RESPONSE TO ENVIRONMENTAL PROTECTION AGENCY'S STATEMENT OF SUBSTANTIAL NEW QUESTIONS FOR PUBLIC COMMENT

PSNH MERRIMACK STATION UNITS 1 & 2
BOW, NEW HAMPSHIRE

PREPARED FOR
PUBLIC SERVICE COMPANY OF NEW HAMPSHIRE
D/B/A EVERSOURCE ENERGY

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1 Executive Summary

On August 2, 2017, the United States Environmental Protection Agency (EPA) and New Hampshire Department of Environmental Services issued a joint public notice of the reopening of the public comment period for the draft Public Service Company of New Hampshire's (PSNH's) Merrimack Station (the Station) National Pollutant Discharge Elimination System (NPDES) permit. This report is prepared in response to EPA's "Statement of Substantial New Questions for Public Comment" and provides engineering evaluations of specific items put forward by EPA for public comment. A summary of the significant items addressed are provided in the list below.

- A description is provided of the most significant engineering responses to the draft permit for the Station that were previously submitted by Enercon Services, Inc. (ENERCON). The response descriptions are provided because they are still applicable and remain relevant comments. The descriptions of these comments incorporate updates based on information gained since the previous submittal as well as advancements in technology.
- An updated conceptual design for the implementation of wedgewire half-screens is presented. This updated conceptual design provides further details and support for the responses to EPA's questions regarding the implementation of wedgewire screens at the Station.
- A discussion of the results from the in-river pilot wedgewire screen testing that was conducted at the Station during the summer of 2017 is provided, as well as various lessons learned from the testing that have been incorporated into the conceptual full scale wedgewire half-screen design.

- A conceptual cost estimate is developed for the implementation of wedgewire half-screens at both of the Station's units. The details of the cost estimate are presented in Attachment 2.
- As part of the cost estimate, a construction schedule for the implementation of wedgewire half-screens at the Station is presented. The total construction schedule for both units is 70 weeks, with the screens being installed at Unit 1 first, and then at Unit 2 a year later. The staggered installation allows lessons learned from the Unit 1 installation to help improve the Unit 2 installation.
- A discussion of the costs of closed-cycle cooling is included. Due to a variety of changes that have occurred on site at the Station since the development of the closed-cycle cooling cost estimate in 2007, the most significant of which is the installation of the new scrubber system, the capital cost estimate for implementing mechanical draft cooling towers is increased by 30%.
- Identification of major concerns regarding the intermittent use of cooling towers in freezing weather are presented, including icing, reliability challenges, plume and drift concerns, and challenges posed with frequent startup and shutdown.

2 Background and Purpose

2.1 Background

PSNH's Merrimack Station electrical generating facility in Bow, New Hampshire is seeking a renewal of its existing NPDES permit. To this end, several engineering and biological assessments have been prepared by ENERCON, Normandeau Associates, Inc. (Normandeau), LWB Environmental Services (LWB), and AST Environmental (AST) and submitted by PSNH to EPA. These assessments have included initial and updated responses to EPA requests for information, technology evaluations, thermal plume modeling, and an engineering response to the 2011 draft NPDES permit (Reference 12.2).

On August 2, 2017, EPA and New Hampshire Department of Environmental Services issued a joint public notice of the reopening of the public comment period for the draft NPDES permit. The comment period was reopened to allow additional comments on information and arguments that pertain to the permit and have become pertinent since issuance of the draft permit in 2011 and the revised draft permit in 2014.

In conjunction with this public notice, EPA prepared a document entitled "Statement of Substantial New Questions for Public Comment" (the Statement) (Reference 12.1). This document outlines the new information that appears to raise substantial new questions which have prompted EPA to reopen the comment period. The Statement includes, amongst other items, discussions on the following topics:

- New information pertaining to requirements for cooling water intake structures under Clean Water Act (CWA) § 316(b), particularly regarding cylindrical wedgewire screens

- New information regarding the application of CWA § 316(a), particularly regarding new thermal information provided by PSNH and the presence of the Asian Clam in the Hooksett Pool
- New information regarding technology-based standards for various waste streams at the Station
- Considerations regarding the interrelationship of permit changes, with potential timing scenarios provided
- Other minor modifications that are intended to be implemented into the final NPDES permit

2.2 Purpose

This report is prepared in response to EPA's Statement and provides engineering evaluations of specific items put forward by EPA for public comment, including the implementation of wedgewire screens at the Station and the compliance schedules presented by EPA for both closed-cycle cooling and wedgewire screens. This report also addresses several items that are relevant to the permitting decisions of EPA that should be carefully considered. These items include engineering design information obtained from the in-river pilot testing conducted in the spring/summer of 2017 as well as a discussion on the challenges of seasonal/intermittent use of cooling towers, particularly in freezing weather conditions. Also included in this report is a refined conceptual design for the use of wedgewire half-screens at the Station. The engineering responses provided in this report are based on past evaluations and assessments prepared for the Station (with the information updated, as required) as well as new information and evaluations that have become available and are relevant to the Station's Best Technology Available (BTA) discussion.

3 Summary of Previously Submitted Comments

A summary of the most significant engineering responses to the EPA Draft NPDES Permit NH 0001465 (Reference 12.1) previously provided in the 2012 ENERCON report "Response to Environmental Protection Agency's Draft NPDES Permit" (2012 Response, Reference 12.3) is presented below. Descriptions of these previously submitted responses are provided because they are still applicable and remain relevant comments. The responses were originally provided to the draft NPDES permit, prior to the release of EPA's Statement, and therefore refer primarily to the draft permit. New responses which refer directly to EPA's Statement are provided in Sections 4 through 10. Note that the previously provided responses regarding the wedgewire screening technology have been updated to include technological developments that have occurred since 2012, including the widespread use of wedgewire half-screen technology.

3.1 Wedgewire Screens – Discussion of Availability for Seasonal Operation

The EPA Draft NPDES Permit NH 0001465 states that there is no technology that provides similar entrainment reduction to that of a closed-cycle cooling tower while allowing the Station to generate the same amount of electricity (Reference 12.3, Page 5). However, conversion to closed-cycle cooling would significantly decrease the Station's power generating capability and implementation of wedgewire screens would allow the Station to generate nearly the same amount of electricity it currently does while providing entrainment reductions similar to those of closed-cycle cooling.

The expected power loss associated with implementation of a closed-cycle cooling system far exceeds the expected power loss for implementation of wedgewire screens. The losses associated with implementation of a wedgewire screen system are minimal and are attributed to parasitic losses associated with the air burst system (ABS) compressors used to backflush and clean the wedgewire screens. These parasitic losses are estimated at approximately 172 MW-hr per year (Section 4.4.2). Alternatively, losses associated with implementation of a closed-cycle cooling system include both parasitic losses due to installation of the new circulating water booster pumps and cooling tower fans, as well as condenser efficiency losses due to increased condenser cooling water inlet temperatures. Total closed-cycle cooling parasitic losses are estimated at 58,700 MW-hr per year, and condenser efficiency losses are estimated at 26,000 MW-hr per year (Reference 12.3, Page 6). The total estimated loss of 84,700 MW-hr per year associated with a closed-cycle cooling configuration is approximately 490 times that expected from implementation of wedgewire screens and equates to the average power needs of 7,800 U.S. households (References 12.3, Page 6 and 12.28).

As shown in Section 4, significant entrainment reduction is achievable with seasonal use of wedgewire screens. The results of the 2017 in-river pilot study, which was conducted during the peak entrainment period and with test parameters that were representative of the conceptual wedgewire half-screen design, show an 89% entrainment reduction due to the wedgewire test screen. Measurements taken during testing also demonstrated a sweeping flow velocity to through-slot flow velocity ratio of 1:1 or greater (Reference 12.5). Note that for the in-river pilot study, the test screen was selected to accurately model the hydraulics of the full scale conceptual half-screen design, so that the test results could be applied to the full scale design (Reference 12.13, Attachment 1).

As noted in the 2009 Normandeau report, the United States Army Corps of Engineers (USACE) and any other applicable regulatory agencies would have to be contacted regarding the permit restrictions associated with the use of wedgewire screens and any impacts resulting from their implementation (Reference 12.3, Page 7). Comparable installations have been previously approved and implemented at other similar facilities, with one example being the installation of CWW screens on the Allegheny River at the Olean Wastewater Treatment Plant in Olean, New York. The plant is located in a region where the Allegheny River is not more than 300 feet wide (Reference 12.3, Page 8), which is slightly more narrow than the Merrimack River at the Station's intakes.

Although the installation of wedgewire screens would result in a minimal reduction in available recreational space in front of the Station, it would not significantly impact the navigability of the Merrimack River. Environmental disturbance could be further reduced through implementation of wedgewire half-screens which allow for fewer screens with larger screen diameters and less river dredging during installation as compared to cylindrical wedgewire screens (Reference 12.6, Page 8). The use of half-screens would also limit the impact to recreational activities that occur on the river.

3.2 Wedgewire Screens - Addressing Concerns of Low River Velocities and Shallow Water Depth

Wedgewire screens have been installed in a number of facilities with cooling water intake system characteristics similar to the Station, including various industrial facilities within the state of New Hampshire (Reference 12.3, Page 8). However, the EPA Draft NPDES Permit NH 0001465 determined that wedgewire screens did not constitute BTA based on EPA's understanding at the time of the conditions at the Station (Reference 12.3, Page 8). As shown below, both the river velocity and water depth are acceptable for use of wedgewire screens at the Station.

Low River Velocities

It has been demonstrated that wedgewire screens work most effectively to reduce entrainment when the ratio of sweeping flow velocity (i.e. flow parallel to the screen length) to through-slot flow velocity is 1:1 or greater (Reference 12.6, Attachment 1). Based on recorded sweeping flow velocities during the peak entrainment period and the conceptual wedgewire half-screen design, it is expected that the ratio of sweeping flow velocity to through-slot velocity would be well above 1:1 when the half-screens are in use[1].

The preliminary conceptual design of wedgewire half-screens at the Station included an approximate through-screen velocity of 0.4 fps. This velocity was selected to limit wedgewire screen suction pressure losses upstream of the cooling water pumps (Reference 12.6, Pages 10-11).

Based on field observations from 2009 and 2012 performed during the peak entrainment period (late May to late June), relatively high and consistent sweeping flow velocities have been observed in the Merrimack River at the Station along the predominant north-south axis where the wedgewire screens would be installed. The average sweeping flow during this time period was observed to be 2.9 fps, which would provide a sweeping flow velocity to through-slot flow

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[1] The wedgewire screens are assumed to operate from April through July, during the period of peak entrainment.

velocity ratio of approximately 7:1, well above the 1:1 ratio demonstrated to effectively increase entrainment reduction (Reference 12.6, Page 11). The sweeping flow velocities observed during the 2017 in-river testing further support this observation, with a river velocity of 0.5 fps or greater observed for almost the entirety of the test (Reference 12.5). These observations indicate that a sweeping flow velocity to through-slot velocity ratio of 2:1 or greater would be present for almost the entirety of the peak entrainment period.

It has been noted that there may be periods during the late summer months where sweeping flow velocities decrease below 1 fps. However, this is not a concern as the wedgewire screens would not be in operation during this period. The wedgewire screens are only intended to operate from April through July, during the periods of peak entrainment (Reference 12.3, Page 7). Additionally, since the design through-slot velocity for the half-screens is approximately 0.4 fps, a flow velocity ratio of at least 1:1 would be maintained for all river flow velocities above 0.4 fps (Reference 12.6, Page 11).

Shallow Water Depth

Wedgewire screen designs typically require a one half-diameter boundary clearance to establish a fully developed flow profile around the screen and account for fluctuations in water depth (Reference 12.7, Page 14). At the Station, the average water depth is approximately 8 feet (Reference 12.6, Page 10). Due to this relatively shallow water level, the Station is ideally suited to implement a wedgewire half-screen design. The half-screen design eliminates the need to provide clearance on the bottom of the screen and allows for installation of larger overall surface area screens in shallow water depths (Reference 12.6, Page 10).

Based on the average water depth of approximately 8 feet and the assumption that minor dredging may be required during installation, a screen diameter of 8 feet has been used for the conceptual half-screen design at the Station (Reference 12.6, Page 12). In addition to accommodating the water depths at the Station, the use of the larger diameter half-screens reduces the number of screens required to meet the flow requirements at the Station, thereby limiting the costs of construction and overall environmental impact on the waterway (Reference 12.6, Page 10).

EPA's Statement

It should be noted that the Statement presents conclusions regarding the use of wedgewire screens at the Station that are consistent with the arguments presented above. Page 18 of the Statement says:

> *"…new information suggests that an effective screen array potentially can be implemented in the Hooksett Pool section of the Merrimack River, and that this technology may be more effective at reducing the Facility's entrainment than previously thought … In particular, a newly proposed screen design variation (i.e., "wedgewire half-screens") would result in a smaller installation without excessive inference with public uses of the river… Furthermore, additional data has been submitted suggesting that adequate sweeping flows are likely to exist during the time period when the majority of eggs and larvae are present."*

3.3 Response to Closed-Cycle Cooling Conclusions

The 2012 Response addressed some of the lack of rigor and explanation associated with the analysis and conclusions within the EPA Draft NPDES Permit NH 0001465. A summary of these responses is provided below. Several of the responses refer to information that was provided in the 2007 Response to United States Environmental Protection Agency CWA § 308 Letter (2007 Response, Reference 12.4). It should be noted that the 2007 Response, which includes details of a preliminary closed-cycle cooling retrofit design, such as estimated power losses, a construction cost estimate, and an estimated project schedule, was provided at the request of EPA, not because it was considered a feasible technology option by PSNH. The information provided was preliminary in nature, and should be used with the appropriate cautions, as described below.

3.3.1 Water Usage

The EPA draft permit does not sufficiently consider the water losses associated with the closed-cycle cooling systems and implies that the evaporation resulting from the Power Spray Modules (PSMs) and thermal plume in the river associated with the current, open-cycle cooling system may equate to a similar loss of water. However, the current cooling system consumes a much smaller volume of water when compared to the water losses associated with using a wet or hybrid cooling tower (Reference 12.3, Page 16).

Unlike cooling towers, the primary mechanisms by which the PSMs and cooling canal remove heat are convection and radiation, not evaporation. There is a small amount of evaporation from the canal and PSMs, but cooling tower systems which remove heat primarily through evaporation are estimated to evaporate 2 to 3 times more water than open-cycle systems (Reference 12.3, Page 17). Additionally, while closed-cycle systems withdraw much less water than open-cycle systems, these closed-cycle systems consume 70-90% of the water they withdraw as opposed to an open-cycle system which discharges nearly 100% of the water they withdraw.

A survey of State Water Managers across the United States designated New Hampshire as one of the more concerning states with respect to expected water shortages. The increased frequency of water shortages is only compounded by increased population growth and a need for more water and electricity. In these circumstances, it is possible that plants retrofitted with closed-cycle cooling may need to return to open-cycle cooling operation for water conservation purposes (Reference 12.3, Page 19).

3.3.2 Cost Considerations

In the draft permit, EPA incorrectly assumes that conceptual cost data presented in the 2007 Response for the construction of a closed-cycle cooling system encompass all expected project costs (Reference 12.3, Pages 19-20). It is well-acknowledged in the power industry that project costs can significantly increase between the conceptual design stage and the detailed design stage. Further, these costs typically also increase from the design stage to the implementation stage as there are many unforeseen difficulties that can arise during implementation of large projects. It is not possible to predict all the unforeseen changes and setbacks that may occur, even with a detailed design, and especially from a conceptual design. The contingency multipliers provided in the conceptual cost estimate and discussed in the draft permit are not intended to cover these unforeseen issues (Reference 12.3, Page 22).

There are many examples of coal-fired power plant projects that have been significantly hampered by increases from initial cost estimates. For example, PSNH's recent experience with the construction of a wet flue gas desulphurization system (FGD or scrubber system) at the Station provides an illustration of the price differential between a preliminary estimate and a final implemented cost. PSNH received a preliminary estimate in 2005 for $250 million for the construction of a scrubber system at the Station. The final cost of the project was $422 million, an increase of nearly 70% over the preliminary conceptual estimate, caused by a range of unforeseen factors and requirements that arose during design and implementation (Reference 12.3, Pages 22-23). These types of cost increases are not limited to just the Station and have been seen at other locations across the country.

Additionally, the conceptual cost data presented in the 2007 Response does not account for new construction interferences associated with the installation of a FGD system to reduce sulfur dioxide and mercury emissions at the Station. A more detailed discussion of the various plant and technological changes that would significantly impact the closed-cycle cooling cost estimate is provided in Section 10.

3.3.3 Air Emissions

The EPA draft permit states that significant air emissions are not anticipated, but remarks that any cooling towers would be subject to air pollution control laws and provides guidelines for properly controlling significant air emissions (Reference 12.3, Page 25). As discussed in the 2007 Response, implementation of a closed-cycle cooling system would result in additional air emissions per unit of electricity. The air emissions would be increased by two different sources: increased stack emissions and new air emissions from the cooling towers (Reference 12.3, Page 25).

Although the content of the stack emissions would be unaffected, the quantity would increase if closed-cycle cooling were to be implemented due to increased parasitic losses resulting from the cooling tower's electricity demands, reduced efficiency of the turbine and condenser due to warmer condenser water, and increased coal consumption to make up for the newly incurred operational efficiency losses (Reference 12.3, Page 25).

There would also be an increase in air emissions resulting from the operation of new cooling towers. Cooling towers are known air emitters that are subject to regulatory air pollution controls. Although EPA dismisses particulate emissions as a serious concern because high quality drift eliminators were specified in the preliminary design, even state-of-the-art drift eliminators still allow some drift to occur. It is estimated that approximately 2,880 gallons of water a day would escape the tower via drift. As a result, it is possible that additional water treatment equipment would have to be installed for any cooling tower to be operated and/or permitted, which could lead to significantly increased costs (Reference 12.3, Page 26).

It should be noted that installation of wedgewire screens would not increase air emissions, either by stack or by cooling tower. Additionally, unlike if closed-cycle cooling were to be implemented, the installation of wedgewire screens would not require installation of additional water treatment equipment or increased water treatment chemicals and concentrations.

3.3.4 Icing / Fogging Concerns

While the EPA draft permit assumes icing/fogging is not a concern for implementation of closed-cycle cooling tower system, this assumption is not based on any quantifiable data. In fact, icing/fogging at/around the plant and neighboring areas is a safety concern that requires a rigorous analysis. Some of the potential negative effects of a cooling tower plume at the Station include reduced visibility around the Station, the possibility of "black ice" forming on the nearby roads and highways during the winter, damage to the vegetation in the vicinity of the Station, degradation of the Station heating, ventilating, and air conditioning (HVAC) systems, increased corrosion on Station equipment, and ice accumulation on electrical equipment which could lead to electrical arcing (Reference 12.3, Page 27).

The conclusions in the 2007 Response were estimates based on prevailing wind directions and predictions of the impacts that could occur, and were not the result of any rigorous analysis or modeling. Given the multiple safety concerns for both site personnel and the public, the estimates provided in the 2007 Response should have been used as a foundation for a more rigorous analysis or modeling (such as SCATI) and not a basis for a final decision. A SCATI or similar model should be either utilized or requested by EPA before a decision is made regarding icing/fogging impacts (Reference 12.3, Pages 27-28).

Installation of wedgewire screens would not cause any additional icing or fogging to occur at the Station.

3.3.5 Power Generation Losses

The EPA draft permit determines the potential power generation loss due to a closed-cycle cooling installation based on the preliminary estimates of the condenser efficiency from the 2007 Response, and not based on any modeling analysis that would have better quantified the impact (Reference 12.3, Page 28). As stated previously, the 2007 Response estimated that the power generation losses resulting from implementation of closed-cycle cooling would eliminate enough electricity from the grid to power 7,900 average American homes (Reference 12.3, Page 28).

It is important to note that the estimates provided in the 2007 Response were preliminary in nature and are not a result of a detailed evaluation or modeling. The exact impact to the generating capacity (given constant coal consumption) of the Station with a conversion to closed-cycle cooling has not been precisely determined thus far. A more rigorous analysis should be undertaken before any decision is made that will impact the generating capacity of the Station (Reference 12.3, Page 30). This more rigorous analysis could include a Performance Evaluation of Power System Efficiency (PEPSE) software model of the Station, which would provide a more quantitative estimate of the impact to the generating capacity and overall plant efficiency, giving a better basis upon which the aforementioned items should be evaluated. A larger than estimated efficiency impact could make other open-cycle options (that do not impact significantly Station efficiency) more feasible alternatives (Reference 12.3, Page 30).

3.4 Summary of Operations and Maintenance Challenges of the Flue Gas Desulfurization Wastewater Treatment System

In a 2016 ENERCON report, a detailed description of the various operations and maintenance challenges associated with the FGD wastewater treatment system was provided. Discharge of FGD wastewater to a receiving water body from a physical/chemical treatment system is common and occurs across the United States. Without the ability to discharge treated FGD wastewater, the secondary wastewater treatment system (SWWTS) was needed to reduce that wastewater to a manageable volume such that whatever wastewater could not be reused could be transported offsite for appropriate disposal.

Operation of the SWWTS is subject to many operating constraints, including the requirement for a purge stream. The SWWTS is designed to evaporate water to increase the wastewater's concentration, thereby facilitating removal of solids. However, several of the chemical constituents have high solubility and cannot be removed unless a portion of the recirculating liquid is purged. Equipment reliability, such that failure of a single piece of equipment does not result in failure of the entire wastewater treatment train, also continues to be an issue. Due to the sensitivity of the process and the highly corrosive environment, maintaining equipment reliability is a continuous operational challenge.

There are several other challenges which currently present operating constraints to the SWWTS. One of these challenges is the frequent on-off cycling of the Station, which creates instability and inventory issues. The SWWTS is not designed to be cycled on and off, and requires several days of continuous operation to fully start up. Additionally, overall water balance and inventory management continue to be an issue, with the problem exacerbated during short-term or reduced load operation. Foaming of the brine concentrator and equipment scaling and plugging due to excess calcium sulfate also continue to be issues.

Although these challenges currently present operating constraints to the SWWTS, they will continue to be addressed through further operating experience and knowledge sharing across the industry. PSNH expects to continue optimizing the SWWTS over time to resolve the various operating constraints as more operating experience and knowledge is gained.

4 Wedgewire Half-Screen Conceptual Design Update

The purpose of this section is to update the conceptual design of the wedgewire half-screens at the Station that was presented in the 2016 technical memo (Reference 12.6). This update includes the development of a conceptual cost estimate and a construction schedule, which will be used as input for a subsequent economic analysis (Reference 12.11). A discussion of the application of the conceptual design of the wedgewire half-screens at the Station is provided, in addition to a preliminary layout design of wedgewire half-screens for both Unit 1 and Unit 2.

4.1 Background

Under the final CWA § 316(b) rule, existing facilities that are designed to withdraw greater than 2 million gallons per day (MGD) from waters of the United States, and that use at least 25 percent of this water exclusively for cooling purposes, are subject to the BTA standard for impingement mortality unless a *de minimis* demonstration can be made, or unless an exemption is given for a low capacity utilization factor. According to the Normandeau evaluation contained in the 2014 Assessment, the impingement rate at the Station is *de minimis* and does not require further controls as stated in the rule (Reference 12.21).

