) are assumed.

As discussed in Section 2.3.1, the operational strategy for the combined service area must include operating the CHPS during periods of high demand to maintain adequate pressure throughout the CHSA. For purposes of the hydraulics analysis presented in this section, one pump is assumed to be operating for 8 hours per day during high demand periods for the average day (water age, source contribution) simulations; one pump is assumed to be operating for 16 hours for the peak hour (pressure) simulations; and two pumps are operating for AFF simulations. Additionally, the PRV located in the CHPS is assumed to be flowing at 200 gpm for 7 hours during the overnight periods for the average day simulations.

Refer to Figure 2-3 for model-predicted pressures under peak hour conditions, with the existing system configuration. For this baseline simulation, the Brushy Plain Tank is in service, one pump is running at the CHPS, and the system is experiencing peak hour demand. Figure 2-7 shows pressure for the proposed combined NBSA/CHSA including the Branford Hill area, with the tank eliminated, the water main improvements discussed above in place, and one pump running in the CHPS. The model predicts minimum pressures of 25 psi and 28 psi in the CHSA and Branford Hill areas, respectively, under existing conditions.

Under proposed conditions, the model predicted pressures are 29 psi for the CHSA and 74 psi for the Branford Hill area.

Figure 2-5 shows model predicted AFF under the existing system configuration, max day demand, and two existing CHPS pumps running. Figure 2-8 shows model-predicted AFF for the proposed combined NBSA/CHSA with the Branford Hill area connected and two upgraded CHPS pumps running. The upgraded pumps are assumed to have a combined discharge of 1,300 gpm at 135 ft total dynamic head. The model predicted AFF results for the two ISO sites within the CHSA under existing and proposed conditions are presented in Table 2-2.

TABLE 2-2
Available Fire Flow – CHSA, NBSA, and Branford Hill Connected

ISO Site	ISO Needed Fire Flow	Model Predicted AFF (gpm)	
		Existing System	CHSA, NBSA, and Branford Hill Connected
Brushy Plain Rd & Cedar St (CHSA)	2,500	4,016	2,562
Green Farm Rd & Hemlock Rd. (CHSA)	2,000	3,061	2,284
West Main St. & Brainerd Rd. (Branford Hill area)	5,000/3,500(1)	4,516	4,087

(1) Needed fire flow at West Main St & Brainerd Rd listed as 5,000 gpm but 3,500 gpm is the maximum required to be provided

As indicated in the table, the AFF would decrease under the proposed conditions; however, the AFF at the two ISO sites within the CHSA and one site within the Branford Hill area would remain above the ISO Needed Fire Flow.

2.3.3 Hydraulics Summary

A summary and comparison of model predicted AFF for existing and proposed conditions is presented in Table 2-3. A summary and comparison of peak hour pressures is presented in Table 2-4.

TABLE 2-3
AFF Summary and Comparison(1)

ISO Site	ISO Needed Fire Flow	Model Predicted AFF (gpm) Existing Conditions	CHSA-NBSA Connected	CHSA, NBSA, and Branford Hill Connected
West Main St & Brainerd Rd (Branford Hill Area)	5,000/3,500(2)	4,516	4,983	4,087
Brushy Plain Rd & Cedar St. (existing CHSA)	2,500	4,016	2,539	2,562
Green Farm Rd & Hemlock Rd (existing CHSA)	2,000	3,061	2,325	2,284

(1) Conditions: MDD, both CHPS pumps on, NBPS on.
(2) Needed fire flow at West Main St & Brainerd Rd listed as 5,000 gpm but 3,500 gpm is the maximum required to be provided

TABLE 2-4
Pressure Summary and Comparison(1)

Item	Existing Conditions	CHSA-NBSA Connected	CHSA, NBSA, and Branford Hill Connected
Min Pressure in CHSA (psi)	25	26	29
Min Pressure in Branford Hill area (psi)	28	27	74

(1) Conditions: MDD, 1 CHPS pump on, NBPS on.

2.4 Model Results – Water Quality

2.4.1 Connection of CHSA to NBSA

Simulations were performed to evaluate water age and source contribution under average day demand conditions, assuming the CHSA and NBSA are connected as described in Section 2.1.

As discussed in Section 2.3.1, the operational strategy for the combined service area must include operating the CHPS during periods of high demand to maintain adequate pressure throughout the CHSA. For purposes of the water quality analysis presented in this section, one CHSA pump is assumed to be operating for 8 hours per day for the average day simulations. Additionally, the PRV located in the CHPS is assumed to operate for 7 hours per day during the overnight period, allowing Lake Gaillard WTP water to flow from the NBSA to the LSSA via the CHSA. The North Branford Pump Station is controlled by the level in the North Branford Tank, such that the tank level fluctuates between 35 feet and 47 feet.

Figure 2-9 shows model-predicted water age under average day conditions, with the existing system configuration. For this baseline simulation, the Brushy Plain Tank is in service, one pump is running at the CHPS, and the NBPS is controlled by the North Branford Tank. Figure 2-10 shows water age for the proposed combined NBSA/CHSA with the tank eliminated, the water main improvements discussed above in place, and one pump and the PRV in the CHPS operating as discussed above. Tables 2-5 and 2-6 present service area-wide water age results for the CHPSA, NBSA, and LSSA.

TABLE 2-5
Average Water Age - All Model Nodes in Service Area

Scenario	Existing Cherry Hill SA	Existing N. Branford SA	Existing Saltonstall SA
Existing Conditions	231	108	38
CHSA-NBSA Connected	96	94	45

TABLE 2-6
Number of Model Nodes in Service Area with Average Water Age > 100 hrs

Scenario	Existing Cherry Hill SA	Existing N. Branford SA	Existing Saltonstall SA
Number of Nodes in SA (1)	117	499	1924
Number of Nodes with Water Age >100 hours			
Existing Conditions	87	272	114
CHSA-NBSA Connected	39	138	151

(1) Excluding nodes on dead ends with no demands

As indicated in the tables, the model predicts that the proposed interconnection results in a significant decrease in water age in the CHSA, a modest decrease in water age in the NBSA, and a small increase in the water age in the LSSA.

Figure 2-11 shows model-predicted source contribution under existing system configuration. Figure 2-12 shows source contribution under the proposed configuration. As indicated in the figures, the Lake Saltonstall WTP contribution in the CHSA is almost 100% under the existing system configuration, but the CHSA is predominantly supplied by Lake Gaillard WTP water under the proposed system configuration. The NBSA is supplied entirely by the Lake Gaillard WTP with the existing system configuration. Under the proposed configuration, the area in the vicinity of the proposed interconnection would be influenced slightly by the Lake Saltonstall WTP.

2.4.2 Connection of CHSA, Branford Hill, and NBSA

Simulations were performed to evaluate water age and source contribution under average day demand conditions, assuming the CHSA and NBSA are connected as described in Section 2.1, and the Branford Hill area is connected to the CHSA as described in Section 2.2.

As discussed in Section 2.3.1, the operational strategy for the combined service area must include operating the CHPS during periods of high demand in order to maintain adequate pressure throughout the CHSA.

Refer to Figure 2-9 for model-predicted water age under average day demand conditions, with the existing system configuration. For the baseline simulation, the Brushy Plain Tank is in service, one pump is running at the CHPS, and the NBPS is controlled by the North

Branford Tank. Figure 2-13 shows model predicted water age for the proposed combined NBSA/CHSA including the Branford Hill area. Tables 2-7 and 2-8 present water age results for the CHSA, NBSA, and LSSA.

TABLE 2-7

Average Water Age - All Model Nodes in Service Area

Scenario	Existing Cherry Hill SA	Existing N. Branford SA	Existing Saltonstall SA
Existing Conditions	231	108	38
CHSA, NBSA, and Branford Hill Area Connected	84	95	46

TABLE 2-8

Number of Model Nodes in Service Area with Average Water Age > 100 hrs

Scenario	Existing Cherry Hill SA	Existing N. Branford SA	Existing Saltonstall SA
Number of Nodes in SA(1)	117	499	1924
Number of Nodes with Water Age >100 hours			
Existing Conditions	87	272	114
CHSA, NBSA, and Branford Hill Area Connected	22	119	181

(1) Excluding nodes on dead ends with no demands

Similar to the results presented in Section 2.4.1, the model predicts that the proposed interconnection results in a significant decrease in water age in the CHSA, a modest decrease in water age in the NBSA, and a slight increase in the water age in the LSSA. It is noted that the Branford Hill area would experience a significant increase in water age if connected to the CHSA.

Figure 2-11 shows model-predicted source contribution under existing system configuration. Figure 2-14 shows source contribution under the proposed configuration. As indicated in the figures, the Lake Saltonstall WTP contribution in the CHSA is almost 100% under the existing system configuration; however, the contribution of the Lake Gaillard WTP is significant under the proposed system configuration, particularly in the northern part of the system near the interconnection point. The influence of the Lake Saltonstall WTP on the NBSA is small under the proposed configuration.

2.4.3 Water Quality Summary

Table 2-9 presents a summary of water age and source contribution results for the CHSA.

TABLE 2-9
Water Quality Summary

Item	Existing Conditions	CHSA-NBSA Connected	CHSA, NBSA, and Branford Hill Connected
Average Water Age			
CHSA	231	96	84
NBSA	108	94	95
LSSA	38	45	46
Number of Nodes with Water Age >100 Hours			
CHSA	87	39	22
NBSA	272	138	119
LSSA	114	151	181
Source Contribution			
CHSA	Entirely LSWTP	Predominantly LGWTP	Mix – Mostly LGWTP
NBSA	Entirely LGWTP	Predominantly LGWTP	Predominantly LGWTP
LSSA	Entirely LSWTP	Predominantly LSWTP	Predominantly LSWTP

3 Costs

A conceptual cost estimate for connecting the NBSA and the CHPSA assuming Water Main Improvement Alternative 1 is presented in Table 3-1. This alternative includes new 16-inch diameter water main from Queach Road to Laurel Hill Road and new 16-inch main in Brookhill Road. Connection of the Branford Hill area to the CHSA is not included in this alternative, nor are improvements to the Cherry Hill PS. More detailed estimates are included in Appendix C.

TABLE 3-1
Conceptual Cost Estimate - Connection of NBSA and CHSA
August 2014

Item	Conceptual Cost Estimate
Alternative 1 Water Main Improvements – Brookhills Road, Queach Road to Laurel Hill Road, Laurel Hill Road. 7,400 ft of 16-inch water main	$2,770,000
Demolish Brushy Plain Standpipe	$120,000
Engineering and Contingency - 40%	$1,156,000
Project Total	$ 4,046,000

A conceptual cost estimate for connecting the NBSA and the Branford Hill area of the LSSA to the CHPSA assuming Water Main Improvement Alternative 2 is presented in Table 3-2. This alternative includes new 12-inch diameter water main from Queach Road to Laurel Hill Road and new 12-inch main connecting the CHSA to the Branford Hill area on Montoya Drive and in West Main Street. Alternative 2 also includes an upgrade to the Cherry Hill PS pumping equipment in order to provide adequate fire flow with reduced pipe diameter along the flow path between the NBSA and the CHSA. More detailed estimates are included in Appendix C.

TABLE 3-2
Connection of NBSA and CHSA, incorporation of Branford Hill Area in CHSA
August 2014

Item	Conceptual Cost Estimate
Alternative 2 Water Main Improvements - Queach Road to Laurel Hill Road, 5,600 ft of 16 inch water main	$2,480,000
Alternative 2 Water Main Improvements -Montoya Drive, West Main Street. 3,800 ft of 12-inch water main	$770,000
CHPS Pumping Equipment Upgrade	$320,000
Demolish Brushy Plain Tank	$120,000
Construction Subtotal	$3,690,000
Engineering and Contingency - 40%	$1,476,000
Project Total	$5,166,000

4 Conclusions

Conclusions regarding the effect of the proposed connections of the CHSA to the NBSA and the Branford Hill area of the LSSA to the CHSA are as follows.

Impact on pressure: In order to maintain adequate pressure in the CHSA the CHPS would need to run during periods of high system demand. If one CHPS pump is running, the minimum pressures experienced in the CHSA would be comparable to those experienced under existing conditions. Minimum pressure in the Branford Hill area would be increased by connection to the CHSA from ~30 psi to ~70 psi.

Impact on available fire flow: The available fire flow in the CHSA and Branford Hill area would be reduced under both of the proposed service area connection concepts compared to the available fire flow with the existing system configuration; however, the model predicts that the ISO needed fire flow could be provided in both cases. The CHPS pumping equipment would need to be upgraded to provide adequate fire flow if the Branford Hill area is connected to the CHSA.

In general, the proposed connections would provide adequate pressure and fire flow. Additionally, the CHPS would need to be available to maintain adequate pressure and fire flow, although it would need to operate for less than half the day under average demand conditions.

Impact on water quality: The proposed connections would result in a significant decrease in water age in the CHSA due to the elimination of the Brushy Plain Tank. A significant portion of the CHSA supply would be provided by the Lake Gaillard WTP, which would also benefit water quality, as the Lake Gaillard WTP produces higher quality water than the Lake Saltonstall WTP.

Costs: The cost of the water main improvements connecting the NBSA and the Branford Hill area to the CHSA and upgrading the Cherry Hill pump station as required to provide adequate fire flow is estimated at approximately $5,166,000. This cost is higher than the $1,755,608 bid received for painting the Brushy Plain Tank and installing a THM removal system. However, the proposed interconnection project would improve water quality, and reduce future maintenance costs by eliminating the Brushy Plain standpipe.

In summary, the proposed distribution system modifications consisting of decommissioning the Brushy Hill Standpipe, connection of the CHSA and NBSA, connection of the Branford Hill area to the CHSA is hydraulically feasible and would improve water quality and provide for some redundancy to the Saltonstall Service Area along with increasing pressure in Branford Hill.

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Pump Station
Source
Tank
Existing Water Main
Proposed Water Main

Figure 2-1
Connection of CHSA to NBSA
Proposed Water
Main Improvements
South Central Connecticut
Regional Water Authority

Tighe&Bond

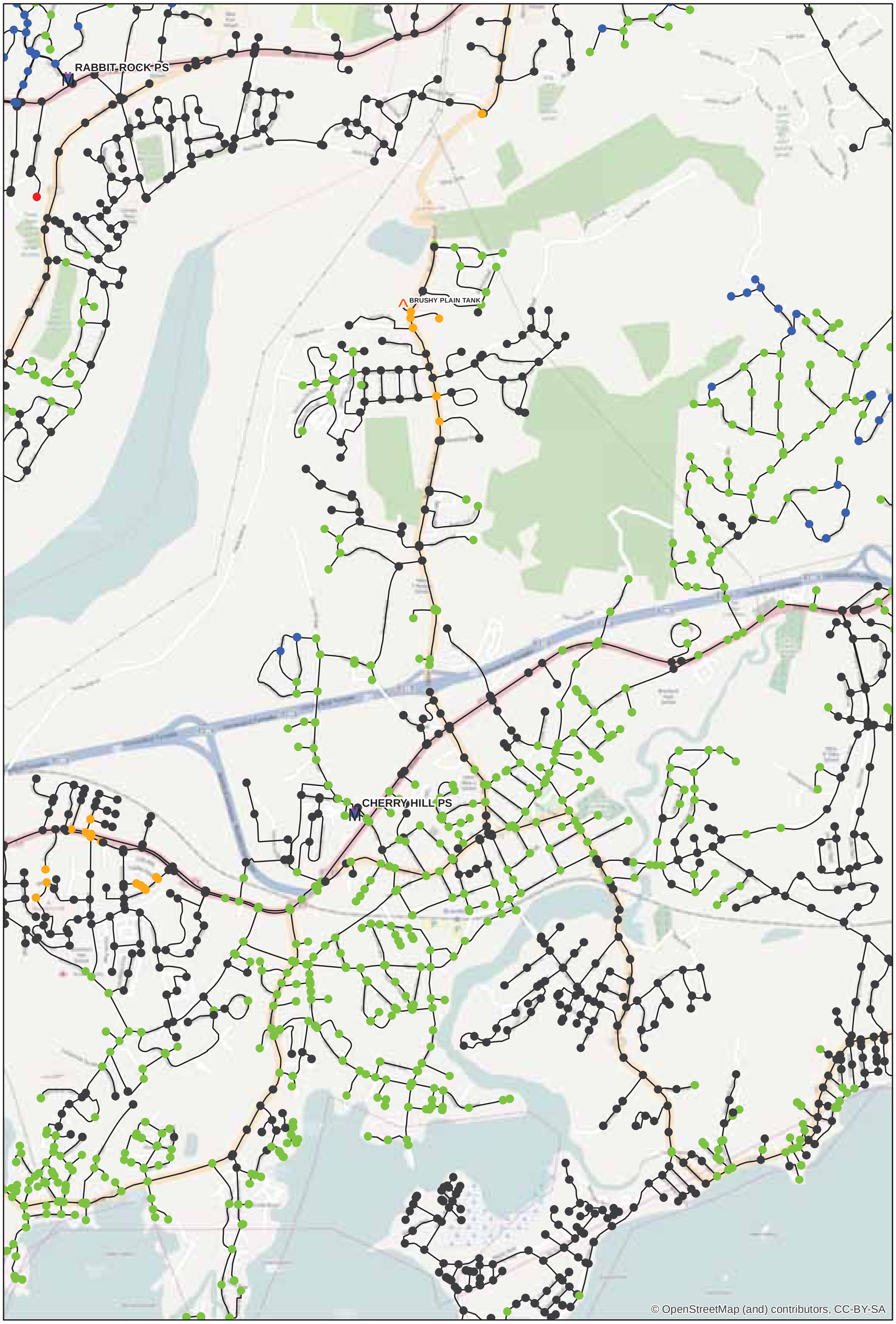
Path: J:\S\S1889 Regional Water Authority\25 - Brushy Plain Tank\Phase 5 - Modeling & Tech Memo\Model\ArcMap\Proposed_WM_Imps.mxd

Pump Station
Source
Tank
Existing Water Main
Proposed Water Main
Expanded Cherry Hill SA

Figure 2-2
Branford Hill
Proposed Water
Main Improvements

South Central Connecticut
Regional Water Authority

Tighe&Bond



Pressure (psi)

- <20
- 21 - 35
- 36 - 70
- 71 - 100
- >100

- Pump Station
- Source
- Tank

Figure 2-3
Model Predicted Pressure
Existing Conditions

South Central Connecticut
Regional Water Authority

Tighe&Bond

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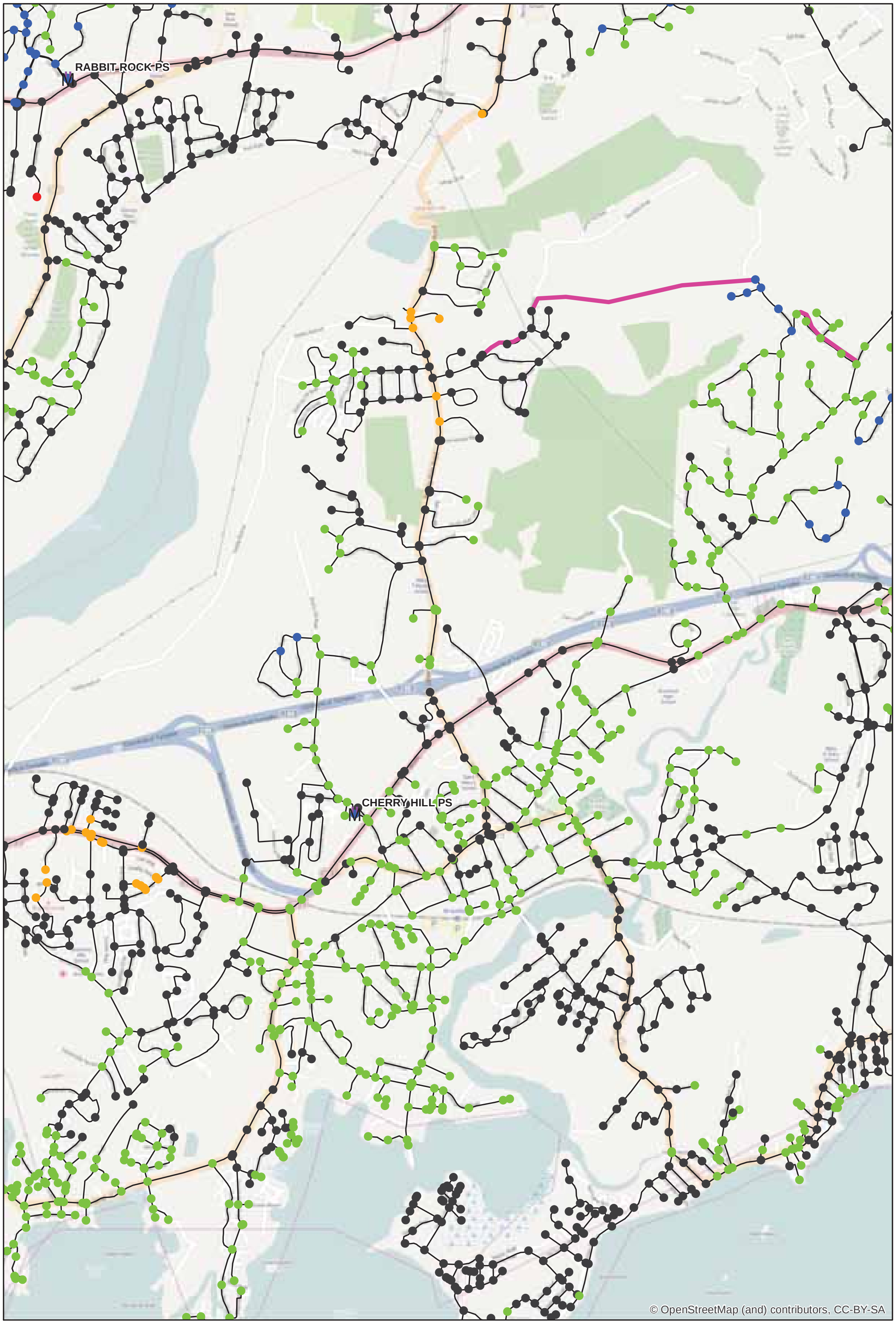

Pressure (psi)

- <20
- 21 - 35
- 36 - 70
- 71 - 100
- >100

Pump Station
Source
Tank
Proposed Water Main

Figure 2-4
Model Predicted Pressure
CHSA Connected with NBSA

South Central Connecticut
Regional Water Authority

Tighe&Bond

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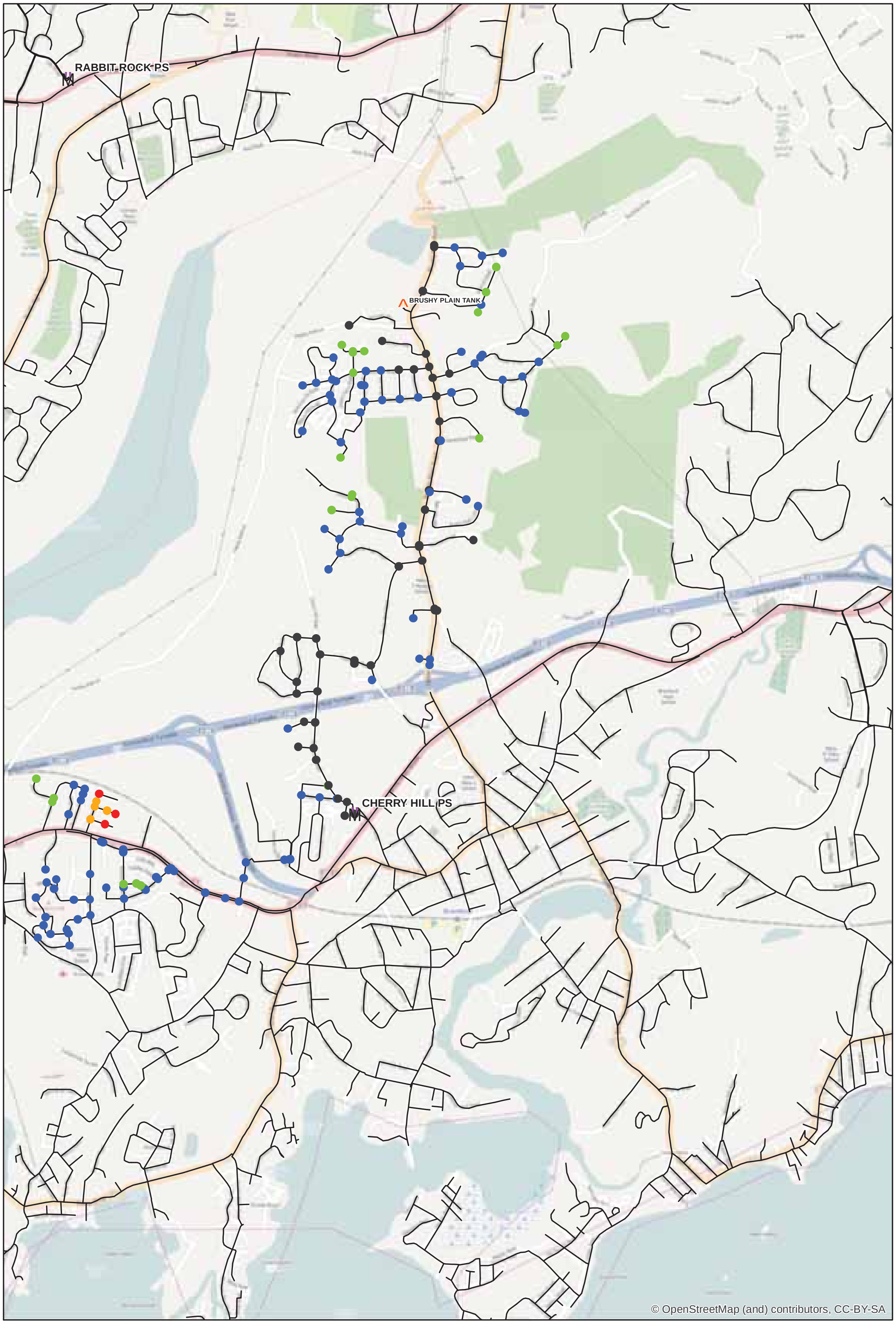


Available Fire Flow (gpm)

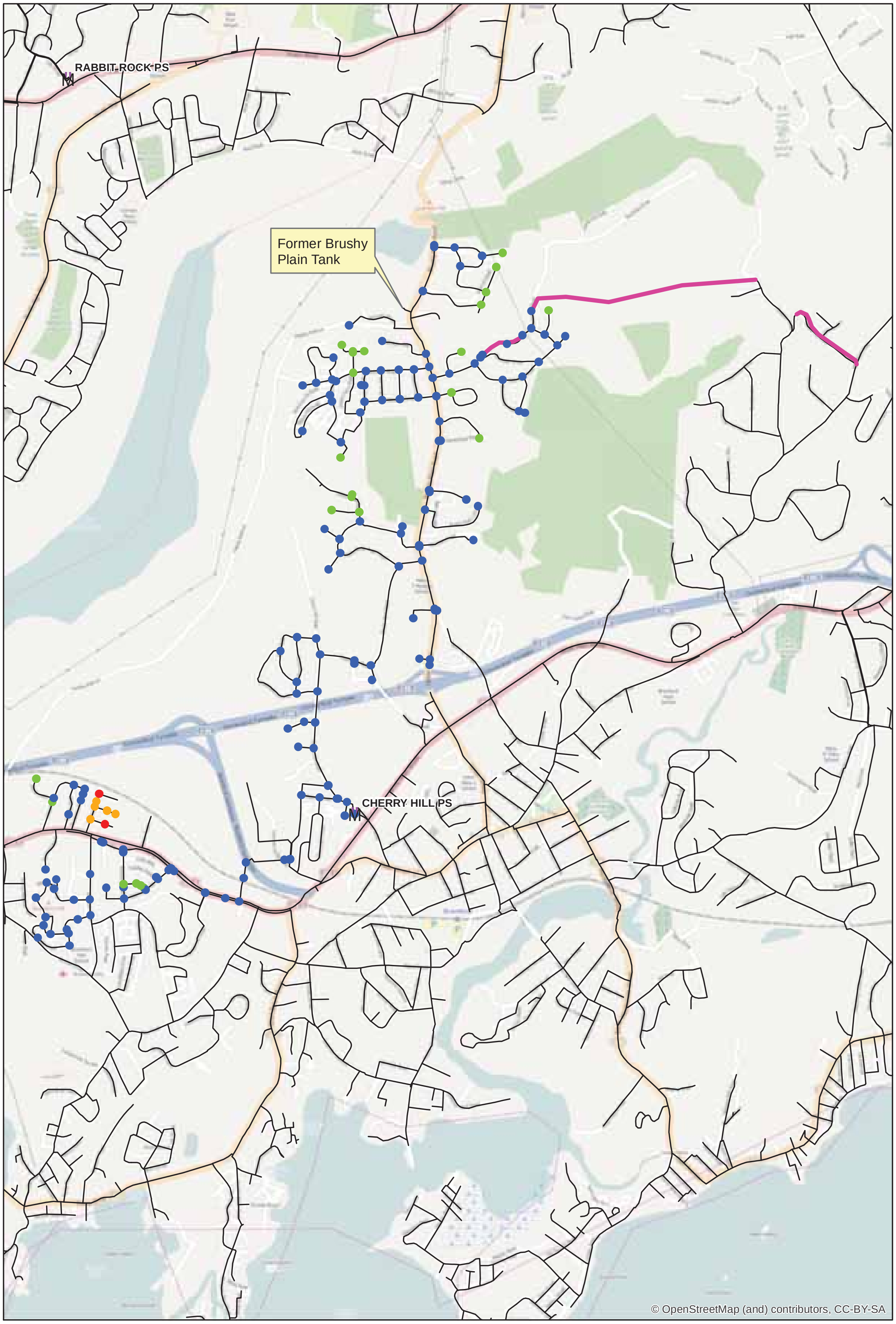
- <750
- 751 - 1000
- 1001 - 2000
- 2001 - 3500
- >3500
- Pump Station
- Source
- Tank

Figure 2-5
Model Predicted Available Fire Flow
Existing Conditions

South Central Connecticut
Regional Water Authority

Tighe&Bond

Path: J:\S\S1889 Regional Water Authority\25 - Brushy Plain Tank\Phase 5 - Modeling & Tech Memo\Model\ArcMap\AFF Expanded CHSA.mxd



Available Fire Flow (gpm)

- <750
- 751 - 1000
- 1001 - 2000
- 2001 - 3500
- >3500

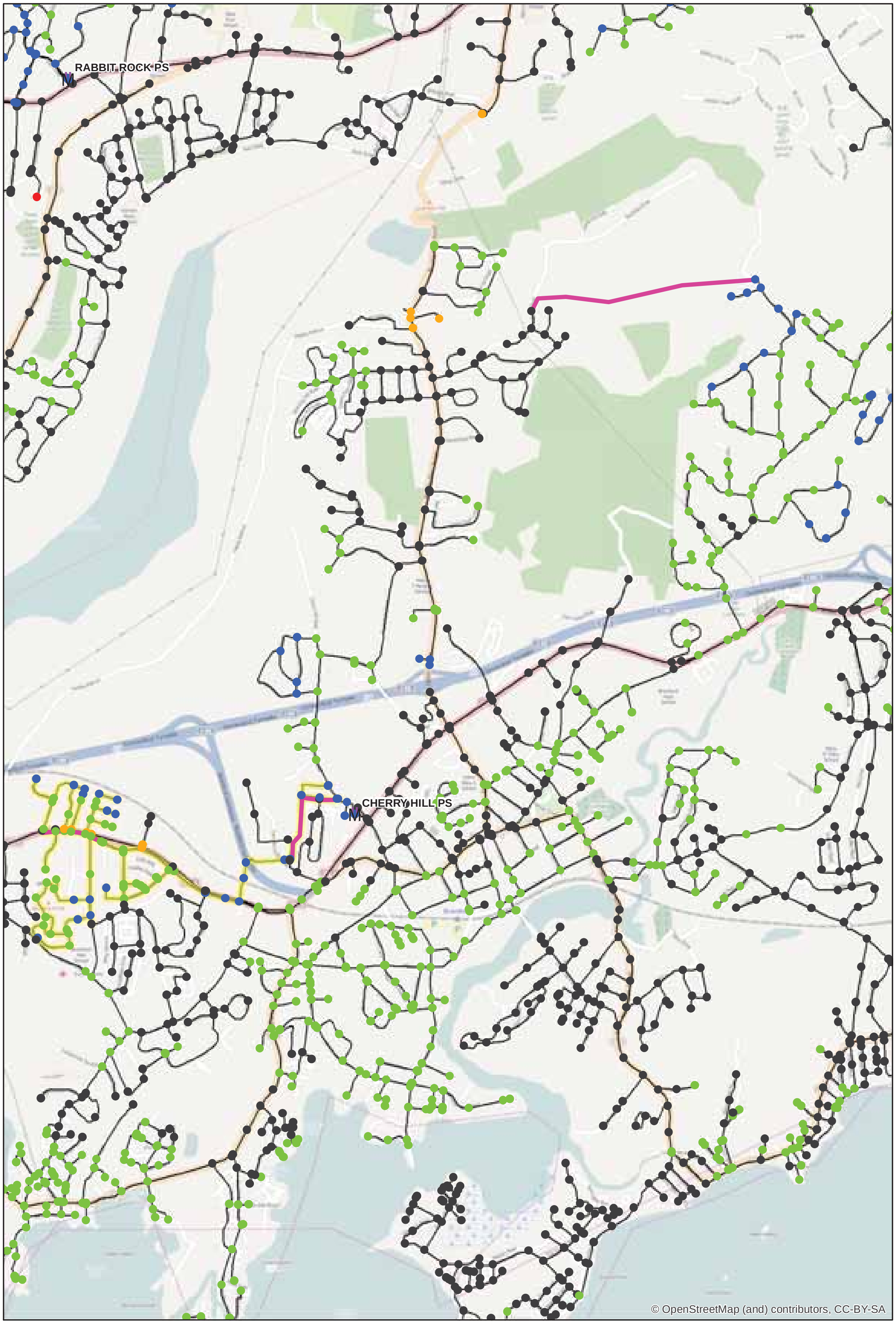
- Pump Station
- Source
- Tank
- Proposed Water Main

Figure 2-6
Model Predicted Available Fire Flow
CHSA Connected with NBSA

South Central Connecticut
Regional Water Authority

Tighe&Bond

Path: J:\S\S1889 Regional Water Authority\25 - Brushy Plain Tank\Phase 5 - Modeling & Tech Memo\Model\ArcMap\AFF Expanded CHSA.mxd



Pressure (psi)