With the *de minimis* classification, the 2014 Assessment of the 2007 Response to the EPA CWA § 308 Letter preemptively evaluated technologies with a specific focus on reducing entrainment abundance. Wedgewire screens are designed to reduce entrainment by excluding organisms from passing through the screen based on screen orientation and by encouraging aquatic avoidance behaviors through achieving low slot velocities. The 2014 assessment included the Johnson Screens Half Intake Screen System. These screens are marketed as a solution for shallow water intakes, and can be installed in water that is half the depth of traditional intake screen systems of the same diameter. Due to the relatively shallow river depth at the Station, and the benefit that the Station would receive from reducing the number of screens used (such as lower costs and less environmental disruption during construction), the wedgewire half-screen technology provides significant advantages over the traditional cylindrical wedgewire screen technology as evaluated at the Station in the 2009 Supplemental Alternative Technology Evaluation (Reference 12.8). Because of this, half-screens are more viable and compatible for the Station than cylindrical wedgewire screens. Because wedgewire half-screens are a viable technology that should be part of the BTA discussion, the remainder of this section evaluates the anticipated construction requirements, construction schedule and cost estimate for the wedgewire half-screen conceptual design. The cost estimate and construction schedule will be input for an economic analysis of the wedgewire half-screen implementation.

4.2 Wedgewire Half-Screen Technology

Wedgewire screens are large, permanent intake screens installed in a waterbody that exclude aquatic organisms and allow a large screening area in support of low through-screen intake velocities. Wedgewire screens can be designed such that a through-screen velocity of 0.5 feet per second (fps) would be achieved, making wedgewire screens a candidate technology for compliance of Section 316(b) of the CWA under §125.94(c)(2). Many wedgewire screen systems are equipped with an air burst system (ABS), which uses periodic bursts of compressed air to blow accumulated objects from the screens, preventing blockage that can lead to higher capture velocities and pressure drops (see Section 4.2.9 for further details on the ABS).

Wedgewire screens have been successfully installed in plant water intakes as a method of minimizing impact to aquatic life, while providing sufficient water for plant operations. Wedgewire screens were installed at the Oak Creek Power Plant intake on Lake Michigan, near Milwaukee, Wisconsin in 2009. This intake system uses 24 Z-Alloy cylindrical wedgewire screens, with a 3/8-in. slot size (Reference 12.26). Z-Alloy (a proprietary copper-nickel alloy) has been shown to substantially reduce bio-fouling compared with stainless steel, while providing excellent corrosion resistance in underwater environments.

This section describes the conceptual design for wide-slot wedgewire screens as it relates to the construction approach, construction schedule and cost estimate.

4.2.1 Technology Overview

Since the station meets the *de minimis* criteria (see Section 4.1), this assessment will focus on the entrainment reduction qualities of Wedgewire screens. Wedgewire screens are designed to reduce entrainment by excluding organisms from passing through the screen and by achieving low velocities due to the large size of the screens. Hydraulic bypass also occurs because of the shape of the screen, particularly when the lengthwise dimension of the screen is oriented parallel to the direction of prevailing flow (see Figure 1). Additionally, due to the round shape of the screens, the velocity pulling the organisms toward the screen is quickly dissipated, increasing the avoidance by organisms.

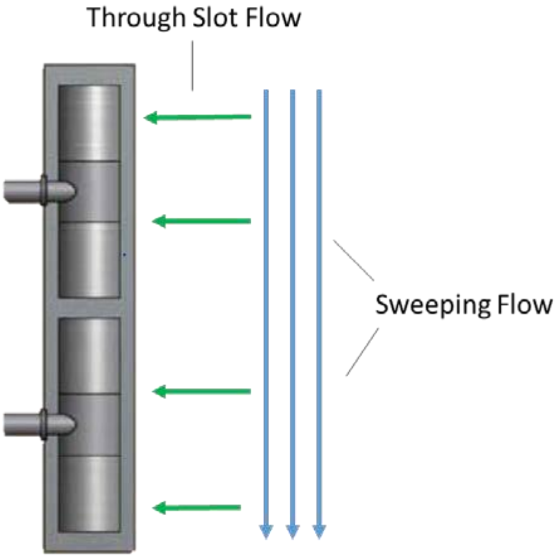

Figure 1 – Sweeping Flow and Slot Flow Illustration

The Johnson Screens Half Intake Screen System is a relatively new development in wedgewire screen technology that is well-suited for the Station, where the river depth is relatively shallow, averaging 6-8 feet deep (Reference 12.21). This screen contains one curved, semi-circular surface and one downward-facing flat surface, as shown below in Figure 2. A benefit of using larger diameter screens is that fewer screens are required, reducing the amount of construction and associated environmental disturbance.

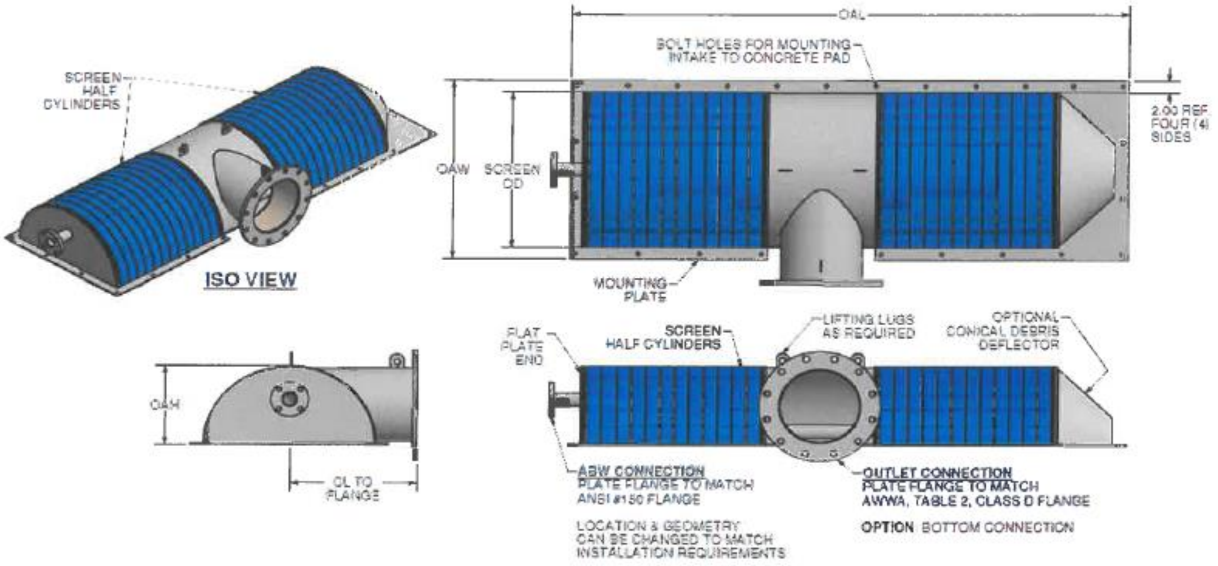

Figure 2 – Johnson Screens Half Intake Screen System (Reference 12.25)

As described in Attachment 1 of Reference 12.6, from a biological perspective, the location of the Station cooling water intake structure appears ideal for effective wedgewire screen entrainment reductions for three reasons. First, 88% of the entrained organisms collected during the 2005-2007 study were post yolk sac larvae. This life stage consistently experienced the greatest reduction in entrainment in the flume and field studies. Second, there is confidence that the observed entrainment reductions in the flume studies would be directly applicable to the Station because White Sucker, Carp, and Minnows were the principal test organisms in the flume studies and were the predominant fish taxa in the Station entrainment samples. Third, based on field observations from two surveys performed during the peak entrainment periods of 2009 and 2010, a relatively high and consistent sweeping velocity has been observed in the Merrimack River at the Station along the predominant north-south axis and confirmed during the measurements taken during the 2017 in-river testing (Reference 12.5). These findings show that the hydraulic conditions are suitable for effective wedgewire screen performance, and that the studies described in Attachment 1 of Reference 12.6, which demonstrated that bypass and avoidance contributes significantly to wedgewire screen effectiveness on these species (White Sucker, Carp, and Minnows), would be applicable to the Station.

The conclusions reached in Attachment 1 of Reference 12.6 were validated by the results of the in-river pilot testing that was performed at the Station during the summer of 2017. The pilot study demonstrated that use of the 3 mm slot width wedgewire screens resulted in an entrainment reduction of approximately 89%. The river current data collected during the testing also demonstrated a constant and high sweeping flow velocity, indicating that hydraulic bypass helped to reduce entrainment through the pilot screen (Reference 12.5).

4.2.2 Site Parameters and Screen Design

Since the development of the new wedgewire half-screen technology, Johnson Screens has completed installations at approximately 20 different sites in multiple different intake water sources, including lakes, reservoirs, and rivers (Reference 12.22). Several installations implemented multiple wedgewire half-screens at a single site, with the largest diameter screen listed being a 5-foot diameter screen. These installations were completed in 2012 or later, after the draft NPDES permit for the Station had been issued.

To size the wedgewire half-screens for application at the Station, several plant design parameters are required, including the intake structure layout and design intake flow rates. Due to the difference in intake flow between Unit 1 and Unit 2, as well as the physical distance between the intakes, two separate wedgewire half-screen designs were prepared – one for each unit.

For Unit 1, an intake flow rate of 59,500 gallons per minute (gpm) was used. This flow rate includes 29,500 gpm for each of the two circulating water pumps (Reference 12.8), as well as 500 gpm to supply the fire pump flow (Reference 12.23). For Unit 2, an intake flow rate of 140,000 gpm was used, which consists of 70,000 gpm for each of the two circulating water pumps (Reference 12.8). For both units, an inlet water depth of 8 feet was considered for the design. This water depth was selected based on the average depth of the river, as well as the assumption that minor dredging may be required during the installation of the wedgewire half-screens.

The screens themselves were designed with a slot width of 3 mm (0.118 inches). The slot width was selected because slot sizes of 2 mm and 3 mm were shown to increase behavioral avoidance in the laboratory flume and Hudson River estuary testing (Reference 12.6, Attachment 1). The 3-mm slot size is beneficial from a maintenance and operational standpoint because it can help reduce fouling and debris accumulation issues.

Measures were taken in the conceptual design to help reduce fouling and debris accumulation on the screens because past testing of fine mesh (0.5 – 1.0 mm) cylindrical wedgewire (CWW) screens has exhibited fouling issues. The State of Maryland conducted testing in 1982 and 1983 of 1, 2, and 3 mm CWW screens at the Chalk Point Generating Station, which withdraws water from the Patuxent River in Maryland. The 1 mm CWW screens were found to reduce entrainment by 80 percent; however, some biofouling and clogging was observed during the tests.

In addition, in the late 1970s, Delmarva Power and Light conducted field testing of fine mesh CCW screens for the proposed 1540 MW Summit Power Plant. Summit Power Plant was to be located south of the Chesapeake and Delaware Canal (the canal connects the waters of the Delaware River with those of the Chesapeake Bay and the Port of Baltimore) in New Castle County, Delaware, but was later cancelled. Field testing in the brackish water of the proposed intake canal required the screens to be removed and cleaned as often as once every three weeks (Reference 12.32).

The biofouling issues demonstrated by field testing are emphasized in EPA's Technical Development Document:

The Agency is not aware of any fine-mesh wedgewire screens that have been installed at power plants with high intake flows (>100 MGD). However, they have been used at some power plants with lower intake flow requirements (25-50 MGD) that would be comparable to a large power plant with a closed-cycle cooling system. With the exception of Logan, the Agency has not identified any full-scale performance data for these systems. They would be even more susceptible to clogging than wide-mesh wedgewire screens (especially in marine environments). It is unclear whether this simply would necessitate more intensive maintenance or preclude their day-to-day use at many sites. Their successful application at Logan and Cope and the historic test data from Florida, Maryland, and Delaware at least suggests promise for addressing both fish impingement and entrainment of eggs and larvae.

> *However, based on the fine-mesh screen experience at Big Bend Units 3 and 4, it is clear that frequent maintenance would be required. Therefore, relatively deep water sufficient to accommodate the large number of screen units, would preferably be close to shore (i.e., be readily accessible). Manual cleaning needs might be reduced or eliminated through use of an automated flushing (e.g., microburst) system.* (Reference 12.33)

Therefore, the 3-mm slot size was used in the design to help reduce fouling and debris accumulation issues. Additionally, the screens were designed to be constructed out of Z-Alloy (a proprietary copper-nickel alloy) metal. Although the original wedgewire screen design specified that 304 stainless steel be used for construction (Reference 12.8), Z-Alloy has been shown to substantially reduce bio-fouling compared with stainless steel, while providing excellent corrosion resistance in underwater environments (Reference 12.12).

As described in the 2014 Assessment, based on the impingement rate at the Station being *de minimis*, the design through-screen velocity of 0.5 fps is no longer a design requirement. However, during the screen design process, it was identified that when the screens are sized for a higher through-screen velocity, an unacceptably high head loss (i.e., energy loss due to friction) through the screens would occur. The increased head loss would result in reduced water level within the intake bays, potentially causing cavitation and damage to the circulating water pumps. Therefore, although the 0.5 fps velocity is no longer a design requirement dictated by impingement concerns, due to the unacceptable head loss through the screens at higher velocities, a design through-screen velocity of approximately 0.4 fps was maintained.

With the above design parameters in consideration, two separate wedgewire half-screen designs, one for each of the units at the Station, were created. For Unit 1, which has a design intake flow rate of 59,500 gpm, two Half T-96HCE Screens (30% extended) are used (percent extension refers to additional percentage in length compared to a standard half-screen). These screens are 8 feet in diameter, 25.25 feet in length, and have a slot size of 3 mm (0.118 inches). A dimensioned drawing of these screens is provided by Johnson Screens in Attachment 4. Each of these screens is designed for a through-screen intake average slot velocity of 0.406 fps with a design flow rate of 29,750 gpm/screen, totaling 59,500 gpm of flow for the entire unit.

For Unit 2, which has a design intake flow rate of 140,000 gpm, five Half T-96HCE Screens (30% extended) are utilized. These screens have the same dimensions as described above for Unit 1. Each of these screens is designed for a through-screen intake average slot velocity of 0.406 fps with a design flow rate of 29,750 gpm/screen.

Wedgewire screens for both units are designed for a through-screen intake average slot velocity of 0.406 fps due to unacceptable head loss through the screens at higher velocities. The sweeping flow velocities observed during the 2017 in-river testing were 0.5 fps or greater for almost the entirety of the test (Reference 12.5). These observations indicate that a sweeping flow velocity to through-slot velocity ratio of 2:1 or greater would be present for almost the entirety of the peak entrainment period.

It has been noted that there may be periods during the late summer months where sweeping flow velocities decrease below 1 fps. However, this is not a concern as the wedgewire screens would not be in operation at this period. The wedgewire screens are only intended to operate from April through July, during the periods of peak entrainment (Reference 12.3, Page 7). Additionally, since the design through-slot velocity for the half-screens is approximately 0.4 fps, a flow velocity ratio of at least 1:1 would be maintained for all river flow velocities above 0.4 fps (Reference 12.6, Page 11).

4.2.3 Screen Layout and Operation

A conceptual layout of the wedgewire half-screens for each unit is shown in Attachment 1. Both units are designed with a concrete plenum encompassing the front of the existing intake structure. To aid with construction, these plenums would likely be built with precast concrete and would not modify or interfere with the existing intake structure, but would instead be built adjacent to the existing structure. The purpose of these plenums is to collect the flow from all of a given unit's wedgewire screens, combining it and providing a suction source for the circulating water pumps. The combination of the flows from the various wedgewire half-screens serves to both simplify how the flow is provided from the screens to the suction of the circulating pumps, as well as to provide design redundancy. Because the wedgewire half-screens feed flow into a common plenum for each unit, if one screen were to fail, flow can still be provided to both circulating water pumps through the remaining screen(s).

For Unit 1, the two wedgewire half-screens are placed co-linearly from north to south, oriented in the direction of the prevailing river flow. The screens are oriented such that the slot width is perpendicular to the river flow (i.e., screen is parallel to river flow) to improve hydraulic bypass (Reference 12.6, Attachment 1). This layout allows for straightforward connections from the screens to the plenum without excessive piping friction losses and keeps the screens relatively close to the river shore, lowering construction costs. The upstream half-screen would sit directly in front of the plenum box and be connected to the downstream half-screen to provide a hydraulic benefit. The upstream and downstream wedgewire half-screens connect to the east and south walls of the concrete plenum, respectively. Attachment 1 provides a layout drawing which illustrates the wedgewire half-screen installation at Unit 1.

For Unit 2, all five wedgewire half-screens are placed co-linearly from north to south, oriented in the direction of the prevailing river flow. The screens are oriented such that the slot width is perpendicular to the river flow to improve hydraulic bypass (Reference 12.6, Attachment 1). Although the length of the wedgewire half-screens would extend beyond the width of the intake structure, this layout is still expected to be the most efficient from an engineering standpoint, allowing for straightforward connections from the screens to the plenum without excessive piping friction losses, and keeping the screens relatively close to the river shore to limit construction costs. The two upstream screens and two downstream screens connect to the north and south plenum wall, respectively. Additionally, the middle screen, which sits directly in front of the plenum box, connects to the east wall of the plenum. Attachment 1 provides a layout drawing, which illustrates the wedgewire half-screen installation at Unit 2.

For both units, the east wall of the concrete plenum includes two bypass gates that provide an alternate source of circulating water should the wedgewire screens become blocked. The water levels within the intake bay would be monitored continuously; if necessary, the auxiliary intake system would be initiated to maintain plant operation. This would also prevent a large pressure differential from building up across the blocked screens, reducing the potential for screen damage due to blockage. Additionally, the bypass gates would be used during portions of the year where entrainment is not of concern. During these portions of the year, the wedgewire screens would be taken out of operation and protective bollards installed in order to minimize risk of screen damage.

It is not expected that screen blockage would become an issue for screen operation during the entrainment season. Due to the Station's *de minimis* classification, the 0.5 fps design criteria to reduce impingement is not a requirement; therefore, a small amount of screen blockage that causes the through velocity to increase above 0.5 fps is not a concern if the ratio of sweeping flow to slot velocity is maintained at 1:1 or greater during the typical entrainment period. It is expected that, even during a minor blockage event, a ratio of 1:1 or greater would be maintained due to the high sweeping flow velocities in the Merrimack River. However, from a hydraulic loss standpoint, blockage could become a concern if it were to induce excessive head loss across the screen. Therefore, each screen would be equipped with an ABS, which uses periodic bursts of compressed air to blow accumulated objects from the screens, preventing excessive blockage from accumulating over time (see Section 4.2.9).

The estimated head loss through a Half T-96HCE Screen (30% extended) operating at 0.406 fps is provided by Johnson Screens as 0.752 psi (Reference 12.24). While it is not expected that this head loss would challenge plant operability, it is possible that at low river levels, the submergence of the circulating water pumps may be challenged due to the increased friction losses that would occur with the installation of the new screens. It is assumed as part of this cost estimate that no pump modifications are required. Vortex suppression features, such as grating or modified features beneath the suction of the pumps, may be required based on the expected intake water level and would be evaluated as part of this detailed hydraulic analysis. The cost of a detailed hydraulic study for each unit has been added to the cost estimate developed herein to include analysis of such hydraulic concerns.

4.2.4 Structural / Construction Considerations

Based on the screen layout described in Section 4.2.3, the wedgewire screen system for Unit 1 would be composed of wedgewire screens, a precast concrete pad and a precast concrete plenum box. Two half-screen type wedgewire screens (Johnson Screens, model T-96HCE [30% extended]) would be attached to the top of a precast concrete pad with embedded stainless steel headed studs. For constructability, the precast concrete plenum would be designed as two segments (i.e., walls and pad), and would be assembled on site during construction, potentially on a construction barge. The precast wall segment would be made up of a stem wall on a strip footing. During construction, the pre-cast walls would be placed in their position and the pre-cast slab would overlay on the footings of the wall. The wall and slab can be properly sealed with waterproof adhesive or grout. The 44-inch diameter stainless steel pipe would connect the outlet pipe of the wedgewire screen and the embedded pipe in the precast wall segment of the plenum. The wall would have two emergency bypass openings (5.75'W x 11.0'H) with stainless steel sluice gates on the river side (east side) to provide an alternative source of circulating water should the wedgewire screens become blocked. The top of the precast concrete portion of the plenum would be open to the water below.

The wedgewire screen system for Unit 2 would be composed of wedgewire screens, a precast pad for the wedgewire screens, and a precast concrete plenum. Five half-screen type wedgewire screens (Johnson Screens, model T-96HCE [30% extended]) would be attached to the top of a precast concrete pad with embedded stainless steel-headed studs. For constructability, the precast concrete plenum would be designed as two segments (i.e., walls and pad), and would be assembled on site during construction, potentially on a construction barge. The precast wall segment would be made up of a stem wall on a strip footing. During construction, the pre-cast walls would be placed in their position and the pre-cast slab would overlay on the footings of the wall. The wall and slab can be properly sealed with waterproof adhesive or grout. The 44-inch diameter stainless steel pipe would connect the outlet pipe of the wedgewire screen and the embedded pipe in the precast wall segment of the plenum. The wall would have two emergency bypass openings (5.75'W x 11.0'H) with stainless steel sluice gates on the river side (east side) to provide an alternative source of circulating water should the wedgewire screens become blocked. The top of the precast concrete portion of the plenum would be open to the water below. The opening would be covered with stainless steel grating with stainless steel support beams to provide working space, coverage of the intake plenum void, and access to the sluice gate system.

For both Units 1 and 2, the selection of materials for the sluice gate, intake piping and submerged ABS piping was based on material availability, durability and cost considerations. For this conceptual design and associated cost estimate (Section 4.4), stainless steel 316L was considered based on availability of 44-inch and 8-inch nominal pipe sizes as well as structural plate and typical structural members. Detailed design considerations should include an allowance in pipe and member sizes to account for corrosion. Higher grade stainless steels can be used to extend the life of submerged structures and reduce maintenance issues.

Each wedgewire screen requires installation of 8-inch diameter ABS piping, which would be connected to the ABS compressor equipment. Typical pipe supports composed of stainless steel channel struts and concrete expansion anchor bolts would be installed along the ABS piping route. For the wedgewire screen intake piping, additional supports are not expected because the span between the outlet of the wedgewire screens and the existing intake piping would be relatively short. However, if detailed design efforts identify that supports are required, concrete ballast blocks can be used.

4.2.4.1 Structural Design Environmental Conditions

The structural design of wedgewire screens and associated structures would be governed by the design loads per ASCE 7-10 and additional industry standards for underwater design considerations and construction practices. Because the wedgewire screen support structures are marine structures, the following additional loads should be also considered.

4.2.4.2 Flood Loads

The site may experience flood conditions; therefore, the flood effects should be considered during detailed design. Design flood load cases should consider hydrostatic load, hydrodynamic load, wave load, and impact load. The plant extreme high-water level should be considered during detailed design.

Flood loads would be determined during detailed design based on these design parameters according to ASCE 7-10 Section 5 and other industry standards.

The Merrimack River is subject to floating debris. The debris can present an impact hazard to underwater components of the wedgewire screen system. According to ASCE 7-10, the impact load can be categorized into three categories; (1) normal impact load, (2) special impact load, (3) extreme impact load. The wedgewire screens are installed on the bottom of the river, and the probability of direct impact from the floating debris is low. However, concrete bollards will be incorporated into the conceptual design of the wedgewire half-screen system. Several removable bollards would be installed in a semi-circle configuration upstream of the site. It is assumed that approximately eight bollards would be installed upstream of the Unit 1 screens. The bollards would be removed during the peak entrainment period, April-July of each year, to avoid any hydraulic interference with the wedgewire screens. This activity is not directly counted in the construction schedule, as it can be completed independent of other implementation tasks. However, coordinating the bollard installation with Unit 1 implementation activities may reduce the mobilization costs included as an additional line item in Attachment 2.

4.2.5 Geotechnical Conditions

New structures for the wedgewire screen system would be constructed near these existing intake structures; therefore, pile foundations are not expected. The bottom of the precast concrete pads would require proper preparation (i.e., gravel course with tremie concrete, as required) to place the precast concrete pads.

During detailed design, a stability check of the plenum box structures is necessary. Considering the weight of the structure, a pile foundation is not expected. However, if additional capacity is required for stability, either anchoring the foundation to the bedrock or tying the plenum to the existing intake structure is recommended. The cost estimate (Section 4.4) does not include the cost of either concept due to the potential that anchorage is not required and due to the relatively minimal additional cost.