- <20
- 21 - 35
- 36 - 70
- 71 - 100
- >100

- Pump Station
- Source
- Tank
- Expanded Cherry Hill SA
- Proposed Water Main

Figure 2-7
Model Predicted Pressure
CHSA Connected witrh NBSA
Expanded CHSA

South Central Connecticut
Regional Water Authority

Tighe&Bond

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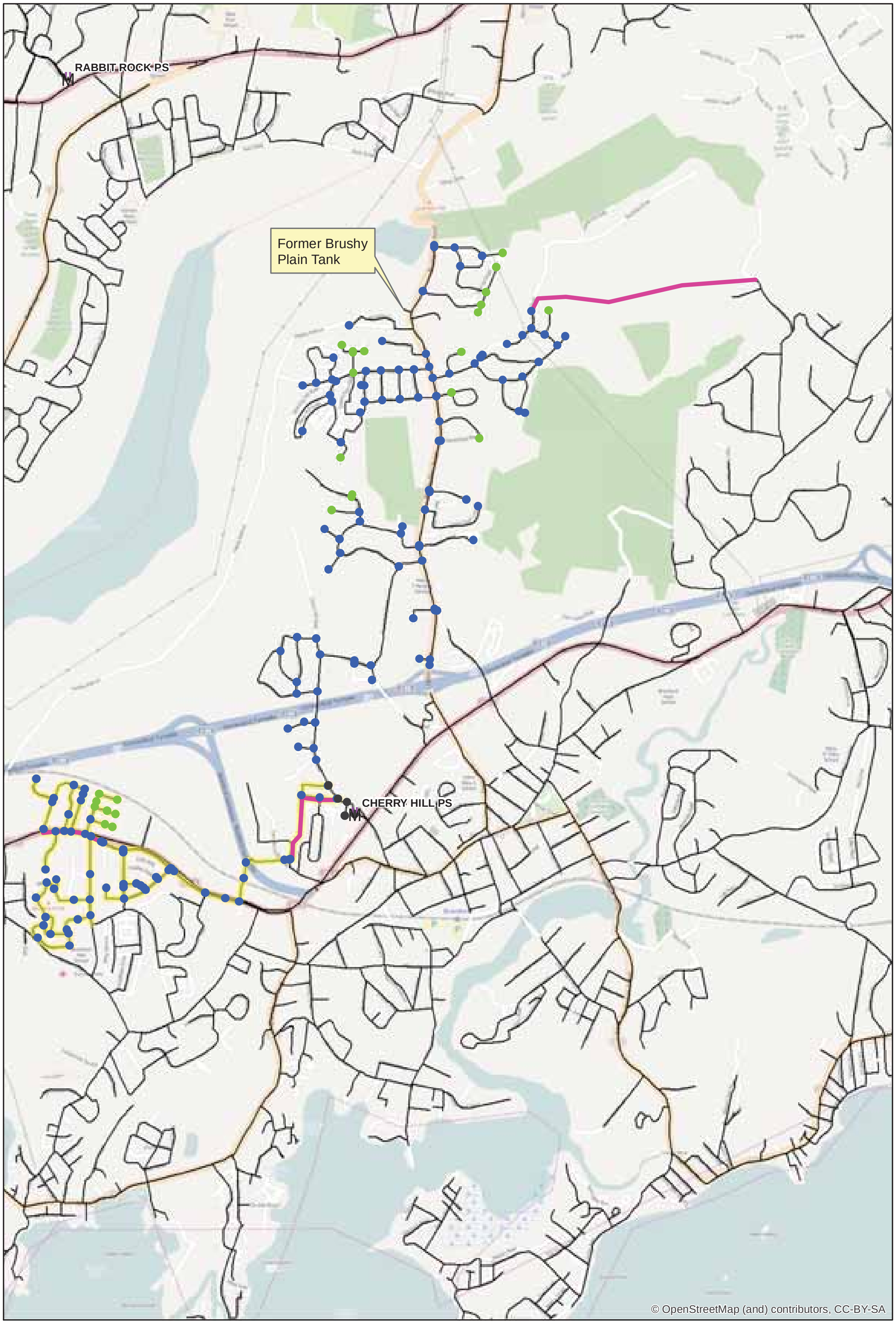

Available Fire Flow (gpm)

- <750
- 751 - 1000
- 1001 - 2000
- 2001 - 3500
- >3500

Pump Station
Source
Tank
Proposed Water Main
Expanded Cherry Hill SA

Figure 2-8
Model Predicted Available Fire Flow
CHSA Connected with NBSA
Expanded CHSA

South Central Connecticut
Regional Water Authority

Tighe&Bond

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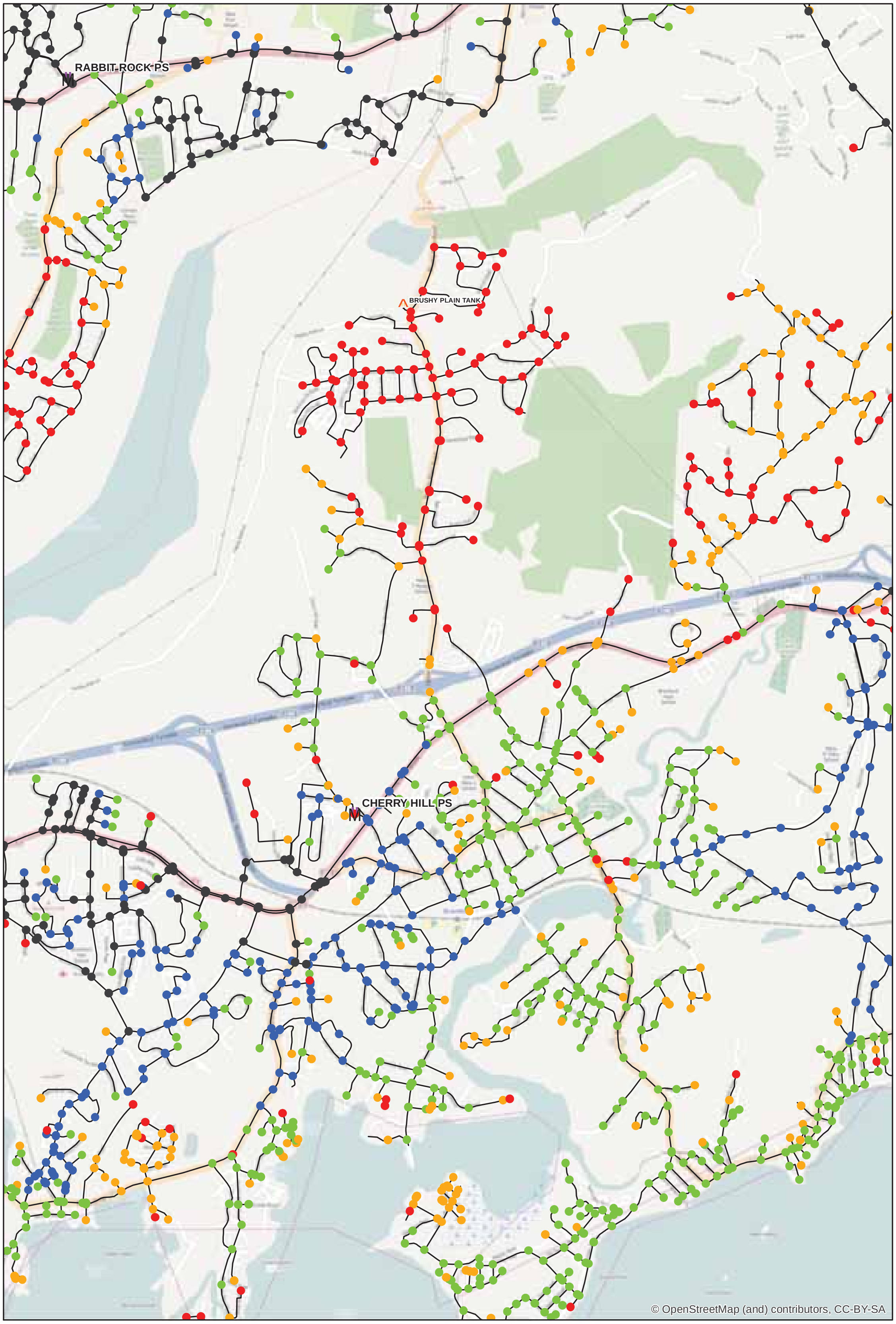


Water Age (hrs)

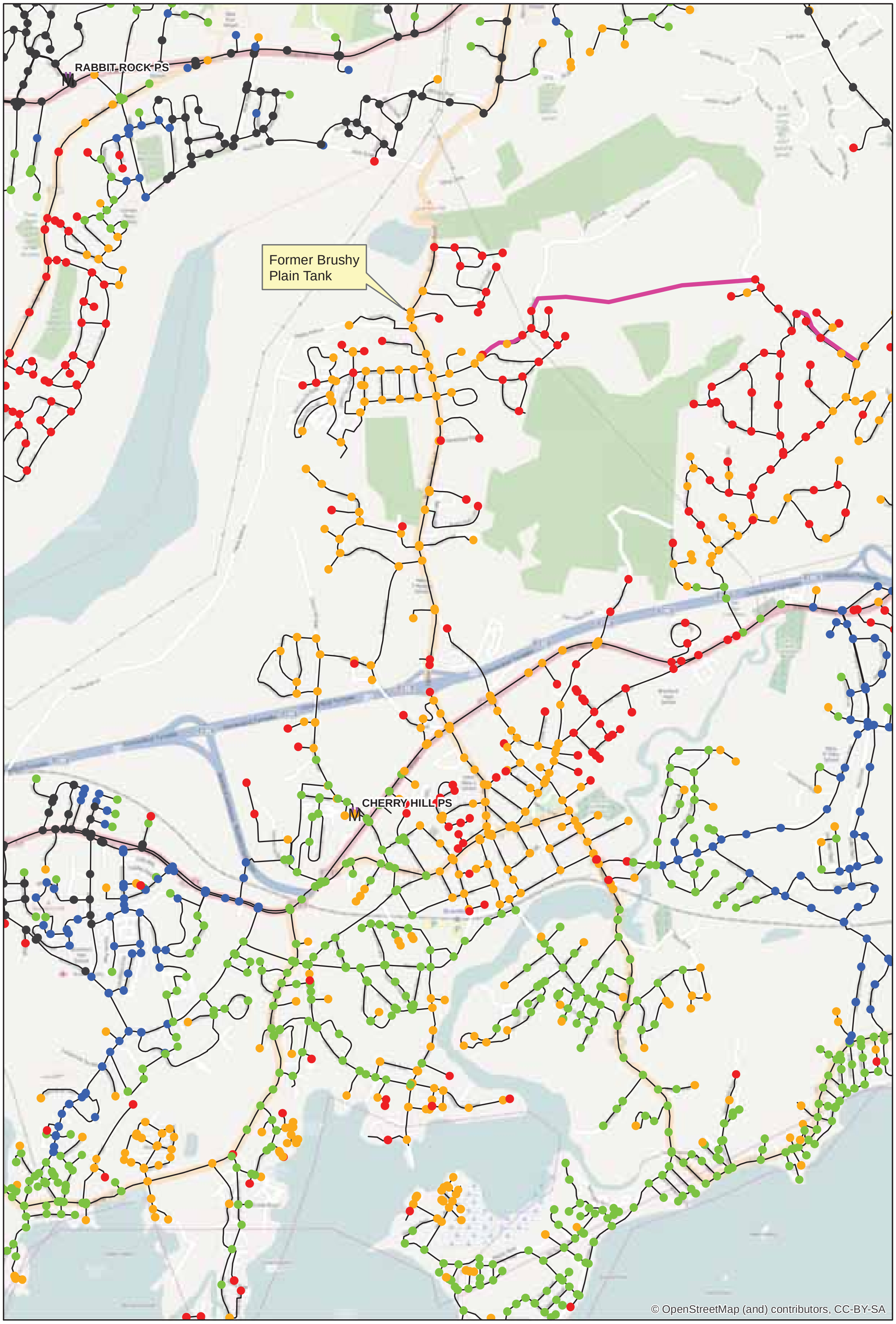
- <10
- 11 - 20
- 21 - 50
- 51 - 100
- >100

- Pump Station
- Source
- Tank

Figure 2-9
Model Predicted Water Age
Existing Conditions

South Central Connecticut
Regional Water Authority

Tighe&Bond



Water Age (hrs)

- <10
- 11 - 20
- 21 - 50
- 51 - 100
- >100

Pump Station

Source

Tank

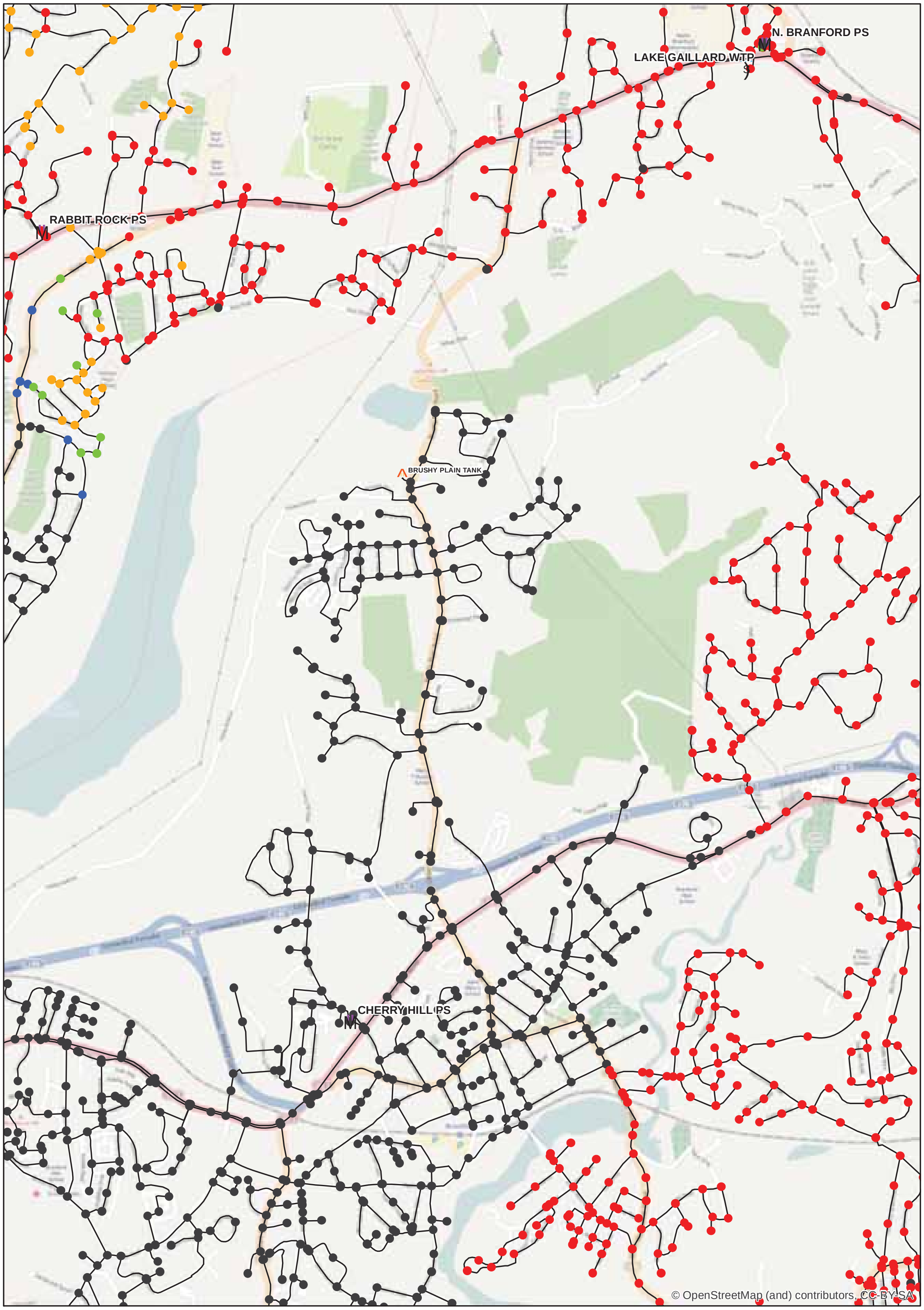
Proposed Water Main

Figure 2-10
Model Predicted Water Age
CHSA Connected with NBSA

South Central Connecticut
Regional Water Authority

Tighe&Bond

Path: J:\S\S1889 Regional Water Authority\25 - Brushy Plain Tank\Phase 5 - Modeling & Tech Memo\Model\ArcMap\Age.mxd



Source Contribution (%)

- >95% LSWTP
- 67%-95% LSWTP
- 33%-67% LSWTP/LGWTP
- 67%-95% LGWTP
- >95% LGWTP

Pump Station

Source

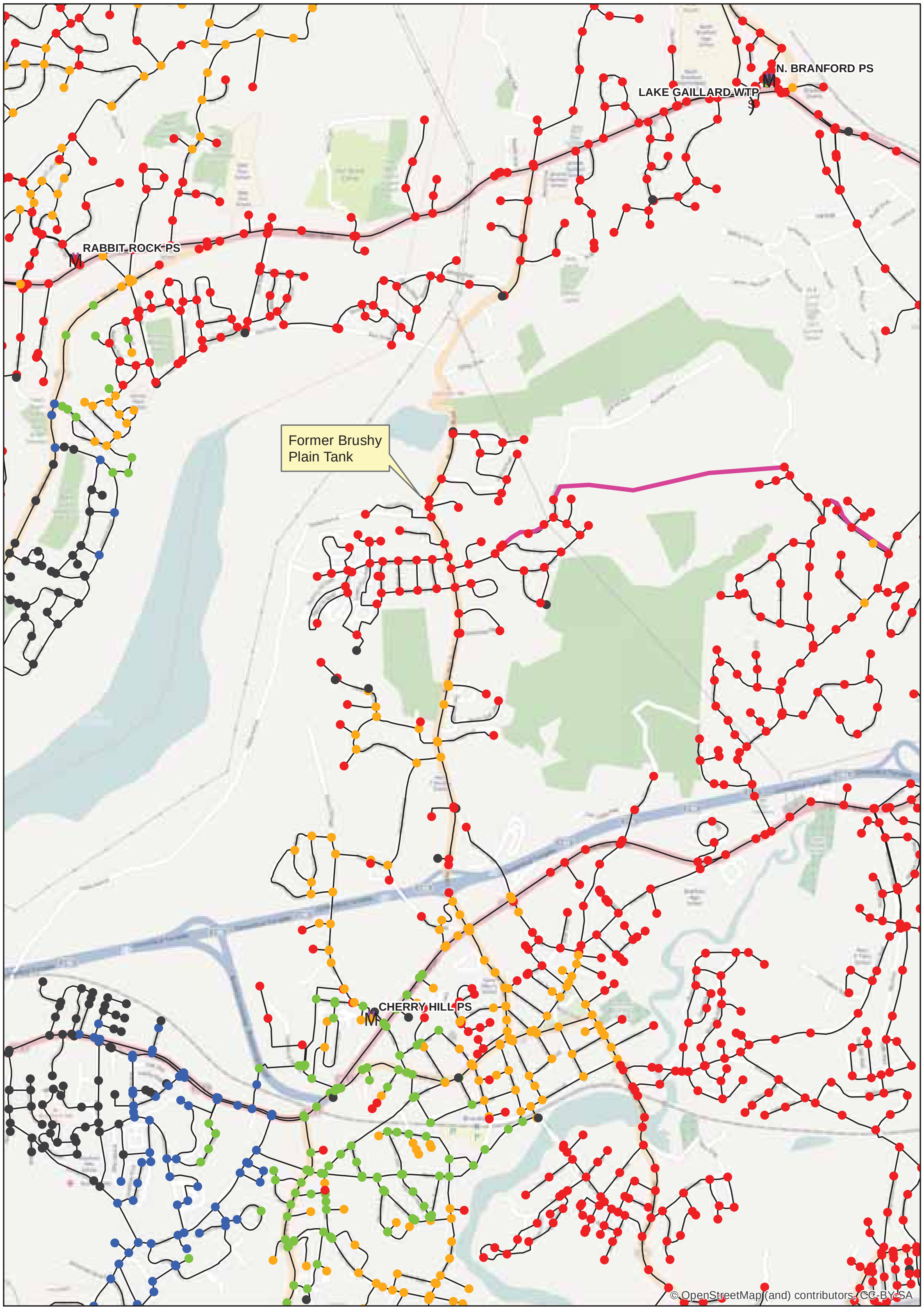
Tank

Figure 2-11
Model Predicted Source Contribution
Existing Conditions

South Central Connecticut
Regional Water Authority

Tighe&Bond

Path: J:\S\S1889 Regional Water Authority\25 - Brushy Plain Tank\Phase 5 - Modeling & Tech Memo\Model\ArcMap\Source.mxd



Source Contribution (%)

- >95% LSWTP
- 67%-95% LSWTP
- 33%-67% LSWTP/LGWTP
- 67%-95% LGWTP
- >95% LGWTP

Pump Station

Source

Tank

Proposed Water Main

Figure 2-12
Model Predicted Source Contribution
CHSA Connected with NBSA

South Central Connecticut
Regional Water Authority

Tighe&Bond

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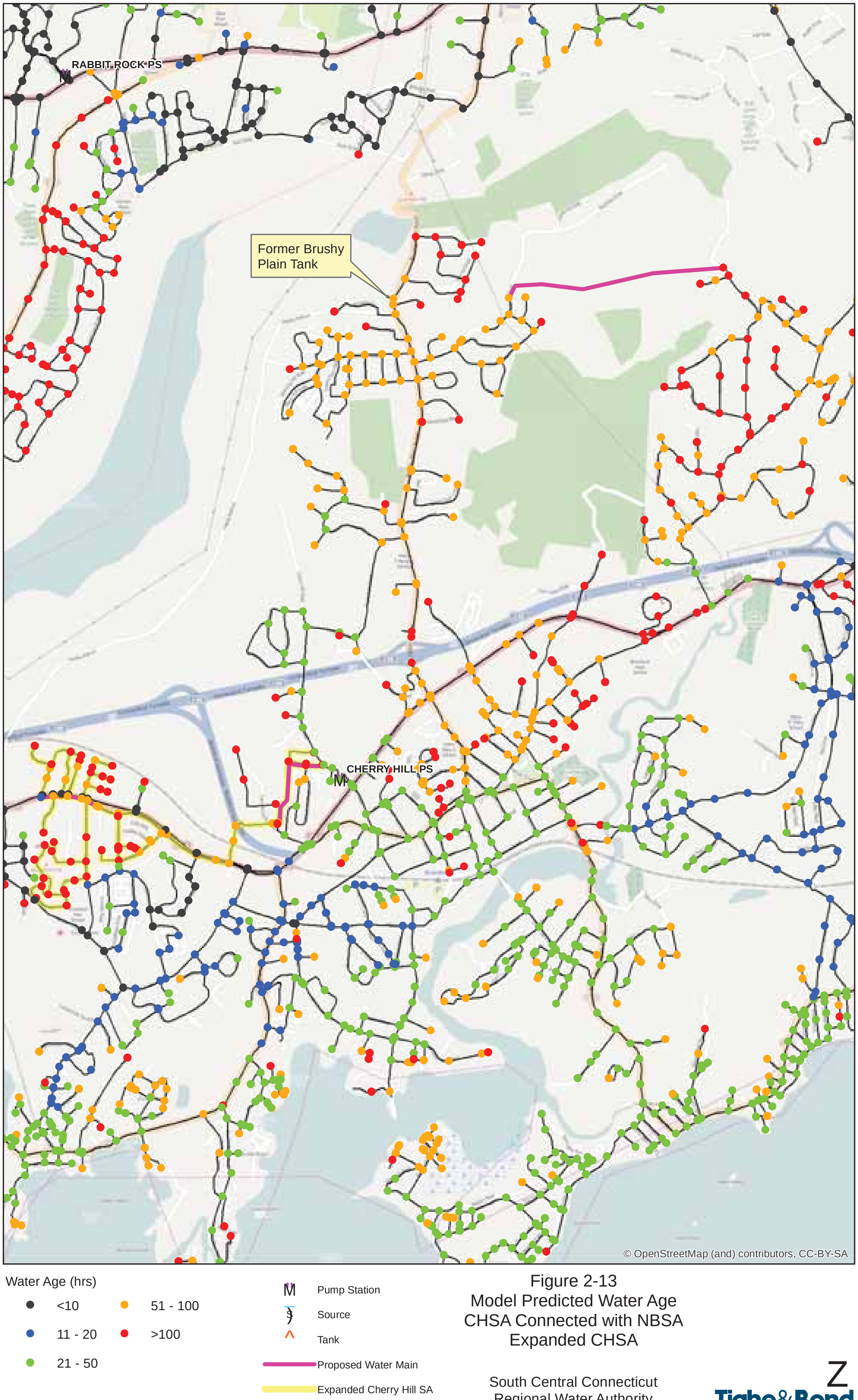

Figure 2-13
Model Predicted Water Age
CHSA Connected with NBSA
Expanded CHSA

South Central Connecticut
Regional Water Authority

Tighe&Bond

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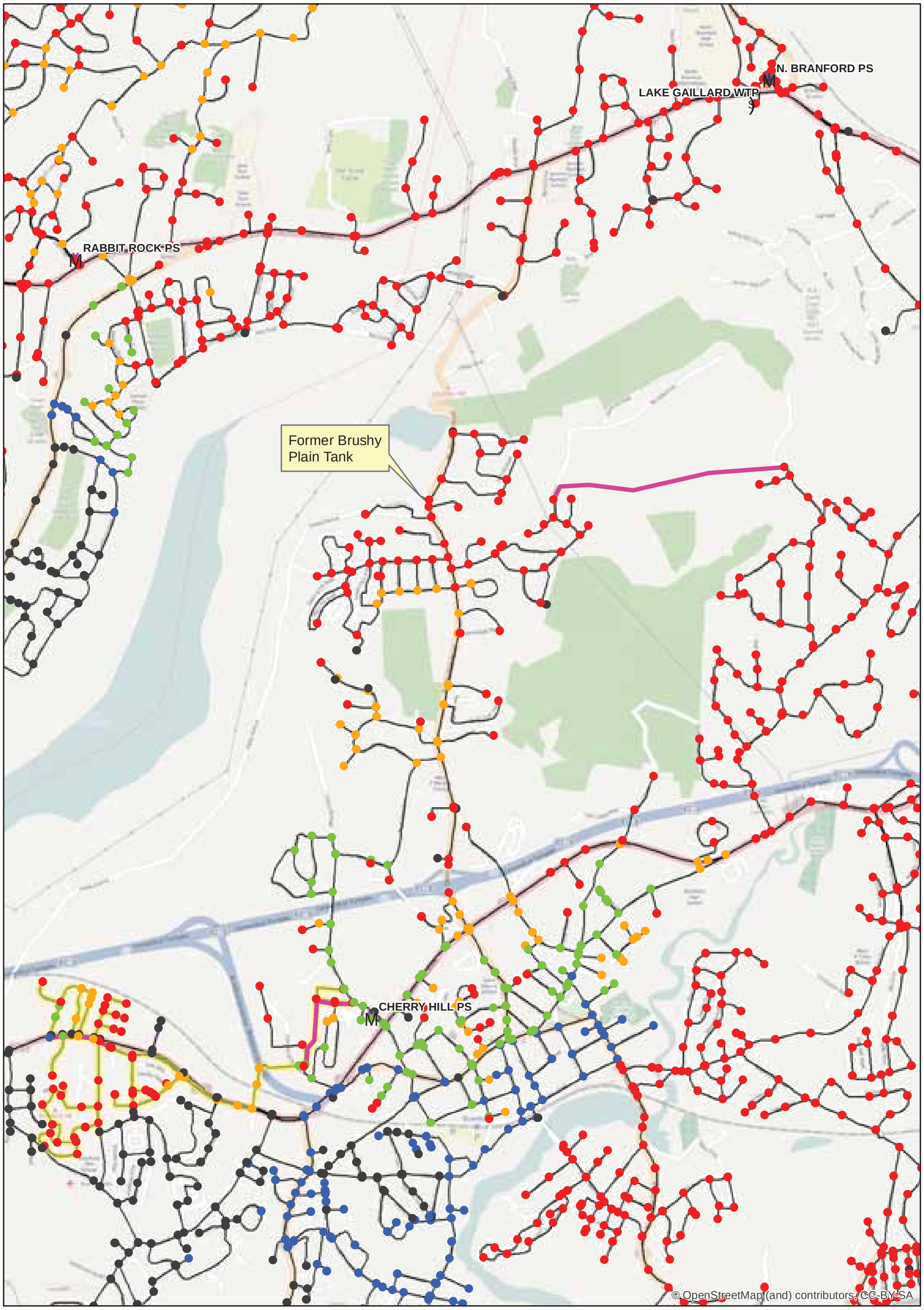

Source Contribution (%)

- >95% LSWTP
- 67%-95% LSWTP
- 33%-67% LSWTP/LGWTP
- 67%-95% LGWTP
- >95% LGWTP

- Pump Station
- Source
- Tank
- Proposed Water Main
- Expanded Cherry Hill SA

Figure 2-14
Model Predicted Source Contribution
CHSA Connected with NBSA
Expanded CHSA

South Central Connecticut
Regional Water Authority

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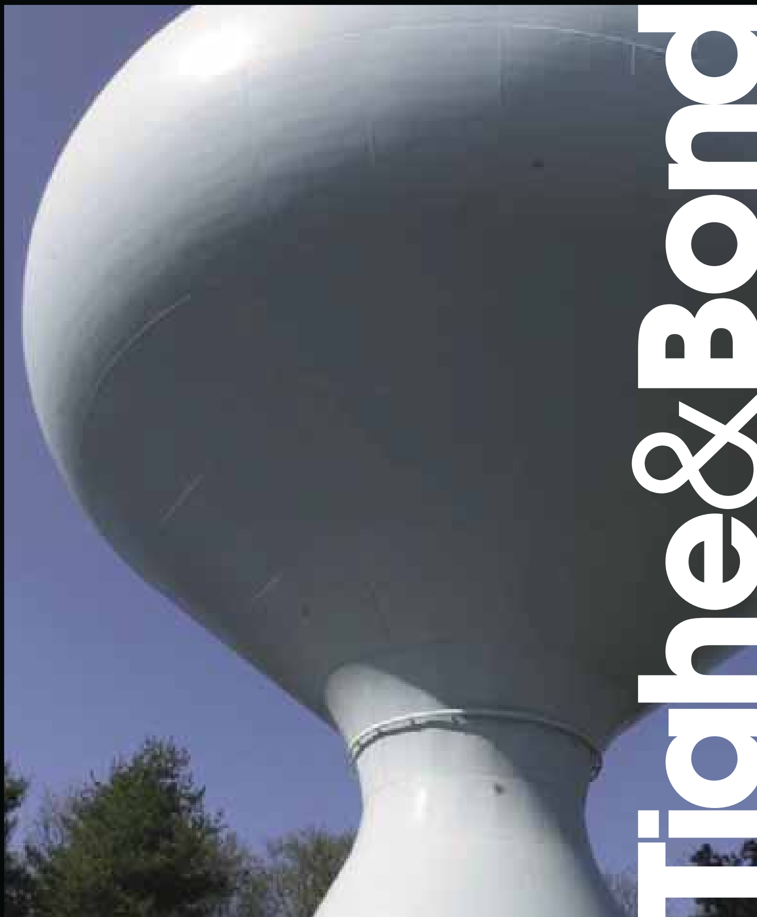

APPENDIX A

Cherry Hill Service Area Water Quality Modeling Analysis

TO: Stephen Rupar, P.E. - RWA

FROM: John McClellan, Ph.D., P.E. and Lesley Eckert

COPY: Brian Lakin, P.E. – RWA, Peter Grabowski, P.E.

DATE: November 26, 2012

1 Background

Storage in the Regional Water Authority's (RWA's) Cherry Hill Service Area (CHSA) is provided by the 1 million gallon capacity Brushy Plain Standpipe. The water level in the standpipe must be maintained above approximately 2/3 full in order to provide adequate distribution system pressure; thus, approximately 2/3 of the volume of the tank is unusable under normal operating conditions. This excess storage results in excessive hydraulic retention time (water age) in the tank. High water age is associated with low or absent chlorine residual and high concentrations of TTHM and HAA5.

One alternative for improving water quality in the CHSA is replacing the Brushy Hill Standpipe with an elevated tank. An elevated tank is expected to reduce the amount of unusable storage, thereby reducing water age in the tank and improving water quality. A study conducted by Tighe & Bond in April 2012 indicated that replacing the existing standpipe with a 750,000 gallon capacity elevated spheroid tank would result in a reduction of water age in the tank, which is expected to result in an increase in chlorine residual and a decrease in TTHM and HAA5 concentrations.

The proposed elevated spheroid tank represents a significant capital expense. Therefore, the RWA wishes to evaluate other alternatives that may be more economical and/or more effective in achieving the RWA's water quality objectives. The objective of the current study is to identify and evaluate other alternatives for improving water quality in the CHSA. This memorandum presents the results of our evaluation.

2 Methodology

The Regional Water Authority's (RWA's) water quality objectives for the CHSA are:

- A measurable chlorine residual must be maintained at all locations in the tank and distribution system at all times
- Locational Running Annual Average (LRAA) TTHM and HAA5 concentrations as required under the Stage 2 Disinfectants and Disinfection Byproduct Rule (DBPR) requirements must be met at all locations in the distribution system at all times

In discussions with the RWA, the following basic concepts for improving water quality in the CHSA were identified:

- Modify operations in the CHSA with the objective of reducing water age
- Modify the existing tank to reduce the amount of unusable storage volume, thus reducing water age
- Provide treatment systems in the existing tank to remove TTHM and add chlorine

- Install blow-offs in the distribution system, thus increasing system demand and reducing water age
- Combinations of the above

The following alternatives were developed from the aforementioned concepts:

1. Spheroid tank: replace the existing Brushy Plain Standpipe with a 750,000 gallon capacity spheroid tank. This is the alternative considered in the April 2012 *Cherry Hill Service Area Water Quality Modeling Study.*
2. Existing tank with aeration system: This alternative consists of installing a spray aeration TTHM stripper/rechlorination/mixing system in the existing Brushy Plain standpipe, such as the systems offered by Pax and SolarBee.
3. Existing tank with false bottom: This alternative consists of installing a false bottom at the mid-point elevation of the existing standpipe, with the objective of reducing unusable volume and decreasing water age in the tank.
4. Blow-offs at dead ends: This alternative consists of installing blow-offs flowing at 5 gpm at five dead-end locations in the distribution system.
5. One large blow-off: This alternative consists of installing one large (25 gpm) blowoff at the east end of Hemlocks Road Extension that would discharge to the Lake Saltonstall watershed.
6. Pipe looping: This alternative consists of installing new water mains (approximately 1,150 ft total) at selected locations in the CHSA to provide looping.
7. Flow from CHSA back to Saltonstall Service Area: This alternative consisted of allowing flow back to the Saltonstall SA through the existing relief valve at the Cherry Hill P.S. at times when the pumps are off, with the objective of increasing overall system turnover.
8. Existing tank with aeration and one large blow-off: This alternative is a combination of Alternatives 2 and 5.
9. Spheroid tank with aeration/mixing/rechlorination: This alternative consists of a new spheroid elevated tank with an aeration/mixing/rechlorination system as proposed under Aternatve 2.
10. Spheroid tank with aeration/mixing/rechlorination with one large blow-off: This alternative is a combination of Alternatives 5 and 9.

It is noted that alternative tank locations and alternative types of tanks were given preliminary consideration. No promising alternatives with respect to improving water quality were identified based on these concepts.

A computer model of the distribution system was utilized to compare the relative impact on water age, TTHM concentrations, and chlorine residual resulting from candidate alternatives. The water quality model developed as part of the April 2012 *Cherry Hill Service Area Water Quality Modeling Study* was used as a starting point. This model was calibrated to water quality sampling results from samples collected in the CHSA and operational data from the SCADA system for August 23, 2012.

A baseline simulation representing “worst-case” conditions with respect to TTHM and chlorine residual concentrations was developed from the calibration model. For the baseline case, system demands were set to represent average day conditions based on SCADA data from May 24-25, 2012. Average day demand is assumed to be the lowest demand condition likely to occur during the summer season. Water age is inversely proportional to demand; thus, the assumed average day demand condition results in the highest water age expected under warm water conditions when TTHM formation and chlorine decay rates are at their highest. The TTHM formation and chlorine decay coefficients developed in the calibration scenario were used for the baseline case, except that the parameter representing the maximum TTHM concentration was raised from 85 μg/L to 100 μg/L.

The baseline scenario thus represents a conservative estimate of the “worst case” TTHM and chlorine residual concentrations that might occur in the CHSA for use as a basis for comparison of alternatives. It is noted that TTHM is selected as a surrogate for disinfection byproducts in general including HAA5 and other non-regulated substances. TTHM is selected for evaluation as TTHM concentrations have been higher relative to regulatory limits compared to HAA5 in the historical sampling data. Reductions in TTHM concentration resulting from system modifications are, in general, expected to result in corresponding reductions in the concentrations of HAA5 and other disinfection byproduct species.

Simulations were prepared representing candidate alternatives. Alternatives were evaluated based on their model predicted effect on water quality. The alternatives are described in more detail including model-predicted water quality impacts in the following sections.

3 Modeling Results

3.1 Calibration Scenario

The purpose of this scenario was to replicate actual conditions that occurred on August 23, 2012 for purposes of calibrating the model. Hourly pump station flow and tank level data from the SCADA system were used to prepare a hydraulic simulation. The diurnal system demand pattern was calculated by mass balance from the tank and pump station flow data. Plots of Cherry Hill Pump Station flow, Brushy Plain Standpipe level, and system demand are presented in Figure 3-1. Overall system demand for the 24-hour period was estimated at approximately 403,000 gallons.

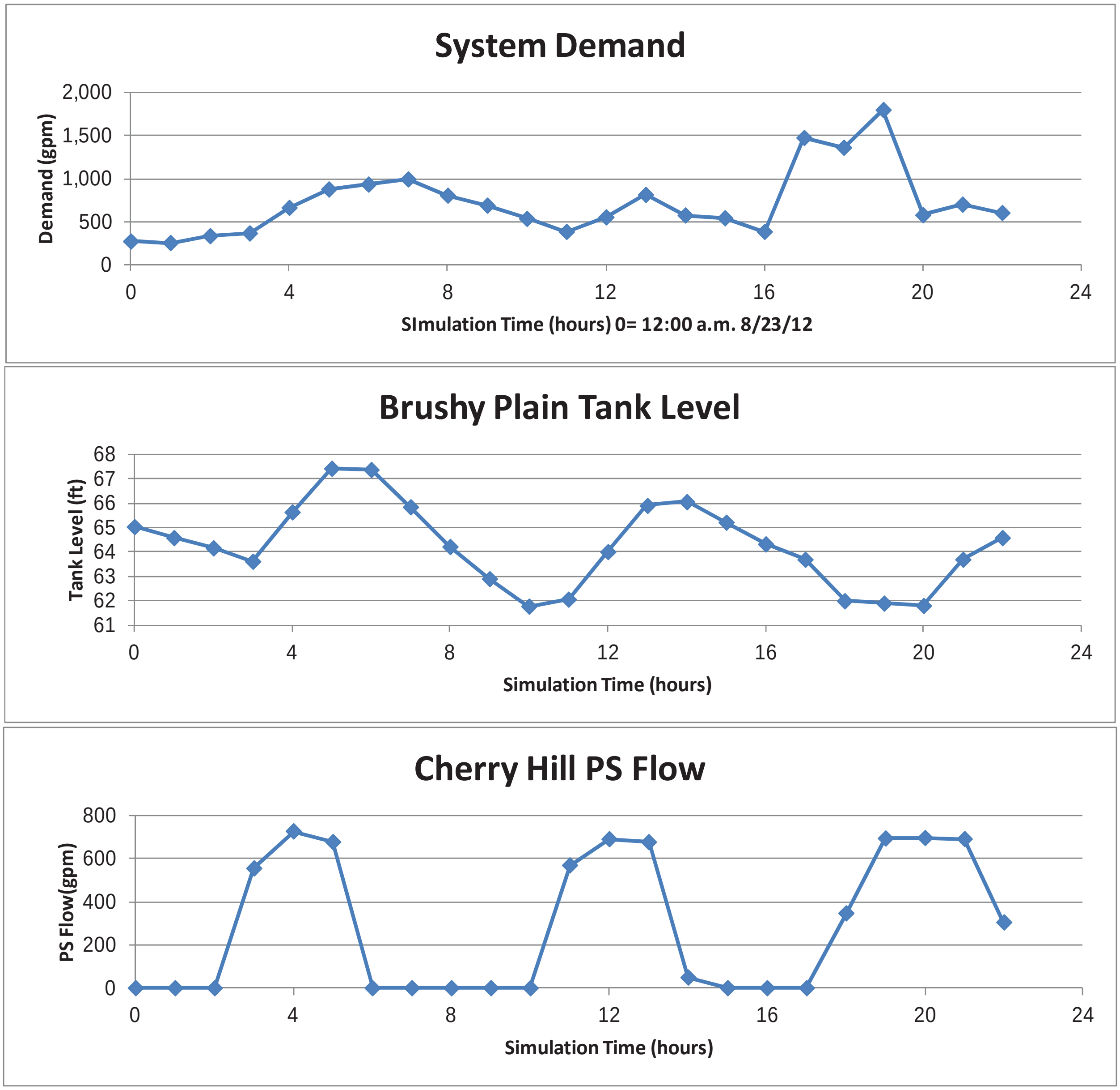

Figure 3-1 System Flows and Tank Level, August 23, 2012

Water quality samples were collected in the CHSA on August 23 to provide model calibration data. The sampling results are presented in Table 3-1.

TABLE 3-1
August 23, 2012 Sampling Results

Sample ID	Chloroform (µg/L)	Chloro-dibromo-methane (µg/L)	Dichloro-bromo-methane (µg/L)	Bromoform (µg/L)	TTHM (µg/L)	Free Chlorine (mg/L)	pH
(#1) Cherry Hill PS	37	2.5	12	<0.50	52	0.10	7.41
#2 (275 Brushy Plain Rd)	53	4.2	18	<0.50	75	0.08	7.25
#3 (321 Brushy Plain Rd)	55	4.6	19	<0.50	79	0.08	7.29
#4 (Mountain Top Drive)	59	4.7	19	<0.50	83	0.06	7.63
#5 (Haystack Road)	61	4.4	19	<0.50	84	0.08	7.57
#6 (Brushy Hill ROW)	47	3.2	16	<0.50	66	0.50	7.32
#7 (Fern Dale ROW)	61	4.6	20	<0.50	86	0.00	7.52
#8 (Wilbraham Ct)	40	2.4	13	<0.50	55	0.71	7.26
#9 (Squire Hill Apts.)	57	4.2	18	<0.50	79	0.06	7.48
#10 (Foxbridge Village Rd)	60	4.8	20	<0.50	85	0.04	7.41

The August 23 sampling event was conducted during a period of the day when the pump station had been off for several hours so that water from the tank was flowing into the distribution system. As indicated in Table 3-1, the objective of capturing high TTHM concentrations and low chlorine residuals in the samples was achieved.

The model parameters representing TTHM formation rate, maximum TTHM concentration, and chlorine decay rate were set to provide reasonable agreement between model predictions and observed chlorine residuals and TTHM concentrations from the August 23 samples. TTHM formation and chlorine decay curves for the calibration scenario are presented in Figure 3-2.

Water quality metrics are presented for each model scenario to provide a basis of comparison. Two sets of metrics are presented. The first set (“Tank”) represents model predicted water age, TTHM, and chlorine concentration in the tank. The second set (“All System Nodes”) provides statistics representing model predictions for the entire service area. Average concentrations for water age, TTHM, and chlorine residual are presented.

It is noted that for the calibration scenario a “two-compartment” mixing model is used for the tank. The two-compartment model captures the effect of tank stratification, where water moving in and out of the tank from the inlet/outlet compartment may have relatively low water age, but the main compartment tends to stagnate and develop high water age. Under normal tank cycling, it is possible for the water quality in the distribution system in the vicinity of the tank to be influenced primarily by the inlet/outlet compartment and thus have relatively good water quality, until such time as the tank level departs from its normal cycle and allows lower quality water from the main compartment to enter the distribution system.

For the scenarios representing future conditions (including the baseline scenario), a “completely mixed” tank model is assumed. The rationale for using the completely mixed model is that a mixing system of some sort is recommended for all scenarios involving retaining the existing standpipe due to the likelihood that such a system would be required in the future by the DPH. Additionally, assuming complete mixing in the tank allows “apples to apples” comparison of the alternatives with respect to water quality impacts in the distribution system.

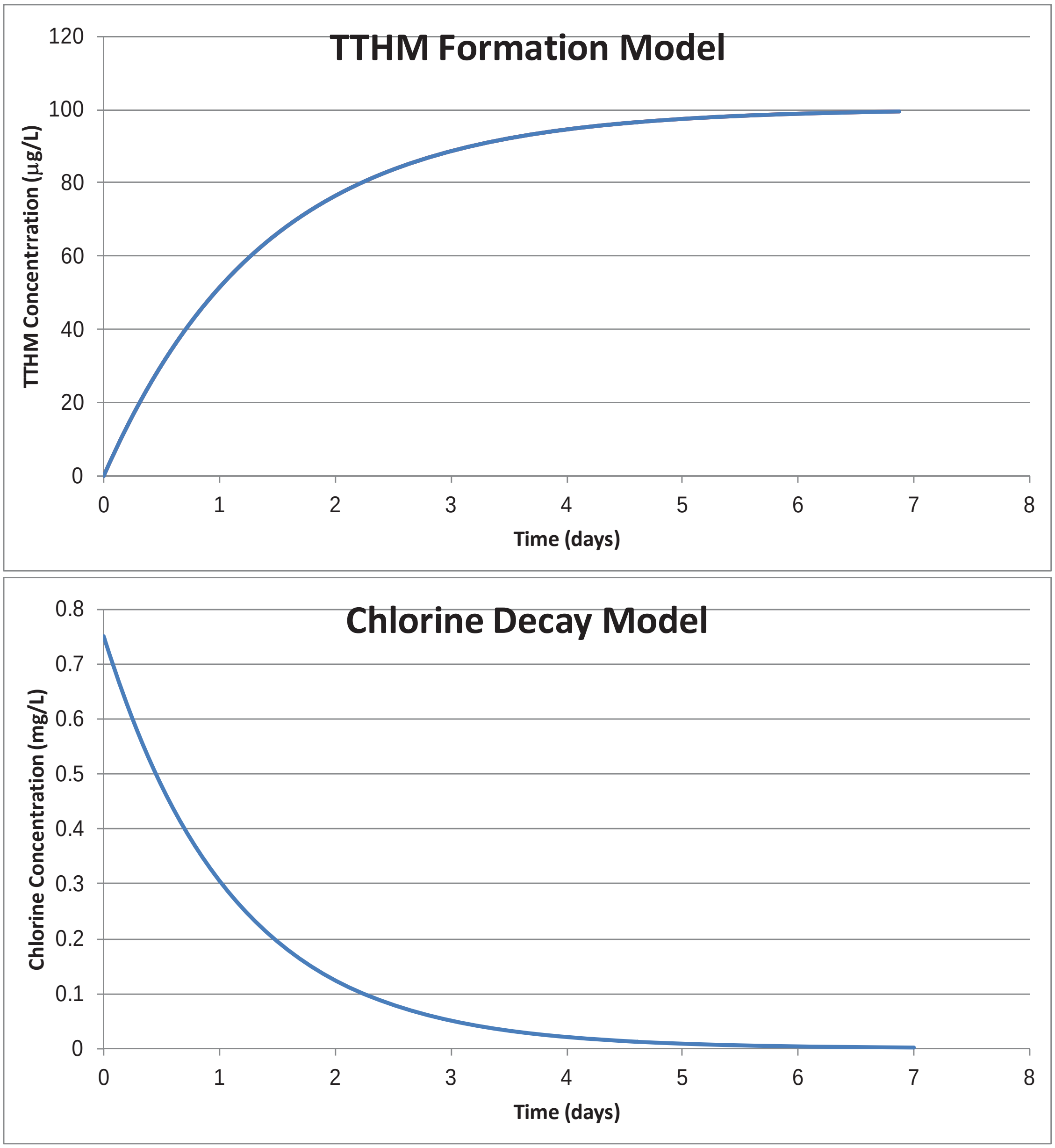

Figure 3-2 TTHM formation and chlorine decay models

3.2 Baseline Scenario

A 48-hour baseline scenario was prepared to provide a basis of comparison for other alternatives. For the baseline scenario, system demand was based on operational data from May 24 and 25, 2012. Plots of system demand, Cherry Hill PS pumping rate, and Brushy Plain tank level for the 48-hour baseline simulation are presented in Figure 3-3.

For this period, the average system demand as estimated from the operational data was approximately 380,000 gpd. This demand is assumed to be at the low end of the range of system demand expected during warm weather conditions when disinfection byproduct formation and chlorine decay rates are high. Thus, the baseline scenario represents a "worst case" combination of high TTHM formation and chlorine decay rates and high water age.

Water quality metrics for the baseline scenario are presented in Table 3-2. Model-predicted water age, chlorine residual and TTHM concentrations for the baseline scenario are shown on Figures 3-4, 3-5, and 3-6, respectively.

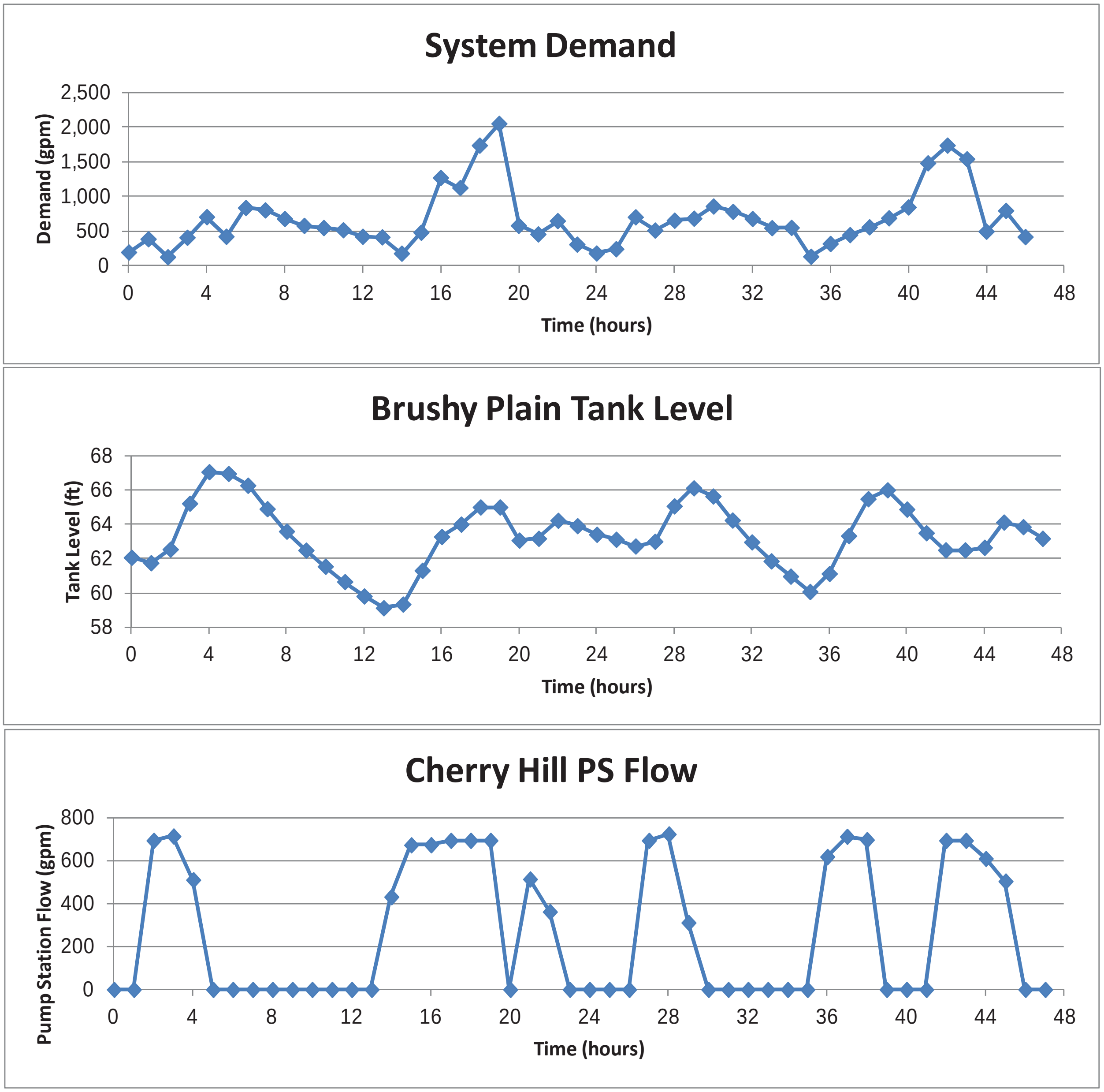

Figure 3-3 System Demand, Flows, and Tank Level – Baseline Scenario

Table 3-2
Baseline Alternative Water Quality Metrics[1]

Scenario	Tank: Water Age (hours)	Tank: Chlorine Residual (mg/L)	Tank: TTHM Conc. (μg/L)	All System Nodes: Average Water Age (hours)	All System Nodes: Average Chlorine Residual (mg/L)	All System Nodes: Average TTHM Conc. (μg/L)
Baseline (with mixer)	150	0.00	89	103	0.15	78

[1]Based on model prediction during extended period simulation with tank at low point in cycle

3.3 Alternative 1: Spheroid Tank

This alternative consists of replacing the existing Brushy Plain standpipe with a 750,000-gallon capacity elevated spheroid tank, as discussed in the April 2012 *Cherry Hill Service Area Water Quality Modeling Study*. The bottom elevation of the proposed tank is 275 feet with an overflow elevation of 315 feet. The majority of the volume of the proposed tank will be useable, allowing increased turnover compared to the existing standpipe. A scenario was prepared representing the proposed spheroid tank under the supply, system demand, TTHM formation, and chlorine decay conditions used for the baseline scenario as discussed above. Water quality metrics for Alternative 1 are presented in Table 3-3.

Table 3-3
Water Quality Metrics - Alternative 1 - Spheroid Tank[1]

Scenario	Tank: Water Age (hours)	Tank: Chlorine Residual (mg/L)	Tank: TTHM Conc. (μg/L)	All System Nodes: Average Water Age (hours)	All System Nodes: Average Chlorine Residual (mg/L)	All System Nodes: Average TTHM Conc. (μg/L)
Baseline (with mixer)	150	0.00	89	103	0.15	78
Alt.1 Spheroid Tank	87	0.08	84	80	0.12	80

[1]Based on model prediction during extended period simulation with tank at low point in cycle

This alternative results in a significant decrease in water age in the tank and in the distribution system, and a detectable chlorine residual in the tank. However, the effect on average chlorine residual and TTHM concentration throughout the distribution system is not significant; in fact, the model predicts a slight decrease in the system-wide average chlorine residual and an increase in the average TTHM concentration. It is noted that for water age greater than about 4 days, there is little change in chlorine or TTHM concentrations as chlorine residual has disappeared and TTHM has reached formation potential (refer to Figure 3-2). Thus, the improvement in water age in the tank from 150 to 87 hours does not produce a significant improvement in TTHM or chlorine residual under the conditions assumed. Additionally, the larger tank volume exchange in the spheroid tank alternative has the effect of projecting water from the tank over a larger area in the distribution system, which has a negative impact on the system-wide metrics.

Model-predicted water age, chlorine residual, and TTHM concentrations for the spheroid tank alternative are shown on Figures 3-7, 3-8 and 3-9, respectively. A conceptual cost estimate for the proposed elevated spheroid tank is included in Appendix A.

3.4 Alternative 2: Existing Tank with Aeration/Mixing/Rechlorination System

This alternative consists of installing spray aeration, rechlorination, and mixing systems in the existing Brushy Plain standpipe. Package systems that provide this functionality are offered by SolarBee and Pax Water Technologies.

Since TTHM is relatively volatile, its removal from water by air stripping is feasible. Commonly used air stripping technologies include diffused (bubble) aeration, packed towers, and spray aeration. Both diffused aeration and spray aeration would be relatively easy to implement in a tank. Research by Dr. Robin Collins and students at the University of New Hampshire demonstrated that spray aeration is more effective in stripping TTHM than diffused aeration. Spray aeration stripping was shown to be very effective where chloroform is the predominant TTHM species as is the case in the RWA system.

Vendor information provided by SolarBee and Pax and the research literature (Brooke & Collins, *JAWWA* 103:10, October 2011) indicate that a reduction of TTHM in the tank of 40% or more can be expected with a spray aeration system. This information is included in Appendix B. The proposed spray aeration system would continuously cycle water drawn from the bottom of the tank through spray nozzles located in the dome of the tank. The amount of TTHM removal that can be achieved depends in part on the flow rate through the stripper. For purposes of this analysis, a flow rate of 230 gpm through the stripper was assumed, with TTHM removal of 50% in the recycle stream, resulting in an overall reduction in TTHM concentration of 40% in the tank, based on vendor information. It may be possible to achieve additional TTHM removal by using larger-size equipment that would result in a higher flow rate through the stripper. The proposed equipment considered in this alternative also includes a mixing system, which was modeled by assuming complete mixing in the tank, and a rechlorination system.

Water quality metrics for Alternative 2 are presented in Table 3-4. As indicated in the table, the model predicts no significant impact on water age, but a significant increase in chlorine residual and a significant decrease in TTHM concentration, both in the tank and in the distribution system.

Table 3-4
Water Quality Metrics - Alternative 2 – Aeration System[1]

Scenario	Tank			All System Nodes		
	Water Age (hours)	Chlorine Residual (mg/L)	TTHM Conc. (μg/L)	Average Water Age (hours)	Average Chlorine Residual (mg/L)	Average TTHM Conc. (μg/L)
Baseline (with mixer)	150	0.00	89	103	0.15	78
Alt.2 Aeration system	147	0.13	60	103	0.24	69

[1]Based on model prediction during extended period simulation with tank at low point in cycle

One potential problem with this alternative is the possibility of increasing HAA5 concentration in the tank as a result of increasing the chlorine concentration in the tank. No significant removal of HAA5 in the aeration system is expected. The low HAA5 concentration currently experienced in the tank is likely due in part to biodegradation; increasing the chlorine concentration would tend to limit biodegradation as well as increase the formation rate of HAA5. The objectives of maintaining a detectable chlorine residual throughout the system and limiting HAA5 formation would have to be carefully balanced.

Model-predicted water age, chlorine residual and TTHM concentrations for the aeration system alternative are shown on Figures 3-10, 3-11, and 3-12, respectively. A conceptual cost estimate for Alternative 2 is included in Appendix A.

3.5 Alternative 3: Existing Tank with False Bottom

For this alternative, it is assumed that a false bottom is installed in the tank at elevation 270.3 ft MSL, corresponding to half way up the tank sidewall. Thus, the volume of the tank would be reduced by half, and most of the unusable volume at the bottom would be eliminated.

Water quality metrics for Alternative 3 are presented in Table 3-5. As indicated in the table, model predictions for this alternative indicate a measurable chlorine residual in the tank, a significant improvement in water age in the tank and in the distribution system, and little impact on distribution system TTHM or chlorine concentrations. Alternative 3 is similar to Alternative 1 from a water quality standpoint; refer to the discussion provided under Alternative 1.

Table 3-5
Water Quality Metrics – Alternative 3 – False Bottom in Existing Tank [1]

Scenario	Tank			All System Nodes		
	Water Age (hours)	Chlorine Residual (mg/L)	TTHM Conc. (μg/L)	Average Water Age (hours)	Average Chlorine Residual (mg/L)	Average TTHM Conc. (μg/L)
Baseline (with mixer)	150	0.00	89	103	0.15	78
Alt. 3 False bottom in existing tank	75	0.10	82	70	0.17	76

[1]Based on model prediction during extended period simulation with tank at low point in cycle

Another consideration for this alternative is the overall reduction in storage volume. Under this alternative, the overall volume of the tank would be reduced by half, from 1 MG to 0.5 MG. It is noted that the volume that would be eliminated is considered “unusable” because it is below the elevation required to provide adequate pressure throughout the service area; thus, the existing “usable” storage capacity, consisting of the top 1/3 of the tank, is maintained under this alternative. However, this volume is less than the volume recommended in the 2011 *Alternative Investigation for Replacement of Brushy Plain Tank* prepared by Roald Haestad, Inc., and the tank operating range is lower than the recommended range.

Preliminary discussions with vendors indicate that installing a false bottom might be possible, but would likely be more expensive than constructing a new tank. In light of the high cost and capacity and elevation considerations, this alternative is eliminated from consideration. A conceptual cost estimate for Alternative 3 is included in Appendix A.

3.6 Alternative 4: Blow-Offs at Dead Ends

This alternative consists of installing blow-offs at selected dead ends. The following locations were selected:

- Foxridge Village Road (N.W. section of loop)
- Brushy Plains Road (end of water main near Brookwood Drive intersection)
- Mountain Top Drive (E. end)
- Haystack Road (N. end)
- Ferndale Road (E. end)

These locations were selected due to high model-predicted water age, and proximity to open space where disposal of water might be feasible. Each blow-off was assumed to flow at 5 gpm. The blow-off locations are shown in Figure 3-13. Water quality metrics for Alternative 4 are presented in Table 3-6.

Table 3-6
Water Quality Metrics – Alternative 4 – Blow-offs at Dead Ends [1]

	Tank			All System Nodes		
Scenario	Water Age (hours)	Chlorine Residual (mg/L)	TTHM Conc. (μg/L)	Average Water Age (hours)	Average Chlorine Residual (mg/L)	Average TTHM Conc. (μg/L)
Baseline (with mixer)	150	0.00	89	103	0.15	78
Alt. 4 Blow-offs at dead ends	143	0.06	89	87	0.17	76

[1]Based on model prediction during extended period simulation with tank at low point in cycle

As indicated in Table 3-6, this alternative does not result in a significant improvement in water age or TTHM concentration in the tank, but provides modest improvement in the tank chlorine residual and a significant improvement in the distribution system average water age. Therefore, while this alternative is not recommended by itself, it may be attractive for use in conjunction with other alternatives. A conceptual cost estimate for Alternative 4 is included in Appendix A.

3.7 Alternative 5: One Large Blow-Off

Under this alternative, one large blow-off would be installed at the end of Hemlocks Road Extension. The proposed blow-off would discharge to the Lake Saltonstall watershed and would flow at 25 gpm. The large blow-off location is shown in Figure 3-13. Water quality metrics for Alternative 5 are presented in Table 3-7.

Table 3-7
Water Quality Metrics – Alternative 5 – One Large Blow-off[1]

Scenario	Tank			All System Nodes		
	Water Age (hours)	Chlorine Residual (mg/L)	TTHM Conc. (µg/L)	Average Water Age (hours)	Average Chlorine Residual (mg/L)	Average TTHM Conc. (µg/L)
Baseline (with mixer)	150	0.00	89	103	0.15	78
Alt 5 One large blow-off	142	0.06	89	92	0.16	77

[1]Based on model prediction during extended period simulation with tank at low point in cycle

As indicated in Table 3-7, Alternative 5 is similar to Alternative 4 from a water quality standpoint. As discussed under Alternative 4, this alternative is not recommended by itself but may be attractive for use in conjunction with other alternatives. A conceptual cost estimate for Alternative 5 is included in Appendix A.

3.8 Alternative 6: Pipe Looping

This alternative consists of installing sections of water main at selected locations in order to provide looping. Installation of 8-inch water main at the following locations is proposed:

- Side Hill Road to Mountain Top Drive – 70 feet
- Hampton Park W. to Jerimoth Drive (cross-country) – 500 ft
- Laurel Hill Road (middle section with no water main) – 670 ft

Water quality metrics for Alternative 6 are presented in Table 3-8. As indicated in the table, this alternative does not provide a significant benefit in distribution system water quality. Therefore, Alternative 6 is eliminated from consideration as a stand-alone alternative. A conceptual cost estimate is included in Appendix A.

Table 3-8
Water Quality Metrics – Alternative 6 – Pipe Looping[1]

Scenario	Tank			All System Nodes		
	Water Age (hours)	Chlorine Residual (mg/L)	TTHM Conc. (µg/L)	Average Water Age (hours)	Average Chlorine Residual (mg/L)	Average TTHM Conc. (µg/L)
Baseline (with mixer)	150	0.00	89	103	0.15	78
Alt. 6 Pipe looping	168	0.05	91	108	0.15	78

[1]Based on model prediction during extended period simulation with tank at low point in cycle

3.9 Alternative 7: Flow from CHSA back to Saltonstall SA

Under this alternative, the overall turnover in the CHSA would be increased by allowing gravity flow from the CHSA back to the Saltonstall SA. Installing a new water main connection with control valve between the service areas was considered, but it was concluded that the most economical way to implement the concept would be to use the existing Cherry Hill Pump Station facilities, which would be modified as required. The concept is to allow flow through the existing relief valve during periods when the pumps are off.

Water quality metrics for Alternative 7 are presented in Table 3-9. As indicated in the table, no significant improvement in distribution system water quality is predicted. Therefore, Alternative 7 is eliminated from further consideration as a stand-alone alternative. A conceptual cost estimate is provided in Appendix A.

Table 3-9
Water Quality Metrics – Alternative 7 – Flow from CHSA back to Saltonstall SA[1]

	Tank			All System Nodes		
Scenario	**Water Age (hours)**	**Chlorine Residual (mg/L)**	**TTHM Conc. (μg/L)**	**Average Water Age (hours)**	**Average Chlorine Residual (mg/L)**	**Average TTHM Conc. (μg/L)**
Baseline (with mixer)	150	0.00	89	103	0.15	78
Alt. 7 Flow back to Saltonstall SA	155	0.05	90	95	0.17	77

[1]Based on model prediction during extended period simulation with tank at low point in cycle

3.10 Alternative 8: Existing Tank with Aeration/ Mixing/Rechlorination and One Large Blow-off

This alternative is a combination of Alternatives 2 and 5, comprised of an aeration/mixing/rechlorination system in conjunction with a 25-gpm blow-off as discussed under Alternative 5. Water quality metrics for Alternative 8 are presented in Table 3-10.

Table 3-10
Water Quality Metrics – Alternative 8 – Aeration with Dead End Blowoff[1]

	Tank			All System Nodes		
Scenario	**Water Age (hours)**	**Chlorine Residual (mg/L)**	**TTHM Conc. (μg/L)**	**Average Water Age (hours)**	**Average Chlorine Residual (mg/L)**	**Average TTHM Conc. (μg/L)**
Baseline (with mixer)	150	0.00	89	103	0.15	78
Alt. 8 Existing tank with aeration/mixing/rechlorination and blow-off	139	0.13	59	92	0.25	68

[1]Based on model prediction during extended period simulation with tank at low point in cycle

As indicated in the table, Alternative 8 is predicted to provide significant improvement in tank water quality and water quality in the entire distribution system. Model-predicted water age, chlorine residual, and TTHM concentrations for Alternative 8 are shown on Figures 3-14, 3-15, and 3-16, respectively. Conceptual cost estimates for Alternatives 2 and 5 are provided in Appendix A.

3.11 Alternative 9: Elevated Spheroid Tank with Aeration/Mixing/Rechlorination

This alternative consists of a new 750,000 gallon spheroid tank (Alternative 1) with an aeration/rechlorination/mixing system similar to the system proposed for the existing tank under Alternative 2. Water quality metrics for Alternative 9 are presented in Table 3-11.

Table 3-11
Water Quality Metrics – Alternative 9 – Spheroid Tank with Aeration[1]

	Tank			All System Nodes		
Scenario	**Water Age (hours)**	**Chlorine Residual (mg/L)**	**TTHM Conc. (μg/L)**	**Average Water Age (hours)**	**Average Chlorine Residual (mg/L)**	**Average TTHM Conc. (μg/L)**
Baseline (with mixer)	150	0.00	89	103	0.15	78
Alt. 9 Spheroid tank with aeration/mixing/rechlorination	89	0.20	42	82	0.23	66

[1]Based on model prediction during extended period simulation with tank at low point in cycle

As indicated in Table 3-11, Alternative 9 is predicted to significantly improve water quality in the tank and in the distribution system. Model-predicted water age, chlorine residual, and TTHM concentrations for Alternative 9 are shown on Figures 3-17, 3-18, and 3-19, respectively. A conceptual cost estimate for Alternative 9 is included in Appendix A.

3.12 Alternative 10: Elevated Spheroid Tank with Aeration/Mixing/Rechlorination and One Large Blow-off

This alternative is a combination of Alternatives 5 and 9, consisting of a new 750,000 gallon spheroid tank with an aeration/rechlorination/mixing system (Alternative 9), in conjunction with a large blowoff flowing at 25 gpm (Alternative 5). Water quality metrics for Alternative 10 are presented in Table 3-12.

Table 3-12
Water Quality Metrics – Alternative 10 – Spheroid Tank with Aeration and Dead End Blowoffs [1]

Scenario	Tank: Water Age (hours)	Tank: Chlorine Residual (mg/L)	Tank: TTHM Conc. (μg/L)	All System Nodes: Average Water Age (hours)	All System Nodes: Average Chlorine Residual (mg/L)	All System Nodes: Average TTHM Conc. (μg/L)
Baseline (with mixer)	150	0.00	89	103	0.15	78
Alt. 10 Spheroid tank with aeration and blow-offs	82	0.20	42	75	0.24	64

[1]Based on model prediction during extended period simulation with tank at low point in cycle

As indicated in Table 3-12, Alternative 10 is predicted to significantly improve water quality in the tank and in the distribution system. Based on model predictions, this alternative is expected to provide the greatest improvement in water quality of all the alternatives considered, but is also the most expensive. Conceptual cost estimates for Alternatives 5 and 9 are included in Appendix A.

3.13 Comparison of Alternatives

Table 3-13 presents a comparison of alternatives in terms of their respective effectiveness in improving water quality, based on model predictions.

Table 3-13
Comparison of Alternatives[1,2]

Scenario	Tank: Water Age (hours)	Tank: Chlorine Residual (mg/L)	Tank: TTHM Conc. (μg/L)	All System Nodes: Average Water Age (hours)	All System Nodes: Average Chlorine Residual (mg/L)	All System Nodes: Average TTHM Conc. (μg/L)	Overall water quality improvement
Baseline (with mixer)	150	0.00	89	103	0.15	78	
Alt.1 Spheroid Tank	87	0.08	84	80	0.12	80	Fair
Alt.2 Existing tank with aeration/mixing system	147	0.13	60	103	0.24	69	Good
Alt. 3 Existing tank with false bottom	75	0.10	82	70	0.17	76	Excellent
Alt. 4 Blow-offs at dead ends	143	0.06	89	87	0.17	76	Poor
Alt 5 One large blow-off	142	0.06	89	92	0.16	77	Poor
Alt. 6 Pipe looping	168	0.05	91	108	0.15	78	Poor
Alt. 7 Flow back to Saltonstall SA	155	0.05	90	95	0.17	77	Poor
Alt. 8 Existing tank with aeration/mixing and large blow-off	139	0.13	59	92	0.25	68	Excellent
Alt. 9 Spheroid tank with aeration/mixing	89	0.20	42	82	0.23	66	Excellent
Alt. 10 Spheroid tank with aeration/mixing and large blow-off	82	0.20	42	75	0.24	64	Excellent

[1]Based on model prediction during extended period simulation with tank at low point in cycle
[2]Shading indicates alternatives selected for detailed evaluation

As indicated in Table 3-13, Alternatives 4 through 7 are not predicted to provide a significant water quality benefit, and are therefore eliminated from consideration as standalone alternatives. Of the remaining alternatives, Alternative 3 is eliminated due to hydraulic deficiencies, structural difficulties, and anticipated high cost.