4.2.6 Construction Methodology

Marine construction introduces additional complexity, challenges, and risk beyond those typically encountered during more traditional onshore construction projects. Thus, the design of marine structures is based substantially on constructability. Construction techniques deemed efficient on land are often considered inappropriate for marine construction. A typical rule of thumb is that, where structures are required at the bottom of the water body, installing a fewer number of large components is generally more efficient than many small components. The components should be large enough to ensure efficient underwater installation and reduce underwater joining, but not so large that they are unmanageable.

In terms of the construction method for installation of prefabricated structural modules, in-the-wet construction can be generally categorized into 'float-in' and 'lift-in' methods. The 'lift-in' method is generally more efficient than the 'float-in' method when river flow velocity is high and where several prefabricated modules have to be assembled on site. The 'lift-in' method should be employed for this project due to the expectation of high river flow velocities during implementation. Construction considerations for the conceptual design are discussed below.

For this project, the Unit 1 and Unit 2 wedgewire half-screens would be implemented independently. The Unit 1 wedgewire half-screens would be installed and tested for one year. At that point, the Unit 2 system would be installed. This would allow for a period of data to better inform the installation and operation of the Unit 2 system. Expected efficiencies are incorporated in the durations provided in the cost estimate (Attachment 2) and construction schedule (Attachment 3).

4.2.7 Prefabrication of Structure

The concrete structures would be cast onshore at the site. After the concrete structures are cured, they would be installed, by crane, in place. The wedgewire screens then would be installed on the top of the precast pads. Two sluice gates would be installed to the walls for both plenum boxes (i.e., four total sluice gates). To minimize the traveling distance to the project site and to provide better access during prefabrication, it is recommended to select the location for prefabrication near the shore of the Merrimack River at the site.

4.2.7.1 Transportation of Prefabricated Structures

The prefabricated structures would be transported from the shore by crane. Overall height restrictions are not significant because the crane can be fully erected at the project site.

The maximum weight of the precast segments is expected to be less than 200 tons. Derrick cranes up to 500-ton capacity are readily available for lease in the United States, although the lead-time required for leasing may run up to 6 months. Therefore, the lead-time should be considered as an important factor in project scheduling.

4.2.7.2 Installation of the Prefabricated Structures

Prefabricated segments would be installed underwater using a large crane and dive team. Derrick cranes have excellent control in positioning precast components, because they are able to quickly reach any point in three-dimensional space with one set of controls.

The prefabricated structure would be slowly lowered to the prepared ground at the bottom of the river. The day of the operation should be selected with mild winds not exceeding 15 knots from any direction.

Environmental factors such as river flow velocity and allowable work windows can impact the installation. Thus, the forecasted and observed river conditions must be considered. Installation of these prefabricated segments would be largely independent of water level, but, somewhat constrained by river flow velocity, with an ideal condition of average river channel flow less than 2.0 fps.

During lift-in installation of the structures, monitoring should be continuously performed to check important parameters, including:

- Environmental conditions – the river current velocities and wind conditions at the time of installation
- Orientation, positioning, and leveling of the structures
- Exact elevation of the segment above river bed or prepared gravel foundation
- Nearby navigation traffic and construction activities
- Hook loads on the lift-in structure

The prefabricated segments should be lowered in a gradual and fully-controlled manner. Any sudden and large motion during the set-down process is to be avoided. The lowering speed generally does not exceed 5 ft/min. When the segment reaches approximately 1 foot above the touchdown position, the lowering would be halted and surveyed to verify the position. The final position of the prefabricated segments would be adjusted as necessary.

4.2.8 Hydraulic Considerations

The pressure drop through the wedgewire screens at full flow would be approximately 0.752 psi. Based on the flow rate and size of the pipe, the pressure drop associated with the new piping would be approximately 0.1 psi per 100 ft of pipe. Assuming that up to 60 ft of new pipe would be required to connect the screens to the existing intake pipe, the additional head loss due to screens and piping is:

$$h_{total} = h_{screens} + h_{pipe} + h_{elbow}$$

$$h_{total} = h_{screens} + L\Delta p + K_{elbow}\frac{v^2}{2g}$$

$$h_{total} = 0.752\, psi\, \left(\frac{2.308\, ft\, H_2O}{1\, psi}\right) + 60\, ft\, \left(\frac{0.1\, psi}{100\, ft}\right)\left(\frac{2.308\, ft\, H_2O}{1\, psi}\right) + 0.3\, \left(\frac{(6.3\, ft/s)^2}{2\, x\, 32.2\, ft/s^2}\right)$$

$$h_{total} = 1.74\, ft\, H_2O + \ 0.14\, ft\, H_2O + 0.18\, ft\, H_2O$$

$$h_{total} = 2.06\, ft\, H_2O$$

where:

L = pipe length (ft)

Δp = pressure drop (psi) per linear 100 ft of pipe

K_{elbow} = 90-degree, flanged elbow loss coefficient (dimensionless) = 0.3

v = pipe velocity (ft/s) = Q / A = 66.3 ft^3/s / 10.6 ft^2 = 6.3 ft/s

Q = pipe flowrate (ft^3/s) = 29,750 gpm = 66.3 ft^3/s

A = cross-sectional area of pipe (ft^2) = Π d^2 / 4 = Π $(44\ in)^2$ / 4 = 1,520 in^2 = 10.6 ft^2

d = pipe diameter (in.) = 44 in.

g = gravitational acceleration (ft/s^2) = 32.2 ft/s^2

As shown above, additional head loss due to installation of screens and piping would be slightly more than 2 feet of water. As a result, the water level within the Unit 1 intake bay would be expected to drop by this amount due to the extra hydraulic resistance along the intake flow path. Drops in intake bay level require consideration of impacts to the circulating water pumps. Lower levels in the intake bay would reduce the submergence of the circulating water pumps, potentially creating concerns for vortexing or air intrusion. A hydraulic model study is recommended to ensure that the circulating water pumps can reliably operate under these new conditions. Another result of lower intake bay levels would be the increased hydraulic head across the circulating water pumps. The increased hydraulic head would result in the pumps operating at a lower point on the curve, potentially reducing flow or increasing power consumption.

The additional head loss of 2.06 ft H_2O is calculated under the assumption that the wedgewire screens are completely clean and free of blockage. However, the water level drawdown (i.e., head loss into the intake structure) in the intake structure bay may be too significant to allow this condition to develop.

4.2.9 Air Burst System

Both sets of screens (for Unit 1 and Unit 2) would be connected to one ABS using 8-inch schedule 10 steel air lines. The ABS would be used to periodically clean the screen by releasing compressed air inside the screen. As the air expands and passes through the screen surface, it dislodges accumulated objects. Any objects that are dislodged from the screens are expected to be easily carried away by the Merrimack River current due to the higher flow velocity. A sketch of a typical ABS design is provided below (Figure 3).

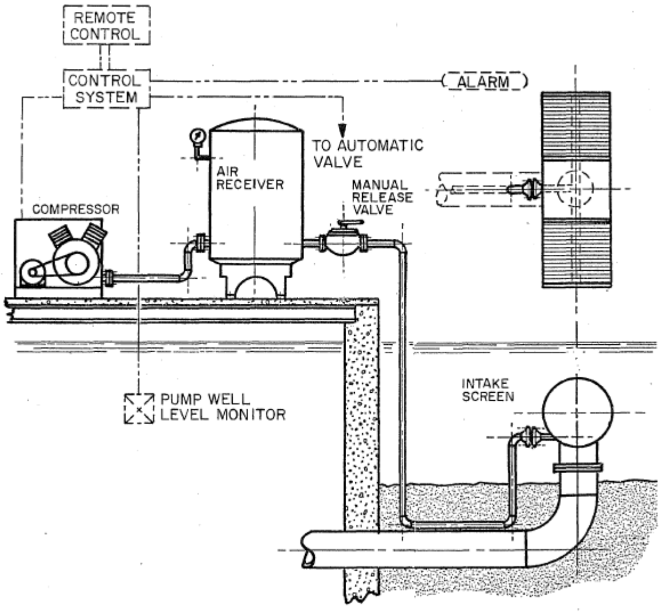

Figure 3 – Sketch of a Typical ABS Design (Reference 12.7)

The ABS would consist of four sets of components: a compressor, an air receiver, release valves, and interconnecting piping. Automated monitoring and control equipment is incorporated into the system. Operating the system involves charging of the ABS receiver tank to the operating pressure and opening the release valve to release the stored volume of compressed air to a single screen during each air burst. This process forces water accumulated in the ABS piping out of the pipe, through the screen, followed by the compressed air burst. Both the water and the compressed air backwash each screen in turn. Each ABS compressor would be connected to the inlet air connection on each wedgewire screen by 8-inch schedule 10 steel air lines.

It is assumed in this preliminary design that the onshore ABS equipment would be located a reasonable distance from the screens, where space is likely available in an existing plant structure. If space is not available to locate these pieces of equipment, engineering feasibility would not be impacted; however, an increase in cost may occur.

The performance of marine intakes is subject to a wide variety of site conditions and is difficult to predict. For marine installations, consideration should be given to installing and monitoring a small test screen early in the design process. Accordingly, in-river pilot testing was performed at the Station during the summer of 2017 (Reference 12.5). While the levels of redundancy have already been discussed, frequency for diver cleaning and inspection would be determined based on either a small-scale study or through operating experience. Lessons learned from the Unit 1 screen installation and operation would be used to better inform the maintenance schedule for the Unit 2 screens. Regardless of the effectiveness of the ABS or presence of screen blockage, occasional diver inspections would be required to verify the integrity and functionality of the wedgewire screen system. The project schedule and cost estimate includes monitoring of the Unit 1 installation for approximately one year prior to the installation of Unit 2.

4.3 Procurement and Construction Schedule

Procurement and construction would begin once both the detailed design and all necessary permits are finalized. The amount of time required for permitting is not included in this schedule; however, the permitting costs are included in the cost estimate. Unit 1 system procurement and installation would be performed in Year 1. That system would be tested and monitored for the remainder of the year; lessons learned would be applied to the procurement and installation of the Unit 2 system. Unforeseen disturbances (e.g., weather conditions, river conditions, construction errors) could result in an extension to the conceptual construction schedule. The construction phase includes the following activities:

- Unit 1 mobilization and general site modifications (~1 week)
    - Placement of construction trailers and construction site layout including temporary power
    - Marking and protecting construction area
- Unit 1 construction activities (~7 weeks)
    - Dredging and Backfilling
    - Onshore Concrete Precasting for Slabs and Plenum Walls
    - Installation of Precasted Slabs and Walls
    - Riprap placement
    - Installation of pipe extensions
    - Installation of ABS pipe system and valves
    - Installation of wedgewire half-screens
    - Commissioning of installed equipment, including inspection of equipment for compliance with design requirements and basic testing
    - Start-up of system with river water
    - Validation of system

- Unit 1 Demobilization (~1 week)

For the remainder of Year 1, the Unit 1 system would be monitored and tested for performance and debris accumulation over all seasons. The data gathered in this period would inform the construction of the Unit 2 system to commence in Year 2:

- Unit 2 mobilization and general site modifications (~1 week)
    - Placement of construction trailers and construction site layout including temporary power
    - Marking and protecting construction area
- Unit 2 construction activities (~7 weeks)
    - Dredging and Backfilling
    - Onshore Concrete Precasting for Slabs and Plenum Walls
    - Installation of Precasted Slabs and Walls
    - Riprap placement
    - Installation of pipe extensions
    - Installation of ABS pipe system and valves
    - Installation of wedgewire half-screens
    - Commissioning of installed equipment, including inspection of equipment for compliance with design requirements and basic testing
    - Start-up of system with river water

  - Validation of system

- Unit 2 Demobilization (~1 week)

A procurement and construction schedule is provided as Attachment 3 to this document. The total duration of the project is 70 weeks or 1.35 years.

4.4 Cost Estimate

4.4.1 Capital Costs

A cost estimate for the implementation of wedgewire half-screens at the Station was developed and is presented in Attachment 2. This cost estimate is an ASTM E2516-11 Class 5 cost estimate (Reference 12.34), which is a high-level estimate that is intended for use in screening and feasibility determinations.

The total recommended construction budget for the implementation of wedgewire half-screens at Unit 1 and Unit 2 is $3,578,000 and $5,400,000, respectively, based upon 2017 U.S. dollars. In addition to the construction costs, the permitting and engineering cost estimate for both units is $1,077,000 based upon 2017 U.S. dollars. Vendor quotes, construction estimation tools and previous project experience are utilized for this estimate. The costs considered are primarily localized for the northeast region of the United States, specifically Manchester, New Hampshire, which is aimed to increase the accuracy of the estimation. The consulting engineering budget does not include geotechnical studies/data collection, engineering field support during construction, or the cost of PSNH's staff support of the project.

Attachment 2 shows an itemized cost estimate which has tabulated categories of procurement, implementation, contingencies, permitting, and construction management costs. Sources for each cost estimate are also included within the table. The items that affect the total cost the most for this option are:

- Wedgewire screens
- Hydraulic sluice gates
- Precast concrete plenum construction

Some information associated with the cost of implementation of the wedgewire screen design such as field conditions, structural design requirements, material selection, and construction schedule demands have yet to be determined. Certain costs have been estimated with assumptions that are aimed to be accurate but remain uncertain, such as:

- Crane type/size, barge size, and rental time
- Material selection for hydraulic sluicegates and piping
- Mobilization and equipment transportation costs
- Piping size
- Specialized equipment and materials required
- Availability of space to house ABS equipment
- Availability of space for onshore concrete precasting

4.4.2 Parasitic Losses and O&M Costs

The parasitic losses associated with the implementation of wedgewire half-screens at the Station would consist of the power required for operating the ABS used to clean the screens. These parasitic losses are estimated based on the assumption that a 75 hp compressor is used that runs 24 hours per day from April 1st through July 31st and once a week for four hours from August 1st through March 31st. Under this operating scenario, the annual power required to operate the ABS is calculated to be 172 MW-hr, as shown below.

$$\left[\left(24\ \frac{hours}{day} * 122\ days * 75\ hp\right) + \left(4\ \frac{hours}{week} * 35\ weeks * 75\ hp\right)\right] * \frac{0.0007457\ MW}{1\ hp} = 172\ MW - hr$$

The wedgewire half-screens would have relatively minimal operation and maintenance (O&M) requirements. These requirements would include ABS inspections and operation, inspections and operations of the butterfly valves, and inspections and cleaning of the wedgewire screens. It is estimated that approximately 495 man-hours would be required annually for these O&M activities. The development of this man-hour estimate is presented in detail in Table 2-3 of Reference 12.8. This estimate is for preventative/routine maintenance only and does not include repair or replacement time.

The United States Bureau of Labor Statistics provides periodic reports on the cost of labor across the country. The most recent such report at the time of this assessment was released September 8, 2017. This document reported a national average hours cost to employer of $62.13 for private sector employees working in utilities (Reference 12.29, Table 10). Based on the city cost factor for Manchester, NH from RS Means, this rate is multiplied by 0.956 to account for geographic differences in local labor rates. Therefore, an adjusted rate of

$59.40 is used. Using this rate, the total annualized O&M costs for wedgewire half-screens is estimated to be $29,400, in 2017 dollars.

An additional O&M cost that should be considered is the replacement cost of the air compressor used for the ABS. The useful life of the air compressor for the ABS is expected to be 20 years (Reference 12.30). Therefore, after 20 years of operation, a cost of $38,900, in 2017 dollars, should be included to account for the replacement of the air compressor (Reference 12.31).

No power losses due to new condenser operating parameters or water treatment costs are anticipated for the operation of wedgewire half-screens at the Station.

4.5 Conclusion

The 2014 Assessment preemptively evaluated several entrainment reduction technologies for viability at the Station. Industry experience and design efforts conducted since 2012 have led to the conclusion that wedgewire half-screens are a viable and compatible technology for the Station.

A high-level conceptual design description was presented for wedgewire half-screen implementation at the Station, demonstrating that the technology provides significant entrainment benefits at a greatly reduced cost. A cost estimate and construction schedule have been developed from this conceptual design.

5 Information from CWW Testing Relevant to Engineering Design

5.1 EPA's Statement of Substantial New Questions

EPA's Statement discusses the potential implementation of wedgewire screens to satisfy CWA §316(b) requirements:

> *In light of the information discussed above, cylindrical wedgewire screen technology appears potentially capable of reducing entrainment at Merrimack Station to a greater degree than previously estimated. In addition, previous logistical and engineering (e.g., low water depths, interference with public uses of the river by a large screen array) may be surmountable. Taking these considerations into account, together with the fact that cylindrical wedgewire screen technology is much less costly than closed-cycle cooling, EPA is now reevaluating whether wedgewire screens should be EPA's preferred BTA technology for controlling entrainment at Merrimack Station in light of the costs and benefits of the options.*

Additionally, EPA noted that PSNH performed pilot testing during the spring/summer of 2017, and invited submission of the test results for consideration:

> *Finally, EPA notes that PSNH has informed the Agency that the Company intends to do on-site pilot testing during the spring/summer of 2017 to investigate the efficacy of cylindrical wedgewire screen technology at Merrimack Station. ... While this testing is not being required by EPA, the Agency welcomes submission of the data by PSNH as soon as it becomes available. If timely submitted, EPA would expect to carefully consider such data.*

5.2 Engineering Response

On-site pilot testing of wedgewire screens was successfully performed at the Station during the summer of 2017 (May 15th-August 28th) (Reference 12.5). The goal of the pilot testing was to characterize the river conditions at the plant intake and quantify the entrainment reduction, if the full scale wedgewire half-screen design were to be implemented at the Station. Pilot testing required both identifying those critical engineering attributes which will maintain similarity between the 12-inch diameter pilot cylindrical wedgewire screen and 96-inch diameter full scale wedgewire half-screens, as well as ensuring that operation of the Station intake during pilot testing did not influence the testing results. Following completion of the testing, the results and lessons learned from pilot testing informed modification of the previously submitted conceptual, full scale design. The updated full-scale design is provided in Section 4.

Certain critical engineering attributes were identified during the design of the wedgewire screen pilot testing as required to maintain similarity between the pilot and full scale testing designs to ensure the pilot testing results were representative of the full scale wedgewire screen design. These attributes included the material of construction of the screens, location of the screens relative to the intake, centerline elevations of the screens within the river, the hydraulic flow-patterns along the screens (angle of deflection and angle of separation), the screen slot widths, and the through-slot velocities of the screens (Reference 12.13).

To minimize the effects of biofouling, the 12-inch diameter pilot CWW screen was constructed of Z-Alloy. This is consistent with the full scale half-screen design, which also includes screens constructed of Z-Alloy. In underwater environments, Z-Alloy has been shown to be substantially better at resisting biofouling and corrosion when compared to stainless steel (Reference 12.12, Page 6). Constructing the pilot screen of Z-Alloy allowed for a confirmatory study of the expected effects of biofouling on the full scale wedgewire screen designs and helped to inform the design of the ABS currently included within the design of the full scale 96-inch diameter screens. The pilot screen was not equipped with an ABS system, and as such, any biofouling of the pilot screen substantially overestimated the expected biofouling of the full scale wedgewire screens (Reference 12.13, Page 9).

As seen in Figure 4 and Figure 5, the pilot CWW screen was installed within the vicinity of the Unit 1 intake. Care was taken to ensure that the screen was installed at a distance from the shore that was outside the estimated hydraulic zone of influence of the intake and discharge. Additionally, a custom tripod support system was developed for the pilot screen such that the centerline elevation of the pilot screens matched the expected elevation of the centroid[2] of the half-screens within the water column. Proper positioning of the pilot screens helped maintain hydraulic similarity between the pilot screen and full screen design while ensuring that the operation of the intake and discharge didn’t influence the testing results (Reference 12.13, Attachment 1).

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[2] A centroid is the arithmetic mean position of all the points in a given shape. It can be thought of as the point at which a cutout of the shape could be perfectly balanced on the tip of a pin.

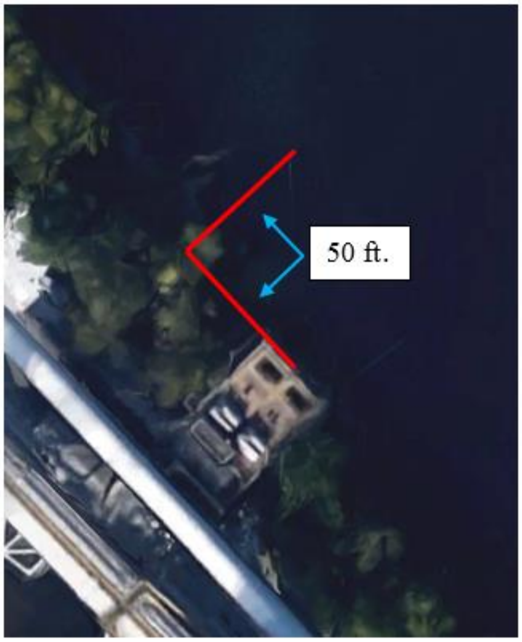

Figure 4 – Position of Test Screen in Merrimack River Relative to Intake

Figure 5 **– Photo of Pilot Test Screen Installation in Merrimack River**

For the in-river testing, it was essential to provide similar hydraulic flow-patterns around the test screen as would be experienced around the full scale half-screens so the entrainment reduction results of the pilot screen could be applied to the full scale design. This was achieved through similarity in the design of the nose cone angles on both the pilot test screen and full scale screens which provided very similar boundary layer flow properties along the lengths of both screens and similar upstream river flow disturbance patterns (Reference 12.13, Attachment 1).

Lastly, the screen slot widths and through-slot velocities of both the test screen and the full scale design were matched at 3 mm and 0.4 fps, respectively. This further ensured that the hydrodynamic and entrainment reduction results of the pilot test screen are applicable to full scale screens (Reference 12.13, Page 8).

Once the critical engineering parameters were developed, the pilot test screen was selected, and the testing procedures were developed. Testing was then performed to characterize the river conditions at the plant intake and quantify the expected full scale wedgewire half-screen performance.

Testing of the river conditions at the plant intake included characterization of the river bed near the plant intake and measurement of the river flow direction and flow velocity. In general, the river bed was observed to consist of loose sand with large sand dunes (up to 2 feet tall, spaced approximately 2 feet to 3 feet apart) periodically developing on the river bed and observed to move throughout the river during periods of high flow. River flow direction was consistent throughout testing with the sweeping flow vector components accounting for greater than 98%

of the observed current velocity. Lastly, river flow velocity was measured at greater than 0.5 fps for almost the entirety of testing. Given the design through slot-velocity of 0.4 fps, this indicates expected normal sweeping flow ratios in excess of 2:1.

Wedgewire screen performance was evaluated through comparison of the entrainment results of the pilot test screen to those of a control sample taken from the current plant intake. Additionally, the susceptibility of the wedgewire screen design to flow blockage due to either large debris or biological fouling was noted through observation.

The overall reduction in entrainment of all ichthyoplankton and life stages due to the operation of the pilot test screen was 89% when compared to the control samples taken from the current plant intake. Entrainment of all life stages was reduced in comparison to the control samples except the egg life stage, which increased but remained low (0.13 eggs/1000 m^3 in the pilot test screen samples compared 0.1 eggs/1000 m^3 in the control samples) (Reference 12.5, Page 11). Additionally as seen in Figure 6, Figure 7, and Figure 8, no significant biofouling was observed on the pilot CWW screen, confirming that the Z-Alloy material mitigates the effects of biofouling on the wedgewire screen.

In one instance, the test screen was partially blocked due to large surface-area debris. However, this debris was successfully removed by backflushing of the pilot screen. As the process of backflushing is hydraulically similar to the ABS system included within the full scale half-screen design, successful removal of the large debris through backflushing of the pilot screen supports use of the ABS system to mitigate the effects of large surface-area debris blockage on the full scale design.