Alternative 8 combines an aeration/mixing/rechlorination system as included in Alternative 2 with a large blow-off as proposed under Alternative 5. Alternatives 9 incorporates an aeration/mixing/chlorination system with the proposed elevated spheroid tank, and Alternative 10 consists of one large blow-off (Alternative 5) in conjunction with Alternative 9. Of these alternatives, Alternative 10 is the "Cadillac", resulting in the best overall system water quality. Alternatives 1, 2, 8, 9, and 10 are selected for additional evaluation.

4 Feasibility and Costs of Selected Alternatives

As discussed in the previous section, Alternatives 1, 2, 8, 9, and 10 are expected to be the most effective of the feasible alternatives considered from the standpoint of improving water quality. In this section, feasibility evaluations and conceptual cost estimates are presented for these alternatives.

4.1 Alternatives Involving Modifications to the Existing Standpipe

Alternatives 2 and 8 involve modifications to the existing standpipe. It is assumed that any alternative that includes keeping the existing tank will include interior and exterior painting, as the coating systems are in need of rehabilitation. It is also assumed that any alternative that includes keeping the existing tank will include a mixing system, because of the modest cost and the likelihood that this type of mixing system will be required in the future.

Painting the tank will require removing it from service for an extended period. This will be logistically challenging due to the need to provide consistent pressure and adequate fire protection to the CHSA during the period the tank is off-line. It is assumed that additional pumping capacity would need to be provided to meet peak demands, and that temporary storage would be provided for fire protection. For purposes of developing budgets, it is assumed that the following would be provided:

- Temporary pumping equipment. We estimate that the combined capacity of the existing pumps is approximately 900 gpm when pumping together against normal system head. The peak system demand calculated for August 23, 2012 is between 1,500 and 2,000 gpm. To provide a flow rate of 2,000 gpm through the existing station, a total pumping head of approximately 450 feet would be required. This required head exceeds the shutoff head of the existing pumping equipment. Therefore, temporary pumping equipment to meet peak demands would be required. For budgetary purposes, a rental unit that would be connected hydrant-to-hydrant is assumed.

- Temporary water storage: three 50,000 gallon water bags (“Insta-Tank” or similar) to be located in the CHSA are assumed. These would not be able to feed the system by gravity due to the system topography, but would be available for fire fighting in an emergency. A budget of $40,000 is included for the water bags.

The concept would be to operate the pump station with the pumps on continuously under VFD control, utilizing the existing pressure relief valve to bleed water back to the Saltonstall SA as necessary. The existing pumps and VFDs would meet normal demands. The temporary pump would provide additional capacity to meet peak demands.

Alternative 2 – Existing tank with aeration, mixing, and rechlorination systems. This alternative includes modifying the existing tank including interior and exterior painting, and installation of an aeration system for TTHM stripping, a mixing system, and chlorination system. Some modifications to the tank would be required to accommodate the spray aeration, including modifying the tank roof to accommodate a blower and vents. A power service and enclosure for instrumentation, electrical equipment, and chemical feed equipment would also be required. The conceptual cost estimate for Alternative 2 is $1,600,000. A detailed conceptual cost estimate is provided in Appendix A.

Alternative 8 - Existing tank with aeration, mixing, and rechlorination systems with one large blow-off. This alternative incorporates Alternative 2 with a large blow-off that would be located at the end of Hemlocks Road Extension, as discussed under Alternative 5. The large blow-off would provide similar water quality benefits compared to several small blow-offs as discussed under Alternative 4, but is considered more feasible because it would be possible to discharge the water back to the Lake Saltonstall watershed. The conceptual cost for Alternative 8 is $2,100,000. A detailed conceptual cost estimate is provided in Appendix A.

4.2 Alternatives involving a new elevated spheroid tank

A 750,000 gallon composite elevated storage tank was recommended in the *Alternative Investigation for Replacement of Brushy Plains Tank* prepared by Roald Haestad, Inc. and dated January 2011. Replacing the existing tank with a new elevated spheroid tank has the following significant advantages compared to alternatives that involve retaining and modifying the existing standpipe:

- The existing tank can remain in service while constructing the new tank, avoiding logistical challenges associated with maintaining adequate pressure and providing fire protection if the existing tank is taken out of service.

- The proposed elevated spheroid tank would provide the recommended storage volume at the recommended operating elevation range, while the existing tank is deficient in this respect.

Alternative 1- New spheroid tank consists of a new 750,000 gallon capacity elevated spheroid tank as recommended in the 2011 *Alternative Investigation*. Tighe & Bond's conceptual cost estimate for this project is $3,200,000 adjusted for inflation to November, 2012. A detailed conceptual cost estimate is provided in Appendix A

Alternative 9 – Spheroid tank with aeration/mixing/rechlorination system. This alternative incorporates the proposed aeration/mixing/rechlorination system proposed for use in the existing standpipe under Alternative 2 in a new elevated spheroid tank. Tighe & Bond's conceptual cost estimate for Alternative 9 is $3,400,000. A detailed conceptual cost estimate is provided in Appendix A

Alternative 10 - Spheroid tank with aeration/mixing/rechlorination system and one large blowoff. This alternative consists of Alternative 9 combined with a 25 gpm blow-off as discussed under Alternative 5. The conceptual cost for Alternative 10 is $3,900,000. A detailed conceptual cost estimate is provided in Appendix A.

4.3 Comparison of Alternatives and Recommendations

Table 4-1 provides a summary of selected alternatives and conceptual cost estimates.

Table 4-1
Comparison of Selected Alternatives

Scenario	Overall effectiveness in improving water quality	Conceptual Cost Estimate	Remarks
Alt.1 Spheroid Tank	Fair	$3,200,000	Provides hydraulic and storage benefits
Alt.2 Existing tank with aeration/mixing/rechlorination system	Good	$1,600,000	Includes tank painting and temporary pumping & water storage equipment
Alt. 8 Existing tank with aeration/mixing/rechlorination and 1 large blow-off	Excellent	$2,100,000	Includes tank painting and temporary pumping & water storage equipment
Alt. 9 Spheroid tank with aeration/mixing/rechlorination	Excellent	$3,400,000	Provides hydraulic and storage benefits
Alt. 10 Spheroid tank with aeration/mixing/rechlorination and 1 large blow-off	Excellent	$3,900,000	Provides hydraulic and storage benefits

As indicated in Table 4-1, Alternative 2, rehabilitation of the existing tank including installation of an aeration/mixing/rechlorination system is the most economical alternative that is considered feasible and is expected to meet the RWA's water quality objectives. Including a blow-off as proposed under Alternative 8 would provide only a modest benefit from a water quality standpoint. Therefore, it would be difficult to justify the capital cost of including this improvement (Alternative 8).

Thus, Alternative 2 appears to be the most attractive from a water quality standpoint. However, in addition to providing superior water quality, Alternative 9 has an advantage from the standpoint of hydraulics because it would provide the storage capacity and operating elevation range recommended in the 2011 *Alternative Investigation for Replacement of Brushy Plains Tank*. Furthermore, this alternative would avoid the significant logistical challenges associated with removing the existing tank from service during rehabilitation. As discussed above, the cost of including the proposed blow-off (Alternative 10) would be difficult to justify based on the modest water quality improvement.

In summary, Alternative 2 (rehabilitated existing tank with aeration/mixing/rechlorination system) and Alternative 9 (new spheroid tank with aeration/mixing/rechlorination system) are considered "finalists." Operation and maintenance costs would be equivalent for these alternatives, so no detailed comparison is provided. It is recommended that the RWA evaluate whether the logistical, hydraulic, and storage capacity benefits provided by Alternative 9 justify the significant difference in capital cost.

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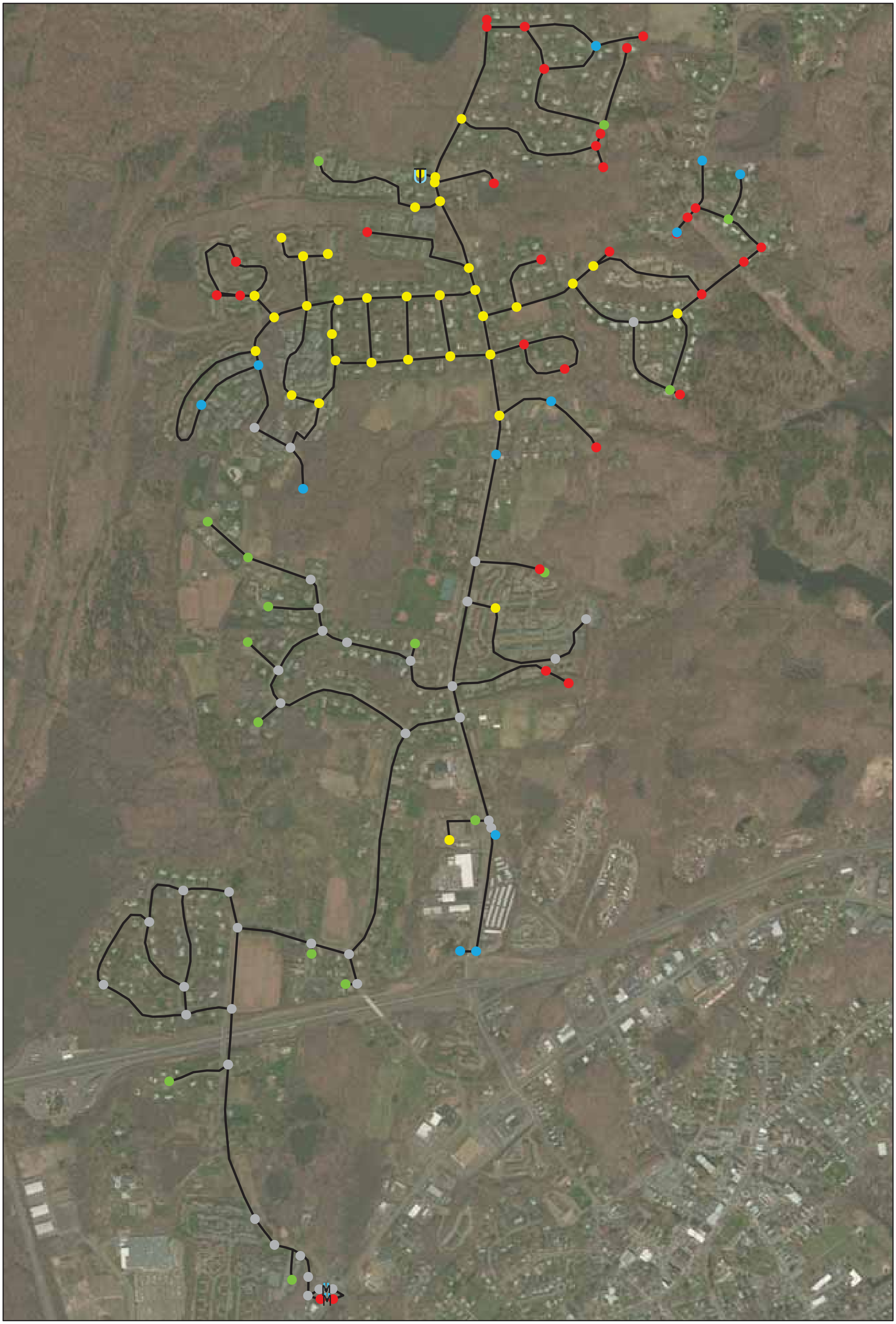

Tank
Cherry Hill Pump Station
Watermain

Water Age (hrs)
<20
21 - 40
41 - 100
101 - 160
>160

Figure 3-4
Model-Predicted Water Age
Baseline Scenario
Cherry Hill Service Area Water Quality Evaluation
South Central Connecticut Regional Water Authority

Tighe&Bond

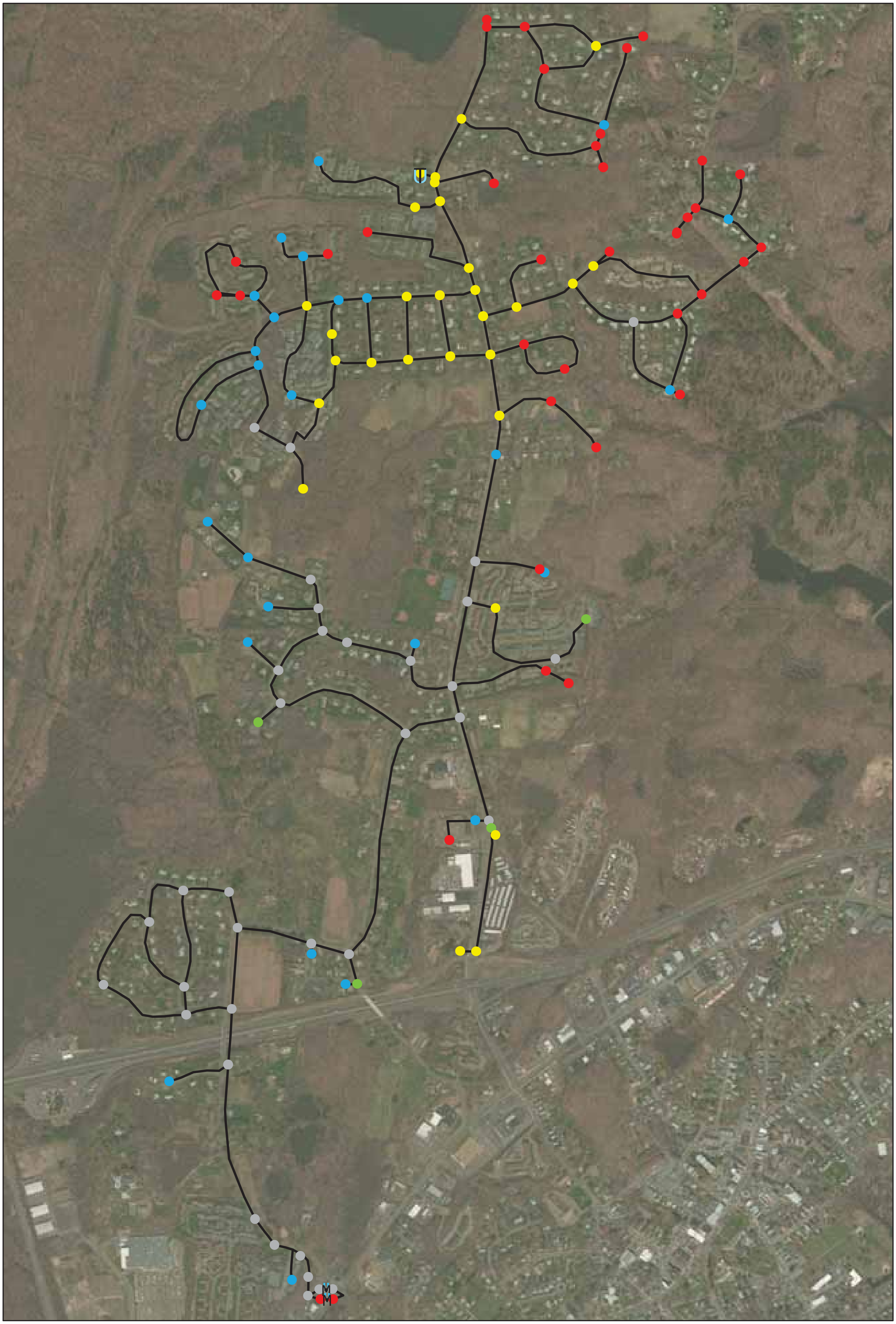

Figure 3-5
Model-Predicted Chlorine Residual
Baseline Scenario
Cherry Hill Service Area Water Quality Evaluation
South Central Connecticut Regional Water Authority

Tighe&Bond

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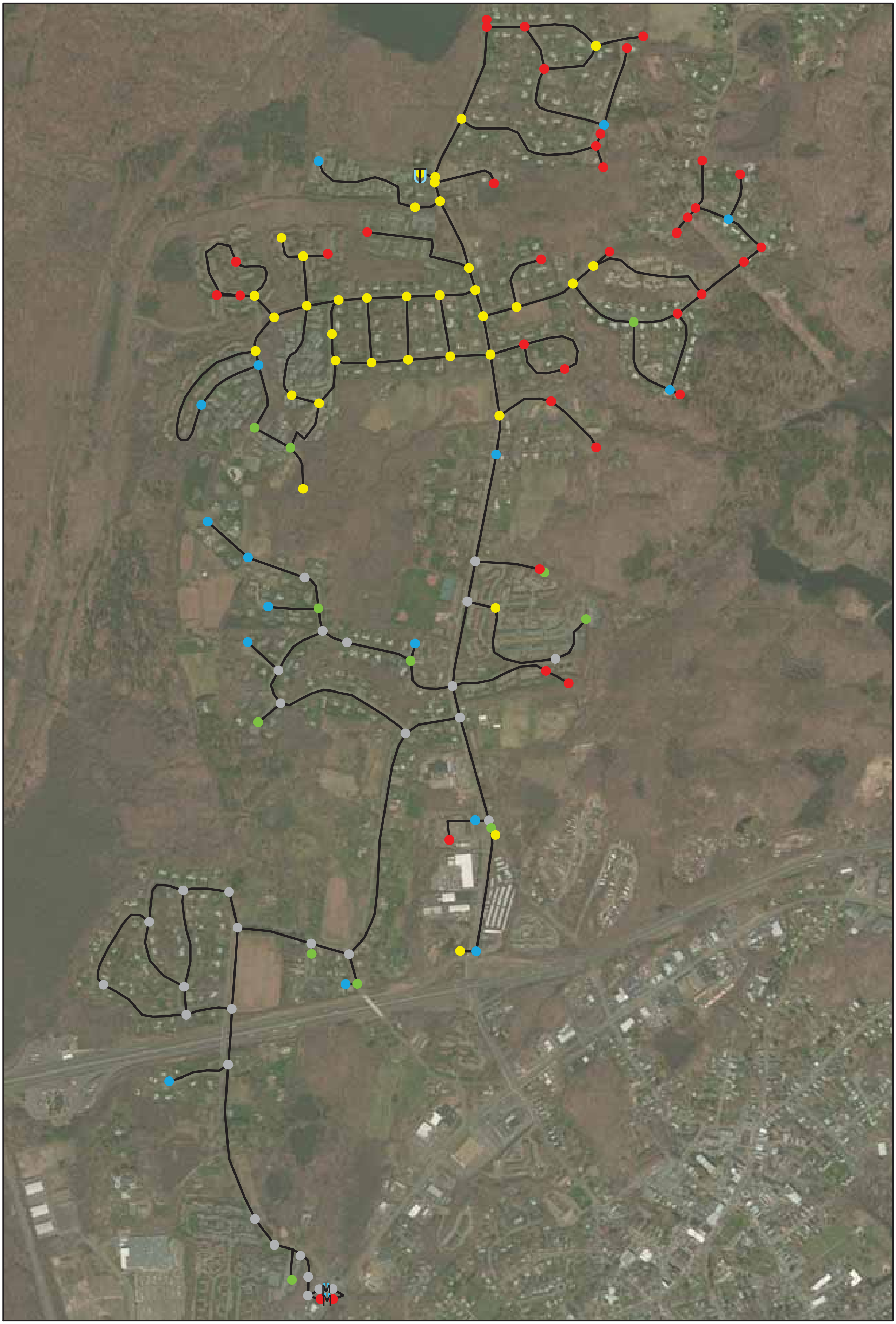

Tank

Cherry Hill Pump Station

Watermain

TTHM Concentration (ug/L)

- <60
- 61 - 70
- 71 - 80
- 81 - 90
- >90

Figure 3-6
Model-Predicted TTHM
Baseline Scenario
Cherry Hill Service Area Water Quality Evaluation
South Central Connecticut Regional Water Authority

Tighe&Bond

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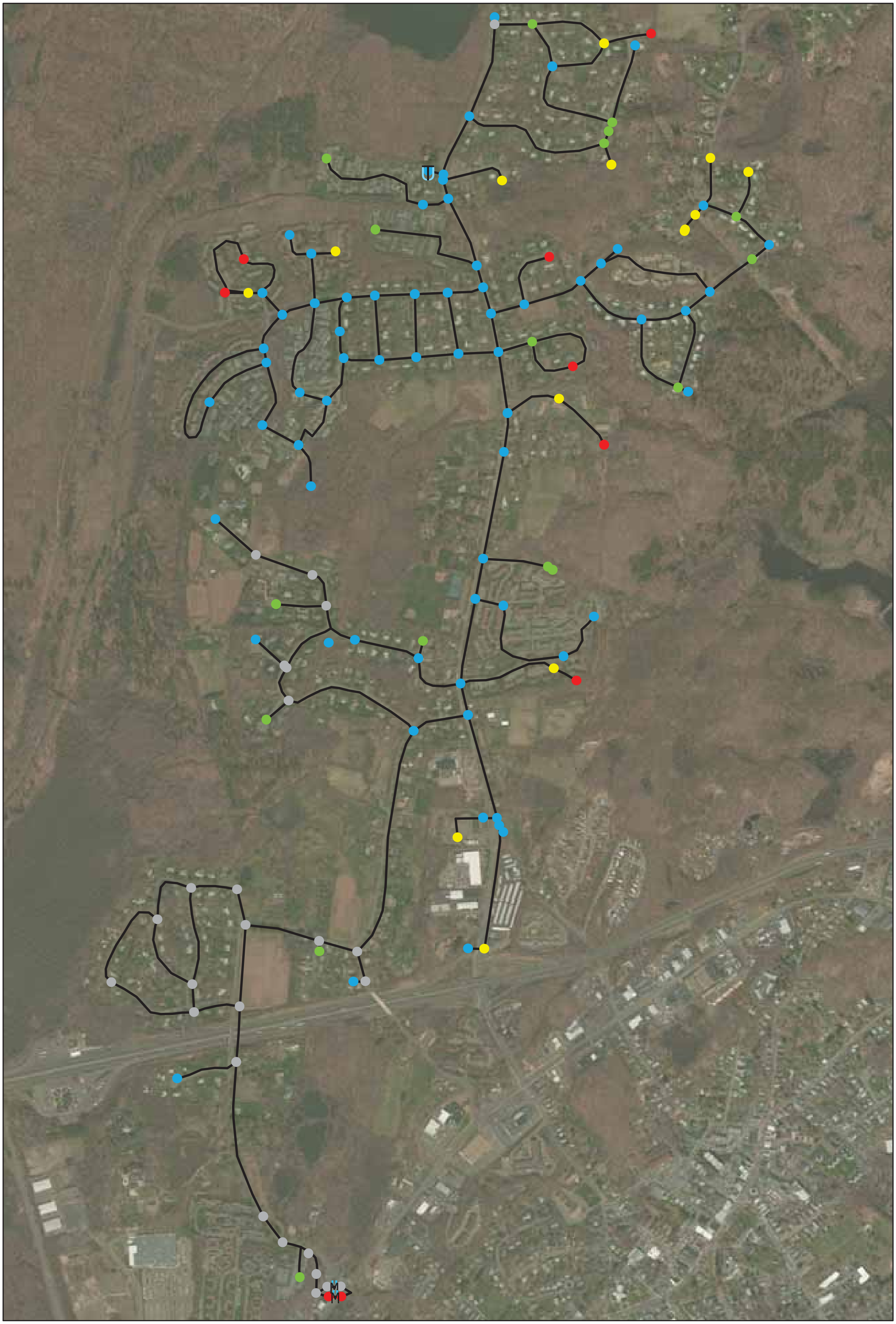

Figure 3-7
Model-Predicted Water Age
Spheroid Tank Scenario
Cherry Hill Service Area Water Quality Evaluation
South Central Connecticut Regional Water Authority

Tighe&Bond

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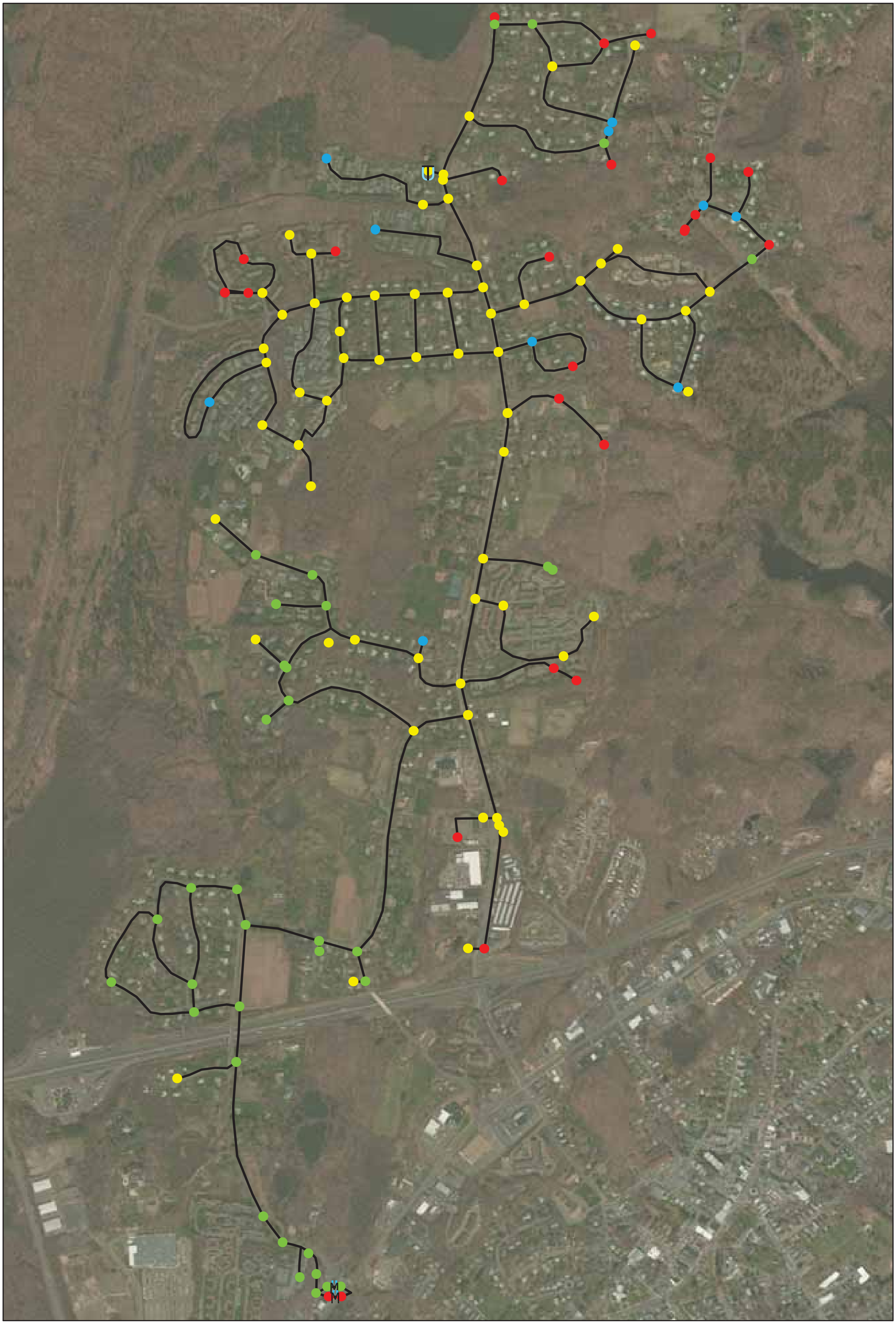

Figure 3-8
Model-Predicted Chlorine Residual
Spheroid Tank Scenario
Cherry Hill Service Area Water Quality Evaluation
South Central Connecticut Regional Water Authority

Tighe&Bond

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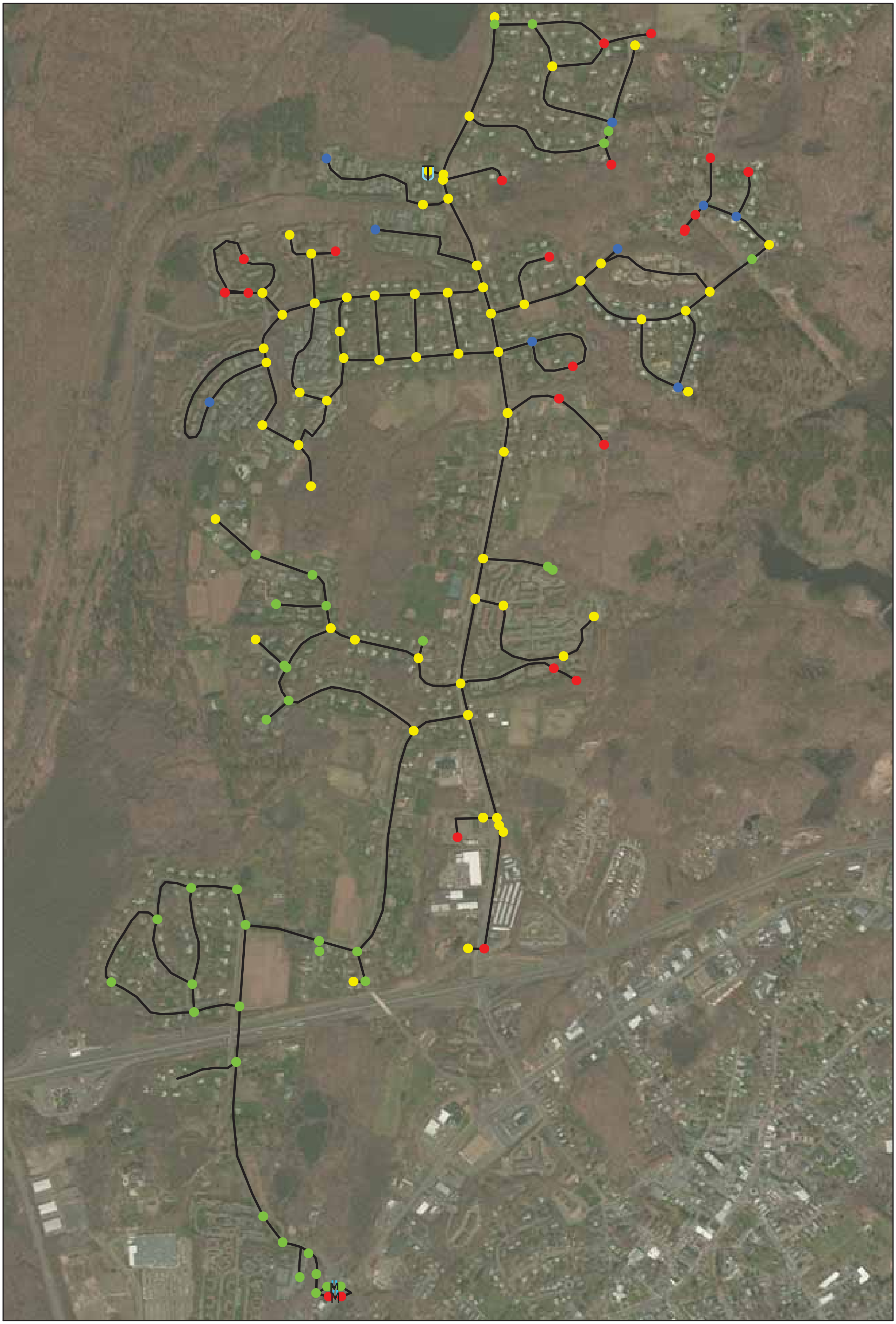

Tank
Cherry Hill Pump Station
Watermain

TTHM Concentration (ug/L)
<60
61 - 70
71 - 80
81 - 90
>90

Figure 3-9
Model-Predicted TTHM
Spheroid Tank Scenario
Cherry Hill Service Area Water Quality Evaluation
South Central Connecticut Regional Water Authority

Tighe&Bond

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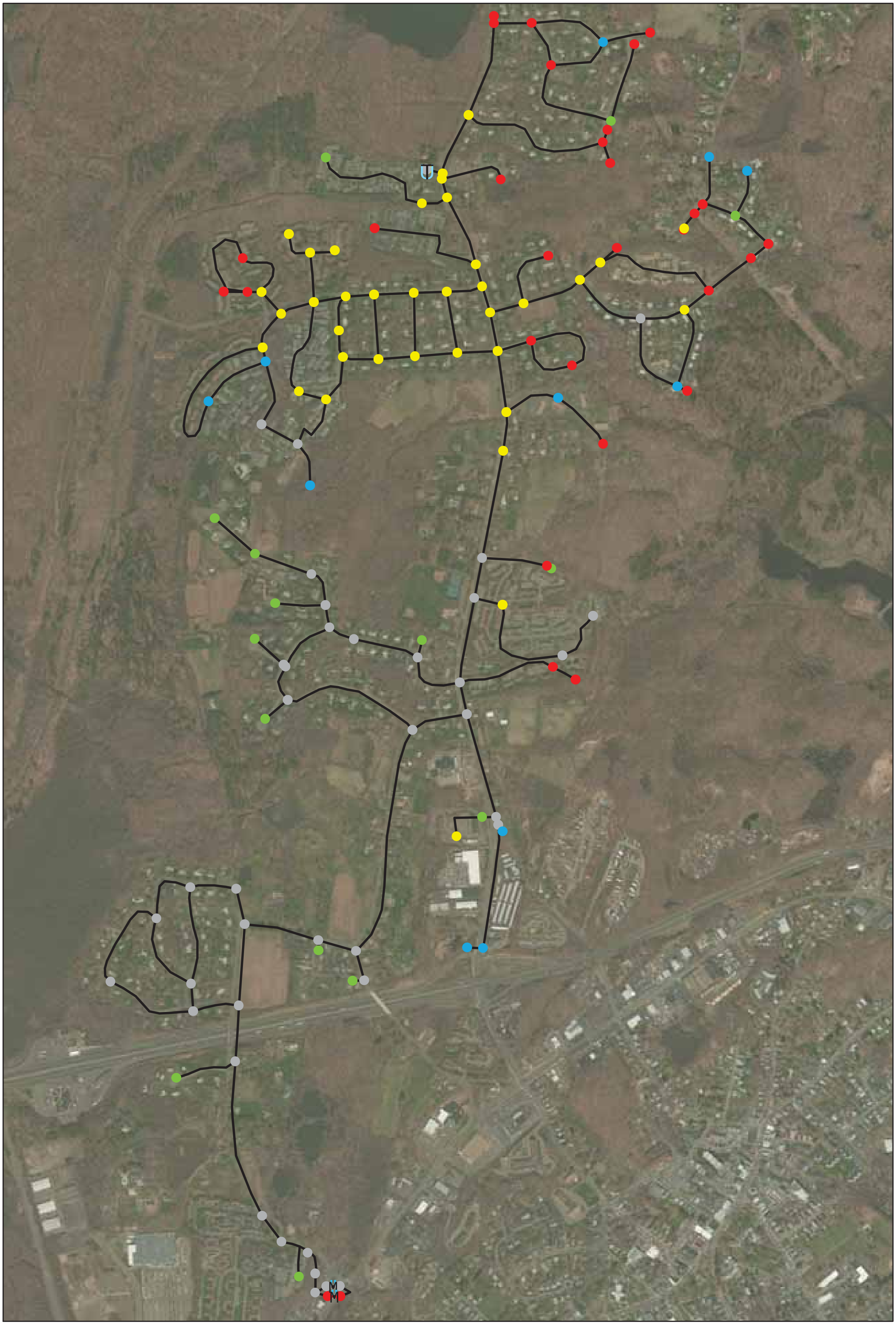

Figure 3-10
Model-Predicted Water Age
Existing Tank with Aeration Scenario
Cherry Hill Service Area Water Quality Evaluation
South Central Connecticut Regional Water Authority