Figure 6 – Post-Test Photo of Entire 12-inch Pilot Test Screen Assembly[3]

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[3] Note that the screen's support legs were constructed out of stainless steel, rather than Z-Alloy

Figure 7 – Post-Test Photo of Upstream Portion of Pilot Test Screen

Figure 8 – Post-Test Photo of Downstream Portion of Pilot Test Screen

These testing results indicate that a significant reduction in entrainment is expected with installation of the full scale wedgewire half-screens at the Station. Also, blockage of the screens (which could lead to head loss and/or screen structural issues) due to either biofouling or large-scale debris is expected to be successfully mitigated by the Z-Alloy screen and inclusion of the ABS.

Lessons learned from the testing of the pilot screen are being applied to the design of the full scale half-screens. Due to the sandy, undulating river bottom, a concrete base is being designed for each half-screen to provide support along the river bed. Periodic dredging may be required to ensure that sand dunes do not build up along the upstream edges of the screens. Secondly, while the ABS is expected to sufficiently clean the screens during operation, upstream bollards (as shown in Attachment 1) are being designed to be implemented during periods when the screens are not in operation to provide structural protection and prevent large debris from settling on/near the screens. These bollards are being designed to be removed during periods of operation to not affect the hydrodynamic performance of the screens. Thirdly, the Station intends to purchase one additional full scale half-screen to store on-site for maintenance replacement of the screens.

The Station plans to install the Unit 1 screens one year ahead of the Unit 2 screens and apply the lessons learned during implementation of the Unit 1 screens to improve and optimize the Unit 2 installation. Lessons learned are expected to include the following items: installation techniques and efficiencies, operation of the ABS and upstream bollards to mitigate large surface-area debris accumulation, and maintenance processes for mitigation of upstream river bed sand accumulation.

6 Response to Questions Regarding Implementation and Operation of Wedgewire Screens

6.1 EPA's Statement of Substantial New Questions

EPA's Statement provides an invitation for public comments on a variety of items regarding the potential implementation of wedgewire screens at Merrimack:

> *EPA invites public comment on all of the issues and information concerning cylindrical wedgewire screens discussed in the paragraphs above, including the following:*
>
> - *the extent to which wedgewire screens with different screen slot sizes can prevent mortality to aquatic life from entrainment and/or impingement and satisfy the BTA requirements of CWA § 316(b);*
> - *the likely expense of using wedgewire screens at Merrimack station;*
> - *if wedgewire screens are the BTA, or part of the BTA, at Merrimack Station, should wedgewire half-screens or standard wedgewire screens be used;*
> - *how the costs of using wedgewire screens compare to the benefits of using them, and how those costs and benefits compare to the costs and benefits of using closed-cycle cooling as part of the BTA;*
> - *which months (e.g. April 1 through August 31, April 1 through July 31), if any, should wedgewire screens be implemented as the BTA for controlling entrainment; and*

- *whether Merrimack Station should be permitted to bypass the screens and if so, under what circumstances should this be allowed.*

6.2 Engineering Response

Wedgewire screens are a viable technology that should be part of the BTA discussion with respect to requirements of CWA § 316(b). A review of the historical use and effectiveness of the wedgewire half-screen led to a conceptual design to implement screens for both Unit 1 and Unit 2. Operation of the wedgewire half-screens only during the season of peak-entrainment would reduce risk of damage to the half-screens, maintain effectiveness of the half-screens, reduce operation costs and increase lifetime of the half-screens. The conceptual design includes a screen bypass for use when the screens are inoperable.

6.2.1 Effectiveness of Wedgewire Screen Slot Size

Normandeau produced a memorandum discussing how cylindrical wedgewire screens reduce entrainment via physical exclusion, behavioral avoidance, and hydraulic bypass, which is provided as Attachment 1 to the Wedgewire Half Screen Technical Memorandum from December 2016 (Reference 12.6). The memorandum reviews laboratory testing of wedgewire screens. The purpose of the testing was to determine the impact of slot size, flume (sweeping) velocity, and through-slot velocity on entrainment efficiency for cylindrical wedgewire screens. The slot sizes tested were between 2-mm and 9-mm.

The screens were placed in controlled flumes of water. More than 4,600 individual tests were conducted using 450,000 fish larvae and a similar number of 1-mm buoyant beads (i.e., artificial larvae). The water carried the larvae and beads over and through the screens and the percent entrained was observed. Behavioral avoidance was observed to be higher for the two smaller slot widths (2 mm and 3 mm), with a negligible difference between either smaller slot width. Normandeau summarized the analysis of the results by stating (Reference 12.6, Attachment 1):

> "Overall, avoidance and hydraulic bypass were higher at higher ratios of sweeping velocity to through-slot velocity, with typically 80% or more of the larvae 12 mm in total length or larger capable of actively swimming to avoid entrainment at a ratio of sweeping velocity to through-slot velocity greater than 1:1."

Therefore, a 3-mm slot width is adopted for the conceptual design (see Section 4.2.2) as this allows for the low through-slot velocity in order to promote behavioral avoidance. In addition, selecting the slightly larger slot width would also reduce the potential for biofouling and debris accumulation, which could result in blockage of the screen.

When the testing was performed in the Hudson River estuary, results of nearly 78% entrainment reduction were observed, confirming the laboratory results. Small scale testing at the Station has confirmed even more effective entrainment reduction (~89% using a 3-mm slot width and a through-slot velocity of 0.4 fps).

Since the impingement rate at the Station is shown to be *de minimis* per the Normandeau evaluation contained in the 2014 Assessment (Reference 12.10), impingement requirements are not reviewed with respect to wedgewire screens. The classification of *de minimis* is strengthened by the periodic use of wedgewire screens with an approach velocity less than

0.5 fps since the behavioral action of the aquatic species becomes a factor in reducing impingement further below *de minimis*.

6.2.2 Expense of Wedgewire Screens

ENERCON prepared a cost estimate for design, implementation and operation of the screens for use in an economic evaluation of entrainment technologies (see Section 4.4 and Attachment 2). Note that all values provided in this section are in 2017 dollars. The construction costs for implementing wedgewire half-screens at Unit 1 and Unit 2 are estimated to be $3,578,000 and $5,400,000, respectively. The permitting and engineering costs for implementing wedgewire half-screens at the Station are estimated to be a total of $1,077,000 for the two units. The parasitic losses associated with the operation of wedgewire half-screens are estimated to be 172 MW-hr per year, and the total annual O&M costs for wedgewire half-screens are estimated to be $29,400. A one-time cost of $38,900 is anticipated to replace the ABS air compressor based on its expected lifetime of 20 years. The expected useful life of the wedgewire half-screens is 30 years.

ENERCON prepared	**Unit 1**	**Unit 2**
Permitting/Engineering	$1,077,000	
Implementation	$3,578,000	$5,400,000
Parasitic Loss	172 MW-hr per year	
Operation & Maintenance	$29,400 per year	
Compressor Replacement	$38,900	

For further description of the half-screen design as well as the details for how the above costs were calculated, refer to Section 4.4 and Attachment 2.

6.2.3 Wedgewire Half-screens versus Cylindrical Wedgewire Screens

Selection of Wedgewire half-screens in the conceptual design is discussed in Section 4.1. Comparison of half-screens to cylindrical screens is elaborated further in this section.

As described in Section 4.2.1, key factors to screen performance are orientation and water velocity. When the screen is oriented with its longest dimension parallel to the direction of prevailing flow, hydraulic bypass is achieved, where aquatic life is carried past the screen by the sweeping flow. In addition, the velocity towards the screen is quickly dissipated due to the round shape of the screen, further impeding entrainment of aquatic life.

As discussed previously, a 1:1 ratio of sweeping velocity (water moving past the screen) to through-slot velocity (water moving through the screen slots) has been shown to be effective at reducing entrainment (Attachment 1 of Reference 12.6). Through-slot velocity correlates to screen surface area, where lower velocities are achieved with larger surface areas. Once the sweeping velocity is established through data collection, a minimum screen surface area is determined to maintain the 1:1 ratio of velocities.

Cylindrical wedgewire screens have a cylindrical shape that require clearance above and below the screen so that intake water may be drawn into the screen and the full surface area of the screen is utilized for entrainment avoidance. The sum of the screen diameter and minimum clearances above and below the screen dictate a minimum water depth required for proper operation. Due to the required clearances above and below the screen, use of this screen design is challenging in shallow waters. Since the screen diameter determines the minimum required clearance, shallow water operation of cylindrical screens is typically achieved by using smaller diameter screens and increasing the total number of screens to maintain the minimum required screen surface area. With an average depth of eight feet in the Hooksett Pool of the Station, preliminary designs using standard wedgewire screens would require up to 76 standard screens (Reference 12.8).

As a variant on their cylindrical screen design, Johnson Screens developed a Half Intake Screen System. This design has been installed and used for various applications starting in 2012. The use of a half-screen wedgewire at the Station was validated through a confirmatory study conducted during the 13-week entrainment period of 2017 (see Section 5.2). A 3-mm slot width screen representative of the 96-inch full scale screens was installed at the Station and samples were periodically collected for counted entrapped eggs and larvae. The collected sample counts were compared to the Unit 1 intake entrainment data to determine an overall entrainment reduction of ~89%.

The selection of half-screens allows for an increase in diameter of the wedgewire screen, which increases the surface area of each install screen. The increase in diameter is realized because the screen sits on a concrete pad, which eliminates the below screen clearance requirement. Since each half-screen has a larger surface area than the cylindrical screen, the total number of screens can be reduced to seven (two for Unit 1 and five for Unit 2). This significant decrease in the number of screens reduces environmental impact during implementation of the design. The half-screen method would also have minimal interference to public recreation of the river.

In comparison of two entrainment reduction technology options between cylindrical wedgewire screens and wedgewire half-screens, it is clear that wedgewire half-screens are the better suited type of wedgewire screen to use at the Station given the site-specific parameters. The half-screens were shown to be effective, would cost less to install and maintain (since fewer screens are necessary to achieve the same screen surface area), and the half-screens would have less environmental impact during installation and minimal influence on public use of the river.

6.2.4 Months of Operation

In 2007, Normandeau Associates issued a report that determined 97% of the annual entrainment at the Station was observed to occur between mid-May to early August (Reference 12.9). The report spanned a two-year observation period of samples taken from intake water. The samples were analyzed to identify the variation of species, developmental stage of each identified species and quantity of each identified species. To cover the peak entrainment period, the screens should be in operation between April 1st and July 31st. This time frame would cover approximately 95% of the entrained species discussed in the 2007 Normandeau report.

The primary reason for operating the site with wedgewire screens during part of the year is to limit unnecessary exposure of the screens to potentially damaging objects. The current design for the screens recommends the placement of bollards around the screens when they are not in use to reduce the risk of damage from objects (e.g., submerged tree limbs, refuse, other waterborne debris, etc.) that are travelling downstream on the river currents.

Submerged debris can collide with the screens, damaging and altering the form of the screen and/or hampering the ability of the screen to operate properly. An alteration to the shape of the screen could decrease the velocity ratio, decrease the hydraulic bypass, and/or alter the slot size of individual slots. Any of these alterations would decrease the effectiveness of the screens' ability to reduce entrainment.

While the screens are not in operation, bollards placed around the screens would keep them protected from river borne objects. The Station would employ divers to remove the protective bollards and perform inspections/repairs prior to the season of operation. Removal of the bollards helps to maintain the hydraulic flow around the screens while they are in operation. The screens would then be placed into operation during the peak entrainment season. At the end of the operation season, divers would return the protective bollards to the screens and the intake bypass system would be employed, effectively removing the screens from operation.

Operation of the screens is recommended from April 1st to July 31st to provide an effective reduction in entrainment while limiting the unnecessary exposure of the screens to potentially damaging objects. The remaining months of the year when entrainment is at a minimum, the screens would be inoperative and protected (by installation of the bollards) to minimize risk of damage to the screens.

6.2.5 Screen Bypass

To maintain operability for the plant when the screens are protected by bollards and not in operation, a bypass system is included in the conceptual design. The same bypass system could be used in the event of a significant screen blockage when the screens are in operation.

For each units' intake system, two bypass gates would be installed that provide an alternate source of circulating water. These bypass gates would be open during periods when entrainment is not of concern and the screens are not operated, as well as if the wedgewire half-screens were to become blocked during screen operation. A low water level alarm initiation in the intake bay would trigger the bypass system into operation. This would prevent a large pressure differential from building up across the blocked screens, reducing the potential for screen damage due to blockage. These bypass gates would be required during times of the year when the screens are not in operation, such as during the winter months when screen damaging frazil ice formation in the river can occur.

Blockage as a result of biofouling is not expected to occur since the material of the half-screens is a proprietary Z-alloy, a copper-nickel based alloy (Reference 12.12). Blockage is more likely to occur from low mass objects becoming fixed on the surface of the screen because of intake suction (e.g., plastic bags).

Since the design through-slot velocity is approximately 0.4 fps, screen blockage is not expected to become an issue for screen operation. A small amount of screen blockage that causes the through-slot velocity to increase above 0.4 fps is not a concern if the ratio of sweeping flow to through-slot velocity is maintained at 1:1 or greater during screen operation.

With respect to hydraulic loss in the intake system, blockage could become a concern if it were to induce excessive head loss across the screen. Therefore, each screen would be equipped with an ABS, which uses periodic bursts of compressed air to blow accumulated objects from the screens, preventing excessive blockage from accumulating over time. This system would also serve to reduce the amount of maintenance required for the screens due to blockage.

To permit plant operability during the time the wedgewire screens are not in operation due to the planned operation schedule or due to a blockage event, the bypass system would be installed to protect the screens from potential damage and minimize maintenance and wear-and-tear costs.

6.2.6 Conclusion

A study case using a representative model of a half-screen in-situ at the Station clearly showed the entrainment reduction capability of the half-screen. The conceptual design shows only a handful of screens are required for operation during the season of peak-entrainment. This defined operational window would reduce risk of damage to the half-screens while maintaining effectiveness of entrainment reduction. The conceptual design includes a screen bypass for use when the screens are not in operation or blocked.

7 Response to Proposed Compliance Schedules

7.1 EPA's Statement of Substantial New Questions

EPA's Statement provides discussion regarding potential compliance schedules for both closed-cycle cooling and wedgewire screens, and invited public comments on the proposed schedules:

> *Now that a compliance schedule may be included in the NPDES permit for steps to comply with CWA § 316(b), EPA is proposing below two potential compliance schedules, one for a BTA based on closed-cycle cooling, and one for a BTA based on wedgewire screens. While EPA believes these schedules provide reasonable timelines for installing the technologies in question at the Facility, EPA invites public comments regarding whether or not the Merrimack Station permit should include a compliance schedule for measures to comply with CWA § 316(b) and what the terms of any such schedule should be. Such comments could range from suggesting adjustments or modifications to the schedules EPA proposes here, to proposing an entirely different compliance schedule.*

7.2 Engineering Response

Under the 2014 CWA § 316(b) Regulations, EPA decided that compliance schedules for installation of cooling water intake structure improvements to meet new permit requirements may be included in the NPDES permit. The regulations call for such compliance schedules to require compliance *as soon as practicable* with entrainment and impingement requirements under 40 C.F.R §§ 125.94(c) and (d), but also directs that permitting agencies should consider the potential effects of such compliance schedules on local electrical service. As such, a compliance schedule may be included in the permit, but should be both realistic and reasonable given the conditions of the Station and local electric grid.

EPA has previously proposed two compliance schedules for the Station; one for compliance based on closed-cycle cooling, and another for compliance based on CWW screens. These proposed compliance schedules were developed by EPA based on past compliance schedules at other, similar plants as well as some preliminary cost estimation data provided by the Station for implementation of closed-cycle cooling and CWW screens. However, these compliance schedules should be revised before being included in any NPDES permit due to the following factors: use of preliminary cost estimating schedules provided by the Station, implementation of a significant modification of the Station which requires revision of the preliminary closed-cycle cooling design, revision of the preliminary CWW screen design to a design based on wedgewire half-screen technology, and the recently announced change in Station ownership.

The conceptual planning schedules provided by the Station were not developed as best estimates of a realistic, practicable compliance schedule. Instead, these schedules were developed to help provide a conceptual estimate of the construction costs (labor, materials, and outage costs). Additionally, the outage duration estimated for implementation of the closed-cycle cooling system represented a best-case construction scenario which could be extended considerably due to emergent issues and/or weather-based delays (Reference 12.4, Attachment 7 and Reference 12.8, Page 2). These conceptual planning schedules should be revised to include more detailed design information before being used as input for determining the compliance schedule. See

Section 10 for additional discussion of the discrepancies between conceptual and actual costing and scheduling.

Since the conceptual design was provided for closed-cycle cooling in 2007, the construction of a new FGD system has taken place at the Station that is now occupying space assumed to be available for routing new piping in the conceptual closed-cycle cooling design. As such, these piping routes may no longer be viable, and the conceptual design (including costing and scheduling) needs to be reviewed because of this modification to assess its viability. See Section 10 for additional discussion of the installation of the new wet flue gas desulphurization system.

Also, the compliance schedule for implementation of wedgewire screens at the Station was based on full CWW screens. However, the current wedgewire screen design at the Station is being developed based on wedgewire half-screens. The planning schedule for the CWW screens should be updated to reflect the wedgewire half-screen design and incorporate the lessons learned from pilot testing, which include: installation of concrete bases along the river bed to mitigate sand accumulation, installation of upstream bollards for large-scale debris mitigation, revised fabrication timelines from the screen manufacturer, and staggered implementation between Unit 1 and Unit 2 to incorporate lessons learned during implementation. See Section 5 for more discussion of the pilot testing.

Finally, the Station is currently undergoing the last stages of a divestiture process. This process introduces a significant amount of uncertainty at the Station and would need to be considered as part of any final compliance schedule.

8 Summary of Thermal Plume CFD Analysis

8.1 EPA's Statement of Substantial New Questions

EPA's Statement includes discussion on the presence of the Asian clam in the Hooksett Pool, and invited public comment to address the information presented:

> *EPA invites public comments addressing the information discussed above indicating the presence of the Asian clam in the Hooksett Pool, as well as comments addressing the import of this information for setting thermal discharge limits for the Merrimack Station permit under CWA § 316(a) and/or New Hampshire water quality standards. (As stated previously, EPA extensively discussed the requirements of CWA § 316(a) and New Hampshire water quality standards related to thermal conditions in Chapters 4 and 8 of the 2011 Draft Permit Determinations).*

8.2 Engineering Response

To support a biological evaluation of the Asian clam in Hooksett Pool by AST Environmental by characterizing the extent of the thermal plume at sampling station S4 during various winter months of interest, a computational fluid dynamics (CFD) model was developed, and the results of this model are presented in ENERCON's CFD Thermal Plume Modeling Technical Report (Attachment 5).

Computational fluid dynamics uses numerical analysis of the governing equations of fluid dynamics – mass, momentum, and energy balance – to simulate the interaction of liquids and gases with surfaces defined by boundary conditions. The CFD analysis included four different cases which characterized the thermal plume in the Merrimack River with the plant operating at design conditions (i.e., both units operating at full-rated power) for the winter months (i.e., December, January, February and March). The purpose of the thermal plume characterization is to act as a screening tool that can be used in the biological evaluation provided by AST Environmental (Reference 12.20) to determine if further analysis for any of the cases is required.

As described in detail in Attachment 5, the ambient river temperature, discharge flow rate, and discharge temperature remained the same for all the CFD cases. These parameters remained constant in order to model a "plant on" scenario, with both units operating at full design conditions, for each winter month of interest. The parameters that were changed from case to case were the ambient river flow rate, ambient air temperature, and wind speed and direction.

The CFD model showed that the ambient river flow rate was the largest driver in the differences among the results of the four cases. For the two cases with relatively high ambient river flows (December and March), the river flow had the effect of "pulling" the plume downstream, creating a relatively thin plume that was attached to the western bank. The mixing was dominated by the river flow, rather than buoyancy effects created by the temperature differential, resulting in a very well mixed plume with little stratification in the water column. By comparison, February, which had an ambient river flow of less than half the March river flow, the temperature-driven buoyancy effects played a larger role in the mixing of the plume, creating a more distinct stratification in the water column. This stratification showed the warmer, less dense portion of the plume rising towards the river surface.

For all cases, the thermal plume was found to be narrower at the river bottom than it was at the water surface and was attached to the western bank of the river. The results presented in Attachment 5 demonstrate that the portion of the plume warmer than 2°C at the river bed ranged from approximately 178 feet to 214 feet from the western bank, depending on the case. For all cases, the portion of the plume at the riverbed was less than or equal to 2°C by the time the water reached the central S4 clam sampling location, which is 246 feet from the western bank (Attachment 5).

A more detailed discussion of the CFD modeling results as well as the inputs and assumptions used to create the model is provided in the CFD Thermal Plume Modeling Technical Report (Attachment 5).

9 Discussion on Seasonal Use of Cooling Towers

9.1 EPA's Statement of Substantial New Questions

EPA's Statement reiterates that EPA expects the use of technology for controlling entrainment would only be required for a portion of the year. This entrainment-based requirement would be applicable to whichever technology is determined to be the BTA, including both closed-cycle cooling and wedgewire screens.

> *Also, to be clear, given that entrainment is expected to be a minor issue from September 1 to March 31, a new BTA determination favoring wedgewire screens would only require use of the technology for controlling entrainment from April 1 to August 31, just as the BTA proposed for the 2011 Draft Permit only required closed-cycle cooling to control entrainment during that period.*

9.2 Engineering Response

While it is expected that entrainment control at the Station would only be required from April 1st to July 31st (See Section 6.2.4), implementation of a closed-cycle cooling system using cooling towers that operate year-round would be a permanent redesign of the Station that presents numerous risks, challenges, and costs to the plant in periods (i.e. from August 1st to March 31st) where there may be neither a requirement for nor benefit from entrainment control. The Station is primarily operated during periods of peak power demand (summer/winter), and these aforementioned risks, challenges, and costs are driven by frequent startup and shutdown of the plant, particularly during freezing conditions (Reference 12.14, Page 21).

Icing is a primary concern for cooling tower systems operating in freezing conditions, particularly those with frequent startups and shutdowns. Excessive icing can be mitigated through proper maintenance of the cooling tower system; however, final mitigative measures are often left to operator action. Of the mechanical draft designs, induced draft cooling towers are more capable of mitigating icing concerns than forced draft designs; this is largely because induced draft designs inherently pass heated air over the mechanical components, reducing their icing risk (Reference 12.15, Page 7). However, even induced draft cooling towers can build unacceptable levels of ice within the tower, beginning with air inlet louvers and heat transfer fill. This ice build-up can challenge the structural design of the cooling tower if appropriate and timely operator action is not taken to mitigate the icing effect. This presents a significant risk and challenge to the operators and additional costs to the plant (Reference 12.15).

Frequent plant startups and shutdowns during freezing conditions only further complicate and increase the icing risk. During shutdown periods, the cooling tower system would need to be winterized to address the risk of complete freezing of the water basin. Winterization could be accomplished through a number of options including full system draining, installation of a bypass system to ensure that basin water does not stagnate, or installation of a basin heating system. However, these options add additional engineering design costs, construction/maintenance costs, and/or required additional operator actions at the Station for a period when there is no requirement for entrainment control (Reference 12.16, Pages 6-7).

In addition to icing of the cooling tower itself, additional concerns exist for fogging and icing of the surrounding area due to the cooling tower plume. The persistency of cooling tower plumes is typically much greater in the winter due to the decreased air temperature and air moisture capacity. Plumes can present visibility issues downwind of the tower due to fogging and localized freezing/icing concerns as entrained water freezes out of the air onto roads, powerlines, and other equipment.

Lastly, there are other maintenance, reliability, and safety issues associated with frequent cooling tower startups and shutdowns, regardless of the concurrent weather. Transients are introduced during each startup and shutdown of the cooling tower equipment which may subject the equipment to excessive mechanical vibration which can degrade plant equipment and present additional maintenance and capital costs for the plant (Reference 12.17, Page ii). Under freezing conditions, ice that has formed on the cooling tower fan blades can be thrown through the air for several minutes upon startup, creating the potential for damage to the surrounding equipment. Additionally, deposits and bacterial growth that form during periods of inactivity must be monitored and remediated before startup. Left unattended, these deposits and bacterial growths can degrade the cooling tower efficiency, damage plant equipment, and in some cases, endanger the health and safety of the plant employees and public (Reference 12.17, Pages 3, 19, and 26; Reference 12.18, Page 6; Reference 12.19, Pages 2 and 10). Growth of Legionella bacteria is of particular concern with cooling tower operation as Legionella bacteria are ubiquitous in aqueous environments, including the recirculating water of cooling towers. If not properly maintained, all 50 species of Legionella can potentially become pathogenic (Reference 12.18, Page 2). Once again, these maintenance and operator requirements present additional risks, challenges, and costs to the Station which would be incurred throughout the life of the plant, including those periods when there is no requirement for entrainment control.

10 Concerns Regarding the Closed-Cycle Cooling Cost Estimate

In 2007, ENERCON developed a cost estimate for retrofitting the Station with closed-cycle cooling using mechanical draft cooling towers in response to EPA's information request under Section 308 of the Clean Water Act with respect to CWA § 316(b). Cost estimates and implementation schedules were developed for two mechanical draft closed-cycle cooling configurations; one configuration for both units combined and one configuration for each unit individually. The closed-cycle cooling cost estimates provided in the 2007 Response include initial capital costs, costs due to new condenser operating parameters, costs due to parasitic losses, costs due to lost generating capacity during implementation, and O&M and water treatment costs.

Since the development of the closed-cycle cooling cost estimates in 2007, various plant and technological changes have occurred that would significantly impact the estimates. The most significant change at the Station since the 2007 cost estimates were developed is the construction of the new wet FGD system, which was installed to reduce sulfur dioxide and mercury emissions. The construction of the scrubber system was a multi-year project that was completed in late 2011, at a total project cost of approximately $422M. The installation was a very large construction project, and as a result, the available free space on site has been significantly altered from 2007. As such, space that was assumed to be available for new piping additions in the conversion to closed-cycle cooling may no longer be available. A portion of the scrubber system installation is shown in Figure 9 and a photo of the Station after the completion of the Scrubber system is shown in Figure 10 to depict the magnitude of the construction that occurred at the Station.

Figure 9: Construction of the Scrubber System Chimney Foundation[4]

Figure 10: Merrimack Station with the Completed Scrubber System

In addition to reducing the available space on site at the Station, the installation of the scrubber system also demonstrated that significant cost discrepancies can occur between preliminary

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[4] Courtesy of New Hampshire Public Radio, http://nhpr.org/post/psnh-scrubber-investigation-set-forge-ahead

conceptual estimates (like the closed-cycle cooling estimates presented in the 2007 Response) and more detailed engineering design estimates. In 2005, PSNH received a preliminary conceptual estimate of $250M for the construction of a scrubber system at the Station. This estimate was based on the vendor's experience and knowledge of direct costs of existing FGD designs and installations in the United States.

In early 2008, a detailed engineering design estimate for the Station scrubber was provided based on site-specific conditions and known operational challenges as well as highly detailed engineering specifications and preliminary bids from vendors for major components. This second, more detailed estimate was for $457M. A number of factors contributed to the price difference between the two cost estimates including a first-in-the-industry guarantee regarding mercury reductions, certain site-specific constraints not accounted for in the first estimate, and a state law which required PSNH to construct and operate the scrubber system "as soon as possible" to provide early emissions reductions.

The Station scrubber system was successfully brought online in late 2011, well ahead of schedule. The final cost of the project was approximately $422M, an increase of nearly 70% over the preliminary conceptual estimate. These types of costs increases are not limited to just the Station and have been seen at other locations across the country. However, the scrubber installation at the Station does provide an example of the type of cost overruns that are possible for major capital projects. Additionally, there are several other project uncertainties not accounted for in the preliminary conceptual design cost estimate presented in the 2007 Response which could increase the cost estimate, including construction management costs, contractor inexperience costs given the relative uniqueness of converting a once-through cooling system to closed-cycle cooling, permitting costs, and environmental testing and monitoring.

As a result of these considerations, it is determined that the closed-cycle cooling cost estimate provided in the 2007 Response needs to be increased to reflect a more accurate implementation cost. Although the final scrubber system cost was nearly 70% higher than the preliminary conceptual estimate, part of this increase was due to the spike in demand that occurred for scrubber systems, which is not anticipated for cooling towers in the near future. Additionally, the experience that the Station gained from managing the large scrubber system project could be applied to help manage future capital projects more efficiently. Therefore, a cost increase of 30% is applied to the initial capital cost estimate provided in the 2007 Response. This 30% cost increase is the result of the increased site congestion and the insight gained into potential cost overruns for major capital projects at the Station through the installation of the scrubber system as well as various other project uncertainties and items that were not accounted for in the preliminary conceptual design cost estimate. This cost increase does not include escalating the cost to 2017 dollars and only applies to the initial capital costs. All other costs (e.g., O&M costs, costs due to parasitic losses) should be used as presented in the 2007 Response.

11 Conclusion

An engineering evaluation of the EPA's statement of substantial new questions has been presented. The evaluation has provided technical insight to a number of topics, summarized below:

- Previously submitted engineering comments that are still relevant or that required updating as a result of new information are presented. The applicability of wedgewire screens is addressed; clarification on water usage, cost, air emissions, icing/fogging and power generation losses with respect to closed-cycle cooling towers is presented; and O&M challenges to the FGD wastewater treatment system are summarized.
- An updated conceptual design for wedgewire half-screens includes a preliminary layout (Attachment 1) to further refine the conceptual cost estimate (Attachment 2) and construction schedule (Attachment 3). Only seven 3-mm slot size screens are necessary to meet the station's cooling flow requirements while reducing entrainment by nearly 89%.
- The effectiveness of entrainment reduction for wedgewire half-screens used at the Station is validated through a pilot study conducted during the peak entrainment season of 2017. Using a scale-modeled screen operated in the Merrimack River, the study demonstrated significant reduction in entrainment compared to the Station's current entrainment rate and the study provided a number of insights for the conceptual design.
- Specific EPA questions regarding wedgewire screens are addressed. The 3-mm slot size is validated for the screens. A more detailed conceptual design has refined the cost of wedgewire screen implementation and O&M. The evaluation clearly demonstrates the applicability of wedgewire half-screens at Merrimack Station instead of the previously

discussed cylindrical wedgewire screens. The half-screens are better suited for the depth of Hooksett Pool, reducing the number of screens required and the impact of installation. The half-screens would operate from April 1st to July 31st to cover the peak entrainment season in order to limit risk of damage from debris and frazzle ice. Bypass gates are used when the screens are not in operation.

- Compliance schedules for both closed-cycle cooling and wedgewire screens are discussed, taking into consideration the effect on local electrical service and the condition of the Station. As a result of a change in the Station's configuration (addition of FGD system), the closed-cycle cooling schedule is discussed. As a result of the recommendation to use wedgewire half-screens in lieu of cylindrical wedgewire screens, the wedgewire screen schedule is updated.
- A CFD model of the Station's thermal plume demonstrates that for all modeled scenarios, the portion of the plume at the riverbed was less than or equal to 2°C by the time the water reached 246 feet from the western bank, which is in the middle of the central clam sampling location.
- A discussion on the seasonal use of cooling towers demonstrates the added risks and costs with operating the towers during freezing conditions. Frequent startup and shutdown during the winter months would require costly mitigative actions, accelerate the degradation as a result of wear and tear of the cooling towers and increase risk of formed ice becoming a projectile and endangering station personnel and equipment.

- Based on implementation experience from the installation of the Station's scrubber system in 2011, the 2007 Response capital cost estimate for implementing mechanical draft cooling towers is increased by 30%.

12 References

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12.2 United States Environmental Protection Agency (USEPA) Draft NPDES Permit NH 0001465, Draft NPDES Permit for PSNH Merrimack Station, 2011.

12.3 Response to Environmental Protection Agency's Draft NPDES Permit, Enercon Services, Inc., February 2012.

12.4 Response to United States Environmental Protection Agency CWA § 308 Letter, PSNH Merrimack Station Units 1 & 2, PSNH with Enercon Services, Inc. and Normandeau Services, Inc., November 2007.

12.5 Evaluation of the Entrainment Reduction Performance of Wedgewire Screens at Merrimack Station, December 2017, Normandeau Associates, Inc.

12.6 Wedgewire Half Screen Technical Memo, Enercon Services, Inc., December 2016.

12.7 Johnson Surface Water Intake Screens Product Application Guide.

12.8 Supplemental Alternative Technology Evaluation, Enercon Services, Inc., October 2009.

12.9 Entrainment and impingement studies performed at Merrimack Generating Station from June 2005 through June 2007, Normandeau Associates, Inc., October 2007.

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12.15 Technical Paper H-003D, Cooling Towers and Freezing Weather, SPX Cooling Technologies Inc., September 2016.

12.16 Technical Paper TR-015, Cold Weather Operation of Cooling Towers, SPX Cooling Technologies Inc., September, 2016.

12.17 Common Operation & Maintenance Manual, Baltimore Aircoil Company, 2011.

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12.19 ASHRAE Guideline 12-2000, Minimizing the Risk of Legionellosis Associated with Building Water Systems, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 2000.

12.20 Asian clam and Lack of Evidence for Appreciable Harm to the BIP in Hooksett Pool, Merrimack River, New Hampshire, AST Environmental, December 2017.

12.21 Assessment of 2007 Response to United States Environmental Protection Agency CWA § 308 Letter, PSNH Merrimack Station Units 1 & 2. October 2014.

12.22 REDACTED - Confidential Business Information

12.23 MK-M-1235, “Schematic of Water Flow Merrimack Station”, Revision 2.

12.24 Johnson Screens Flow/Screen vs. Headloss Chart, provided 10/19/2016.

12.25 Johnson Screens Half Intake Screen System: A Solution for Shallow Water Intakes, provided 10/7/2016.

12.26 Aqseptence Group, Inc. Quote for Johnson Low Profile Half T-96HCE and Hydroburst System, provided 9/27/2017.

12.27 RSMeans Online, 2017, Commercial New Construction, MasterFormat 2014, https://www.rsmeansonline.com/ManageAccount/QuickStart.

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12.30 ASHRAE Equipment Life Expectancy Chart, http://www.f22designs.com/cullum/wp-content/uploads/2013/02/ASHRAE_Chart_HVAC_Life_Expectancy%201.pdf.

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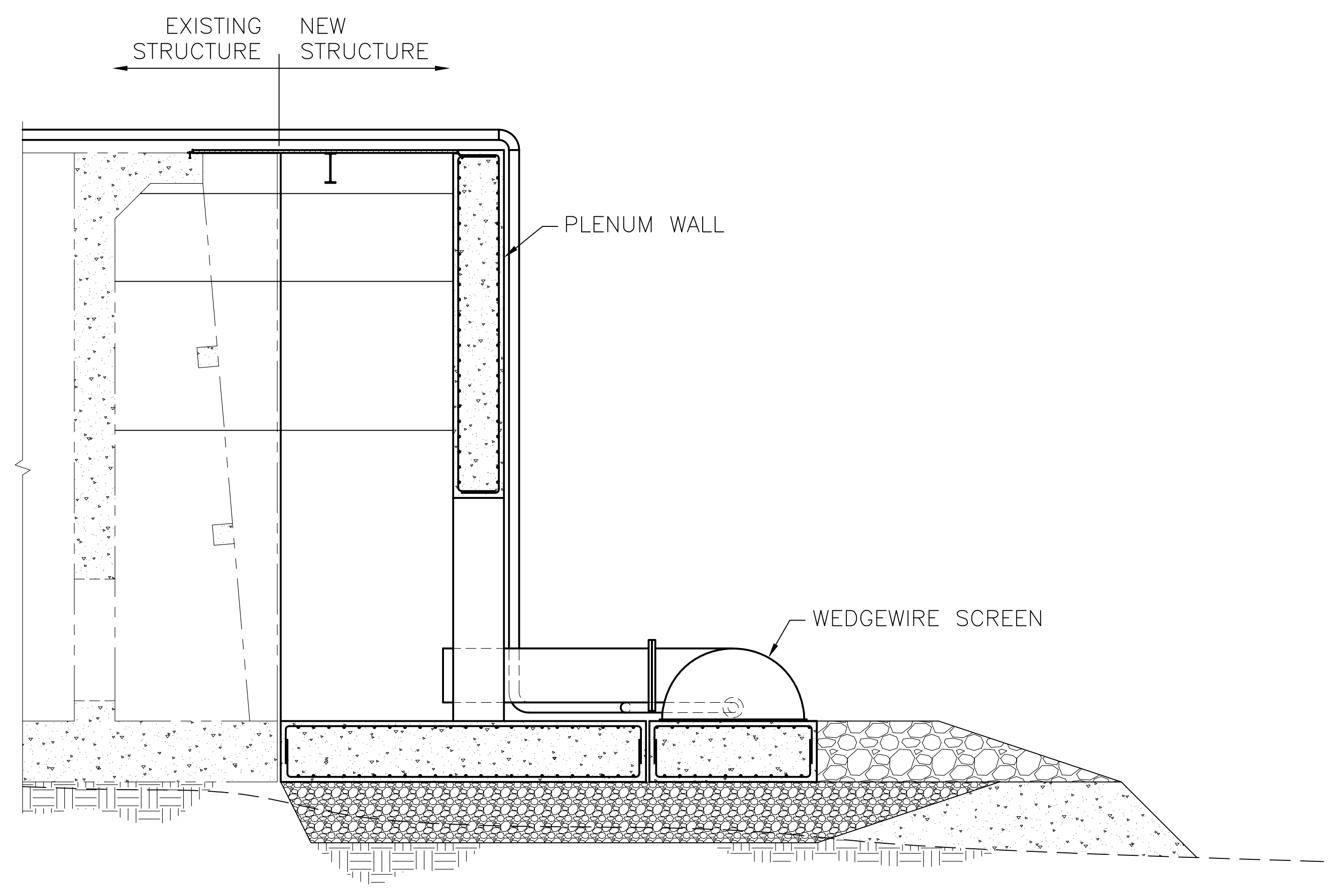
Response to EPA's Statment of Substantial New Questions
Attachment 1, Page 1 of 2



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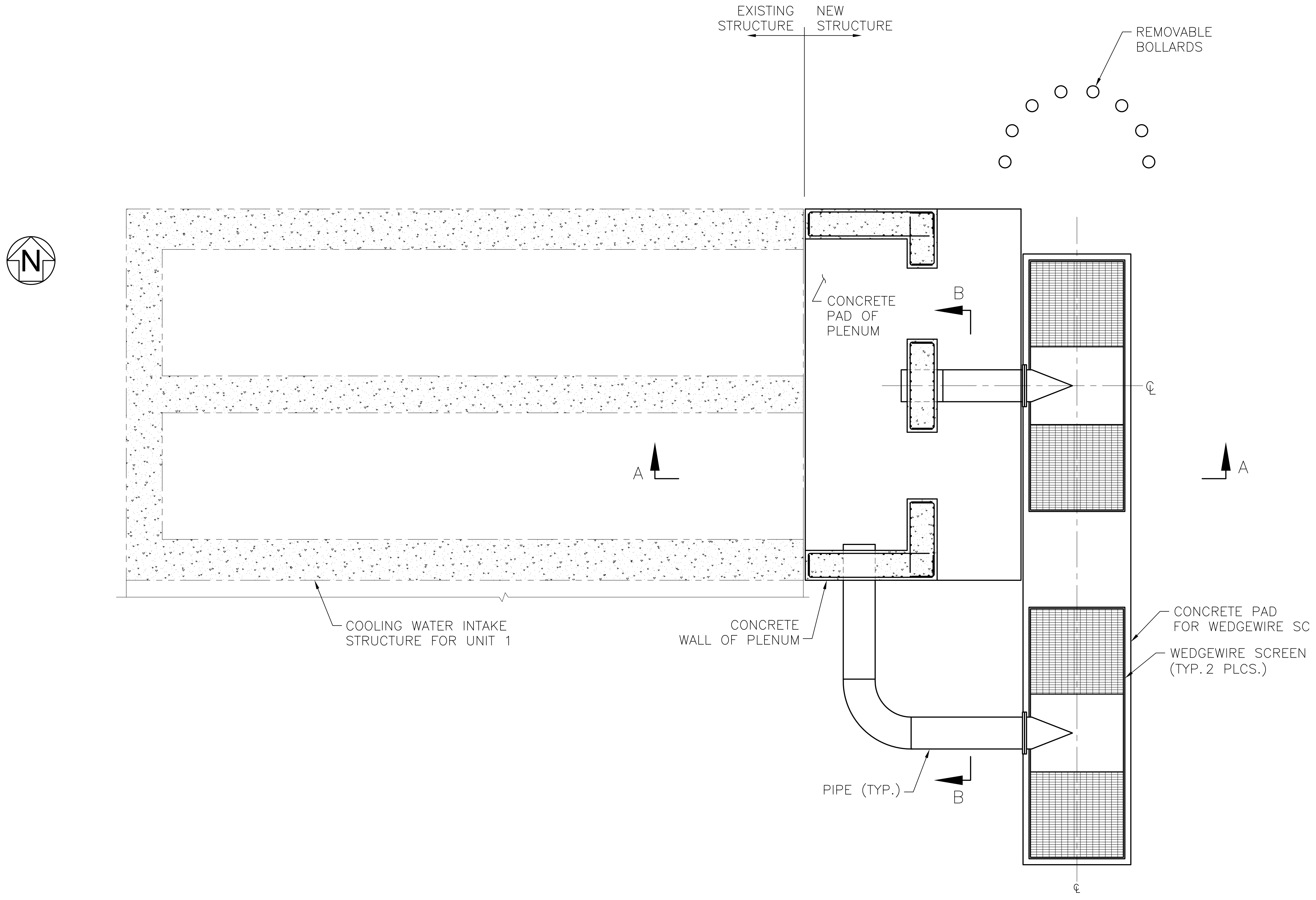
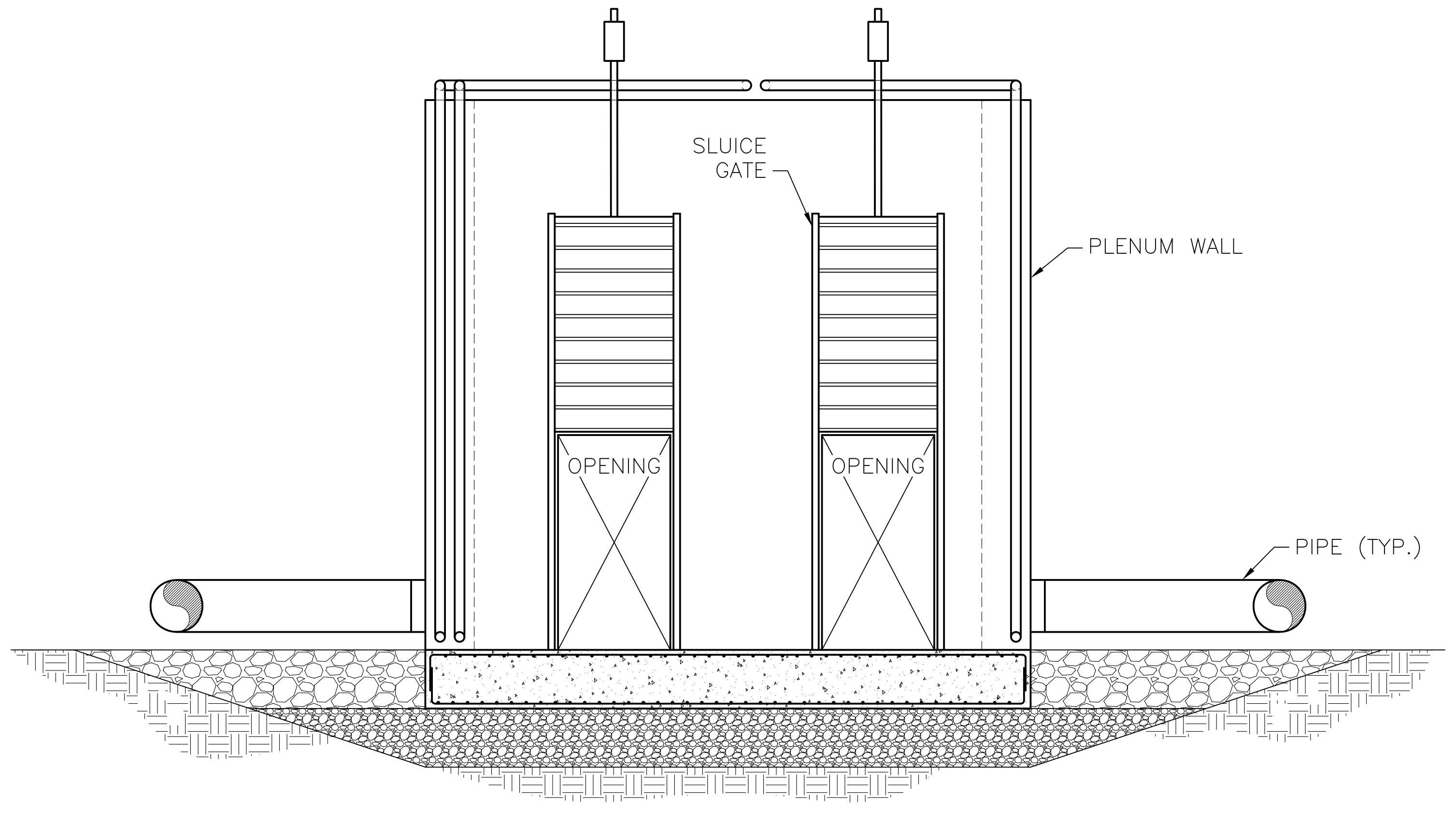


PLAN VIEW



SECTION B–B

NOTES:

1. THIS DRAWING IS PRELIMINARY AND SUBJECT TO CHANGE, NOT FOR CONSTRUCTION.

PRELIMINARY

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0	INITIAL ISSUE					

ENERCON
Kennesaw, GA 30144

PUBLIC SERVICE CO. OF NEW HAMPSHIRE
MERRIMACK STATION-UNIT NO. 1

CONCEPTUAL DRAWING FOR PROPOSED WEDGEWIRE SCREENS AND PLENUM (SCREEN HOUSE #1)