Tighe&Bond

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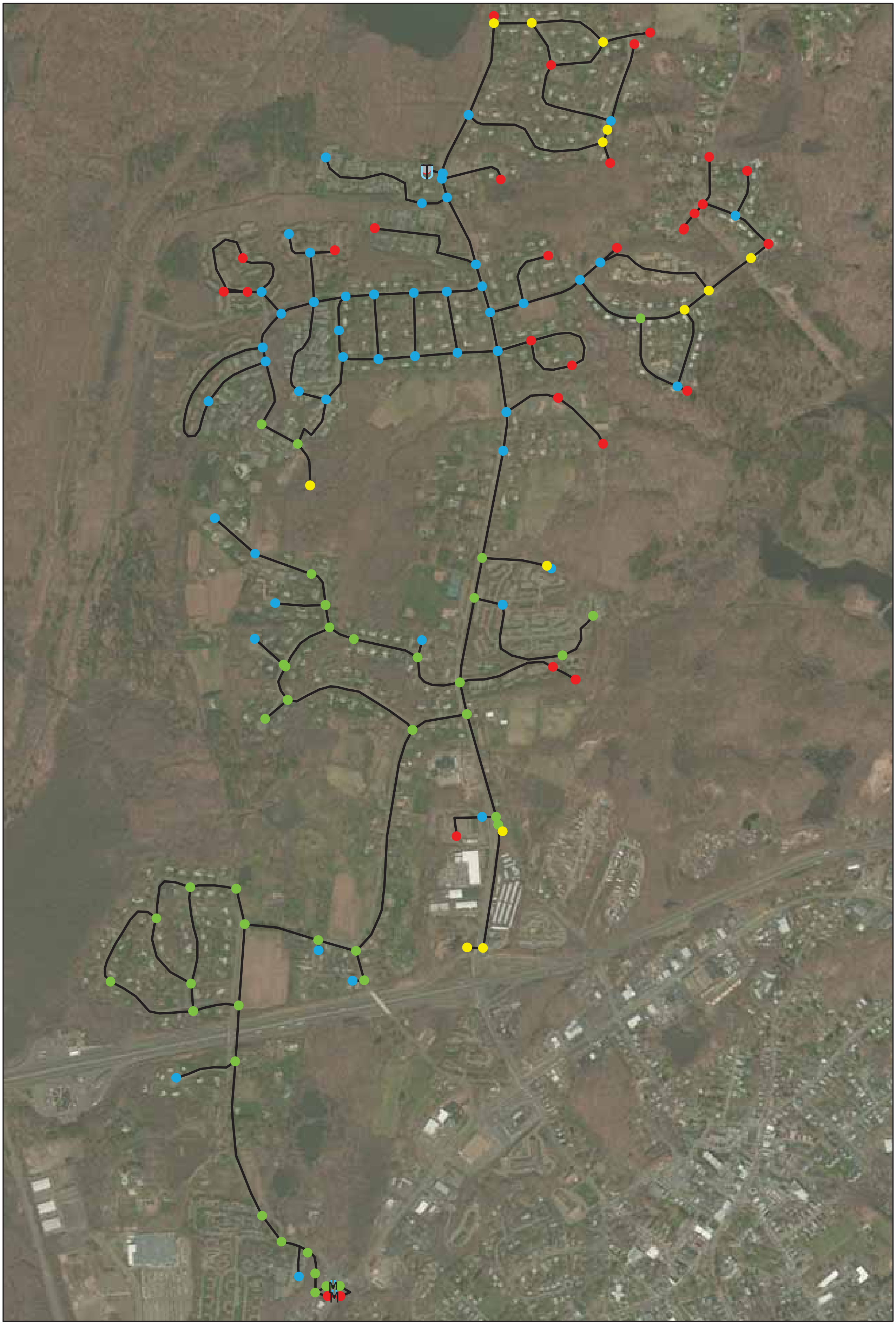

Tank

Cherry Hill Pump Station

Watermain

Chlorine Residual (mg/L)

- <0.05
- 0.05 - 0.10
- 0.10 - 0.20
- 0.20 - 0.30
- >0.30

Figure 3-11
Model-Predicted Chlorine Residual
Existing Tank with Aeration Scenario
Cherry Hill Service Area Water Quality Evaluation
South Central Connecticut Regional Water Authority

Tighe&Bond

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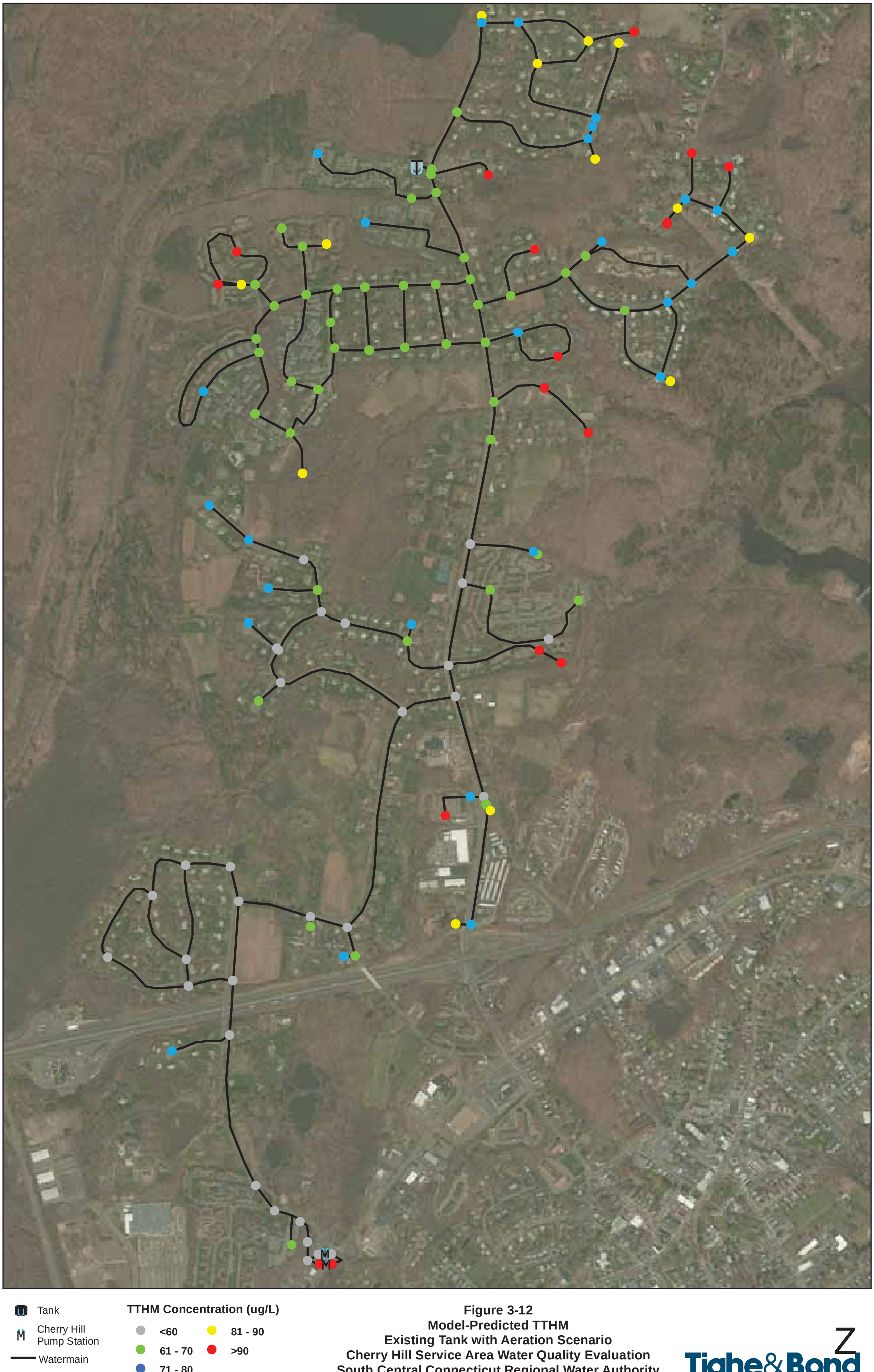

Figure 3-12
Model-Predicted TTHM
Existing Tank with Aeration Scenario
Cherry Hill Service Area Water Quality Evaluation
South Central Connecticut Regional Water Authority

Tighe&Bond

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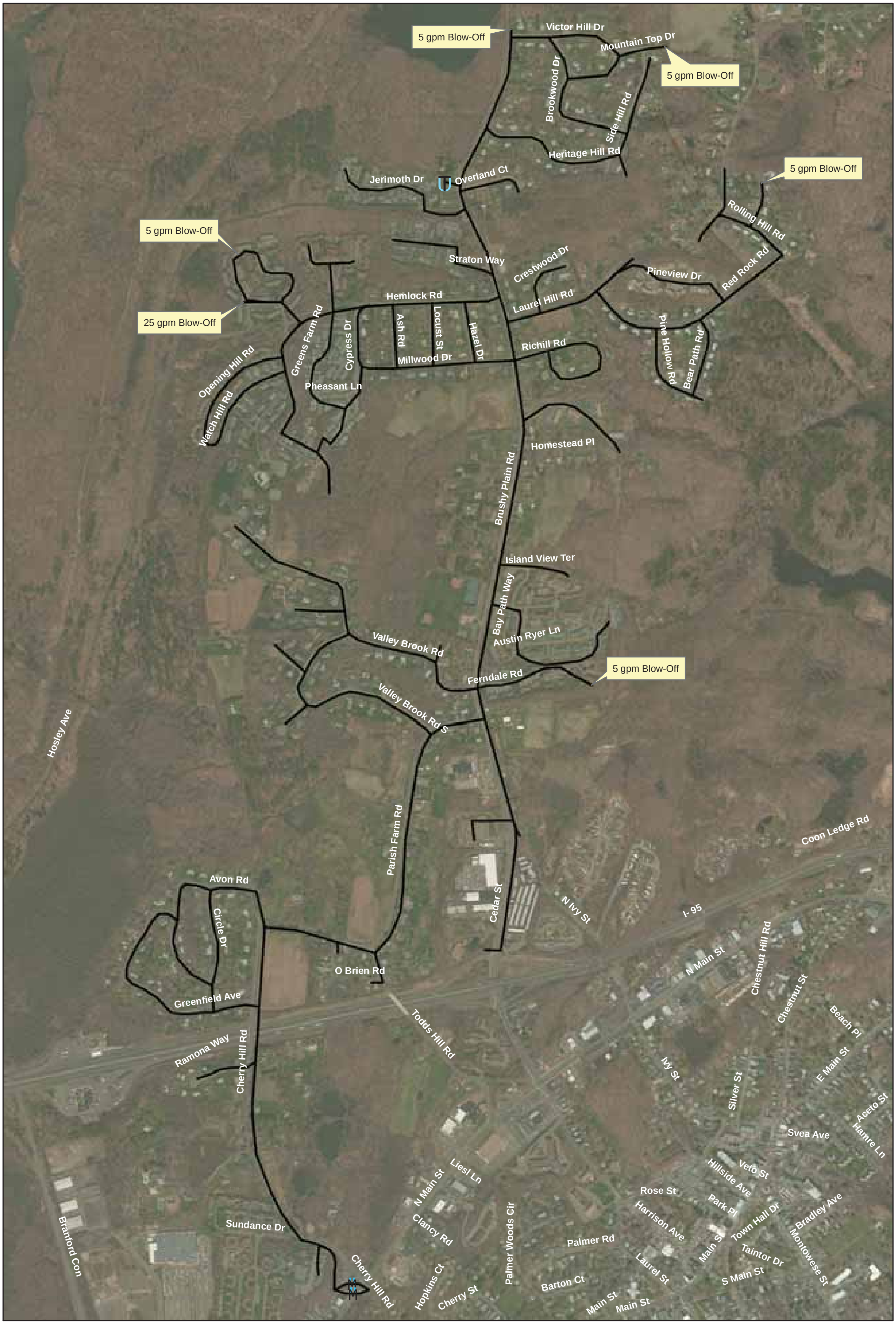

Tank

Cherry Hill Pump Station

Watermain

Figure 3-13
Blow-Off Locations
Cherry Hill Service Area Water Quality Evaluation
South Central Connecticut Regional Water Authority

Tighe&Bond

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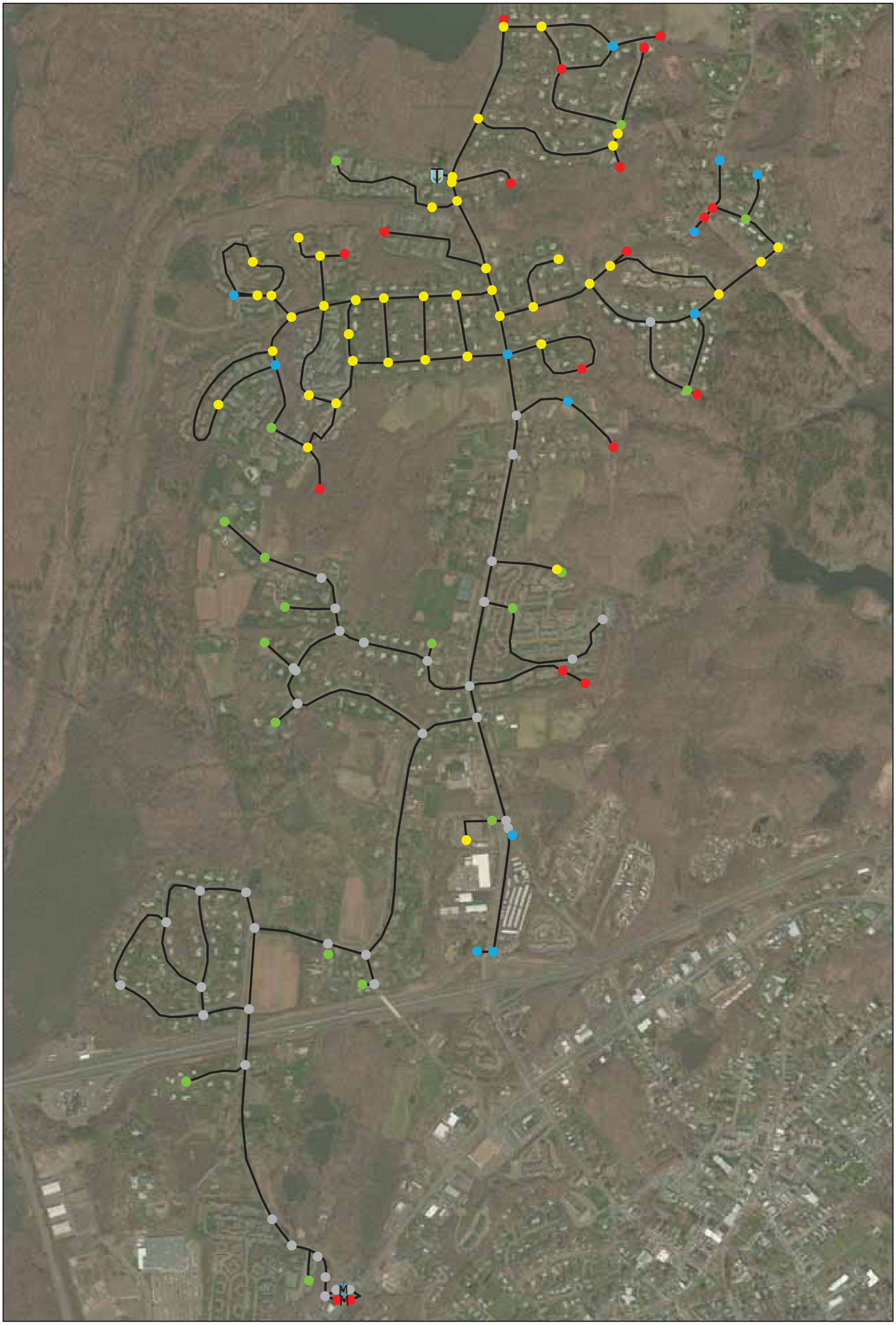

Figure 3-14
Model-Predicted Water Age
Existing Tank with Aeration and Large Blow-off Scenario
Cherry Hill Service Area Water Quality Evaluation
South Central Connecticut Regional Water Authority

Tighe&Bond

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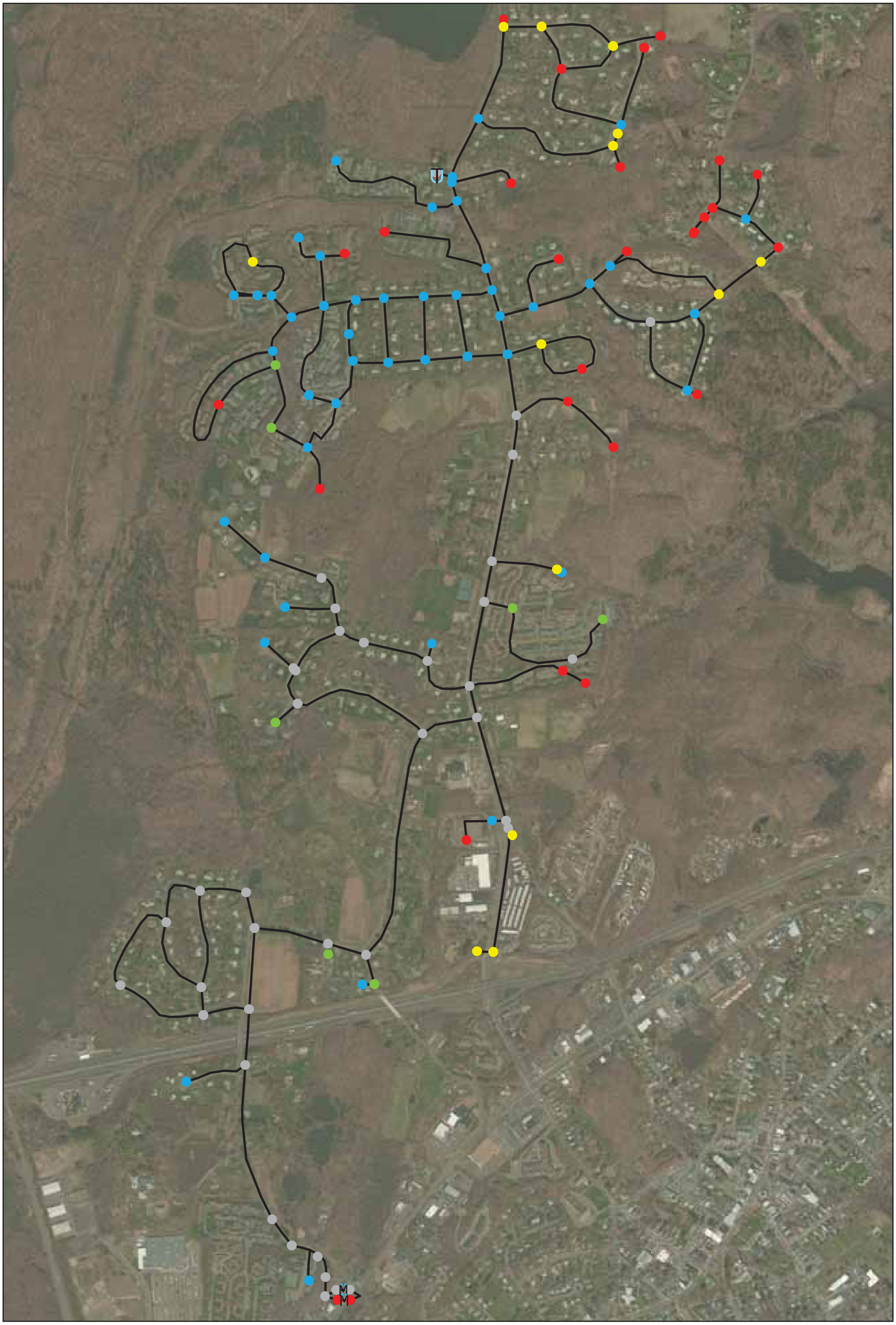

Figure 3-15
Model-Predicted Chlorine Residual
Existing Tank with Aeration and Large Blow-off Scenario
Cherry Hill Service Area Water Quality Evaluation
South Central Connecticut Regional Water Authority

Tighe&Bond

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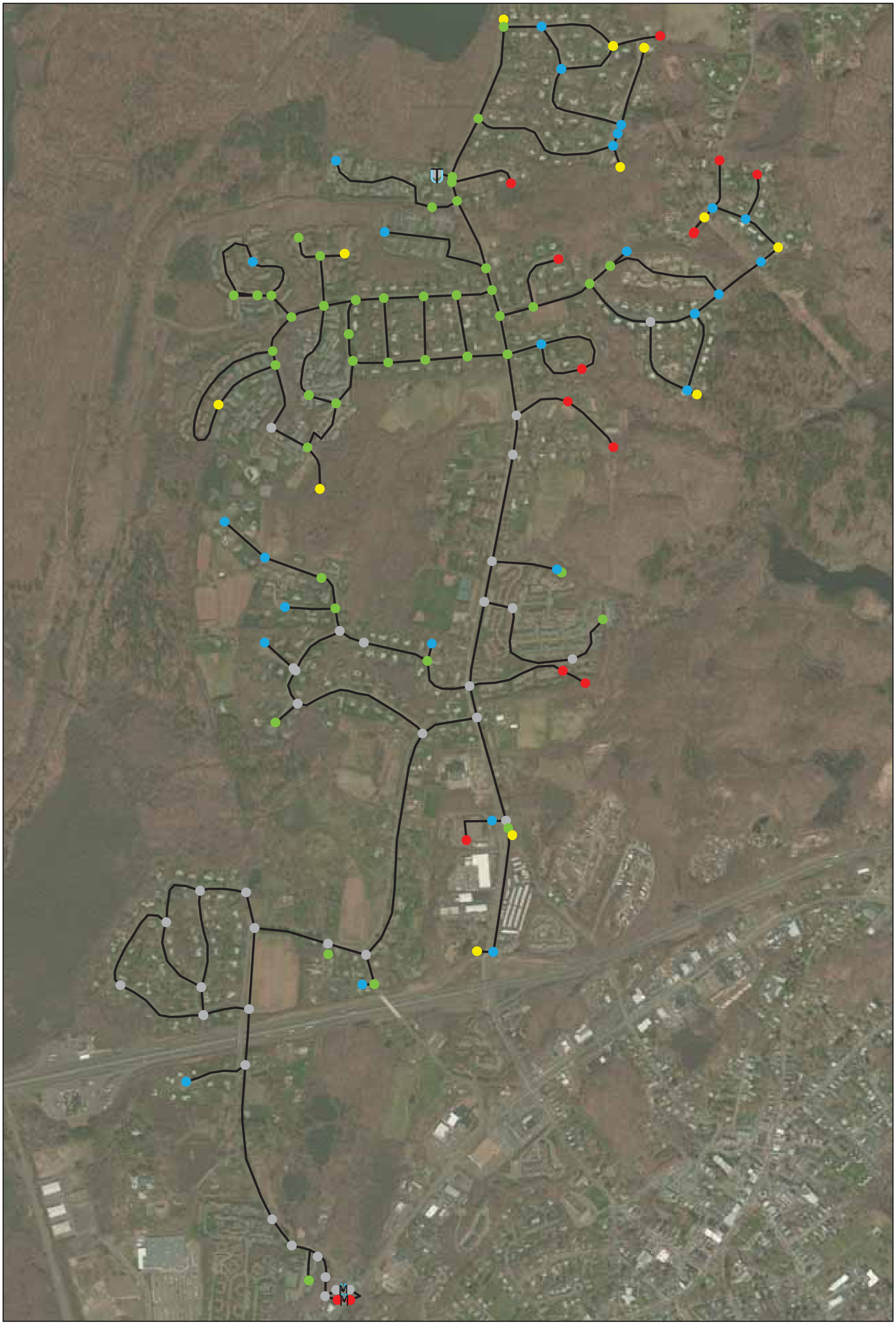

Tank
Cherry Hill Pump Station
Watermain

TTHM Concentration (ug/L)

- <60
- 61 - 70
- 71 - 80
- 81 - 90
- >90

Figure 3-16
Model-Predicted TTHM
Existing Tank with Aeration and Large Blow-off Scenario
Cherry Hill Service Area Water Quality Evaluation
South Central Connecticut Regional Water Authority

Tighe&Bond

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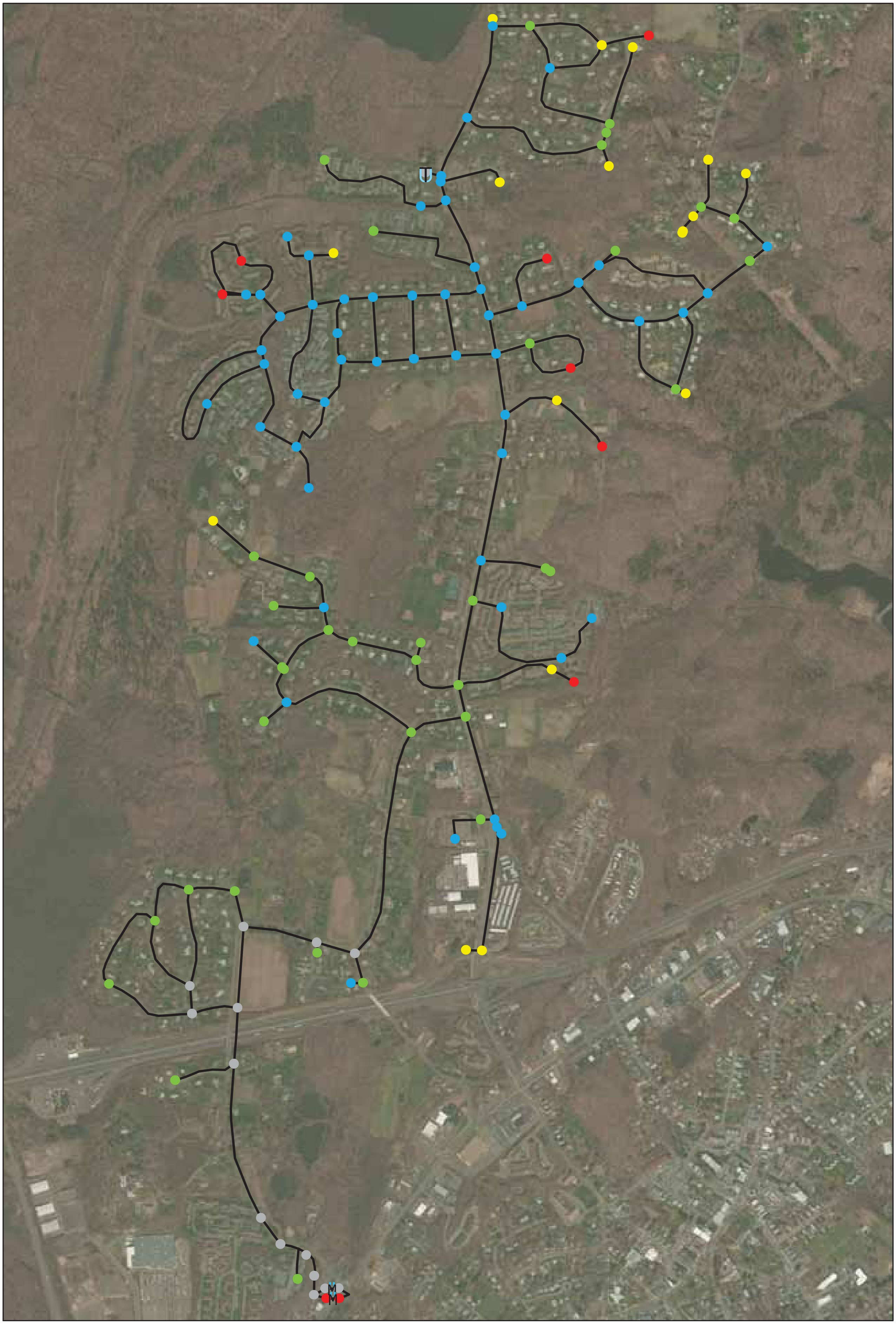

Figure 3-17
Model-Predicted Water Age
Spheroid Tank with Aeration Scenario
Cherry Hill Service Area Water Quality Evaluation
South Central Connecticut Regional Water Authority

Tighe&Bond

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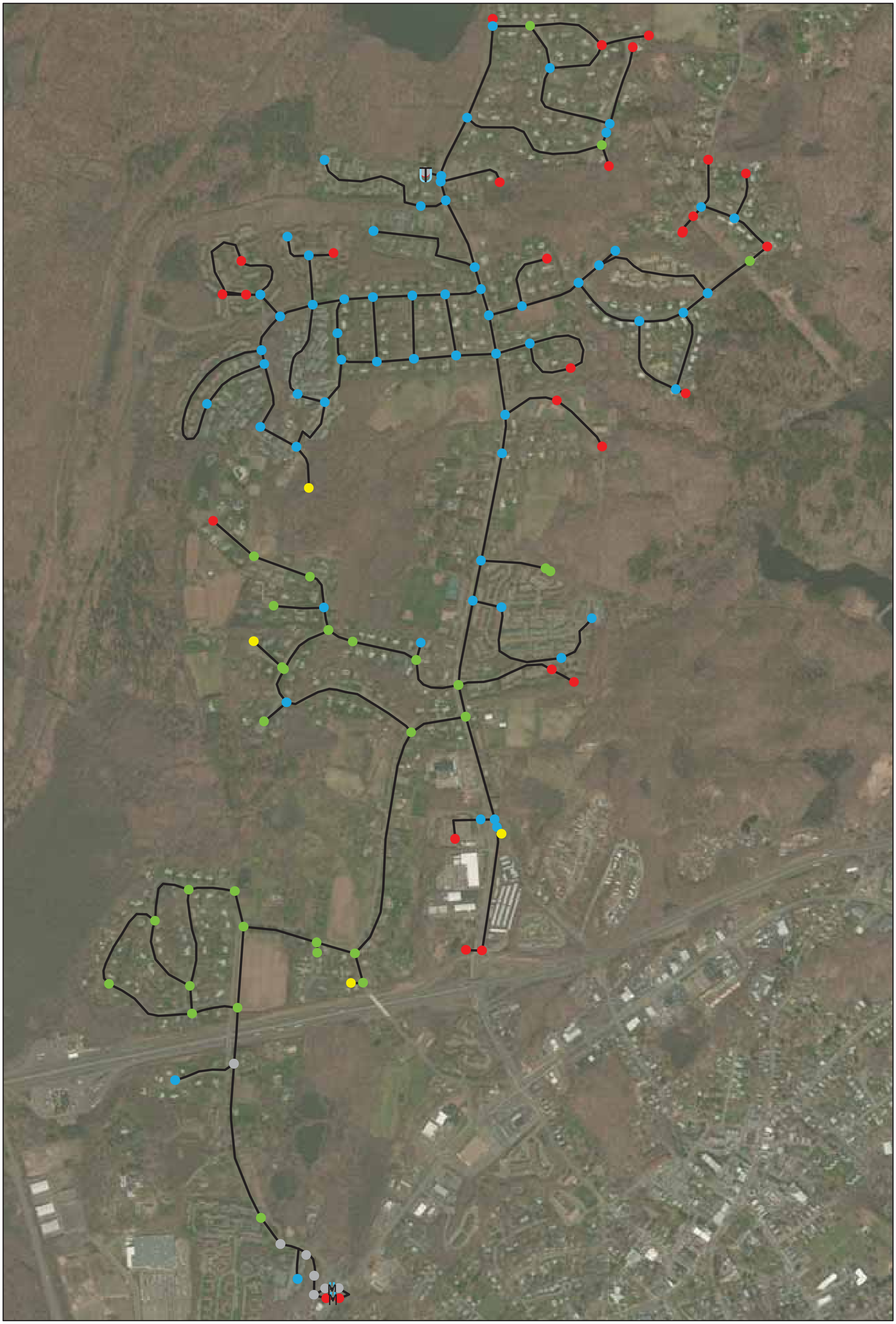

Tank

Cherry Hill Pump Station

Watermain

Chlorine Residual (mg/L)

- <0.05
- 0.05 - 0.10
- 0.10 - 0.20
- 0.20 - 0.30
- >0.30

Figure 3-18
Model-Predicted Chlorine Residual
Spheroid Tank with Aeration Scenario
Cherry Hill Service Area Water Quality Evaluation
South Central Connecticut Regional Water Authority

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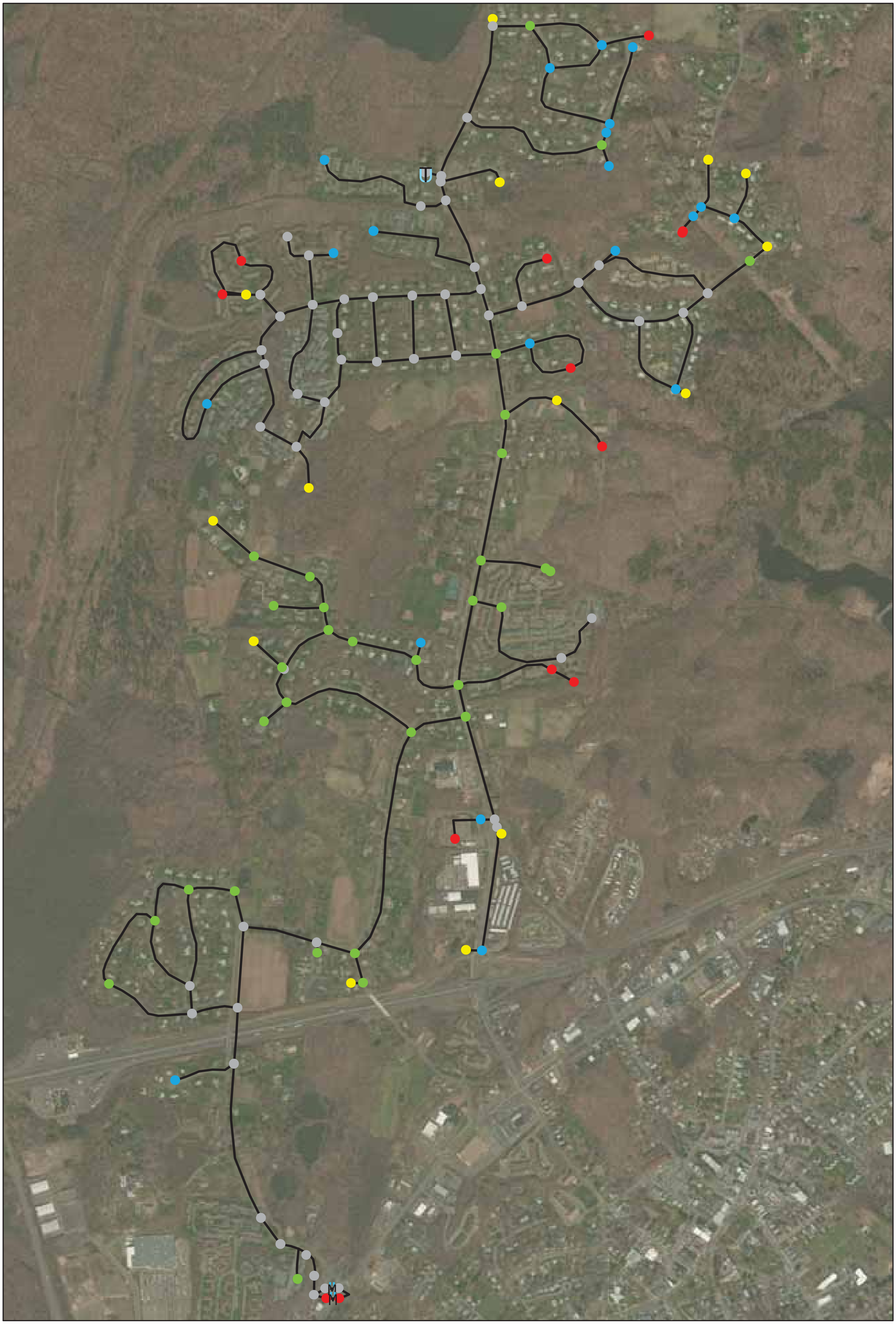

Figure 3-19
Model-Predicted TTHM
Spheroid Tank with Aeration Scenario
Cherry Hill Service Area Water Quality Evaluation
South Central Connecticut Regional Water Authority