SIZE	DWG NO.	REV
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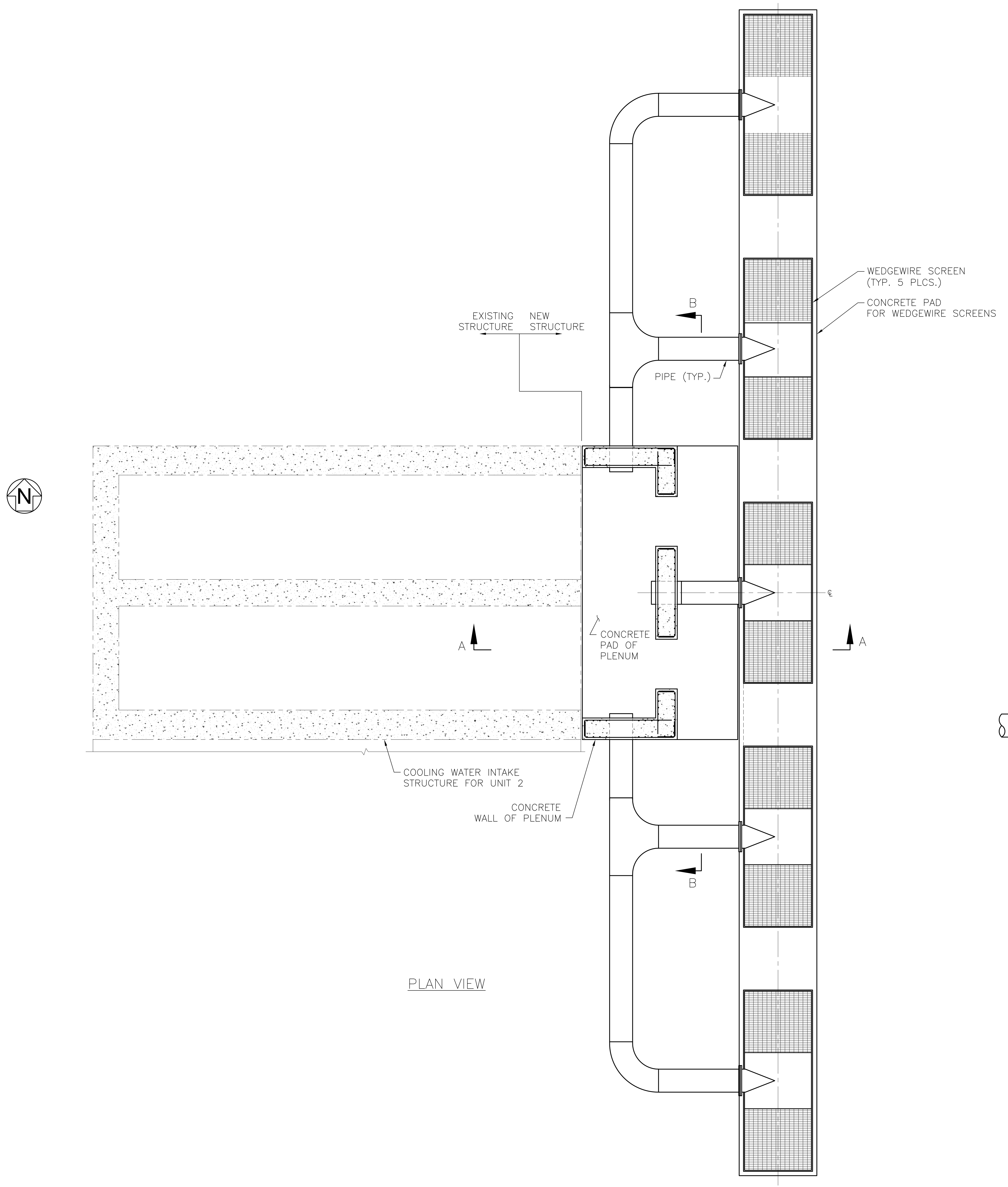
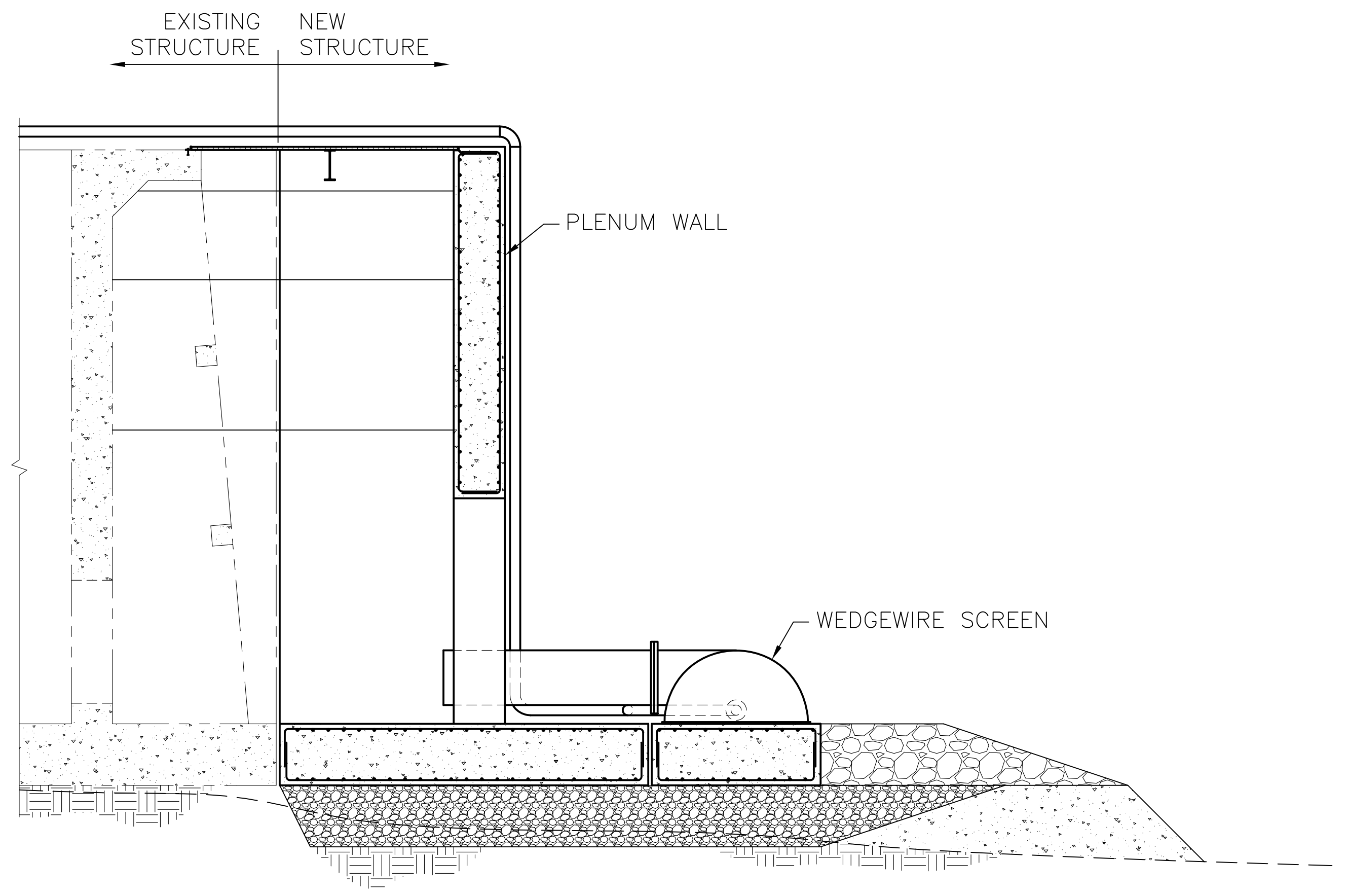
SCALE NONE
SHEET 1 of 1



PLAN VIEW



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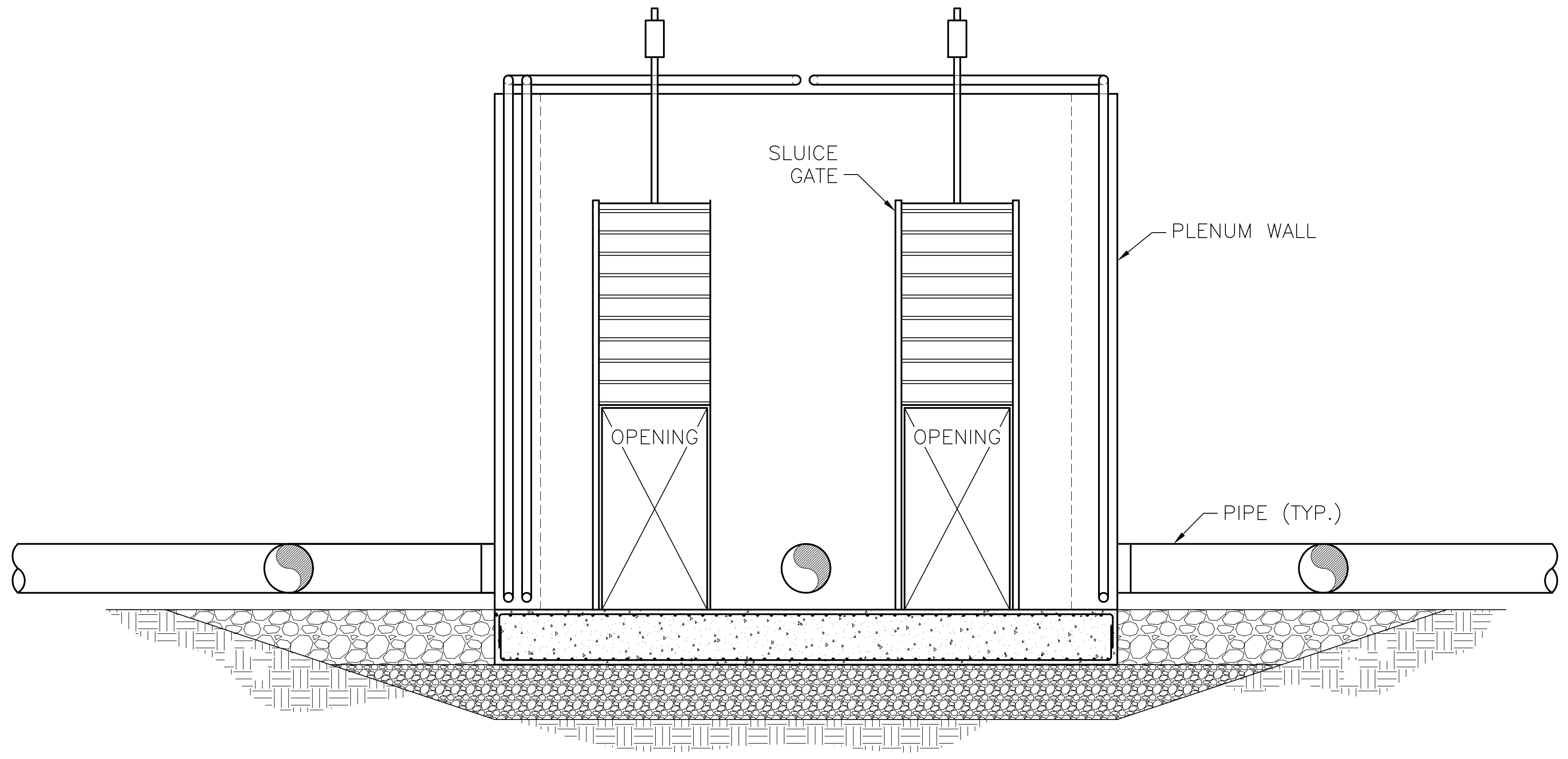


SECTION B–B

NOTES:

1. THIS DRAWING IS PRELIMINARY AND SUBJECT TO CHANGE, NOT FOR CONSTRUCTION.

PRELIMINARY

REV	DESCRIPTION	DRN	CHK	REV	APP	DATE
0	INITIAL ISSUE					

ENERCON
Kennesaw, GA 30144

PUBLIC SERVICE CO. OF NEW HAMPSHIRE
MERRIMACK STATION-UNIT NO. 2

CONCEPTUAL DRAWING FOR PROPOSED
WEDGEWIRE SCREENS AND PLENUM
(SCREEN HOUSE #2)

SIZE D
DWG NO. PSNH014-SK-002
REV 0
SCALE NONE
SHEET 1 of 1

Wedgewire Screen Option Construction Cost Estimate - Unit 1

Item	Description	Quantity	Unit	Unit Price	Cost	Source
Procurement Costs						
Wedgewire Screens for Unit 1	Johnson Low Profile Half T-96HCE, (49" height, 303" length), Z-Alloy	2	Each	$ 283,956	$ 567,912	Aqseptence Group, Inc. Quote
316 Stainless Steel Piping (44" NPS)	Piping from Wedgewire Screen to Intake (black steel, plain end, welded, 3/8" thickness, 44" diameter)	30	LF	$ 1,957	$ 58,715	RSMeans 2014 Line Number 33 11 13.40 1090, scaled by exponential size ratio (n=1.33), multiplied by a factor of 3 for SS**
Hydroburst System	3,000 gallon air receiver tank, compressor/motor assembly, automatic control panel, control valves	1	Each	$ 97,000	$ 97,000	Aqseptence Group, Inc. Quote
316 Stainless Steel Piping (8" NPS)	Piping from Wedgewire screen to ABS (Schedule 40, 8" diameter, includes coupling & clevis hanger assemblies)	200	LF	$ 453	$ 90,600	RSMeans 2017 Line Number 22 11 13.48 1140, multiplied by a factor of 3 for SS**
Tasks for Wedgewire Screen Implementation						
River Bed Dredging	Hydraulic dredging, pumped 1000' to shore dump, maximum	200	BCY	$ 17	$ 3,430	RSMeans 2017 Line Number 35 20 23.23 1100
Mobilization/Demobilization of Dredger	Dredging mobilization and demobilization, average of maximum and minimum	2	Each	$ 47,550	$ 95,100	RSMeans 2017 Line Numbers 35 20 23.13 0020 & 35 20 23.13 0100 Average
Backfill	Crushed stone, 3/4" - 1/2"	100	LCY	$ 42	$ 4,168	RSMeans 2017 Line Number 31 23 23.16 0100
Backfill Haul	Structural backfill, 300' haul sand and gravel	100	LCY	$ 4	$ 379	RSMeans 2017 Line Number 31 23 23.14 2400
Backfill Compacting	Compacting bedding in trench	100	ECY	$ 6	$ 575	RSMeans 2017 Line Number 31 23 23.16 0500
Riprap	Riprap and rock lining, machine placed for slope protection, 18" minimum thickness, not grouted	75	SY	$ 104	$ 7,800	RSMeans 2017 Line Number 31 37 13.10 0200
Precast Concrete Walls	Plenum walls over 3% reinforcing (4,000 psi)	225	CY	$ 2,687	$ 604,575	RSMeans 2017 Line Number 03 30 53.40 0740
Precast Concrete Foundation Pads	Foundation mat (3000 psi), over 20 CY (includes forms, rebar, concrete, placement and finish)	200	CY	$ 356	$ 71,112	RSMeans 2017 Line Number 03 30 53.40 4050
Crane on Bridge	Crane, 350-ton capacity, 80' boom, crawler mounted, 1/2 CY, 15 tons at 12' radius	1	Month	$ 37,800	$ 37,800	RSMeans 2017 Line Number 01 54 33.60 1500
Mobilization/Demobilization of Crane	Mobilization, over 75-ton capacity crane (with chase vehicle), up to 25 mile haul distance (50 mile RT)	2	Each	$ 18,575	$ 37,150	RSMeans 2017 Line Number 01 54 36.50 2400
Cable Jacks	Thirty five(35) cable jacks, 10-ton capacity with 200' cable	1	Month	$ 36,750	$ 36,750	RSMeans 2017 Line Number 01 54 33.60 6600
Operation	Daily crane crew, 80-ton truck-mounted hydraulic crane	10	Day	$ 3,900	$ 39,000	RSMeans 2017 Line Number 01 54 19.50 0500
Hydraulic Sluice Gates	316 stainless steel hydraulic sluice gate	2	Each	$ 325,712	$ 651,424	Past project experience for 96" x 166", 3.4% inflation added from 2014 to 2017 dollars
Pipe Lay Materials						
44" Elbow	44" welded elbow and 150-lb flange connection, stainless steel 316	1	Each	$ 39,760	$ 39,760	Past project experience, approximate cost of 30" elbow flanges, scaled by exponential size ratio (n=1.33), 3.4% inflation added from 2014 to 2017 dollars
44" Flange	44" welded neck flange	2	Each	$ 19,336	$ 38,672	RSMeans 2017 Line Number 22 11 13.47 6559, scaled by exponential size ratio (n=1.33), multiplied by a factor of 3 for SS**
8" Elbow	8" elbow butt-welded, stainless steel 316	20	Each	$ 1,860	$ 37,200	RSMeans 2017 Line Number 22 11 13.66 3380
8" Flange	8" slip-on welded flange connection, stainless steel 316	4	Each	$ 2,268	$ 9,070	RSMeans 2017 Line Number 22 11 13.66 6400
8" Pipe Clamp	8" pipe clamp, galvanized steel	20	Each	$ 197	$ 3,940	Carpenter and Patterson Price List CP-0114, Figure C1108
Structural	for clamp attachment	250	LF	$ 18	$ 4,500	Carpenter and Patterson Price List MS-0114, M132-RS Channel
Spring Nuts	3/8" nuts and screws	20	Each	$ 8	$ 160	Carpenter and Patterson Price List MS-0114, Regular Spring and HHC Screws
Hilti Bolts	3/8" Dia x 3 3/4" KB3, SS316	50	Each	$ 7	$ 373	HILTI Website, Item No. 282568 (1 box [50 pc] @ $373)
Dive Team	EM-385-1-1 Compliant Dive Team, 2 divers, 5 total with equipment	20	Day	$ 5,627	$ 112,540	Past Project Experience, 3.4% inflation added from 2014 to 2017 dollars
Field Service Johnson Screens	One technician for one trip consisting of 1.5 days. Additional days billed at $1,500 per day.	---	---	---	$ 4,500	Aqseptence Group, Inc. Quote
Upstream Bollards	Metal parking bumpers, pipe bollards, concrete filled/painted, 8 ft L x 4 ft diameter hole, 12" diameter	8	Each	$ 1,423	$ 11,382	RSMeans 2017 Line Number 32 17 13.13 1500 (Total O&P) and RSMeans Line Number 06 13 33.52 0220 (Bare Labor and Equipment for installation surcharge)
Mobilization	Mobilization, barge, by tug boat	100	Mile	$ 81	$ 8,050	RSMeans 2017 Line Number 06 13 33.52 0300
Hydraulic Model Study	Develop model for Unit 1 intake	---	---	---	$ 45,496	Past Project Experience, 3.4% inflation added from 2014 to 2017 dollars
Total Work Scope						
			Subtotal	---	$ 2,654,205	
			Conceptual Design Contingency	20%	$ 530,841	RSMeans 2017 Line Number 01 21 16.50 0100
			Construction Management	4%	$ 106,168	RSMeans 2017 Line Number 01 11 31.20 0350
			Unique Project Inexperience	10%	$ 265,420	RSMeans 2017 Line Number 01 21 55.50 0600
			Material Storage Area	2%	$ 53,084	RSMeans 2017 Line Number 01 21 55.50 1000
			Work Space Not Available	5%	$ 132,710	RSMeans 2017 Line Number 01 21 55.50 1400
				Procurement and Construction Subtotal	$ 3,742,429	
Location Factor						
			Manchester, New Hampshire Location Factor	95.6		RSMeans 2017 City Index 031 (Manchester, New Hampshire)
				Recommended Unit 1 Construction Budget	**$ 3,578,000**	(Rounded to Nearest $1,000)

Wedgewire Screen Option Construction Cost Estimate - Unit 2

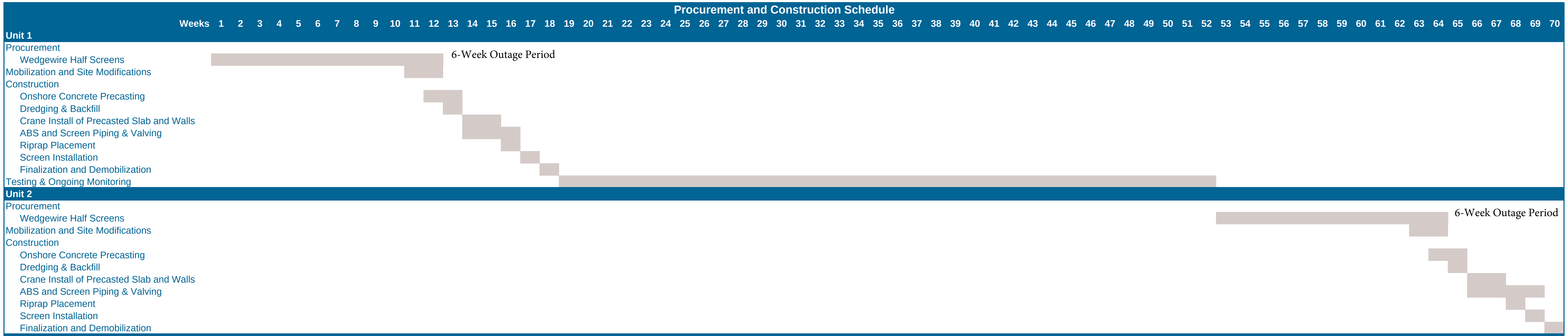
Item	Description	Quantity	Unit	Unit Price	Cost	Source
Procurement Costs						
Wedgewire Screens for Unit 2	Johnson Low Profile Half T-96HCE, (49" height, 303" length), Z-Alloy	5	Each	$ 283,956	$ 1,419,780	Aqseptence Group, Inc. Quote
316 Stainless Steel Piping (44" NPS)	Piping from Wedgewire Screen to Intake (black steel, plain end, welded, 3/8" thickness, 44" diameter)	100	LF	$ 1,957	$ 195,717	RSMeans 2014 Line Number 33 11 13.40 1090, scaled by exponential size ratio (n=1.33), multiplied by a factor of 3 for SS**
316 Stainless Steel Piping (8" NPS)	Piping from Wedgewire screen to ABS (Schedule 40, 8" diameter, includes coupling & clevis hanger assemblies)	500	LF	$ 453	$ 226,500	RSMeans 2017 Line Number 22 11 13.48 1140, multiplied by a factor of 3 for SS**
Tasks for Wedgewire Screen Implementation						
River Bed Dredging	Hydraulic dredging, pumped 1000' to shore dump, maximum	200	BCY	$ 17	$ 3,430	RSMeans 2017 Line Number 35 20 23.23 1100
Mobilization/Demobilization of Dredger	Dredging mobilization and demobilization, average of maximum and minimum	2	Each	$ 47,550	$ 95,100	RSMeans 2017 Line Numbers 35 20 23.13 0020 & 35 20 23.13 0100 Average
Backfill	Crushed stone, 3/4" - 1/2"	100	LCY	$ 42	$ 4,168	RSMeans 2017 Line Number 31 23 23.16 0100
Backfill Haul	Structural backfill, 300' haul sand and gravel	100	LCY	$ 4	$ 379	RSMeans 2017 Line Number 31 23 23.14 2400
Backfill Compacting	Compacting bedding in trench	100	ECY	$ 6	$ 575	RSMeans 2017 Line Number 31 23 23.16 0500
Riprap	Riprap and rock lining, machine placed for slope protection, 18" minimum thickness, not grouted	75	SY	$ 104	$ 7,800	RSMeans 2017 Line Number 31 37 13.10 0200
Precast Concrete Walls	Plenum walls over 1% reinforcing (4,000 psi)	225	CY	$ 2,687	$ 604,575	RSMeans 2017 Line Number 03 30 53.40 0740
Precast Concrete Foundation Pads	Foundation mat (3000 psi), over 20 CY (includes forms, rebar, concrete, placement and finish)	200	CY	$ 356	$ 71,112	RSMeans 2017 Line Number 03 30 53.40 4050
Crane on Bridge	Crane, 350-ton capacity, 80' boom, crawler mounted, 1/2 CY, 15 tons at 12' radius	1	Month	$ 37,800	$ 37,800	RSMeans 2017 Line Number 01 54 33.60 1500
Mobilization/Demobilization of Crane	Mobilization, over 75-ton capacity crane (with chase vehicle), up to 25 mile haul distance (50 mile RT)	2	Each	$ 18,575	$ 37,150	RSMeans 2017 Line Number 01 54 36.50 2400
Cable Jacks	Thirty five(35) cable jacks, 10-ton capacity with 200' cable	1	Month	$ 36,750	$ 36,750	RSMeans 2017 Line Number 01 54 33.60 6600
Operation	Daily crane crew, 80-ton truck-mounted hydraulic crane	15	Day	$ 3,900	$ 58,500	RSMeans 2017 Line Number 01 54 19.50 0500
Hydraulic Sluice Gates	316 stainless steel hydraulic sluice gate	2	Each	$ 325,712	$ 651,424	Past project experience for 96" x 166", 3.4% inflation added from 2014 to 2017 dollars
Pipe Lay Materials						
44" Elbow	44" welded elbow and 150-lb flange connection, stainless steel 316	2	Each	$ 39,760	$ 79,520	Past project experience, approximate cost of 30" elbow flanges, scaled by exponential size ratio (n=1.33), 3.4% inflation added from 2014 to 2017 dollars
44" Flange	44" welded neck flange	5	Each	$ 19,336	$ 96,679	RSMeans 2017 Line Number 22 11 13.47 6559, scaled by exponential size ratio (n=1.33), multiplied by a factor of 3 for SS**
44" Tee	44" welded tee, stainless steel 316	2	Each	$ 55,664	$ 111,328	Add 40% for tee to past project experience estimate for elbow flange
8" Elbow	8" elbow butt-welded, stainless steel 316	30	Each	$ 1,860	$ 55,800	RSMeans 2017 Line Number 22 11 13.66 3380
8" Flange	8" slip-on welded flange connection, stainless steel 316	10	Each	$ 2,268	$ 22,675	RSMeans 2017 Line Number 22 11 13.66 6400
8" Pipe Clamp	8" pipe clamp, galvanized steel	30	Each	$ 197	$ 5,910	Carpenter and Patterson Price List CP-0114, Figure C1108
Structural	for clamp attachment	500	LF	$ 18	$ 9,000	Carpenter and Patterson Price List MS-0114, M132-RS Channel
Spring Nuts	3/8" nuts and screws	50	Each	$ 8	$ 400	Carpenter and Patterson Price List MS-0114, Regular Spring and HHC Screws
Hilti Bolts	3/8" Dia x 3 3/4" KB3, SS316	50	Each	$ 7	$ 373	HILTI Website, Item No. 282568 (1 box [50 pc] @ $373)
Dive Team	EM-385-1-1 Compliant Dive Team, 2 divers, 5 total with equipment	30	Day	$ 5,627	$ 168,810	Past Project Experience, 3.4% inflation added from 2014 to 2017 dollars
Field Service Johnson Screens	One technician for one trip consisting of 1.5 days. Additional days billed at $1,500 per day.	---	---	---	$ 4,500	Aqseptence Group, Inc. Quote
Hydraulic Model Study	Develop model for Unit 2 intake	---	---	---	$ 45,496	Past Project Experience, 3.4% inflation added from 2014 to 2017 dollars
Total Work Scope						
			Subtotal	---	$ 4,005,755	
			Conceptual Design Contingency	20%	$ 801,151	RSMeans 2017 Line Number 01 21 16.50 0020
			Construction Management	4%	$ 160,230	RSMeans 2017 Line Number 01 11 31.20 0350
			Unique Project Inexperience	10%	$ 400,576	RSMeans 2017 Line Number 01 21 55.50 0600
			Material Storage Area	2%	$ 80,115	RSMeans 2017 Line Number 01 21 55.50 1000
			Work Space Not Available	5%	$ 200,288	RSMeans 2017 Line Number 01 21 55.50 1400
				Procurement and Construction Subtotal	$ 5,648,115	
Location Factor						
			Manchester, New Hampshire Location Factor	95.6		RSMeans 2017 City Index 031 (Manchester, New Hampshire)
				Recommended Unit 2 Construction Budget	**$ 5,400,000**	(Rounded to Nearest $1,000)