Tighe&Bond

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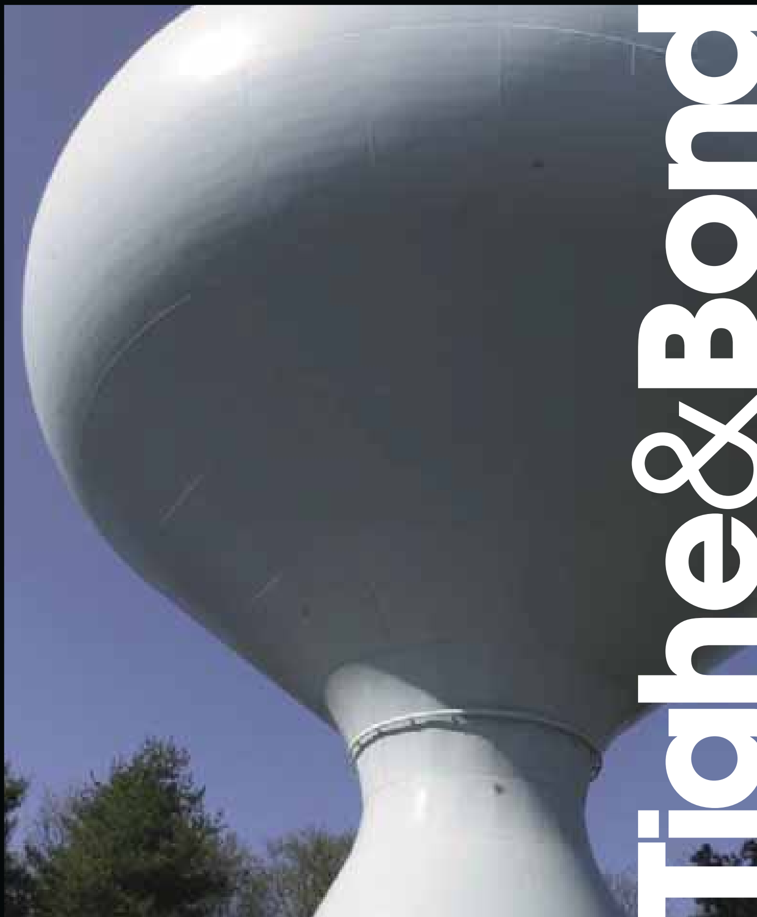


APPENDIX A

Alternative No. 1

New 750,000 gallon Elevated Spheroid Tank

ESTIMATE OF PROBABLE CONSTRUCTION COST

South Central Connecticut Regional Water Authority

November 2012

ITEM	DESCRIPTION	UNITS	QTY	UNIT PRICE	TOTAL
1	Design & Construct Tank incl. General Conditions	LS	1	$1,600,000	$1,600,000
	Contingency - 20%				$320,000
	Design & Construct Tank Total				**$1,920,000**
2	General Contract				
	Excavation & Site Work	LS	1	200,000	200,000
	Rock Excavation	LS	1	30,000	30,000
	Concrete - Class A	CY	50	1,250	62,500
	Concrete - Class B	CY	300	500	150,000
	Gravel Fill	CY	120	50	6,000
	Gravel base & surfacing	CY	375	60	22,500
	Piping & Valves	LS	1	125,000	125,000
	Misc. Site Finishes	LS	1	40,000	40,000
	Demolish existing tank, foundation, and valve chamber	LS	1	100,000	100,000
	Electric Service	LS	1	7,500	7,500
	Electrical Work	LS	1	5,000	5,000
	Instrumentation	LS	1	15,000	15,000
	SCADA Programming	LS	1	10,000	10,000
	Subtotal				773,500
	General Conditions - 15%				116,025
	General Contract Total				889,525
	General Contract Engineering and Contingency - 40%				355,810
	Total - General Contract incl. Engineering and Contingency				**1,245,335**
				PROJECT TOTAL	**$3,165,335**
				SAY	**$3,200,000**

Alternative No. 2

Brushy Plain Standpipe with Aeration/Mixing System

ESTIMATE OF PROBABLE CONSTRUCTION COST

South Central Connecticut Regional Water Authority

November 2012

ITEM	DESCRIPTION	UNITS	QTY	UNIT PRICE	TOTAL
1	Grid Bee Mixing system	EA	1	$20,000	$20,000
2	THM Removal System	EA	1	$51,000	$51,000
3	Tank Modification	LS	1	$25,000	$25,000
4	Chlorine Chemical Feed System	LS	1	$25,000	$25,000
5	Enclosure for Chem Feed and Electrical Systems	LS	1	$20,000	$20,000
6	Electric service	LS	1	$7,500	$7,500
7	Electrical Work	LS	1	$30,000	$30,000
8	Instrumentation	LS	1	$10,000	$10,000
9	SCADA Programming	LS	1	$10,000	$10,000
10	Site Work	LS	1	$15,000	$15,000
	Subtotal - Mixing/TTHM/Chorine Systems				$213,500
11	Tank Painting	LS	1	$650,000	$650,000
12	Temporary pumping equipment rental	LS	1	$75,000	$75,000
13	Temporary pumping equipment installation & controls	LS	1	$40,000	$25,000
14	Temporary storage (bladder tank)	LS	1	$25,000	$40,000
	Subtotal - Tank painting and temporary storage				$790,000
				SUBTOTAL - All Construction	**$1,003,500**
	General Conditions - 15%				**$150,600**
				CONSTRUCTION - SUBTOTAL	**$1,154,100**
	Engineering and Contingency - 40%				**$461,700**
				TOTAL	**$1,615,800**
				SAY	**$1,600,000**

Notes:

1 Minimum roof hatch opening for Solar Bee installation is 18".

Tank currently has one 24" by 24" equipment hatch located on the roof, which is sufficient.

Alternative No. 3

False Bottom in Brushy Plain Standpipe

ESTIMATE OF PROBABLE CONSTRUCTION COST

South Central Connecticut Regional Water Authority

November 2012

ITEM	DESCRIPTION	UNITS	QTY	UNIT PRICE	TOTAL
1	Tank structural alteration & false bottom	LS	1	$1,000,000	$1,000,000
2	Tank painting	LS	1	$650,000	$650,000
3	Temporary modifications to pump station	LS	1	$50,000	$50,000
4	Temporary storage (bladder tank)	LS	1	$25,000	$75,000
				SUBTOTAL	**$1,775,000**
5	**General Conditions - 15%**				**$266,300**
				CONSTRUCTION - SUBTOTAL	**$2,041,300**
6	**Engineering and Contingency - 50%**				**$1,020,700**
				TOTAL	**$3,062,000**
				SAY	**$3,062,000**

Notes:

1 This alternative consists of installing a false bottom at the mid-point elevation of the existing standpipe, with the objective of reducing unusable volume and decreasing water age in the tank.

2 Additional Engineering and Contingency is included due to structural uncertainties.

Alternative No. 4

Blow-offs at Dead Ends

ESTIMATE OF PROBABLE CONSTRUCTION COST

South Central Connecticut Regional Water Authority

November 2012

ITEM	DESCRIPTION	UNITS	QTY	UNIT PRICE	TOTAL
1	Curb Stop, Corporation, and Valve Box	EA	5	$2,000	$10,000
2	Copper Pipe	EA	5	$500	$2,500
3	Continuous Flushing Device	EA	5	$500	$2,500
4	PVC Pipe and Fittings	EA	5	$500	$2,500
5	Connect to Sanitary Sewer	EA	5	$7,000	$35,000
6	Backflow Prevention	EA	5	$400	$2,000
				SUBTOTAL	**$54,500**
7	**General Conditions - 15%**				**$8,200**
				CONSTRUCTION - SUBTOTAL	**$62,700**
8	**Engineering and Contingency - 40%**				**$25,100**
				TOTAL	**$87,800**
				SAY	**$90,000**

Notes:

1 This alternative consists of installing continuous flushing devices flowing at 5 gpm at five dead-end locations in the distribution system.

2 Kupferle Model 5100 Continuous Flusher

Alternative No. 5

One Large Blow-off

ESTIMATE OF PROBABLE CONSTRUCTION COST

South Central Connecticut Regional Water Authority

November 2012

ITEM	DESCRIPTION	UNITS	QTY	UNIT PRICE	TOTAL
1	Water main - 6"	LF	2,300	$70	$161,000
2	Valve	EA	1	$2,500	$2,500
3	Concrete headwall	EA	1	$2,500	$2,500
4	Rip Rap Channel	LS	1	$20,000	$20,000
5	Pavement repair	SY	1,000	$90	$90,000
6	Traffic Maintenance & Protection, Flaggers, Details	LS	1	$10,000	$10,000
7	Surface repair/landscaping	LS	1	$5,000	$5,000
				SUBTOTAL	**$291,000**
7	**General Conditions - 15%**				**$43,700**
				CONSTRUCTION - SUBTOTAL	**$334,700**
8	**Engineering and Contingency - 40%**				**$133,900**
				TOTAL	**$468,600**
				SAY	**$470,000**

Notes:

1 This alternative consists of installing one large blow-off that would discharge back to the Lake Saltonstall watershed

Tighe&Bond

Alternative No. 6

Pipe Looping

ESTIMATE OF PROBABLE CONSTRUCTION COST

South Central Connecticut Regional Water Authority

November 2012

ITEM	DESCRIPTION	UNITS	QTY	UNIT PRICE	SUB TOTAL	TOTAL
1	Water main - 8"	LF	1,240	$80	$99,200	$99,200
2	Valves	EA	6	$2,500	$15,000	$15,000
3	Special Connections	EA	6	$12,500	$75,000	$75,000
4	Test Pits	CY	75	$50	$3,750	$3,750
5	Pavement Repair	SY	1,100	$90	$99,000	$99,000
6	Traffic Maintenance & Protection, Flaggers, Details	LS	1	$10,000	$10,000	$10,000
7	Surface repair/landscaping	LS	1	$15,000	$15,000	$15,000
					SUBTOTAL	**$316,950**
8	**General Conditions - 15%**					**$47,600**
					CONSTRUCTION - SUBTOTAL	**$364,550**
0	**Engineering and Contingency - 40%**					**$145,900**
					TOTAL	**$510,450**
					SAY	**$510,000**

Alternative No. 7

Flow Back to Saltonstall SA

ESTIMATE OF PROBABLE CONSTRUCTION COST

South Central Connecticut Regional Water Authority

November 2012

ITEM	DESCRIPTION	UNITS	QTY	UNIT PRICE	TOTAL
1	Modify controls on existing relief valve	LS	1	$2,000	$2,000
2	Flow instrument & transmitter	LS	1	$5,000	$5,000
3	SCADA programming	LS	1	$2,500	$2,500
				SUBTOTAL	**$9,500**
4	**General Conditions - 15%**				**$1,500**
				CONSTRUCTION - SUBTOTAL	**$11,000**
5	**Engineering and Contingency - 40%**				**$4,400**
				TOTAL	**$15,400**
				SAY	**$15,000**

Alternative No. 9

New 750,000 gallon Elevated Spheroid Tank with Aeration/Mixing System

ESTIMATE OF PROBABLE CONSTRUCTION COST

South Central Connecticut Regional Water Authority

November 2012

ITEM	DESCRIPTION	UNITS	QTY	UNIT PRICE	TOTAL (Grid Bee Mixer)
1	Design & Construct Tank incl. General Conditions	LS	1	$1,600,000	$1,600,000
	Contingency - 20%				$320,000
	Total - Tank incl. Engineering & Contingency				**$1,920,000**
2	General Contract				
	Excavation & Site Work	LS	1	200,000	200,000
	Rock Excavation	LS	1	30,000	30,000
	Concrete - Class A	CY	50	1,250	62,500
	Concrete - Class B	CY	300	500	150,000
	Gravel Fill	CY	120	50	6,000
	Gravel base & surfacing	CY	375	60	22,500
	Piping & Valves	LS	1	125,000	125,000
	Misc. Site Finishes	LS	1	40,000	40,000
	Demolish existing tank, foundation, and valve chamber	LS	1	100,000	100,000
	Grid Bee Mixing system	EA	1	20,000	20,000
	THM Removal System	EA	1	51,000	51,000
	Chlorine Chemical Feed System	LS	1	25,000	25,000
	Enclosure for Chem Feed and Electrical Systems	LS	1	20,000	20,000
	Electric Service	LS	1	7,500	7,500
	Electrical Work	LS	1	30,000	30,000
	Instrumentation	LS	1	25,000	25,000
	SCADA Programming	LS	1	10,000	10,000
	Subtotal				924,500
	General Conditions - 15%				138,675
	General Contract Total				1,063,175
	General Contract Engineering and Contingency - 40%				425,270
	Total - General Contract incl. Engineering and Contingency				**1,488,445**
				PROJECT TOTAL	**$3,408,445**
				SAY	**$3,400,000**

APPENDIX B

Medora Brands:

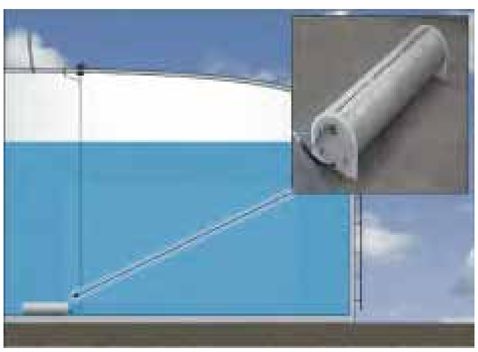
SolarBee®
www.solarbee.com
GridBee™
www.gridbee.com

Michelle McCadden - Regional Manager
518-541-3543 • Michelle@SolarBee.com

Budget Estimate for SolarBee and GridBee Potable Water Mixers




August 20, 2012



GS-12-120v / GS-12-48v

SB500PWc v18

Factory contact information; if placing an order, purchase order should be made out to:

Medora Corporation
3225 Highway 22 • Dickinson, ND 58601
Tel: (701) 225-4495 • www.MedoraCo.com

1.0 INVESTMENT OPTIONS - Call us to discuss the appropriate model(s) for your system

1.1 Grid-Powered Models (See Appendix A)

Quantity	Description	Purchase Cost Each	Purchase Cost Total
1	GS-12 120v submersible grid-powered mixer:	$7,800	$7,800
1	GS-12 48v submersible grid-powered mixer:	$12,800	$12,800
		Applicable Taxes:	to be determined
1	Estimated freight and handling:	$200	$200

For installation cost options and additional services, see Options list in Section 2.1

1.2a Solar-Powered - Small Frame Model (See Appendix A)

Quantity	Description	Purchase Cost Each	Purchase Cost Total
1	SB500PWc solar-powered mixer:	$18,000	$18,000
		Applicable Taxes:	to be determined
1	Estimated crate & freight:	$2,000	$2,000

For installation cost options and additional services, see Options list in Section 2.2

1.2b 5-Year Lease Purchase for Solar-Powered Models

Cost for recommended machine per above:	- Included -
Potable factory delivery, installation and startup (see Appendix B):	- Included -
Monthly Beekeeper cost during the term of the lease (see Appendix C):	- Included -
SB500PWc - Estimated monthly lease purchase cost (excluding taxes):	*$665*

1.3 Solar-Powered - Large Frame Models

Solar-powered large frame models are also available. These large frame models are typically used for large volume tanks where multiple small frame models may be considered. Typically, one large frame model is sufficient for tank sizes up to 45 MG, for tanks larger than 45 MG, multiple large frame units are recommended. Contact us for more information and pricing.

2.0 OPTIONS - Call us to discuss pricing for the following items:

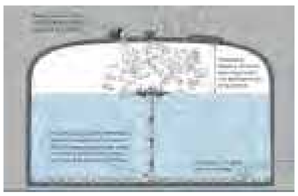
2.1 Options for Grid-Powered Model

GS-12 Monitoring (SCADA)	4-20mA output, for system operation monitoring - integration of 4-20mA output into site PLC/RTU shall be provided by others.	$1,000
Chemical Injection Line for the GS-12	60 ft injection hose kit, connects to fitting on intake of machine and to top of tank, shipped loose with machine for customer / contractor installation.	$300
Factory Delivery, Installation and Startup for the GS-12 Model *(Customer installable, this option is provided for customer convenience.)*	*Factory Delivery, Installation and Startup.* Factory will send a team of trained representatives to deliver equipment and to perform on-site final assembly, placement and startup functions, and to train the customer's personnel on the operation and maintenance of the SolarBees. The teams are trained to meet confined space, over-water and at-elevation safety requirements. Special safety equipment is utilized, and special safety procedures are followed to meet all OSHA safety requirements.	Costs can vary from $6,500 to $12,500 depending on the quantity, distance from the factory and the tank requirements.
Customer or Contractor Responsibility for Installation of the GS-12 Model (*If factory install is purchased.)*	*Customer or contractor responsibility for installation of GS-12 Units:* to provide an electrical connection from the junction box on top of the tank to the control box near ground level, and to provide a 115 VAC / 5 amp power supply to the GS-12 control box. Since the cost can vary depending on distance to the electrical supply source, local electrical codes and the tank design, the customer or contractor should contact a local electrician for a firm cost.	Costs can vary depending on distance to the electrical supply source, local electrical codes and the tank design.

2.2 Options for Solar-Powered Models

Factory delivery, installation and startup for Solar-Powered Units (*Customer installable, but typically not recommended for the solar-powered units*)	*Factory Delivery, Installation and Startup.* Factory will send a team of trained factory representatives to deliver equipment and to perform on-site final assembly, placement and startup functions, and to train the customer's personnel on the operation and maintenance of the SolarBees. The teams are trained to meet confined space, over-water and at-elevation safety requirements. Special safety equipment is utilized, and special safety procedures are followed to meet all OSHA safety requirements.	Costs can vary from $10,000 to $14,000 depending on the quantity, distance from the factory and tank design.
SCADA for the solar-powered v18 units	*All v18 models come standard with a SCADA brain-board with six outputs.* For on-site communication options, please contact our SCADA Engineering Department.	Please request option list
LED RPM Indicator for solar-powered units	*Recommended when SCADA is not available.* An electronic pulsing monitor is added to the digital controller and a flashing green LED beacon is located outside of the tank. The LED indicates the SolarBee impeller rotational speed, and the beacon can be directionally targeted for ground level viewing.	$950
Additional 80-watt PV panel	*Recommended when ice is an issue.* The extra photovoltaic solar panel will improve ice control during winter periods when solar energy is at its lowest.	$950

2.3 Options for all Models

 Portable Disinfectant Boost System	*Consider when occasional on-site boosting is desired.* Portable Disinfectant Boost System (designed to be installed in the back of a pickup), safe, durable chemical transfer system to boost disinfectant in potable water reservoirs. Boosting rate up to 4 gpm, one system can treat multiple tanks, approximate dimensions: 20" W x 52" L x 20" H. Air compressor (4 cfm @ 60 psi) is required to operate the air-powered diaphragm pump; air compressor not included. Brochure available upon request.	$5,800
 Beekeeper Program	A maintenance and support program is available for all models.	Call for pricing
 THM Removal System	Effective and economical air-stripping system to strip TTHM from potable water storage tanks and clearwells. For more information on the THM removal system, please contact us.	Call for pricing

Appendix A: Equipment

GS-12 Mixer: This high-flow submersible mixer rests on the tank floor, and has polymer pads to protect the floor. It is constructed of 316 stainless steel and non-corrosion polymer construction, and the entire mixing system and motor are certified to NSF'ANSI Standard 61. This mixer can easily be installed by the City or a contractor through any hatch with a 12" diameter minimum unobstructed clearance. The user is to provide a 120 VAC power source, and on/off disconnect to meet the local electrical code. **NOTE**: This machine comes in a 120v or 48v version. The 120v model comes with 60' of submersible cable, the tank roof junction box, through-tank fitting for the power cord, and the motor pigtail & splice kit. The power service should be sized for 120 vac, 10 amps, with a circuit breaker or fuse as follows: 20 amp std or 15 amp delay type. The 48v model comes with a 120v-to-48v voltage converter box and 48v motor, 60' of submersible cable, the tank roof junction box, through-tank fitting for the power cord, and the motor pigtail & splice kit. The power service should be sized for 120 vac, 6 amps, with a circuit breaker or fuse as follows: 15 amp std.

SB500PWc v18: High-flow NSF / ANSI Std 61-G Certified mixer, 316-stainless steel and non-corrosion polymer construction, 25-year life high-efficiency brushless electric motor designed to provide day and night operation with a solar-charged battery power system, digital control system for intelligent power management specific to this application, six parameter SCADA outputs, one (1) 80-watt solar panel and control box mounted on a 316SS pedestal, 6” diameter fluid intake hose, and fluid intake injection assembly (injection hose from the intake to the top of the tank). NOTE: (A) This collapsible unit can be installed through a hatch with 18" diameter minimum unobstructed clearance; (B) There is minimal impact from mounting PV panels and control box (typically only one penetration), and the integrity of the tank coating is maintained; (C) See Appendix D for information on the most extensive warranty in the industry.

Appendix B: Factory Delivery , Installation and Startup

Factory Delivery, Installation and Startup:

The Factory will typically send a team of 3-4 trained factory representatives to deliver equipment, perform on-site final assembly, placement and startup functions, and to train the customer's personnel on the operation and maintenance of the SolarBees / GridBees. The teams are trained to meet confined space, over-water and at-elevation safety requirements. Special safety equipment is utilized and special safety procedures are followed to meet all OSHA safety requirements.

Complete details of the factory delivery, installation and startup, including safety information, are available upon request.

Appendix C: General Provisions

This is a Budget Estimate, please call for a firm Quotation:

This budget estimate replaces all prior budget estimates for this project. It is valid until replaced by a subsequent budget estimate, or else for 60 days, whichever occurs first.

Medora Brands:

www.solarbee.com

www.gridbee.com

Michelle McCadden - Regional Manager
518-541-3543 • Michelle@SolarBee.com

Represented locally by:
David F. Sullivan & Associates, Inc.
Tim Bezler • 203-373-9261

Amy Dinius - Inside Sales
866-437-8076 • AmyD@SolarBee.com

Proposal for:

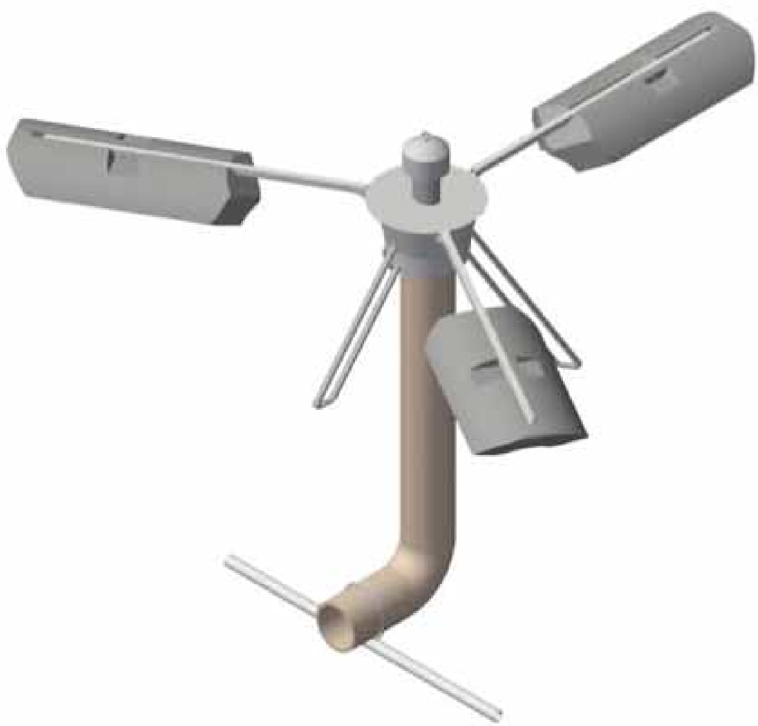
Regional Water Authority

c/o Kimberly Woodward
Tighe & Bond

Project # 4837




August 22, 2012



GridBee Electric-Powered THM Removal System, Model SN5

Factory contact information; if placing an order, purchase order should be made out to:

Medora Corporation
3225 Highway 22 • Dickinson, ND 58601
Tel: (701) 225-4495 • www.MedoraCo.com

1.0 PROJECT DESCRIPTION

1.1 Tank Name & Location:

Brushy Plain Standpipe is located on Brushy Plain Road in Branford, CT.

1.2 Description of Tank:

This is cylindrical, welded steel ground storage tank with a domed roof. It is 70.6 feet tall, has a 50-foot diameter, a 3-foot headspace, a 63-foot normal water level, a 58-foot low water level, and a 24-inch by 24-inch equipment hatch located on the roof. Brushy Plain Standpipe has a 300,000-gallon daily inflow, a 250-gallon per minute maximum fill rate, and a 1-million gallon capacity.

1.3 Project Objectives:

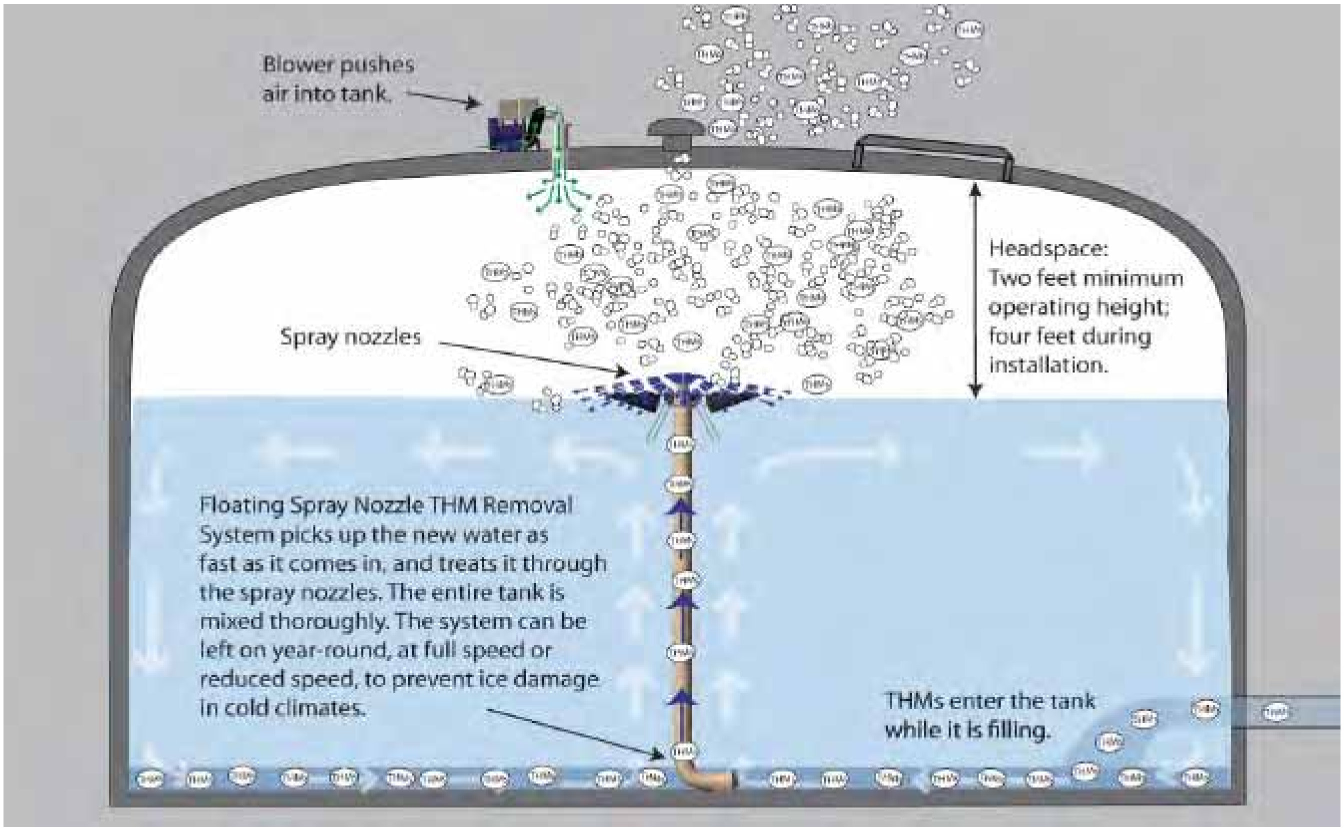
THM Removal System: To provide complete mixing throughout the tank in conjunction with an interior spray system to lower the total trihalomethane (TTHM) levels in this system.

Note: Every municipal water system has unique water chemistry, types and amounts of THMs, and variable flow rates, flow patterns, temperatures, detention times, and other parameters. Therefore, no manufacturer can guarantee exactly what level of TTHM will be removed throughout the water system until a full-sized THM removal system is actually deployed. Medora Corporation sized the system in this proposal based on the information made available to us and our 30+ year history of solving water quality and fluid handling problems. Medora Corporation's intent is to not oversize or undersize the system, but to work with our customers until an acceptable level of TTHM compliance is achieved.

1.4 Recommendation / System Design:

To meet the above objectives, we recommend the installation of one (1) SN5 (5-hp Floating Pump / Mixer / Spray Nozzle THM Removal System) and Blower Ventilation System.

The system design calculation used for this tank is based on an estimated TTHM peak concentration of 60 ug/l, with chloroform as the predominant type. The THM Removal System presented in this quotation is designed to reduce the maximum level of TTHM occurring in this tank by 30-40% or more.



2.0 INVESTMENT OPTIONS

2.1 Budget Estimate for the Recommended THM Removal System

Equipment Purchase (See Appendix D)

Quantity	Description	Purchase Cost Total
1	One (1) SN5 THM Removal System:	- Included -
1	Blower Ventilation System:	- Included -
1	Lifting Device during installation of the above systems:	- Included -
1	Factory Delivery, Installation and Start-up:	- Included -
	Total Investment (excluding taxes):	$50,600

THM Reduction Equipment Scope of Supply

Item	To be supplied by:
THM Floating Spray Nozzle Machine(s):	
Manufacture, deliver, and install floating THM removal machines into tank	SolarBee / GridBee
Bring the electric cord from each floating machine to the junction box for that machine, supplied by customer, located outside of tank	SolarBee / GridBee
Assist at startup to ensure proper motor rotation and functioning of equipment	SolarBee / GridBee
Assist at startup to ensure proper motor rotation and functioning of equipment	SolarBee / GridBee

Electrical system for floating THM removal machine(s):

Supply and install power supply line from power pole or other source to the magnetic starters mentioned below	City / Water District
Supply and install magnetic starters, for the THM removal machines, to owner's specification. Typically each starter will be a combination box with circuit breakers, starter, extra quick-trip heaters, HOA switch, City SCADA controller if desired, in Nema 3R rainproof enclosure. NOTE: Factory can supply exact breaker and heater size desired, if needed, call 800-437-8076 if have questions.	City / Water District
Quantity and size: 1 x 5 hp	
Supply and install wiring from each magnetic starter to a separate junction box that the magnetic starter will control. Supply the junction box and the tank penetration for the motor lead. Factory crews will bring the motor lead cord from each floating THM removal machine in the tank to a respective junction box.	City / Water District
Be present when Factory crews install the floating machines into the tank, to assist at startup by switching the equipment on and, if necessary, rotate motor leads at the magnetic starters for proper motor rotation	City / Water District

Ventilation fan(s) for tank:

Supply and deliver the ventilation fans and filter system on a baseplate	SolarBee / GridBee
Quantity and size: 1 x 2 hp	City / Water District
Locate the fan baseplate assemblies where desired.	City / Water District
Make the air supply hole through tank wall into the headspace	City / Water District
Supply exterior air hose or duct from blower to tank headspace opening	City / Water District
Supply interior air hose from tank penetration to 1 ft above tank overflow level	City / Water District

Electrical system for ventilation fans:

Supply and install power supply line from power pole or other source to the magnetic starters mentioned below	City / Water District
Supply and install magnetic starters, for the ventilation fan, to owner's specification. Typically each starter will be a combination box with circuit breakers, starter, extra quick-trip heaters, HOA switch, City SCADA controller if desired, in Nema 3R rainproof enclosure. NOTE: Factory can supply exact breaker and heater size if needed, call 800-437-8076 if have questions.	City / Water District
Quantity and size: 1 x 2 hp	
Supply and install wiring from each magnetic starter to the respective fan motor it will control	City / Water District
Be present to assist at startup by switching the equipment on and, if necessary, rotating motor leads at the magnetic starters for proper motor rotation	City / Water District

Appendix A: Equipment

SN5: 5-hp floating, grid powered, circulation and Trihalomethane (THM) removal equipment for potable water tanks and reservoirs. Materials of construction include 316 stainless steel frame, hardware, fittings, stainless steel pump, ANSI 61 Approved Motor and other NSF Approved Materials. Designed for continuous operation and installed through 18-inch minimum clear roof opening. The spray unit direct flow rate is 330,000 GPD. Each SN5 will also come with one (1) 2-hp single stage ventilation blowers supplying 750 cfm @ 6.0" H2O. Note: requires single-phase or 3-phase power; all switches, breakers, emergency stop buttons, control panels and other controls shall be installed in accordance to all NEC, State, and local regulations (not supplied by Medora Corporation).

Appendix B: Delivery , Installation and Startup Options

Factory Delivery, Installation and Startup:

Medora Corporation will send a team of trained factory representatives to deliver equipment and to perform on-site final assembly, placement and startup functions, and to train the customer's personnel on the operation and maintenance of the GridBee / SolarBees. The teams are trained to meet confined space, over-water and at-elevation safety requirements. Special safety equipment is utilized and special safety procedures are followed to meet all OSHA safety requirements. On-site testing during installation includes a temperature profile taken in one-meter increments. A comprehensive report is compiled and forwarded to the customer including all location, testing, and machine operation data collected during the call.

Appendix C: Beekeeper Service Program

The Beekeeper Service Program utilizes trained factory crews to keep proprietary designed equipment operating at optimal efficiency and performance. In addition to full maintenance and service, the Beekeeper:

- extends the warranty during the term of the Beekeeper,
- covers damage from Acts of God and vandalism,
- provides for power system upgrades and updates,
- provides hardware, firmware, and software for computer upgrades,
- provides scientific and technical support,
- provides for scheduled and unscheduled field service calls, and much more.

Please request the Beekeeper brochure for more details.

Appendix D: General Provisions

This is a Budget Estimate, please call for a firm Quotation:

This budget estimate replaces all prior budget estimates for this project. It is valid until replaced by a subsequent budget estimate, or else for 60 days, whichever occurs first.

Purchase of the Medora Corporation circulation equipment in this quotation is an "Equipment Purchase," not a "Construction Project":

Medora Corporation circulation equipment is portable, and can be easily relocated or removed entirely from the premises at any time. They do not become an integral part of any building or other structure, and never become part of "real estate". Therefore, to purchase Medora Corporation circulation equipment, the city or other organization purchasing GridBees / SolarBees should use the same procedure as for purchasing other portable equipment, such as a forklift, a drill press, or an office desk. Medora Corporation reserves the right not to accept an order if the purchase is incorrectly characterized as a "construction" project. Medora Corporation. has not found any state or other jurisdiction where construction or contractor statutes apply to portable equipment that is sold by a factory, with on-site final assembly and startup performed by factory personnel.

Assumptions:

This quotation may be based on worksheets and calculations that have been provided to the customer, either previously or else attached to this quotation. The customer should bring to our attention any discrepancies in data used for these calculations.

Medora Corporation Limited Replacement Warranty:

THM Removal Systems:

The GridBee THM Removal System (THMRS) is warranted to be free of defective parts, materials and workmanship for a period of two years from the date of installation. This warranty is valid only for use of the THMRS is accordance with the owner's manual and any initial and ongoing factory recommendations. This warranty is limited to the repair or replacement of defective components only. There is no liability for consequential damages of any type, or for items that wear out from normal wear and tear.