Permitting and Engineering Cost Estimate - Both Units

Allowance for Permitting	2%	$ 179,560.00	RSMeans 2017 Line Number 01 41 26.50 0110
Detailed Engineering Design	10%	$ 897,800.00	RSMeans 2017 Line Number 01 21 16.50.0100
	Permitting and Engineering Total	**$ 1,077,000**	(Rounded to Nearest $1,000)

Additional Line Items						
Additional Wedgewire Screen Backup	Johnson Low Profile Half T-96HCE, (49" height, 303" length), Z-Alloy	1	Each	$ 283,956	$ 283,956	Aqseptence Group, Inc. Quote
				Additional Line Item Subtotal Budget	**$ 283,956**	

Procurement and Construction Schedule



Notes

1. Procurement requires approximately 12 weeks, with construction drawing approval about 2-3 weeks after receipt of PO and shipment about 7-9 weeks after approval.
2. Schedule assumes no additional testing or studies prior to start of this phase of work.
3. Schedule is contingent upon suitable river and environmental conditions.

Aqseptence Group, Inc.
1950 Old Hwy 8 NW
New Brighton, MN 55112
Tel no : 1-800-833-9473
Fax no : 651 - 638 - 3132

Aqseptence Group

Quotation

Number/Date 20043719 / 09/27/2017
Reference no./Date Enercon - Fossil Power Plant
Sold-To 10004012
Validity period 09/27/2017 to 09/27/2017
Sales person name Mark Watson
Entered by Billy Emmers

We deliver according to the following conditions:
Currency USD
Terms of payment: Within 30 days without deduction
Terms of delivery: FCA New Brighton, MN
Shipping conditions : US: Collect

BUDGET QUOTE

Contact: Jacob Morris
Email: jrmorris@enercon.com
Tel: (770) 701-3415

NOTE
Johnson Intake Screens are covered by one or more of the following patents - #6,05,131; #6,712,959; #8,297,448; other patents pending

SHIPMENT ON INTAKES
2-3 weeks for drawing submittals
12-14 weeks after drawing approval, subject to manufacturing capacity

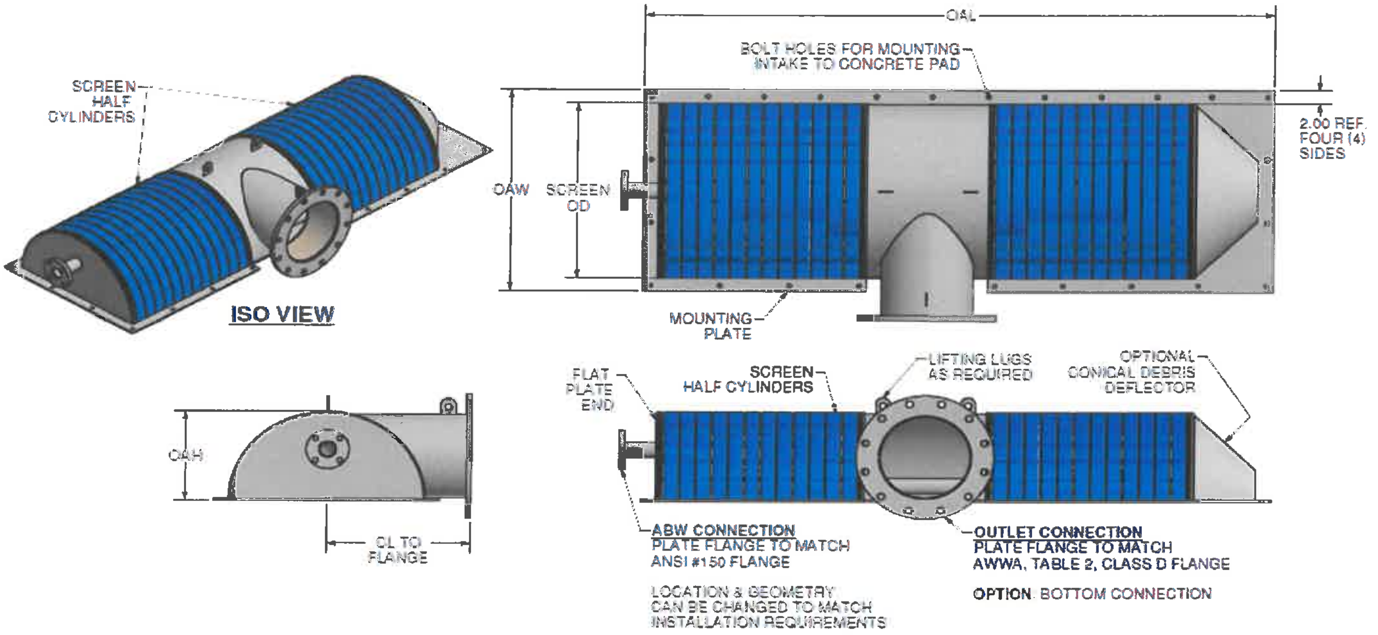
SHIPMENT ON HYDROBURST
3-4 weeks for drawing submittals,
12-14 weeks after drawing approval, subject to manufacturing capacity

REV-A 9/27/2017

Doc. no./Date
20043719 / 09/27/2017

Item	Material Description	Qty	UoM	Price		Value
000010	Johnson Low Profile Half T-96HCE Low Profile Half T96 High Capacity Extended Intake Screen Height: 49" Length: 303" Wire: #69 Slot: 0.118" Material: Z-Alloy Air Backwash: 8" PS flange Flow: 29,750 GPM / Screen has under 0.5 ft/sec max thru slot velocity Depth: 10 ft Collapse Rating: 4.33 PSI Outlet: Flange pattern to match AWWA C-207 class D 44" PS with pipe connect End connection: Endplate x Endplate	7.000	EA	283,956.00	USD	1,987,692.00
000020	Johnson Hydroburst System ADDER HYDROBURST Based on an airline distance of 100 feet and a screen depth of 10 feet you would need a 3000 gallon air receiver tank with 8" sch 10 steel air lines. Price would be in the range of $92,000-$97,000 for a fully automatic system. Price would include air receiver tank, compressor/motor assembly, automatic control panel, control air receiver and valves for the above screen. Airlines provided by others.	1.000	EA			
000030	FIELD SERVICE - WIS JOHNSON SCREENS Onsite Commissioning / Training One (1) Technician for One (1) Trip consisting of One and a half (1.5) days. Additional days billed at $1,500/day	1.000	EA	4,500.00	USD	4,500.00

Aqseptence Group, Inc., on behalf of its designated affiliates and subsidiaries (such term shall include any subsidiary, division or affiliate of Aqseptence Group, Inc. as designated (hereinafter Aqseptence Group) will furnish requested equipment, materials or service (hereinafter Goods) to buyer. Such provision shall be governed by Aqseptence Group's terms and conditions published at : www.aqseptence.com (follow the link to Johnson Screens product page. The Terms and Conditions are located on the bottom right of the landing page) and/or that are forwarded with the order request [hereinafter Terms]. These Terms shall control and govern all transactions between Buyer and Aqseptence Group, whether under subsequent verbal and/or written requests, unless subject to an express, duly executed agreement which is not a pre-printed form)for the particular subject matter effective either upon buyer signing the Terms or order confirmation or quote, or upon Aqseptence Group shipping the Goods or otherwise commencing performance, whichever occurs first. The Terms, together with the specifications, drawings and other requirements specified, constitutes the entire agreement between the parties, and all prior [illegible] rseded and of



Dimension/Sizes	Value	Unit	Comments
Model	HT-96		
Screen OD	96.00	in	Nominal - See Note 1
OAL	303.00	in	Nominal - See Note 1
OAW	100.00	in	Nominal - See Note 1
OAH	49.00	in	Nominal - See Note 1
CL to Flange	72.00	in	Nominal - See Note 1
Outlet Connection Size	44 PS		See Note 2
Outlet Connection Orientation	Side		
ABW Connection Size	8 PS		See Note 2 - Two (2) Outlets Req'd, one for each side
Left End Closure	Plate		
Right End Closure	Plate		
Estimated Weight	10190	lbs	

Screen Specifications			
Slot Opening	0.118	in	
Open Area Percentage	62.43%		
Effective Screen Length	124.81	in	
Wire Type	69		

Design			
Installation Depth	10	ft	
Collapse DP Rating	4.33	psi	
Material	Z-ALLOY		

Flow Capacities			
Flow/Intake	29,750	GPM	See Note 3
Maximum Slot Velocity	0.478	ft/sec	See Note 3
Average Slot Velocity	0.406	ft/sec	See Note 3
Estimated DP-Screen	0.0031	psi	Thru Clean Screen Surface Only - See Note 4
Estimated DP-Assembly	0.7520	psi	Thru Entire Clean Intake Assembly - See Note 4

Design covered by the following patents:

#6,051,131
#6,712,959
#8,297,448
Other patents pending

Notes:

1. Dimensions shown are nominal. All screens are made to order and can be adapted to a wide variety of installation requirements.
2. Outlet and ABW connections are based on the size of the project-specific connecting and abw pipe. These sizes may vary from the values listed in the technical brochure. Bottom connections will be a hole in the Intake mounting plate that will fit over a pipe stub.
3. Flow capacities are based on use of the patented Johnson Screens flow modifier design
4. Pressure drops below 0.1 psi should be considered an order of magnitude only as testing data for these low values is not available.

The concepts and assemblies shown should be considered proprietary and should not be copied or redistributed without the permission of Johnson Screens. All dimensions are preliminary. Changes can be made and can effect final pricing and configuration.

Johnson Screens
A brand of Aqseptence Group

Model HT-96

Preliminary Half Intake Screen Specification
Enercon - Fossil Power Plant
0

Date:
September 27, 2017

CFD THERMAL PLUME MODELING TECHNICAL REPORT

PSNH MERRIMACK STATION UNITS 1 & 2
BOW, NEW HAMPSHIRE

PREPARED FOR
PUBLIC SERVICE COMPANY OF NEW HAMPSHIRE
D/B/A EVERSOURCE ENERGY

Prepared by:

Enercon Services, Inc.
500 Townpark Lane
Kennesaw, GA 30144

December 2017

TABLE OF CONTENTS

1 Introduction and Purpose

Public Service Company of New Hampshire ("PSNH") operates Merrimack Station (the Station), located in Bow, New Hampshire. Merrimack Station is the largest of PSNH's fossil-fueled power plants, and has a total electrical output of approximately 480 MW. Merrimack Station operates two steam electric generating units (Unit 1 and Unit 2) and two combustion turbines. Unit 1 began operating in 1960 and has a rated production of 108 MW, while Unit 2 began operating in 1968 and has a rated production of 330 MW (Reference 6.8, Page 1).

Several engineering and biological assessments have been prepared by Enercon Services, Inc. (ENERCON), Normandeau Associates, Inc. (Normandeau), AST Environmental (AST), and LWB Environmental Services (LWB) and submitted by PSNH to the United States Environmental Protection Agency (EPA) to respond to EPA's requests for certain technology and fisheries information to support development of a new permit for the Station.

The purpose of this technical report is to document the analysis that was performed to characterize the extent of the thermal plume at sampling station S4 in the Merrimack River during various winter months of interest. This thermal assessment was performed by using the FLOW-3D® Computational Fluid Dynamics (CFD) modeling software to quantify the size, location, and extent of thermal plumes that develop when the plant is operating at design conditions for the winter months of December, January, February, and March.

Computational fluid dynamics utilizes numerical analysis of the governing equations of fluid dynamics – mass, momentum, and energy balance – to simulate the interaction of liquids and gases with surfaces defined by boundary conditions. The resolution of the CFD model is based on the number of cells or nodes (the mesh density) used to conduct the analysis. As the number of cells is increased, the resolution of the model is increased and the detailed flow patterns around smaller changes in river bathymetry are better captured. Reducing the overall area analyzed within the model domain allows the use of a higher cell density in the analysis to increase the resolution. When performing CFD analyses, the increase in the resolution of the results must be balanced with the increased computational time and cost associated with higher cell counts. The goal when generating a mesh is to develop a model that adequately represents the flow conditions and produces results to the level of resolution necessary to draw accurate conclusions, but does not require an unacceptably high computational time.

The CFD evaluation was performed using FLOW-3D® Version 10.1 which is a commercially available general-purpose computer code for modeling the dynamic behavior of liquids and gasses influenced by a wide variety of physical processes. The program is based on the fundamental laws of mass, momentum, and energy conservation. It has been constructed for the treatment of time-dependent multi-dimensional problems, and is applicable to most flow processes.

The CFD analysis included four different cases which characterized the thermal plume in the Merrimack River with the plant operating at design conditions for the four winter months of December, January, February, and March. These four winter months were selected because they are of particular biological significance with regards to the survival of the Asian clam. In order to assess these four cases, historical ambient data from the most recent six-year period of data available was used and averaged over the six-year time frame to develop average values for the given month. The six-year range provides a representative data set which fully encompasses a 5-year NPDES permit renewal cycle.

The purpose of this analysis is to characterize the thermal plume at sampling station S4 in the Merrimack River for each of the four cases described above. In order to do this, design plant operational discharge parameters were used in conjunction with historical ambient conditions to inform the input parameters to the CFD model, providing a plume characterization for design plant operation in historical winter month conditions. The purpose of this characterization is to act as a screening tool that can be used in the biological evaluation provided by AST (Reference 6.1) to determine if further analysis for any of the cases is required.

2 Case-Dependent Model Parameters

Both the effluent and the ambient conditions affect the mixing in the CFD model and can impact the predicted thermal plume. Many of the conditions, such as geometry, remain constant for all cases considered. However, several of the effluent and ambient parameters required for the CFD model vary at Merrimack Station based on the winter month being considered. These parameters include ambient river flow rate, air temperature, wind speed, and wind direction.

To account for the variability in these parameters, four cases were developed to model the thermal plume during each of the four months of interest. Case 1 assesses plume behavior using average ambient conditions for the month of December, Case 2 uses average ambient conditions for the month of January, Case 3 uses average ambient conditions for the month of February, and Case 4 uses average ambient conditions for the month of March. These four months were recommended by AST for analysis to support the biological evaluation of the Asian clam's presence in Hooksett Pool (Reference 6.1).

To analyze these four cases, values for the variable parameters listed above were averaged across the most recent six-year range of complete data available. This was done for each month of interest, creating an overall average for each parameter, for each case. These overall monthly averages are presented in Table 1. The explanations and sources for each parameter are provided in detail in Sections 2.1 through 2.4.

Table 1: Case-Dependent Model Parameters

Case	Month	River Flow (cfs)	Air Temperature (°F)	Wind Speed (mph)	Wind Direction (degrees)[1]
1	December	6,030	31.5	4.8	145.9
2	January	4,405	23.9	5.9	164.9
3	February	3,158	24.2	6.5	162.7
4	March	6,545	33.9	6.9	176.8

2.1 River Flow Rate

The daily average Merrimack River flow rate values at Merrimack Station were provided by PSNH for years 1984-2015 in Reference 6.2. These flow values were taken upstream from the Goffs Falls United States Geological Survey (USGS) gage. The flow values were corrected by Normandeau for Merrimack Station in order to accurately reflect the ambient river flow at the plant. As described above, all of the daily values in the month of interest were averaged across the most recent six-year range of complete data available (2010-2015) to create an overall average for that month's case.

---

[1] Wind direction is reported using a 360-degree compass indicating the direction from which the wind was blowing with respect to true north. See Section 2.4 for more details.

2.2 Air Temperature

Hourly averages of air temperature for years 2011-2016 were taken from Reference 6.3, which was ordered and downloaded from the National Oceanic and Atmospheric Administration (NOAA) database. These air temperature measurements were taken at Concord Municipal Airport, which is the closest location to Merrimack Station that reports quality controlled air temperature. As described above, all of the hourly values in the month of interest were averaged across the most recent six-year range of complete data available (2011-2016) to create an overall average for that month’s case.

2.3 Wind Speed

Hourly averages of wind speed for years 2011-2016 were taken from Reference 6.3, which was ordered and downloaded from the National Oceanic and Atmospheric Administration (NOAA) database. These wind speed measurements were taken at Concord Municipal Airport, which is the closest location to Merrimack Station that reports quality controlled wind speeds. As described above, all of the hourly values in the month of interest were averaged across the most recent six-year range of complete data available (2011-2016) to create an overall average for that month’s case.

2.4 Wind Direction

Hourly averages of wind direction for years 2011-2016 were taken from Reference 6.3, which was ordered and downloaded from the National Oceanic and Atmospheric Administration (NOAA) database. These wind direction measurements were taken at Concord Municipal

Airport, which is the closest location to Merrimack Station that reports quality controlled wind direction. Wind direction was reported using a 360-degree compass indicating the direction from which the wind was blowing with respect to true north (Reference 6.4). For example, a wind direction of 180° would indicate a wind blowing from due-south, towards true north. As described above, all of the hourly values in the month of interest were averaged across the most recent six-year range of complete data available (2011-2016) to create an overall average for that month’s case.

3 Constant Model Parameters

A few model parameters required for the CFD model remain constant for all four cases. A summary of the constant model parameters is provided in Table 2 and detailed descriptions of each parameter are shown in Sections 3.1 through 3.3.

Table 2: Summary Table of Constant Model Parameters

Parameter	Value
Ambient River Temperature	33°F
Discharge Flow Rate	443.4 cfs
Discharge Temperature	53.6°F

3.1 Ambient River Temperature

Typically, temperature readings from the probes at sampling station N10, upstream of the Merrimack Station intake and discharge locations, would be used to inform the ambient river temperature input for the CFD model. However, during the winter months of interest (Dec., Jan., Feb., and Mar.), the temperature probes at N10 are removed from the river to avoid potential damage from icing. Therefore, historical data for the ambient river temperature during the winter months of interest is not readily available, and an assumption must be made to perform the CFD analysis.

Based on anecdotal reports, the Merrimack River has been observed to partially ice over during the winter months. Under these conditions, portions of the river would freeze into solid ice at the top of the river, while liquid water continues to flow underneath the ice, maintaining continuous river flow. Therefore, the coldest that the liquid portion of the river could theoretically be under these conditions would be 32°F, which is the coldest temperature the liquid portion of a water/ice slurry can physically be during a phase change (i.e. the liquid phase of the river freezing into ice or the ice phase of the river melting into liquid). Although the theoretical lowest temperature of the liquid portion of the river under these circumstances is 32°F, it is likely that, in reality, the flowing river is not a perfectly mixed liquid/ice slurry and the liquid portion of the river is slightly warmer 32°F, particularly towards the bottom of the river water column where there is a large gap between the water and the ice.

Therefore, to characterize the thermal plume under the river conditions described above, it was assumed that the ambient river temperature was 33°F for all four cases. A temperature of 33°F, slightly above the freezing temperature of 32°F, was selected to avoid unnecessary complications within the model that could result in inaccurate results. If the ambient temperature were set to 32°F, then any loss of energy from a single cell would result in the software considering that cell to be a solid during the next time-step. This could result in pockets of solid ice throughout the river, not only on the surface, which would significantly increase the complexity and solving time of the model and would not be representative of reality. Additionally, as described above, the flowing river is not a perfectly mixed liquid/ice slurry, and it is likely that most of the liquid is slightly warmer than 32°F and not undergoing continuous phase changes between liquid and solid.

3.2 Discharge Flow Rate

To characterize the thermal plume during a “plant on” scenario, where both Merrimack Station Units 1 and 2 are operating at design conditions, the discharge flow into the cooling canal was assumed to be equal to the combined design intake flows of the two units. The design circulating water (CW) intake flow for Unit 1 is 59,000 gallons per minute (gpm) and the design CW intake flow for Unit 2 is 140,000 gpm (Reference 6.5, Page 9). These two flow rates combine to a total design intake flow of 199,000 gpm, or approximately 443.4 cubic feet per second (cfs). Therefore, for the CFD analysis, the plant flow into the discharge canal was assumed to be 443.4 cfs for all four cases.

3.3 Discharge Temperature

The temperature of the plant’s discharge flow as it interacts with the Merrimack River is primarily a function of three factors:

1. The ambient temperature of the cooling water withdrawn from the river
2. The heat load applied to the cooling water as it passes through the plant
3. The amount of cooling that occurs as the flow travels through the length of the discharge canal, prior to mixing with the ambient river flow

As described above, the ambient temperature of the river water is assumed to be 33°F for all four cases. Additionally, since all four cases are evaluating “plant on” scenarios, with both units operating at design conditions, the heat load applied to the water will be the same for all four cases. Finally, because the Power Spray Modules (PSMs) only operate under specific thermal conditions and would most likely not be in operation during the winter months of interest, the amount of cooling that occurs as flow travels through the length of the discharge canal is primarily a function of the time it takes to reach the river. The ambient air temperature and wind speed also affect the amount the discharge is cooled while traversing the canal, with colder air temperatures and higher wind speeds expected to increase the cooling experienced prior to mixing with the ambient river flow.