Except as stated above, Medora Corporation and its affiliates expressly disclaim any and all express or implied conditions, representations and warranties on products furnished hereunder, including without limitation all implied warranties of merchantability or fitness for a particular purpose.

Please consult your state law regarding this warranty as certain states may have legal provisions affecting the scope of this warranty.

Lesley J. Eckert

From:	David G. Goncalves
Sent:	Monday, October 22, 2012 11:08 AM
To:	John N. McClellan
Subject:	FW: False bottom

John,

Here's the cost from Rockwood regarding the tank false bottom. If you need anything else, please let me know.

I think that active mixing may be the way to go for your Client, based on their issues.

Regards,
David

From: dggoncalves@aol.com [mailto:dggoncalves@aol.com]
Sent: Monday, October 22, 2012 9:22 AM
To: David G. Goncalves
Subject: Fwd: False bottom

Sent from my Verizon Wireless Phone

----- Forwarded message -----
From: "Pierce A. Law, Jr." <PALawJr@RockwoodCorporation.com>
Date: Mon, Oct 22, 2012 8:59 am
Subject: False bottom
To: "David G. Goncalves" <DGGoncalves@tigheBond.com>, <dggoncalves@aol.com>

David,

As requested, we are providing our estimate to install a bottom in the
70 x 50 standpipe, as follows:

Extend inlet/outlet to 35 foot elevation... $35,000
Add coarse sand to 35 foot elevation (2,545 cu yd)...$294,000
Install new 1/4" steel floor (API 653 slot installation through wall)... $311,000

Concept must be engineered and stamped by a MA PE, access to site must be provided,
MA prevailing rates figured, no special MBE/WBE.

Thanks,
Pierce

Pierce A. Law, Jr
Rockwood Corporation
6979 Laura St.
Lyons Falls, NY 13368
315-382-4341 T

Posttreatment aeration inside water tanks or in chlorine contact basins to strip trihalomethanes (THMs) after formation is an underused and cost-effective treatment option to reduce disinfection by-products. In this study, diffused aeration achieved removal rates of 9 to > 99.5%, depending on air-to-water ratio, water temperature, and THM species. Spray aeration—a more efficient process—achieved THM reductions of 20 to > 99.5%, depending on droplet diameter, droplet travel distance, water temperature, and THM species. Droplet diameter is an important design variable and is controlled by operating pressure and nozzle characteristics. Droplet travel distance, however, exerted a greater influence on THM removals. The average droplet diameter and travel distance variables can be developed into a unit air-to-water volumetric ratio that can be used to reasonably predict total THM removals. Free chlorine does not appear to be reduced by aeration because only a small fraction of it will be amenable to removal in a closed-system environment.

Posttreatment aeration to reduce THMs

ETHAN BROOKE

AND M. ROBIN COLLINS

Meeting the new maximum contaminant levels (MCLs) for trihalomethanes (THMs) established under Stage 1 of the Disinfectants/Disinfection Byproduct Rule (D/DBPR) is a challenge for many drinking water providers, both large and small. The Stage 1 and 2 D/DBPRs regulate the amount of total THMs (TTHMs), the amount of total haloacetic acids, and the amount of free disinfectant that can be present in finished drinking water by setting MCLs for each of these groups of compounds. The MCLs established in the Stage 1 D/DBPR remain the same in the Stage 2 D/DBPR and are summarized in Table 1 (USEPA, 2006, 1998).

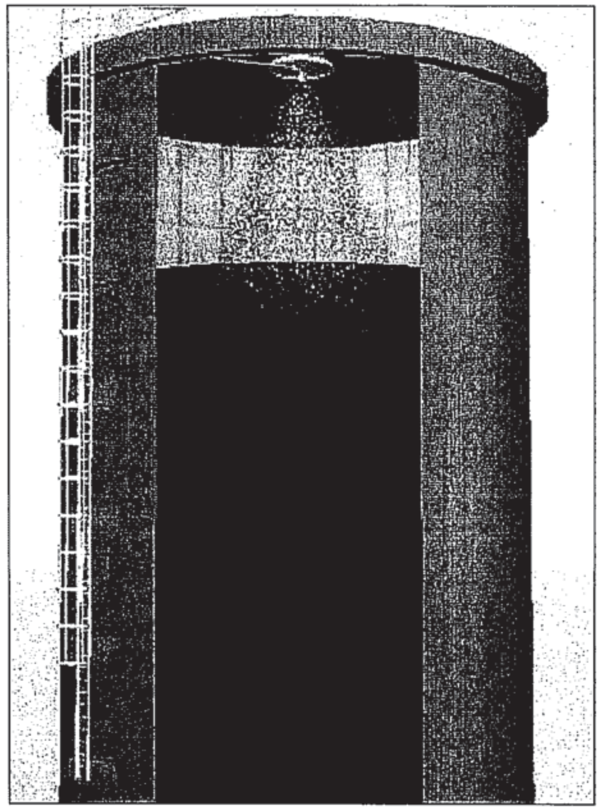
Three general strategies have been adopted to deal with THM violations: switch from chlorination to an alternative disinfectant or disinfection regime, reduce THM precursors in the raw water by enhanced treatment processes, or remove THMs after they have formed (USEPA, 1981). Although aeration is a DBP control strategy for THMs, it is not effective for treatment of haloacetic acids. Although posttreatment aeration has not received as much attention as the other two control strategies, i.e., switching from chlorination and reducing organic precursors before the disinfection process, it has the potential to be the most cost-effective treatment option.

The most common form of air-stripping is via counter-current packed columns; this process is highly effective for THM reduction but requires additional infrastructure. The significant advantages offered by diffused and spray aeration are their simplicity and suitability for addition to existing treatment processes or water storage tanks; thus, both diffused and spray aeration are considered suitable for small and large water supply systems.

Diffused and spray aeration can both be described by an air-to-water ratio that is a dimensionless volumetric ratio of the volume of air that comes in contact with a volume of water (AWWA, 1999). Diffused aeration is the process of introducing air into the bottom of a vessel of water and allowing the air to bubble up through the water column, creating air-to-water contact. A diffused aeration device consists of an air compressor to provide the required air pressure, a matrix of pipes to distribute the air, and a set of diffusion devices to break up the air into bubbles. Diffused aeration has long been a recognized means to remove THMs (USEPA, 1981). Recent research has shown diffused aeration to be an inexpensive approach to THM reduction in water storage tanks (Sherant et al, 2007). In contrast, spray aeration facilitates the creation of an air–water interface by spraying water through the air. The interfacial surface area is the combined surface area of the individual droplets that are formed by the nozzle(s). A spray aeration device consists of a pump or some means of creating water pressure, piping to distribute the water, and a nozzle(s) to break the water up into droplets. In this research, a bench-scale diffused-aeration assessment using a factorial design and statistical analysis of variance (ANOVA) was conducted to determine the importance and interaction of variables known to affect air-stripping of THMs. On the basis of variable assessments from the bench-scale experiments, a fractional–factorial spray aeration study was designed to identify the critical design variables of THM reduction by spray aeration.

THM stripping by spray aeration is a relatively unexplored treatment option. After examination and quantification of the role of all significant variables (including water temperatures, THM speciation, droplet travel distance, and droplet interfacial surface areas), a modeling foundation was proposed to predict potential THM reductions under various spray-aeration operating and design conditions. The developed model suggests that design and installation of spray-aeration systems can be considered a feasible and effective THM reduction technique for both large and small water systems.

Because the US Environmental Protection Agency (USEPA) requires maintenance of a free chlorine residual > 0.2 mg/L in finished drinking water (USEPA, 2004), assessing the influence of aeration on free chlorine residual was an important component of this research. Bench-scale diffused-aeration tests were performed at high air-to-water ratios in order to assess potential changes in free chlorine levels during aeration.



In this research, spray aeration achieved trihalomethane (THM) reductions of 20 to > 99.5%, depending on droplet Sauter mean diameter, droplet travel distance, water temperature, and THM species. Some storage systems may require nothing more than a redesign of water tank influent piping and addition of a spray nozzle, similar to what is shown in this illustration, system in order to realize significant THM reductions.

EXPERIMENTAL APPROACH

General methodology. The research was conducted in three major phases: a diffused-aeration bench-scale study, a spray-aeration pilot-scale optimization study, and an assessment of chlorine-stripping potential during diffused aeration. Results of each phase of experimentation contributed to the experimental direction of the succeeding phase. The influence of experimental factors on overall performance of diffused and spray aeration was determined by ANOVA statistical analysis. Data were analyzed using statistical analysis software.[1] Because the software does not determine the percent contribution of individual variables in overall experimental analysis, Taguchi methods were used to establish the percent contributions of each variable to overall THM removal (Ross, 1988).

Assessment of diffused aeration. Bench-scale experimentation focused on identifying key operational and design variables that affect air-stripping performance. Temperature, airflow rate, contact time, mixing intensity, and THM concentration were selected on the basis of published literature (Bilello & Edward, 1986; Bishop & Dwarkanath, 1985; Roberts & Levy, 1985, 1983; Chrostowsk et al, 1982; Dykson & Hiltebrand, 1982; Symons et al, 1981). Variable values evaluated in this study are summarized in Table 2. A fractional–factorial experimental design was used to quantify the influence of each variable and all two-variable interactions. Therefore, this design achieved a level three experimental resolution, meaning that all main factors and two-factor interactions can be evaluated through ANOVA (Ross, 1988).

A stock solution was used to spike all challenge water used in bench- and pilot-scale experiments. Chloroform ($CHCl_3$) was the constituent that was emphasized in respect to the other THM species, with the final concentration of $CHCl_3$ accounting for 40% of TTHMs, and dichlorobromomethane ($CHBrCl_2$), chlorodibromomethane ($CHBr_2Cl$), and bromoform ($CHBr_3$) each accounting for 20% of TTHMs. The final target concentration of the stock solution was 600 mg/L TTHM. Initial source water TTHM concentrations for the bench-scale experiments were set at two levels—100 and 400 µg/L. Average concentrations were within 2% of the target for both concentrations, and the standard deviation for both initial concentrations for both levels was < 10% of the target concentration.

Bench-scale experimentation focused on identifying key operational and design variables that affect air-stripping performance.

All bench-scale tests were performed using an in-house fabricated diffused aeration apparatus. As shown in Figure 1, four individual aeration vessels—each containing 3 L of water—were built from glass, stainless steel, and PTFE parts and were housed in a cooler. Air was supplied to each aeration vessel via a single air compressor, and airflow rates to each aerator were controlled by a 1- to 10-L/min flowmeter. All supplied air was run through a hydrocarbon trap[2] to ensure that the air was not contaminated with oil droplets from the compressor. Temperature probes were placed inside each aeration vessel to monitor water temperature. An additional thermometer was placed in the air tube to monitor air temperature. Fine-bubble diffuser stones[3] were plumbed in place by custom-fabricated PTFE fittings. A four-diffuser-stone air-tube configuration and a single-stone air-tube configuration were fabricated from PTFE tubing. All tubing in contact with the THM-spiked water was PTFE or stainless steel. Water temperature was controlled at the low temperature level by immersion of the aeration vessel in an ice bath and at high temperature by immersion of the aeration vessel in a hot water bath.

Because of analytical and physical constraints, complete randomization of the experiments was not possible. Instead, all experiments conducted at air temperature of 20°C were conducted first, and all experiments at air temperature of 4°C were conducted second. Mixing of the challenge solution in one vessel allowed for reduction in sample analysis cost and resulted in four trial blocks of equal initial THM concentrations.

Challenge solutions were prepared by adding 20 L of reverse osmosis (RO)-filtered and distilled water with a measured free chlorine residual below detection limits (measured by a colorimeter[4] with a resolution of 0.012 mg/L) to a glass carboy. For water temperatures of 1°C, it was necessary to chill the 20 L of RO water in an ice bath overnight before addition of stock solution. Stock solution was used to bring the TTHM concentration to either 100 or 400 µg/L. A stainless-steel paddle mixer was then lowered into the center of the carboy and run at a low speed for 5 min. Care was taken not to entrain air in the challenge solution. Initial THM concentrations were then measured directly from the carboy via motorized pipette as described subsequently. Next each individual aeration vessel was filled via a tube exiting from a valve in the bottom of the carboy. Care was taken not to introduce air, and turbulence was minimized during this process.

After each aeration vessel was filled, the device was allowed to aerate for 60 min. Samples from selected aeration vessels were taken after 45 min, and others were taken after 60 min to achieve a desired air-to-water ratio of 22.5:1 to 60:1 (as shown in Table 3). Samples were taken by motorized 25-mL pipette, which was

TABLE 1 MCLs for disinfection by-products and disinfectants under the Stage 1 and 2 D/DBPRs

Regulated Contaminants	MCL *mg/L*	Regulated Disinfectant	MRDL *mg/L*
TTHM	0.08	Chlorine	4.0 as Cl_2
HAA5	0.06	Chloramines	4.0 as Cl_2
Bromate (plants that use ozone)	0.01	ClO_2	0.8
Chlorite (plants that use ClO_2)	1.0		

Source: USEPA, 2000; 1998

Cl_2—free chlorine, ClO_2—chlorine dioxide, D/DBPR—Disinfectants/Disinfection Byproducts Rule, HAA—haloacetic acid, MCL—maximum contaminant level, MRDL—maximum residual disinfectant level, TTHM—total trihalomethane

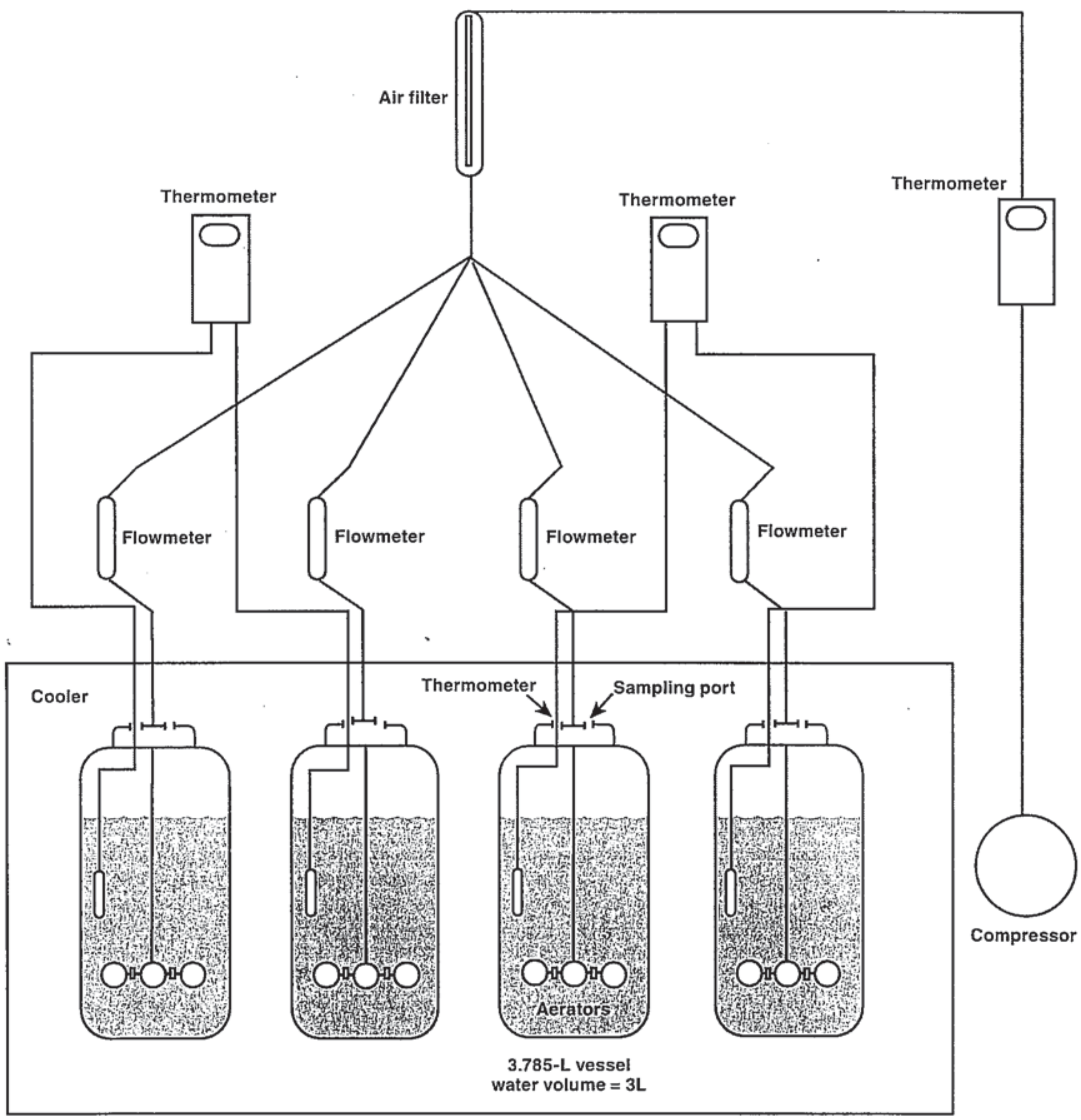
TABLE 2 Bench-scale experimental variables for diffused aeration study

Variable	Level 1	Level 2
Water temperature—*°C*	1	20
Air temperature—*°C*	4	20
Airflow rate—*L/min*	1.5	3
Contact time—*min*	45	60
Concentration—*µg/L*	100	400
Number of diffusers (i.e., bubble size)	1	4

lowered into the center of the vessel, filled, and then emptied into a 40-mL glass sample vial with PTFE septa. Again, care was taken not to introduce additional air-to-water contact by poor sample handling. Samples were inverted and inspected for air bubbles to ensure that they were headspace-free. All samples were taken in duplicate. Because the free chlorine residual of the stock solution was below the detection limit as measured by the colorimeter, a buffering agent was not used to prevent additional THM formation during sample storage time. Samples were stored in a refrigerator, shipped in coolers, and analyzed within 14 days according to method 551.1 for determination of organic compounds in drinking water (USEPA, 1995).

Assessment of spray aeration. After diffused aeration had been studied, the decision was made to investigate spray aeration. Spray aeration has the advantage of increased interfacial area and avoids the problem of individual gas bubbles reaching equilibrium (Munz & Roberts, 1989). Pilot testing of spray aeration to remove THMs was conducted in order to examine the role of Henry's constant (as a function of water temperature and THM species), droplet travel distance (or air–water contact time), and droplet Sauter mean diameter (SMD). The droplet travel distance and size reflect enough variation to statistically evaluate their overall contribution to THM removal. Operating conditions and design variables for each phase of pilot experimentation are summarized in Table 4. The

FIGURE 1 Schematic of bench-scale diffused-aeration apparatus



temperature range was chosen to encompass the changes that can be experienced throughout the calendar year. The design for the initial and final spray-aeration pilot-scale experiments was performed using the experimental design function of the statistical analysis software.[1]

As shown in Figure 2, the pilot-scale experimental apparatus consisted of a 208-L drum connected to a 1.5-hp centrifugal pump[5] with the spray aerator located at various heights over a collection container. An initial concentration sample port was located immediately after the influent pump with water flowing continually through the sampling tube. A large ball valve located down line from the sampling tube served to control the flow rate, which was monitored by a digital flowmeter.[6] The average initial TTHM concentration before aeration was 99 μg/L with a standard deviation of 12.6 μg/L over 12 samples. Samples were collected using a funnel that channeled the spray directly into 40-mL sample vials. Additional experimental details associated with the pilot apparatus may be found elsewhere (Brooke, 2009).

Assessment of diffused-aeration influence on chlorine residual. The same diffused aeration used in the bench-scale experiments apparatus with the four-diffuser-stone configuration was also used for the free chlorine–stripping evaluation. To ensure that the experimental apparatus was chlorine demand–free, the apparatus was allowed to soak overnight in a strong bleach solution and then rinsed with RO water until it no longer produced a free chlorine residual before each experiment. The challenge solution was made from 20-L batches of RO water mixed with sodium bicarbonate to add alkalinity, hydrochloric acid and/or sodium hydroxide to control pH, and sodium hypochlorite to add free chlorine. For the chlorine residual assessment, air-to-water ratios varied from 33:1 to 200:1, with pH conditions ranging from initial values of 9.3 to 6.1 in water containing an original free chlorine residual of ~1.0 mg/L and an alkalinity of 80 to 100 mg/L as calcium carbonate.

The pH was monitored by a probe with an accuracy of ±0.05. Free chlorine residual was monitored by a colorimeter[4] with a resolution of 0.012 mg/L. Water temperature was allowed to equilibrate to room temperature, which averaged 22°C. The aeration vessel was filled with 3 L of challenge solution. The airflow rate through the diffuser stones was held constant at 10 L/min. Samples were analyzed every 10 min for 1 h, resulting in air-to-water volumetric ratios of 33:1, 67:1, 100:1, 133:1, 167:1, and 200:1. The first two experiments were run in duplicate with two aeration vessels operating independently. The pH was not controlled over the course of the initial two experiments. The final experiment was run in a single aeration vessel with the pH levels held constant by titration with hydrochloric acid.

THM analytical procedure. All THM concentration analyses were conducted by the Environmental Engineering Department at the Pennsylvania State University at Harrisburg. A modified version of method 551.1 was used for all analyses (USEPA, 1995). The electron capture gas chromatograph[7] used in analysis was fitted with an auto sampler[8] and auto injector. Each batch of samples included a lab-created spiked sample for calibration. The squared correlation coefficient (R^2) for spiked samples (provided by the lab) was > 0.99 for all four species of THMs, indicating satisfactory analytical accuracy.

TABLE 3 Calculated air-to-water ratios for a 3-L fixed-volume diffused-aeration reactor

Airflow Rate—*L/min*	Time—*min*	Air-to-Water Volumetric Ratio (Dimensionless)
1.5	45	22.5:1
1.5	60	30:1
3	45	45:1
3	60	60:1

TABLE 4 Operating and design variables evaluated during spray-aeration assessment

Parameter	Experimental Conditions 1	2	3	4
Operating Conditions				
Water temperature—°*C*	1	22	36	NT
Design Variables				
Droplet travel distance—*m*	0.74	2.13	4.27	NT
Droplet SMD—*μm*	140	350	690	1,100

NT—not tested, SMD—Sauter mean diameter

RESULTS AND DISCUSSION

Diffused aeration assessment. Diffused aeration was an effective approach to removing THMs from water. Figure 3 shows experimentally derived percent removals of each THM species versus air-to-water ratio (AWWA, 1999) at 1 and 20°C. As expected, the air-to-water ratio had a significant effect on THM concentration, with TTHM removal rates increasing proportionally with an increasing air-to-water ratio. For example, $CHCl_3$ removals were consistently > 90% when air-to-water ratios were > 45:1. The influence of the Henry's constant on removals was also significant (Staudinger & Roberts, 1996). $CHCl_3$, having the highest Henry's constant, was the species most amenable to removal by diffused aeration followed by (in order of descending Henry's constants) $CHBrCl_2$, $CHBr_2Cl$, and $CHBr_3$. As expected, warmer temperatures resulted in higher THM removals as can be seen by comparing removals of each species at 20 and 1°C, shown in Figure 3, parts A and B, respectively.

Bubble size did not significantly influence or affect overall removal rates as was also observed by other researchers (Bilello & Edward, 1986). The lack of bubble-size influence for the range of bubble sizes created in these experiments may be attributable to the bubbles reaching THM saturation before they breached the surface of the water, thereby reducing the concentration gradient driving force (Roberts & Levy, 1983).

Several diffused aeration models based on a minimum air-to-water ratio were evaluated. The model that best matched experimental results in this study was initially proposed by other researchers (Sherant et al, 2007) and is derived from a mass balance approach to a fixed-volume water reactor as outlined in Eq 1:

$$\ln C_e = -\left(\frac{H_{cc}Q_a}{V_w}\,t\right) + \ln C_0 \qquad (1)$$

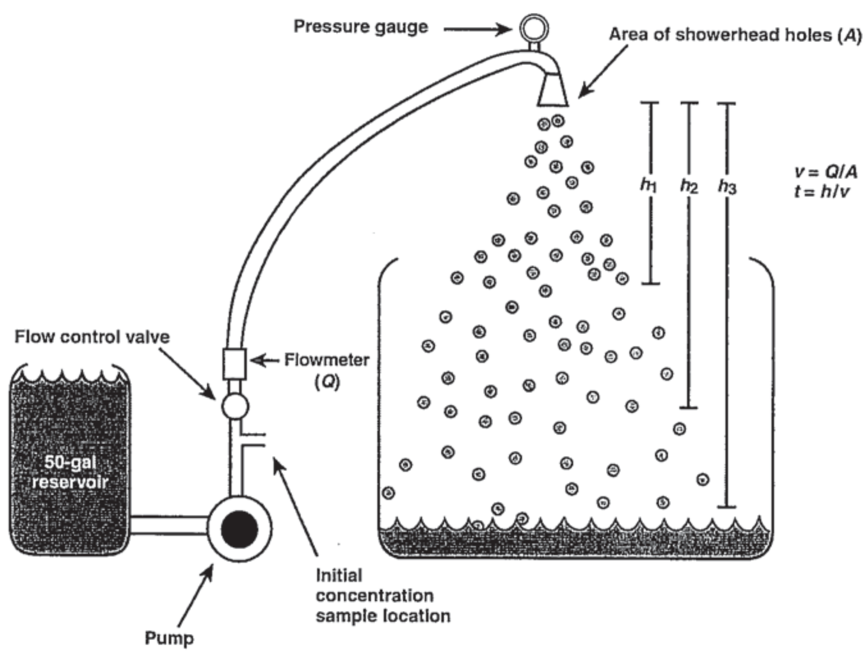
in which C_0 is the initial concentration (μg/L), C_e is the effluent concentration (μg/L), H_{cc} is Henry's constant (dimensionless), V_w is the water volume (L), Q_a is the airflow rate (L/s), and t is time (s).

Figure 4 shows comparisons between the air-to-water ratios and percent removal predictions from Eq 1 and the experimental results. Overall the mass balance model was a satisfactory predictor of the empirical results. Removals for the various THM species varied; $CHCl_3$ removals were consistently > 90% whereas $CHBr_3$ was the most problematic species, with removals ranging between 30 and 60%. This model is applicable only to batch-mode diffused aeration.

The operational variables that had the overall greatest influence on THM removals by diffused aeration were quantified from the ANOVA (Ross, 1988) and are summarized in Table 5. Overall water temperature had a significant effect on THM removal rates, with warmer temperatures resulting in higher removals, especially for the $CHBr_3$ species. The airflow rate (which when associated with a fixed volume of water resulted in varying air-to-water ratios) also exhibited a significant influence with higher airflow rates, resulting in higher removals, especially for $CHCl_3$.

The overall percent error rate for the diffused aeration bench-scale experiments was < 15% for all four THM species, which implies that all major factors were considered, all major factors were reasonably controlled, and overall analytical error was acceptable (Ross, 1988). Interactions between these variables also were examined and accounted for. All factors and factor interactions

FIGURE 2 Schematic of final pilot-scale experimental apparatus



A = area of showerhead holes, Q = volumetric flow rate (m^3), v = exit flow velocity (m/s), h = distance from showerhead to water surface (m), and t = time (s).

contributing < 3% to overall percent removal rates were dropped from this analysis, and their contribution was pooled into the error term.

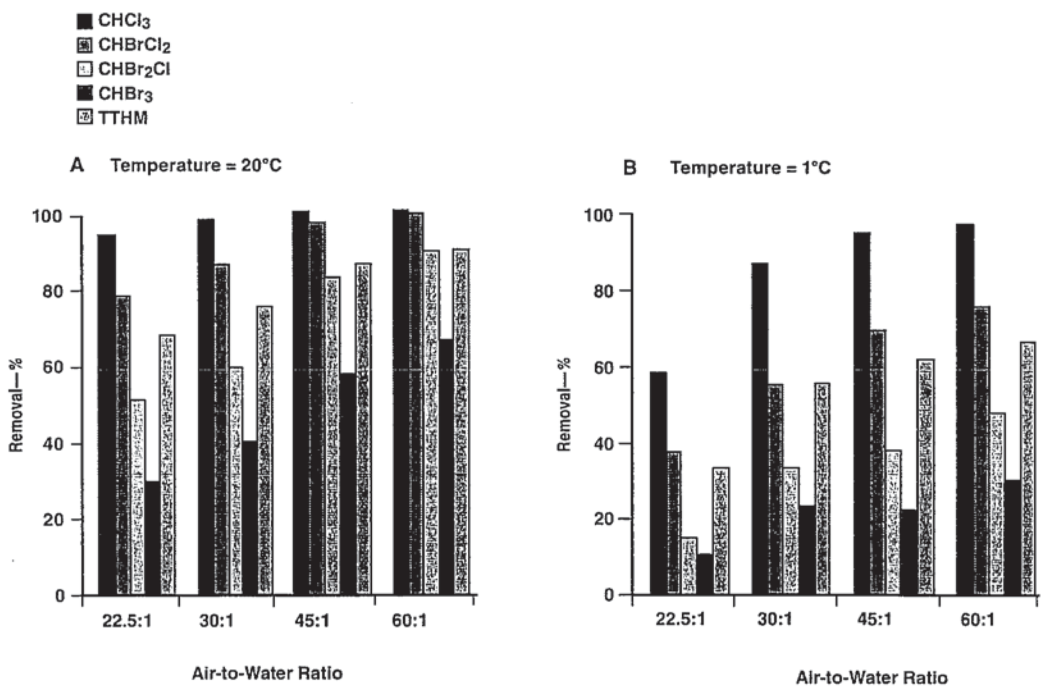
Spray aeration assessment. Diffused and spray aeration rely on the same basic mechanism for mass transport; a concentration gradient drives the THMs through an interfacial surface area, thus moving the THMs from liquid phase to gas phase. The key difference between diffused and spray aeration is that the bubbles created in diffused aeration have a finite volume and can reach saturation rapidly, meaning that the maximum THM removal may occur only for the first half metre of bubble contact (Roberts & Levy, 1983). Because bubbles have a small volume, the gas concentration of THMs inside the bubbles increases over time, thereby lessening the concentration gradient that provides the driving force for mass transfer. Diffused aeration is not recommended for depths greater than 5 m, which adds a design challenge for deep tanks (AWWA, 1999).

Spray aeration, in contrast, offers exposure to a larger air volume that greatly diminishes the effect of a decreasing concentration gradient, thereby offering the potential for a more efficient aeration strategy. Some storage systems may require nothing more than a redesign of water tank influent piping and the addition of a spray nozzle system in order to realize significant THM reductions. As with a diffused-aeration apparatus, a spray aerator could be placed in either a water tower or at the ends of a clearwell chlorine contact chamber.

Air-stripping of trihalomethanes is a viable posttreatment strategy for finished drinking water.

The spray aeration pilot-scale experiments focused on an assessment of operating and design variables affecting THM removal rates, with an emphasis on gathering enough information to create a qualitative model that could be used to design, build, and operate a spray aeration apparatus in the field. Operating experimental variables were chosen to reflect likely worst-case operating conditions. Operating variables likely to influence THM removals, as indicated from the previous diffused aeration study, were selected for additional assessment. The operating and design variable levels used in the spray aeration experiment are summarized in Table 4.

FIGURE 3 Bench-scale diffused-aeration removal of four THM species as a function of air-to-water ratio at 20°C (A) and 1°C (B)



$CHBr_3$—bromoform, $CHBrCl_2$—dichlorobromomethane, $CHBr_2Cl$—chlorodibromomethane, $CHCl_3$—chloroform, THM—trihalomethane, TTHM—total trihalomethane

Droplet travel distance and droplet SMD were selected as the primary design variables. Because the air–water interface is where mass transfer of THMs occurs during spray aeration, analysis of the droplet-size distribution and average droplet size—given by the SMD of the droplet created by a given nozzle—was necessary (AWWA, 1999). SMD analysis is performed using still photography or laser analysis, usually by the nozzle manufacturer, and is considered a nominal assessment of droplet size. The amount of pressure at the nozzle (or the resulting water flow rate) and the characteristics of the nozzle openings determine the SMD of droplets produced. When a nozzle vendor is contacted, it is important to know how much (if any) excess operating pressure is available or else have an estimate of the SMD required to meet treatment objectives. For this study, SMDs of 140, 350, 690, and 1,100 µm were selected.

Spray nozzles[9] for the spray aeration pilot-scale optimization experimental trials were selected for their ability to produce a wide variety of droplet sizes (based on nozzle type and operating pressure) but have only one nozzle orifice. The large nozzle opening was considered a design advantage because it should help to prevent nozzle clogging. Nozzle clogging attributable to scaling is possible for water with elevated levels of calcium, especially at higher water temperatures, and should be considered during the design process.

The second design variable selected for this experiment was droplet travel distance, i.e., the distance a droplet travels after exiting the nozzle before contacting the water surface. Water droplet travel distance was considered an important variable because the opportunity for mass transfer increases with air–water contact time. An investigation was conducted to quantify droplet travel time on the basis of nozzle exit velocity, nozzle exit angle, drag, and droplet terminal velocity. Estimating and especially measuring or quantifying droplet travel time can be problematic, with numerous factors to consider. On the basis of observational comparisons of experimental results, it was estimated that droplet travel times were directly proportional to droplet travel distance. The simpler approach of using droplet travel distance rather than droplet travel time was used in this study and is recommended for practicable design purposes. Varying the droplet travel distance and keeping the nozzle exit velocity and droplet SMD constant also provided an overall assessment of the influence of air–water contact time.

Because appropriate mass transfer coefficients for volatile organic chemicals (VOCs) with relatively low Henry's constants have not been adequately developed for spray aeration, the authors investigated the possibility of creating design graphs to predict THM removals on the basis of a proposed volumetric ratio of the air volume the droplet moves through to the average droplet volume. This ratio, referred to as a unit air-to-water volumetric ratio, is depicted in Figure 5. As a water droplet falls, the space it moves through has a volume that can be visualized as a long cylinder with a height (h_{avg}) equal to the average distance the droplet travels from nozzle exit to the water surface and a diameter (d_{SMD}) equal to the droplet SMD. The average droplet travel distance was assumed to be equal to a droplet travel path halfway between the maximum droplet travel distance at the exterior of the spray cone and the shortest vertical droplet travel distance at the center of the spray cone. This volumetric ratio, which is analogous to an air-to-water ratio used in counter-current packed towers or diffused aeration reactors, is derived in Eq 2:

Unit air-to-water volumetric ratio =

$$\frac{\frac{\pi d^2_{SMD}\, h_{avg}}{4}}{\frac{\pi d^3_{SMD}}{6}} = \frac{1.5\, h_{avg}}{d_{SMD}}, \text{ where } h_{avg} = \frac{h}{\cos\frac{\theta}{4}} \qquad (2)$$

in which h = nozzle height (m), θ = nozzle spray angle (degree), h_{avg} = average droplet travel distance (m), and

TABLE 5 ANOVA and percent contribution of experimental factors to bench-scale diffused-aeration removal of chloroform and bromoform

Chloroform ANOVA

Source	df	Sum of Squares	F Ratio	Probability > F	Percent Contribution
Water temperature	1	1,243	141	< 0.0001	28.0
Airflow rate	1	1,244	141	< 0.0001	28.1
Air temperature × concentration	1	512	58	< 0.0001	11.5
Water temperature × airflow rate	1	646	73	< 0.0001	14.5
Airflow rate × number of diffusers	1	573	65	< 0.0001	12.9
Error	23	203	NA	NA	5.0

Bromoform ANOVA

Source	df	Sum of Squares	F Ratio	Probability > F	Percent Contribution
Water temperature	1	6,903	196	< 0.0001	64.0
Airflow rate	1	2,844	81	< 0.0001	26.5
Error	27	1,009	NA	NA	9.5

ANOVA—analysis of variance, df—degrees of freedom, NA—not applicable

d_{SMD} = droplet SMD (m). This model also assumes that the air concentration of THMs is maintained close to zero. In order to maximize concentration driving force in a relatively confined space (such as a water storage tank or chlorine contact basin), proper ventilation including the use of motorized fans may be required to enhance removals.

The unit air-to-water volumetric ratio can be used to successfully predict THM removals as shown in Figure 6 for various THM species and temperatures (2, 22, and 36°C). As depicted, spray aeration can achieve significant removals (> 80%) for all THM species with unit air-to-water volumetric ratios of 30,000:1, independent of temperature. As noted previously, increasing temperature will increase removals by spray aeration for all THM species (although the data associated with the lower temperature of 2°C were more variable).

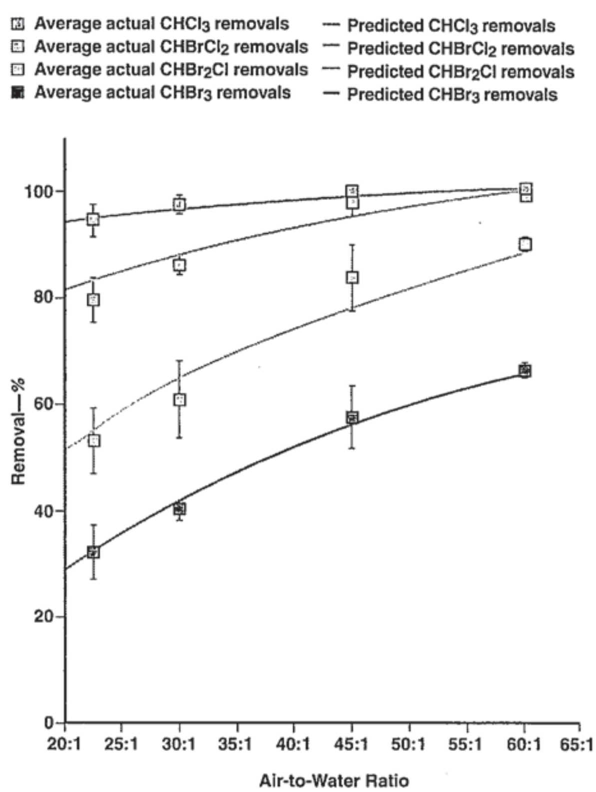
Plots similar to Figure 6 are potentially useful to design engineers and utility personnel because they can facilitate reasonable estimates and control of both the droplet SMD of the spray aerators and average travel distance. As an example of the potential use of the design plots shown in Figure 6, in order to achieve an 80% reduction of $CHCl_3$ at 22°C, a dimensionless unit volumetric air-to-water ratio of roughly 9,000:1 will be required. Thus, using a spray nozzle that produces droplets with an SMD of 690 μm will require an average droplet travel distance of 4.14 m. The actual vertical travel distance (h) will be a function of the spray pattern angle as shown in Eq 2.

The influence of individual spray aeration pilot-scale experimental factors was quantified and is summarized in Table 6. The most important factors in THM removal by spray aeration were droplet travel distance, water temperature, and droplet SMD, with droplet travel distance being significantly more influential to THM removal than droplet SMD. From an engineering design perspective, optimizing water storage tank fill levels to allow for greater droplet travel distance easily outweighs the benefit of spending energy on creating smaller droplet SMDs by increasing spray pressure. If at all possible, greater emphasis should be applied to increasing average travel distance, given that its influence on THM removals is considerably greater than the effect of smaller droplet SMDs.

The 27% error rate for the final spray aeration experiment listed in Table 6 is between 15 and 50%, which typically indicates an incomplete but statistically valid model (Ross, 1988). Consequently, some variables were either imprecisely controlled or unaccounted for, analytical error may have been more than expected, or the initial concentration of THMs was not controlled with sufficient accuracy. Although initial concentration was not important in the bench-scale diffused aeration experiments, it is possible that in spray aeration in which the concentration of THMs in the air does not reach equilibrium with that in the water droplets, the difference in initial concentrations may have resulted in an unequal driving force for mass transfer between experimental runs. Another possible source of error was that all spray aeration experiments were conducted outside, where wind may have influenced droplet trajectory and therefore droplet travel distance as well as unequally influencing concentration gradient driving forces. Moreover, variations in droplet SMD because of a significant standard deviation in droplet distribution could also have influenced the outcome. Manufacturer evidence notes the variation in nominal droplet size may be significant from a given nozzle and flow rate.

One difference between diffused and spray aeration is that for spray aeration, removals of individual THM species at the same experimental conditions were significantly closer. The average difference between $CHCl_3$ and $CHBr_3$ removals in a given run for diffused aeration was 56%, but this difference was only 12% for spray aeration under similar operating conditions. This unexpected, relatively small difference between

FIGURE 4 Actual and predicted THM removals at 20°C for bench-scale diffused aeration



$CHBr_3$—bromoform, $CHBrCl_2$—dichlorobromomethane, $CHBr_2Cl$—chlorodibromomethane, $CHCl_3$—chloroform, THM—trihalomethane

Predicted removals are based on Eq 1.

$CHCl_3$ and $CHBr_3$ removals may be attributable to the fact that VOCs with Henry's constants of < 0.55 are not controlled by the liquid-phase mass transfer coefficient but instead may be controlled by the gas-phase mass transfer coefficient (Roberts & Levy, 1983); the resulting removal differences between the THM species may be diminished when aeration regimes that maintain low THM concentrations in the bulk air phase are used.

Chlorine-stripping study. Spray and diffused aeration both demonstrated significant potential for THM removal, but an assessment of the effects of aeration on free chlorine residual was needed to satisfy concerns of water utilities that are required by USEPA to maintain a free chlorine residual of > 0.2 mg/L. Because of its ability to more precisely control operating conditions, the bench-scale diffused aeration system was used to assess the effect of various stripping conditions on free chlorine residual.

As shown in Figure 7, diffused aeration had minimal effect on free chlorine residuals even up to air-to-water ratios of 200:1, even when pH was controlled at 6.1 and where the majority of the chlorine would be in a nonionic form, i.e., hypochlorous acid (HOCl). Other researchers reported similar trends (Sherant et al, 2007).

An explanation for the apparent stability of free chlorine during aeration becomes clear upon examination of free chlorine water chemistry from a thermodynamic perspective. The corresponding overall electrical potential is shown in Eq 3 (Benjamin, 2001):

$$HOCl + Cl^- + H^+ \leftrightarrow Cl_2(g) + H_2O \quad E^\circ = 0.09\ V \tag{3}$$

in which E° is the cell potential at standard conditions.

The cell potential of a redox reaction is related to the equilibrium constant via Eq 4:

$$\ln K_{eq} = \frac{n\, F\, E^\circ\text{cell}}{Rt} \tag{4}$$

in which K_{eq} is the equilibrium constant, n is the number of electrons transferred, R is the universal gas law constant, t is temperature, and F is Faraday's constant. The equilibrium constant can be calculated from Eq 4, and the equilibrium expression can be developed as shown in Eqs 5 and 6:

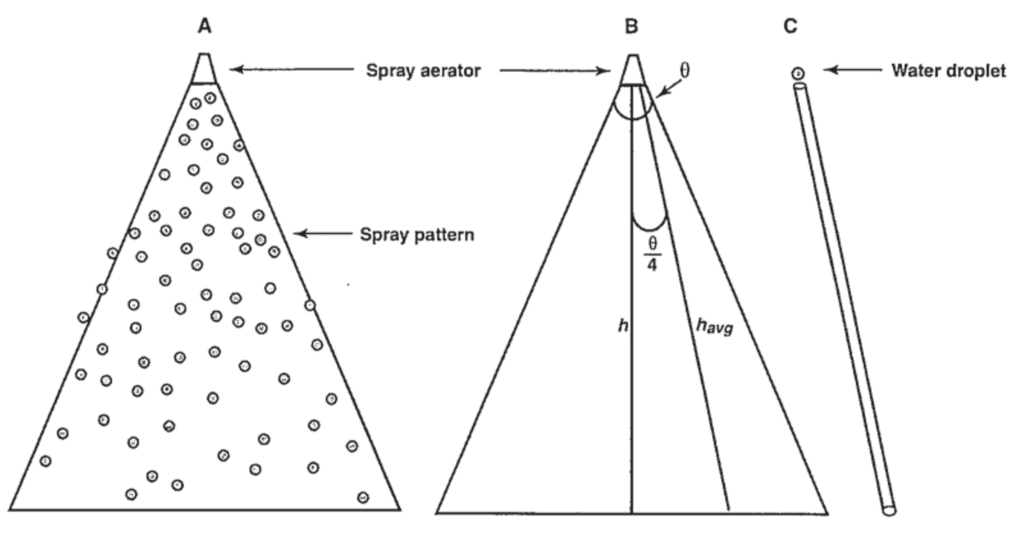
$$\ln K_{eq} = \frac{n\, F\, E^\circ\text{cell}}{Rt} = \frac{(2)(23{,}061)(0.09)}{(1.99)(298)} = 6.99 \tag{5}$$

or

$$K_{eq} = 1{,}096 = \frac{[Cl_{2(g)}]}{(HOClL)(Cl^-)(H^+)} \tag{6}$$

Assumptions of pH, chloride level, temperature, and free chlorine dose must be made for this example. Assuming a worst-case scenario (pH of 6, Cl^- of 250 mg/L, 20°C, and a total free chlorine residual of 1.0 mg/L as

FIGURE 5 Depiction of total air volume to total water-droplet volume in spray cone (A), average droplet travel distance (B), and volumetric ratio of cylindrical droplet path through the air to droplet volume of the water (C)

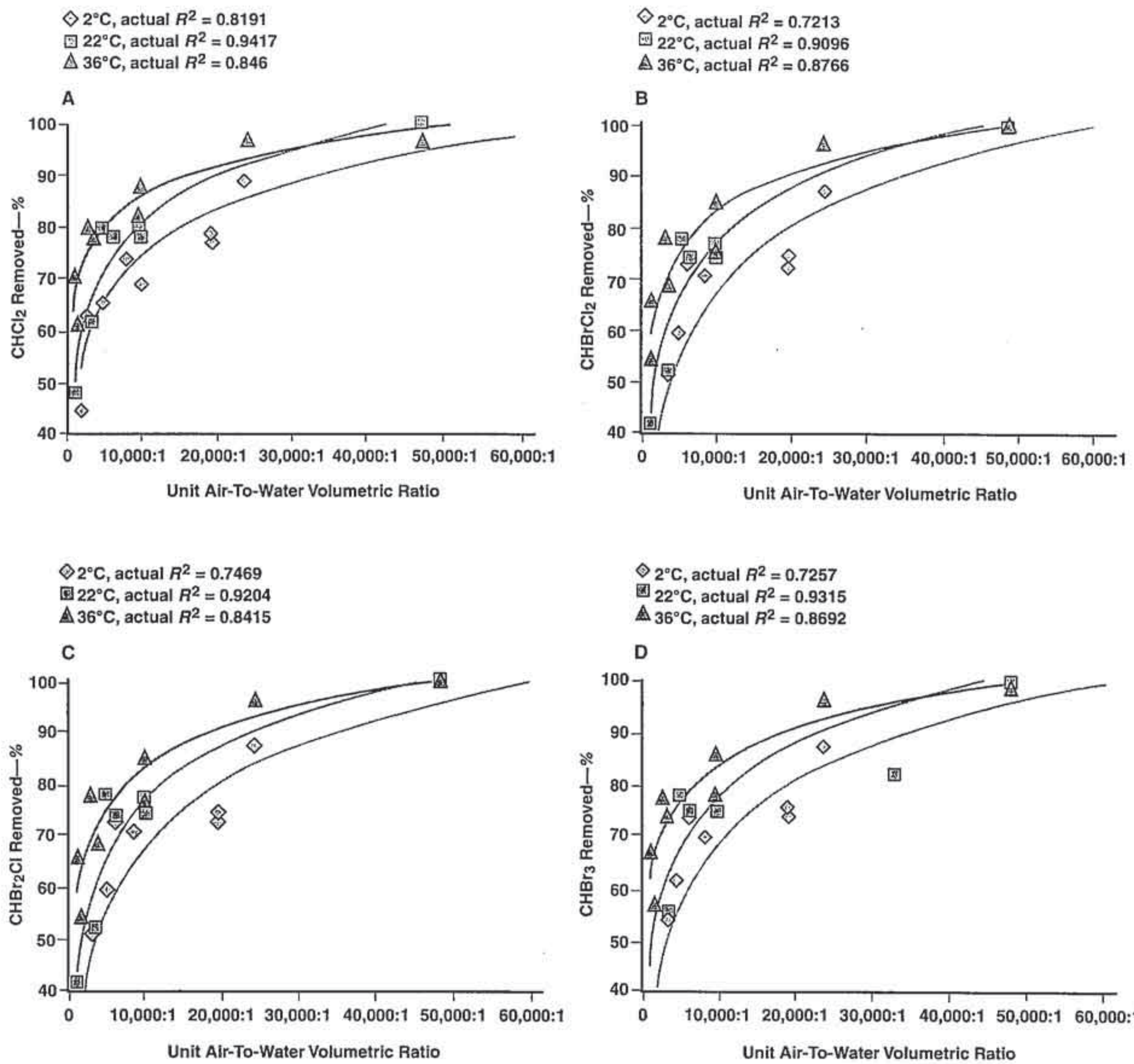


h—height of nozzle, h_{avg}—average droplet travel distance

Cl_2) results in a total chlorine gas partial pressure of 1.1 × 10^{-10} atm and, on the basis of Henry's constant, would be in equilibrium with an aqueous free chlorine concentration orders of magnitude below typical chlorine detection limits. In short, free chlorine should not be significantly stripped by typical posttreatment aeration processes. The previous calculations are based more on a closed-system assessment, however, and the correlation between an enclosed storage tank vented to the atmosphere and an enclosed diffused-aeration reactor vented to the atmosphere should be ascertained.

Despite this theoretical enclosed storage tank assessment, experience in the field working with a water utility in California did result in significant observed free chlorine residual reductions following implementation of spray aeration inside a storage tank. An investigation into the probable causes concluded that the change in influent flow pattern inside the storage tank exposed the

FIGURE 6 Percent removal of $CHCl_3$ (A), $CHBrCl_2$ (B), $CHBr_2Cl$ (C), and $CHBr_3$ (D) versus unit air-to-water volumetric ratio for spray aeration



$CHBr_3$—bromoform, $CHBrCl_2$—dichlorobromomethane, $CHBr_2Cl$—chlorodibromomethane, $CHCl_3$—chloroform

influent water to chlorine-demanding surfaces that consumed the influent chlorine residual. After roughly 5 to 7 days of implementing this flow pattern change, the chlorine residual moved toward normal influent levels. Water utilities wanting to implement similar influent flow-pattern changes to storage tanks should be aware of this temporary reduction in chlorine residual, especially if the storage tanks have not been cleaned or serviced for an extended period of time.

TABLE 6 ANOVA and percent contribution of experimental factors to spray aeration efficiency for removal of chloroform and bromoform

Chloroform ANOVA					
Source	df	Sum of Squares	F Ratio	Probability > F	Contribution %
Height	2	3,114.3	106.6	< 0.0001	34.4
Temperature	2	1,710.11	58.5	< 0.0001	18.7
SMD	3	1,171.9	26.7	< 0.0001	12.6
Height × temperature	4	738.3	12.6	< 0.0001	7.6
Error	22	321.3	NA	NA	26.7
Bromoform ANOVA					
Source	df	Sum of Squares	F Ratio	Probability > F	Contribution %
Height	2	4,592.0	131.1	< 0.0001	29.9
Temperature	2	2,803.8	80.1	< 0.0001	18.2
SMD	3	2,851.0	54.3	< 0.0001	18.6
Height × temperature	4	992.0	14.2	< 0.0001	6.5
Error	22	385.3	NA	NA	26.8

ANOVA—analysis of variance, df—degrees of freedom, NA—not applicable, SMD—Sauter mean diameter

CONCLUSION

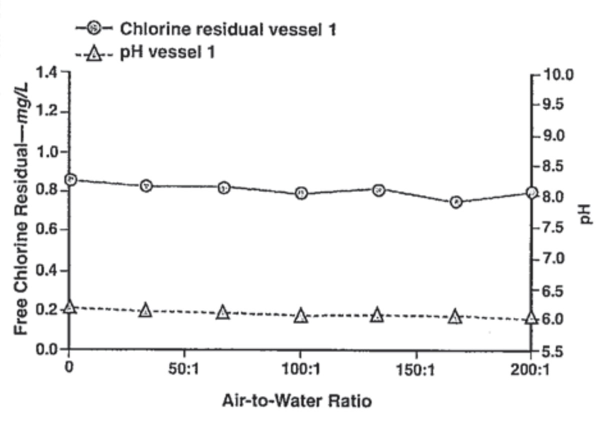
Air-stripping of THMs is a viable posttreatment strategy for finished drinking water. In the current research, the THM species most amenable to removal by aeration was $CHCl_3$, but significant reductions in all THM species are possible. Percent reduction of THMs during aeration was significantly influenced by water temperature, with warmer water having a greater stripping potential than colder water. In this study at the bench-scale level, diffused aeration achieved removal rates of 9 to > 99.5%, depending on air-to-water ratio, water temperature, and THM species. Because THMs have Henry's constants < 0.55, mass transfer may not be controlled exclusively by liquid film resistance but instead appears to be influenced by both gas and liquid film resistance. Consequently, spray aeration appears to be a more efficient approach to THM stripping, especially for THM species with lower Henry's constants.

In this study, spray aeration achieved THM reductions of 20 to > 99.5%, depending on droplet SMD, droplet travel distance, water temperature, and THM species. Droplet diameter is an important design variable and is controlled by operating pressure or nozzle flow rate and nozzle characteristics. Droplet travel distances, however, exerted a greater influence on THM removals. Thus, when a spray aeration system is designed for installation inside a water tank, variations in water levels inside the tank must be taken into account. Both the droplet SMD and travel distance variables can be developed into a unit air-to-water volumetric ratio that can be used to reasonably predict TTHM removals.

Free chlorine does not appear to be significantly reduced by aeration because only a small fraction of it will be amenable to removal. The assumption that spray aeration in an enclosed storage tank vented to the atmosphere is similar to an enclosed diffused-aeration reactor vented to the atmosphere must be verified. Water utilities should be aware of temporary reductions of free chlorine residuals when initiating flow pattern changes in water storage tanks.

Recommendations. A study comparing the power costs of spray aeration and diffused aeration to determine a best available practice should be undertaken. In addition, a study to determine gas-phase and liquid-phase mass transfer coefficients for the THM species

FIGURE 7 Influence of diffused aeration on free chlorine residual as a function of air-to-water ratio and pH at pH 6.1



A computer-aided titrator was used to maintain the pH at 6.1.

would allow for a better theoretical understanding and optimization of THM stripping. A better mass transfer coefficient correlation model should be developed to take into account both liquid and gas film mass transfer resistances. The effects of increasing THM concentrations in the bulk air inside a water tank should be considered to allow for proper design of air ventilation systems. A more in-depth study of chlorine-stripping potential to confirm the results of these experiments would be appropriate. Additional spray-aeration assessments conducted indoors without the presence of atmospheric disturbances would likely result in lower experimental error.

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FOOTNOTES

[1]JMP statistical analysis software, SAS, Cary, N.C.
[2]Hydrocarbon trap, Restek, Bellefonte, Pa.
[3]Fisher Scientific, Pittsburgh, Pa.
[4]Cat. 6700-00, Hach, Loveland, Colo.
[5]Sta-rite 1f98V, Sta-rite, Delavan, Wis.
[6]Great Plains Digital Instruments, Wichita, Kan.
[7]6890N GC-ECD, Agilent Technologies, Santa Clara, Calif.
[8]7683 Series, Agilent Technologies, Santa Clara, Calif.
[9]BETE, Greenfield, Mass.

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APPENDIX B

A system-wide hydraulic/water quality model was prepared by combining models of individual service areas that were provided by RWA in EPANet format. These models included diurnal demand patterns and nodal demands representing high-demand conditions. The EPANet files were imported into the InfoWater software package and assembled into a system-wide model.

In the original RWA models, pressure zones were modeled separately, and all supplies and large withdrawals were modeled as negative or positive nodal demands, respectively. Therefore, the EPANet files provided by the RWA did not contain system features that connect pressure zones (e.g. pump stations and control valves). These features were added during preparation of the system-wide model. Pump stations were represented in the model as single pumps, sized based on the flow rates and operating heads from the EPANet models. Where possible, sources in the combined model were represented as negative demands, consistent with the original RWA models. Controls were added to the combined model as necessary to allow extended period model simulations.

The system demands and water production as represented in the combined model as received from the RWA in the EPANet models are summarized in Tables B-1 and B-2.

The system demands presented in Table B-1 represent a Max Day Demand condition, with a system-wide demand of 89.49 MGD. It is noted that the Mt. Carmel Well and City of Derby Well No. 1 are not producing in the EPANet models provided by the RWA. Therefore, these wells are assumed to be off in the Max Day Demand model.

TABLE B-1
System demands as represented in the Max Day Demand model

Service Area Name	System Demand (MGD)	Percent of Total
Ansonia/Derby	3.33	3.7%
Branford Gravity	1.77	2.0%
Burwell Hill	6.96	7.8%
Cherry Hill	0.53	0.6%
Clintonville/Northford	1.20	1.3%
Cheshire	6.24	7.0%
High Rock	1.12	1.3%
Milford	5.23	5.8%
North Branford	1.93	2.2%
New Haven	30.41	34.0%
Rabbit Rock	3.35	3.7%
Stoney Creek	0.12	0.1%
Shingle Hill	7.76	8.7%
Saltonstall	7.02	7.8%
West River	3.09	3.5%
Whitney/Wintergreen	8.12	9.1%
York Hill	1.31	1.5%
Total	**89.49**	**100%**

TABLE B-2
Water production by source as represented in the Max Day Demand model

Source	Production (MGD)	Percent of Total
South Sleeping Giant Wellfield	1.27	1.4%
South Cheshire Wellfield	1.89	2.1%
Seymour Wellfield	2.13	2.3%
Lake Whitney Water Treatment Plant	2.46	2.7%
North Sleeping Giant Wellfield	2.61	2.8%
North Cheshire Wellfield	5.25	5.7%
West River Water Treatment Plant	7.39	8.0%
Lake Saltonstall Water Treatment Plant	8.70	9.4%
Lake Gaillard Water Treatment Plant	60.4	65.6%
Total	**92.1**	**100.0%**

The RWA provided SCADA data for June 25 and June 26, 2012, which represent an average system demand condition. An Average Day Demand model was prepared based on these data. Tables B-3 and B-4 provide a summary of system demands and source production for the Average Day Demand model.

TABLE B-3
System demands as represented in the Average Day Demand model

Service Area Name	System Demand (MGD)	Percent of Total
Ansonia/Derby	2.51	5.1%
Branford Gravity	0.87	1.8%
Burwell Hill	3.36	6.8%
Cherry Hill	0.30	0.6%
Cheshire	3.22	6.6%
Clintonville/Northford	0.50	1.0%
High Rock	0.99	2.0%
Milford	2.19	4.5%
New Haven	16.53	33.7%
North Branford	1.29	2.6%
Rabbit Rock	2.46	5.0%
Saltonstall	4.15	8.5%
Shingle Hill	4.83	9.8%
Stoney Creek	0.06	0.1%
West River	1.28	2.6%
Whitney/Wintergreen	3.35	6.8%
York Hill	1.13	2.3%
Total	**49.03**	**100%**

TABLE B-4
Water production by source as represented in the Average Day Demand model

Source	Production (MGD)	Percent of Total
South Sleeping Giant Wellfield	0.74	1.4%
South Cheshire Wellfield	1.10	2.1%
Seymour Wellfield	0.50	1.0%
Derby Well No. 1	0.41	0.8%
North Sleeping Giant Wellfield	2.09	4.0%
North Cheshire Wellfield	2.83	5.5%
West River Water Treatment Plant	6.13	11.8%
Lake Saltonstall Water Treatment Plant	4.75	9.2%
Lake Gaillard Water Treatment Plant	33.2	64.1%
Total	**51.8**	**100.0%**

The following items regarding the system supplies and demands represented in the models are noted:

- The differences between total production and system demand (92.1 MGD vs. 89.45 MGD for the MDD model, 51.8 MGD vs. 49.03 MGD for the ADD model) represent the net system-wide change in storage volume over the courses of the respective simulations.
- The Lake Whitney WTP is producing in the Max Day Demand model but not in the Average Day Demand model. The Derby Well No. 1 is not producing in the Max Day Demand model but is producing in the Average Day Demand model. The Max Day Demand model reflects the conditions represented in the model files provided by the RWA. The Average Day Demand model reflects SCADA data from June 25 and June 26, 2012.

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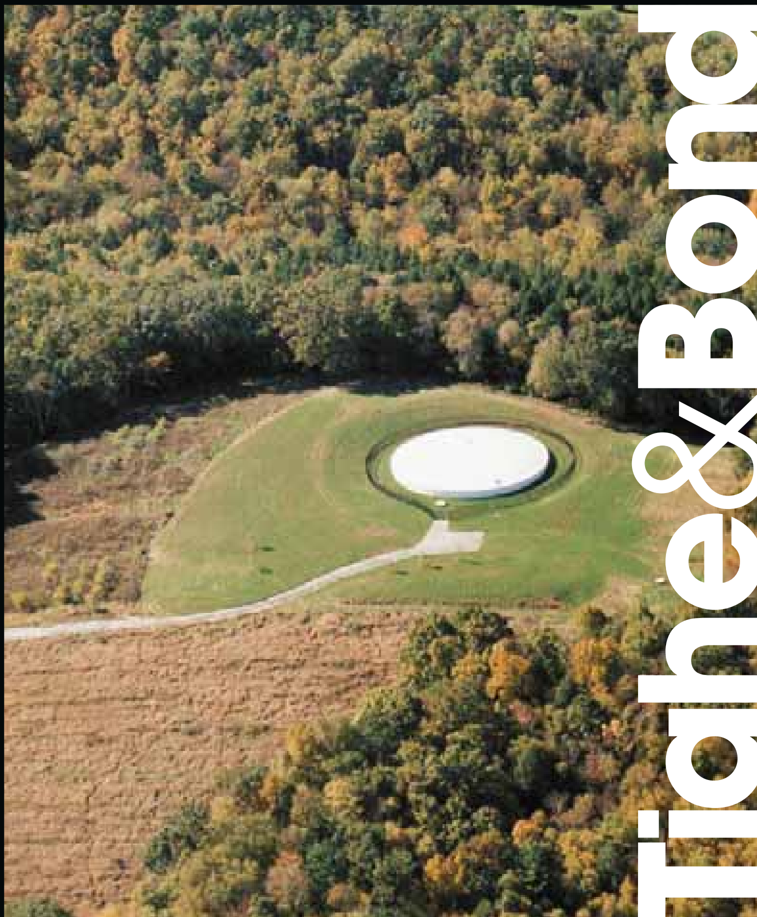

APPENDIX C

Connection of CHSA to NBSA - Alternative 1

ESTIMATE OF PROBABLE CONSTRUCTION COST

South Central Connecticut Regional Water Authority

August 2014 **ENR CCI - 9845.59**

ITEM	DESCRIPTION	UNITS	QTY	UNIT PRICE	SUB TOTAL	TOTAL
1	**Pipeline**					**$2,263,000**
	16" DI Pipe - Cross Country -HDD	LF	5000	$400	$2,000,000	$2,000,000
	16" DI Pipe and Fittings - Laurell Road	LF	560	$100	$56,000	$56,000
	16" DI Pipe and Fittings -Brookhills	LF	1,750	$100	$175,000	$175,000
	16" Gate Valves	EA	1	$2,000	$2,000	$2,000
	Hydrant Assemblies	EA	2	$5,000	$10,000	$10,000
	Special Connections	LS	2	$10,000	$20,000	$20,000
2	**Traffic Control**					**$15,000**
	Maintenance and Protection of Traffic	LS	1	$4,000	$4,000	$4,000
	Uniformed Police/Flaggers for Traffic Control	LS	1	$11,000	$11,000	$11,000
3	**Restoration**					**$102,000**
	Temporary Bituminous Concrete Repair	SY	900	$40	$36,000	$36,000
	Permanent Bituminous Concrete Repair	SY	1,500	$40	$60,000	$60,000
	Bituminous Concrete Driveway Repair	SY	100	$60	$6,000	$6,000
4	**Excavation**					**$6,000**
	Test Pits	LS	1	$2,000	$2,000	$2,000
	Gravel Borrow	LS	1	$3,000	$3,000	$3,000
	Haybales and Silt Fence	LS	1	$1,000	$1,000	$1,000
5	**Other**					**$20,000**
	Site Clearing	LS	1	$20,000	$20,000	$20,000
					SUBTOTAL	**$2,406,000**
6	**General Conditions - 15%**					**$360,900**
					CONSTRUCTION - SUBTOTAL	**$2,766,900**
7	**Engineering and Contingency - 40%**					**$1,106,800**
					TOTAL	**$3,873,700**
					SAY	**$3,870,000**

Notes:

1 Costs for permitting and easements are not included.

2 Since subsurface conditions are unknown, costs for rock excavation are not included.

Connection of CHSA to NBSA - Alternative 2

ESTIMATE OF PROBABLE CONSTRUCTION COST

South Central Connecticut Regional Water Authority

August 2014 **ENR CCI - 9845.59**

ITEM	DESCRIPTION	UNITS	QTY	UNIT PRICE	SUB TOTAL	TOTAL
1	**Pipeline**					**$2,088,000**
	16" DI Pipe - Cross Country -HDD	LF	5000	$400	$2,000,000	$2,000,000
	16" DI Pipe and Fittings - Laurell Road	LF	560	$100	$56,000	$56,000
	16" Gate Valves	EA	1	$2,000	$2,000	$2,000
	Hydrant Assemblies	EA	2	$5,000	$10,000	$10,000
	Special Connections	LS	2	$10,000	$20,000	$20,000
2	**Traffic Control**					**$7,000**
	Maintenance and Protection of Traffic	LS	1	$1,000	$1,000	$1,000
	Uniformed Police/Flaggers for Traffic Control	LS	1	$6,000	$6,000	$6,000
3	**Restoration**					**$34,000**
	Temporary Bituminous Concrete Repair	SY	300	$40	$12,000	$12,000
	Permanent Bituminous Concrete Repair	SY	400	$40	$16,000	$16,000
	Bituminous Concrete Driveway Repair	SY	100	$60	$6,000	$6,000
4	**Excavation**					**$6,000**
	Test Pits	LS	1	$2,000	$2,000	$2,000
	Gravel Borrow	LS	1	$3,000	$3,000	$3,000
	Haybales and Silt Fence	LS	1	$1,000	$1,000	$1,000
5	**Other**					**$20,000**
	Site Clearing	LS	1	$20,000	$20,000	$20,000
					SUBTOTAL	**$2,155,000**
6	**General Conditions - 15%**					**$323,300**
					CONSTRUCTION - SUBTOTAL	**$2,478,300**
7	**Engineering and Contingency - 40%**					**$991,400**
					TOTAL	**$3,469,700**
					SAY	**$3,470,000**

Notes:

1 Costs for permitting and easements are not included.

2 Since subsurface conditions are unknown, costs for rock excavation are not included.

Tighe&Bond

Demolish Brushy Plain Tank

South Central Connecticut Regional Water Authority

August 2014 **ENR CCI - 9845.59**

ITEM	DESCRIPTION	UNITS	QTY	UNIT PRICE	SUB TOTAL	TOTAL
1	**Demolish Existing Tank**					**$105,000**
	Demolish existing tank	LS	1	$125,000	$125,000	$125,000
	Value of scrap steel	LS	1	($20,000)	($20,000)	($20,000)
					SUBTOTAL	**$105,000**
6	**General Conditions - 15%**					**$15,800**
					CONSTRUCTION - SUBTOTAL	**$120,800**
7	**Engineering and Contingency - 40%**					**$48,400**
					TOTAL	**$169,200**
					SAY	**$170,000**

Cherry Hill Pump Station Pump Upgrade

ESTIMATE OF PROBABLE CONSTRUCTION COST

South Central Connecticut Regional Water Authority

August 2014 **ENR CCI - 9845.59**

ITEM	DESCRIPTION	UNITS	QTY	UNIT PRICE	SUB TOTAL	TOTAL
1	**Pumping Equipment**					**$52,500**
	Demolition of old pumps	LS	1	$2,500	$2,500	$2,500
	New pumps	EA	2	$25,000	$50,000	$50,000
2	**Mechanical**					**$15,000**
	Process piping demolition	LS	1	$5,000	$5,000	$5,000
	New process piping	LS	1	$10,000	$10,000	$10,000
3	**Electrical**					**$207,500**
	Elctrical demolition	LS	1	$7,500	$7,500	$7,500
	New VFDs	EA	2	$25,000	$50,000	$50,000
	New generator	EA	1	$75,000	$75,000	$75,000
	Power & control wiring	LS	1	$75,000	$75,000	$75,000
					SUBTOTAL	**$275,000**
6	**General Conditions - 15%**					**$41,300**
					CONSTRUCTION - SUBTOTAL	**$316,300**
7	**Engineering and Contingency - 40%**					**$126,600**
					TOTAL	**$442,900**
					SAY	**$440,000**

Notes:

1 Costs for permitting and easements are not included.

2 Since subsurface conditions are unknown, costs for rock excavation are not included.

Branford Hill Water Main Improvements

ESTIMATE OF PROBABLE CONSTRUCTION COST

South Central Connecticut Regional Water Authority

August 2014 **ENR CCI - 9845.59**

ITEM	DESCRIPTION	UNITS	QTY	UNIT PRICE	SUB TOTAL	TOTAL
1	**Pipeline**					**$503,000**
	12" DI Pipe and Fittings -RT 1	LF	1,300	$70	$91,000	$91,000
	16" DI Pipe and Fittings -RT 1	LF	1,600	$100	$160,000	$160,000
	16" DI Pipe and Fittings -Montoya	LF	2,200	$100	$220,000	$220,000
	12" Gate Valves	EA	1	$2,000	$2,000	$2,000
	Hydrant Assemblies	EA	2	$5,000	$10,000	$10,000
	Special Connections	LS	2	$10,000	$20,000	$20,000
2	**Traffic Control**					**$77,000**
	Maintenance and Protection of Traffic	LS	1	$15,000	$15,000	$15,000
	Uniformed Police/Flaggers for Traffic Control	LS	1	$62,000	$62,000	$62,000
3	**Restoration**					**$62,000**
	Temporary Bituminous Concrete Repair	SY	600	$40	$24,000	$24,000
	Permanent Bituminous Concrete Repair	SY	800	$40	$32,000	$32,000
	Bituminous Concrete Driveway Repair	SY	100	$60	$6,000	$6,000
4	**Excavation**					**$6,000**
	Test Pits	LS	1	$2,000	$2,000	$2,000
	Gravel Borrow	LS	1	$3,000	$3,000	$3,000
	Haybales and Silt Fence	LS	1	$1,000	$1,000	$1,000
5	**Other**					**$20,000**
	Site Clearing	LS	1	$20,000	$20,000	$20,000
					SUBTOTAL	**$668,000**
6	**General Conditions - 15%**					**$100,200**
					CONSTRUCTION - SUBTOTAL	**$768,200**
7	**Engineering and Contingency - 40%**					**$307,300**
					TOTAL	**$1,075,500**
					SAY	**$1,080,000**

Notes:

1 Costs for permitting and easements are not included.

2 Since subsurface conditions are unknown, costs for rock excavation are not included.