To determine the average temperature increase of the discharge flow over the ambient river temperature, historical temperature data from sampling station S0 (where the discharge canal flows into the Merrimack River) were compared to the corresponding N10 river temperature data, and the average temperature increase was calculated (Reference 6.6). To do this, a data set of 20 years of daily average temperatures was initially considered. This data set was then filtered for days where both Unit 1 and Unit 2 were simultaneously operating at 90% of their rated generation capacity or greater. Only days where both units were simultaneously operating at 90% capacity or greater were considered so that the cases analyzed would represent true “plant on” scenarios, with the plant operating at approximately its design capacity. Once the data set was filtered, the average temperature difference between the upstream ambient river temperature (N10) and the effluent temperature at the mouth of the discharge canal (S0) was calculated. This temperature difference inherently captures both the increase in fluid temperature due to the plant’s heat load and the cooling experienced as the fluid traveled through the discharge canal. The average temperature rise was calculated to be 20.6°F.

It should be noted that the data set used to calculate the average temperature rise of 20.6°F only included the months April through November, due to the temperature probes at N10 being removed during the winter to avoid potential damage from icing (see Section 3.1). As described above, air temperature has an impact on the amount of cooling experienced as the discharge flow travels through the discharge canal. It is expected that the cooler winter-time air temperatures would provide more cooling to the effluent in the canal than the warmer summer-time temperatures. Therefore, by considering data for the months April through November, the average temperature increase between N10 and S0 of 20.6°F is likely conservatively higher than the temperature increase that would actually be experienced if both units were to be operating at design conditions during the winter months evaluated in the four CFD cases.

When the average temperature increase of 20.6°F between N10 and S0 is considered in conjunction with the assumed ambient river temperature of 33°F, the discharge temperature then becomes 53.6°F for all four cases. The combination of using an average temperature increase that is conservatively high for the winter months of interest and using the design discharge flow rates for both units (Section 3.2) creates cases which model what is expected to be the most significant thermal plume scenario during each of the winter months of interest.

4 Model Description

To characterize the thermal plume for the four winter months of interest, first a physical model of the Merrimack River and Merrimack Station discharge canal was constructed. Once the model was constructed, it was imported into the CFD software and a computational mesh was built to accurately resolve the model to the level of detail required to characterize the plume. Next, the relevant physical models (i.e. gravity, heat transfer, viscosity and turbulence, etc.) and boundary conditions were applied to the model. Finally, the CFD model was run for four different cases, varying the case-dependent model parameters described in Section 2 to characterize the plume for the “plant on” scenario in the months December, January, February, and March.

4.1 3-Dimensional Computer Aided Design (CAD) Model

The first step in performing the CFD analysis was to construct a 3-dimensional CAD model of the Merrimack Station discharge canal and the Merrimack River in the vicinity of the discharge canal. In order to develop this 3-dimensional model and accurately capture the geometry of the river and discharge canal banks, detailed bathymetry data of the discharge canal and the Merrimack River was required. The raw bathymetry data in these areas of interest was provided by Normandeau in Reference 6.7. This raw data was then processed using a geographic information system (GIS) software to capture the river bed geometry data in a format that could be imported into the CAD software. Once the bathymetry data was imported into the CAD software, the discharge canal and riverbed geometry files were exported in a stereolithography (STL) format, which can be imported directly into the CFD software. The discharge canal and river bed geometries were captured in separate STL files so that different initial properties could be assigned to each. For example, the initial temperature of the discharge canal was set to 53.6°F, equal to the effluent discharge temperature, and the initial temperature of the river bed was set to 33°F, equal to the ambient fluid temperature. To capture the heat transfer between the fluid and the river geometry, both the discharge canal and river bed STL files were assigned a thermal conductivity of 1.39 Btu/(hr·ft·°F) (Reference 6.12) and a surface roughness of 0.0164 feet. The surface roughness was calculated based on the following equation (Reference 6.12, Page 469):

$$k_s = 2.5 * d_{50}$$

Where k_s is the surface roughness and d_{50} is the grain diameter where 50% of the material by weight is finer. The Merrimack River in the vicinity of the Station has been reported to be coarse sand, and therefore a d_{50} grain diameter of 2 mm (0.00656 feet) is assumed (Reference 6.12, Appendix C). Using the equation above, this yields a surface roughness of 0.0164 feet.

A plan view of the discharge canal and river bed geometry files is shown in Figure 1 below.

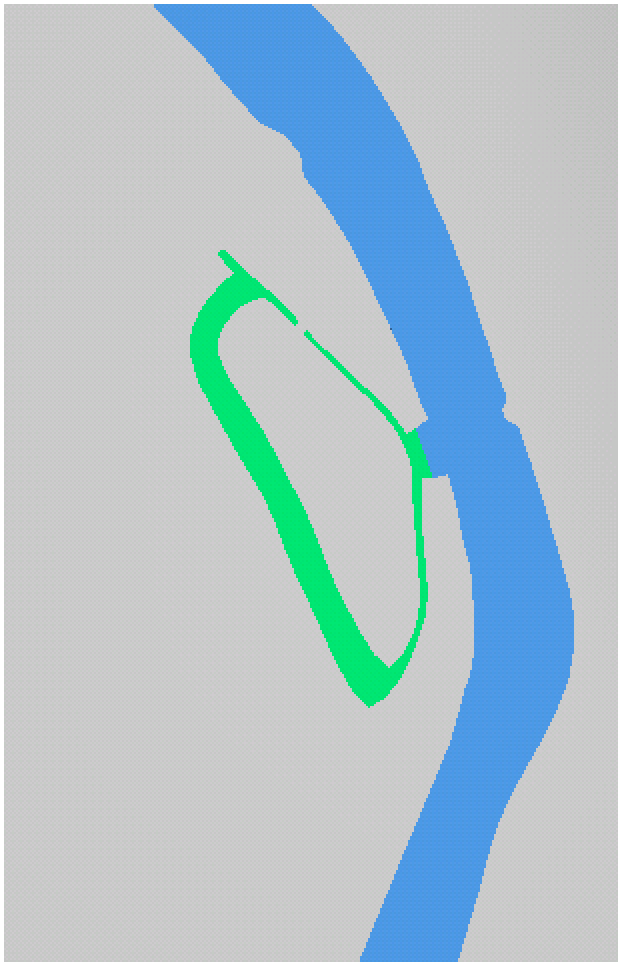


Figure 1: Discharge Canal and Merrimack River STL Files

4.2 Computational Mesh

A single rectangular mesh was defined in the CFD model to characterize the thermal plume. The mesh included a total of 2,624,000 cells, with 400 cells in the X-direction (east to west), 820 cells in the Y-direction (north to south), and 8 cells in the Z-direction (vertical direction). The maximum cell sizes in the x, y, and z directions were 2.5’, 3.0’ and 1.5’, respectively.

A hydraulic diameter is a characteristic length used to calculate Reynolds numbers for flows in non-circular pipes, such as flows through square ducts or open channels. For open channel flow, the hydraulic diameter is a function of the area and wetted perimeter of the fluid flow. In order to accurately model the mixing of the river and effluent flows, the north end of the mesh was positioned approximately 15 hydraulic diameters upstream of the mouth of the discharge canal, far enough that the ambient river flow would have ample time to fully develop the flow profile before it met the discharge flow. The south end of the mesh was positioned at approximately the same location downstream as sampling station S4, so that the thermal plume could be characterized at that location of interest. As shown in the figure below, the east end of the mesh was positioned so that the entire river was encompassed and the west end was positioned to capture the relevant portion of the discharge canal.

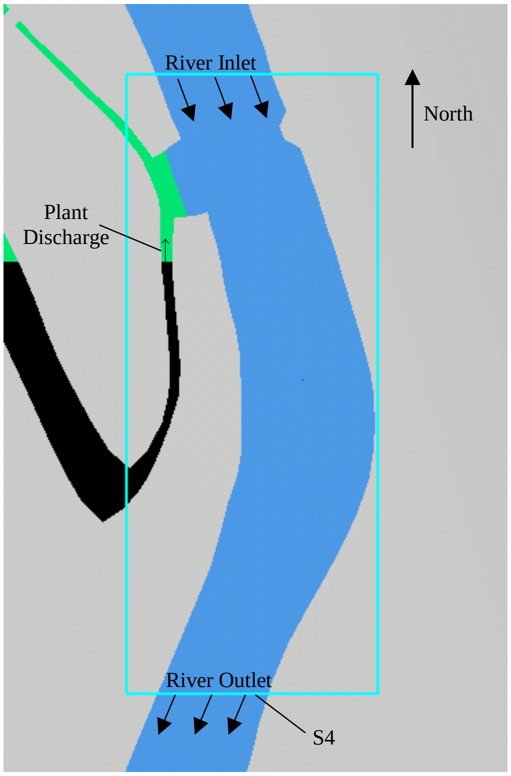


Figure 2: Mesh Configuration

In the CFD model, a portion of the discharge canal was filled with a solid filler block, shown in black in Figure 2. The model was configured such the effluent discharged from the northern-most end of the black filler block and into the discharge canal, initially flowing north until it mixed with the ambient river flowing the opposite direction. The purpose of filling a portion of the discharge canal and starting the effluent discharge flow at this location was to minimize the heat transfer from the effluent flow that occurred prior to mixing with the ambient river flow, ensuring that the effluent exited the discharge canal at the correct temperature (see Section 3.3). Additionally, modeling the effluent discharge in this manner significantly reduced the complexity of the model and the computational time required to solve it. The discharge point was set approximately 12 hydraulic diameters back from the mouth of the discharge canal, far enough that the flow had ample time to create a fully developed flow profile prior to mixing with the ambient river flow.

4.3 Physical Models

Within the CFD model, various physical models were utilized to accurately capture the appropriate thermal and hydraulic effects. The significant physical models that were used in the thermal plume CFD model are described below.

Gravity and Non-Inertial Reference Frame

In order for the CFD model to accurately depict reality, the gravity physical model was activated. The gravity force was set to 32.17 ft/s^2 in the negative Z-direction.

Heat Transfer

The heat transfer physical model was activated to capture the various thermal effects within the CFD model. The full energy equation was used to model fluid-to-solid heat transfer, so that the temperature profile of both the fluid and the solid discharge canal and river bed were calculated for each time-step. The viscous heating option was also activated. The primary areas of heat transfer within the model include the heat transferred during the mixing of the effluent and ambient river flows, the heat transferred between the thermal plume and the river banks/bottom, and the heat transferred between the fluid in the river and the ambient air.

Density Evaluation

The density evaluation physical model was activated so that the buoyancy of the thermal plume (created by the temperature difference between the heated effluent and the cooler ambient water) was captured in the CFD model. The density was evaluated as a function of temperature, and volumetric thermal expansion was included.

Viscosity and Turbulence

The viscosity and turbulence physical model was activated to capture any areas of turbulent flow within the model. Additionally, this physical model allowed the viscous effects between the fluid and the river bed bottom to be captured. Several different turbulence modeling approaches can be selected for a FLOW-3D® calculation. The approaches are (ranging from least to most sophisticated):

- Prandtl mixing length
- Turbulent energy model
- Two-equation k-ε model
- Renormalized group theory (RNG) model
- Large eddy simulation model

The RNG turbulence model was judged to be the most appropriate for this CFD analysis due to the large spectrum of length scales that exist in the river model. The RNG approach applies statistical methods in a derivation of the averaged equations for turbulence quantities (such as turbulent kinetic energy and its dissipation rate). RNG-based turbulence schemes rely less of empirical constants while setting a framework for the derivation of a range of models at different scales. Sensitivity calculations have shown that FLOW-3D® calculations utilizing the more sophisticated turbulence models (the RNG model included) give results that differ significantly from calculations utilizing the less sophisticated models. Differences in results between calculations made with the more sophisticated models have been shown to be slight.

The other options within the viscosity and turbulence model that were selected include the viscous flow option, the “No-slip or partial slip” wall shear boundary condition option, and the viscous heating option.

Wind

The wind physical model was activated to capture the convective heat transfer between the fluid flow and the ambient air, as well as any mixing effects that the wind had on the thermal plume. The constant wind option was selected, and the X-velocity and Y-velocity components of the wind for each case were determined from the wind speeds and wind directions presented in Section 2. The void for each case (volume within the CFD model not occupied by the fluid) was set to the air temperatures presented in Section 2.

4.4 Boundary Conditions

In CFD modeling, boundary conditions are used to define the inputs of the simulation model, such as set rate of fluid flow into the model or a pressure differential used to drive flow. Boundary conditions are set at the minimum and maximum bounds of the x, y, and z planes. The minimum z boundary condition (discharge canal and river bed bottoms) was set to a wall boundary with a temperature of 33°F, equal to the assumed ambient river temperature. A wall roughness of 0.0164 feet was applied to this boundary condition to capture the viscous mixing and heat transfer that occurred at the interface of the fluid and river bottom. The maximum z boundary condition (above the water level) was set as a pressure boundary to model a constant atmospheric temperature and pressure above the free surface. The maximum y boundary (north, upstream of the discharge canal mouth) was set as a volumetric flow boundary, with the flow rates presented in Section 2 used for the various cases. For all four cases, the flow through this boundary condition was set to a temperature of 33°F. The direction of the flow was set approximately parallel to the river banks at the mesh boundary so that the flow could quickly become fully developed. The minimum y boundary (south, downstream of the discharge canal mouth) was set as an outflow boundary so that the flow could exit the model as needed. The maximum and minimum x boundaries were both set as symmetry boundaries.

4.5 Modeling of the Mass Source

As described earlier, the model was configured such that the effluent discharged through only a portion of the discharge canal to ensure that the effluent was the correct temperature at the mouth of the discharge canal (S0) and to reduce the overall complexity of the model. A rectangular mass source was placed at the edge of the solid part used to fill a portion of the discharge canal to provide a discharge source into the canal. The mass source was partially embedded in the solid filler block, and a “cap” was placed on top of the mass source to ensure that water only discharged from the northern most face, directly into the discharge canal. The mass source’s placement (orange rectangle) in the discharge canal is shown Figure 3. To model the plant’s discharge, the mass source was assigned a constant volumetric rate of 443.4 cfs (see Section 3.2) at a temperature of 53.6°F (see Section 3.3).

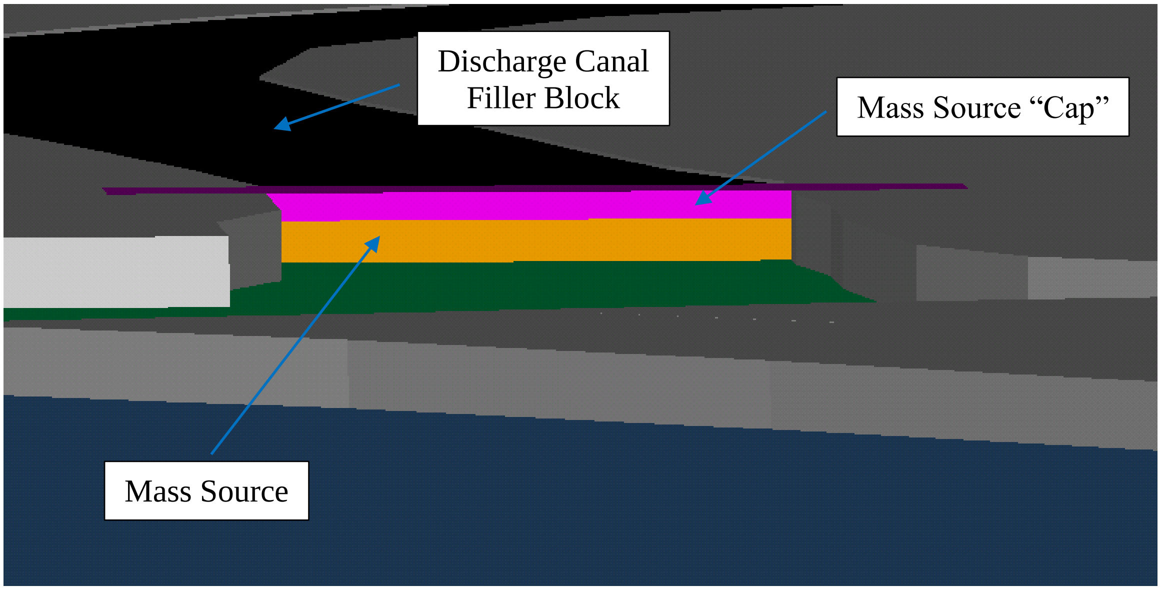


Figure 3: Mass Source Location

4.6 Calculation Termination

For all four cases, the CFD model was run long enough for steady-state conditions to develop and for the results to remain constant over time so that the true thermal plume could be characterized. Calculated mean kinetic energy in the model was used as the indicator for determining steady state. When this parameter stops changing, it is a good indication that steady-state has been achieved and the results will remain the same. The steady state criterion was set as a 1% change or less in the mean kinetic energy over a 45-minute period within the simulation (i.e. 45 minutes of flow within the model).

All four cases met the steady state criteria listed above except for Case 3, which evaluated the month of February. Rather than the standard steady state solution, where the mean kinetic energy stabilized and changed 1% or less over a 45-minute period, the February case instead reached a periodic steady state solution. Due to the relatively low ambient river flow in February

(3,158 cfs), the plant discharge interacted with the river flow in a manner that allowed the plume to build-up near the mouth of the discharge and eventually release and travel downstream. Once one build-up released and flowed downstream, a new plume build-up began to occur. This process occurred consistently, with an average period of approximately 75 minutes. Although this phenomenon prevented the mean kinetic energy from meeting the steady-state criteria used for the other cases, the model was run long enough to determine that this periodic steady state had been achieved.

5 Results

A total of four different CFD cases were modeled using the parameters described in Sections 2 and 3. These four cases were developed to characterize the thermal plume downstream of the plant in the winter months of December, January, February, and March with both units operating at design conditions. The results of these four models were processed in the CFD post-processing software EnSight, and are presented in Sections 5.1 through 5.4. Note that although the models were developed and run using English units (i.e. °F), all temperatures were converted to °C during post-processing to allow for ease of use in AST's biological evaluation (Reference 6.1).

5.1 Case 1 – December

The December CFD case was characterized by relatively high ambient river flow (6,030 cfs) and relatively warm ambient air (31.5°F). The thermal plume at the water surface for this case is shown in Figure 4 and was observed to be attached to the western river bank and relatively thin, taking up a small overall percentage of the river. Although the temperature of the plume dissipates as it travels downstream, a small temperature increase over ambient was observed downstream of the discharge at sampling station S4.

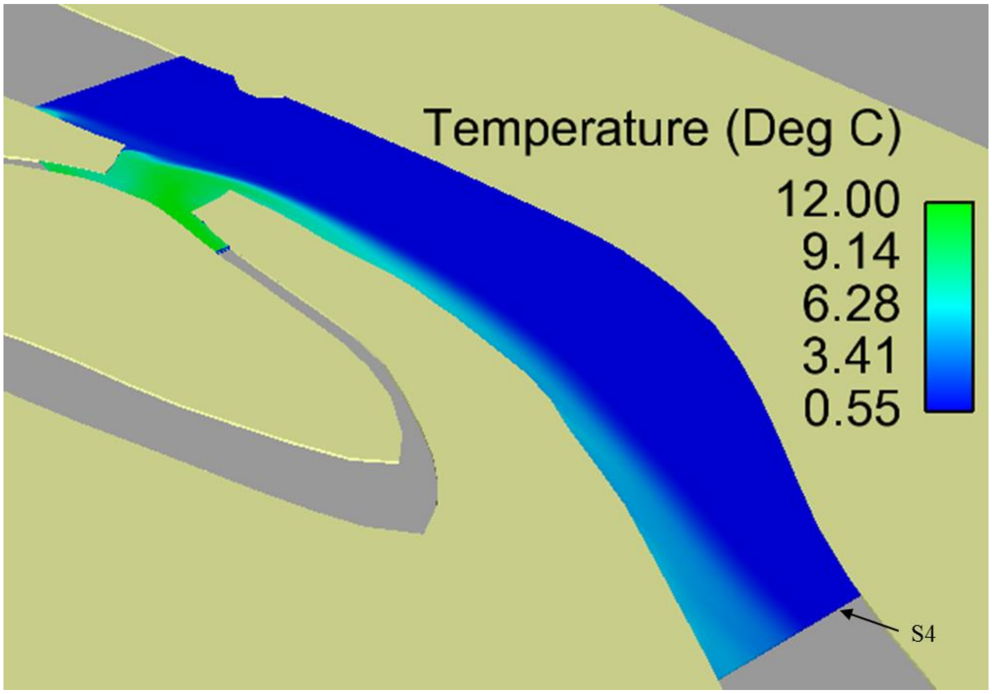


Figure 4: Isometric View of December Results

A cross-sectional view of the thermal plume at S4 is provided in Figure 5 for the December case. The cross-sectional view starts from the western bank on the left side of the graph and traverses the width the river to the eastern bank, shown on the far-right side of the graph. The x-axis shows the distance from the western bank, in feet. Black temperature contours lines for the temperatures 3.77°C, 2.00°C, and 1.63°C are shown on the output, and the 2.00°C contour is designated by white shading. The maximum water temperature at the riverbed is approximately 4.85°C, and, as shown in the figure below, approximately 56% of the river bottom remains at a temperature below 2°C.

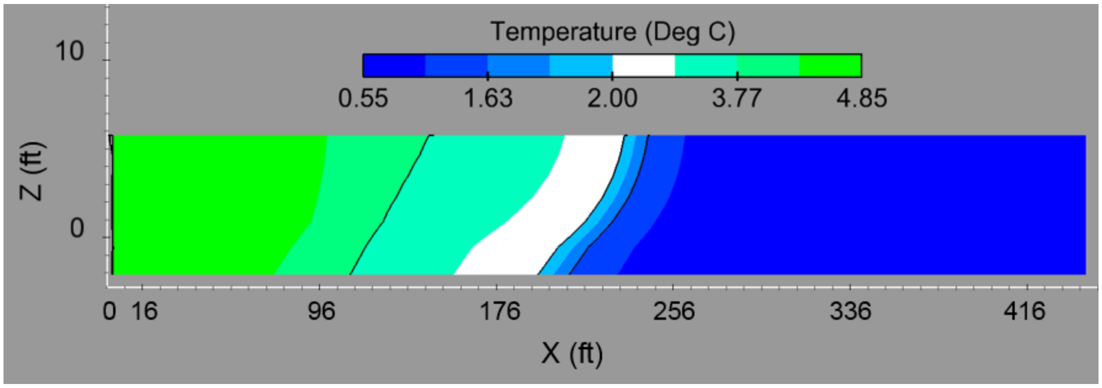


Figure 5: Cross-Sectional View of December Results at S4

Note that although the contours shown in the figure above are displayed in a relatively coarse gradient, the temperature results are calculated for every cell within the CFD model. With a total of 400 cells in the X-direction, the computational mesh was sufficiently fine to provide a detailed resolution of the model and an accurate characterization of the thermal plume. The contours in Figure 5 are shown in a coarser gradient for the purpose of simplifying the presentation of the model results and allowing them to be easily interpreted.

5.2 Case 2 – January

The January CFD case was characterized by relatively low ambient river flow (4,405 cfs) and relatively cold ambient air (23.9°F). The thermal plume at the water surface for this case is shown in Figure 6 and was observed to be attached to the western river bank, somewhat irregular as it traveled downstream, and relatively thin, taking up a small overall percentage of the river. Although the temperature of the plume dissipates as it travels downstream, a small temperature increase over ambient was observed downstream of the discharge at sampling station S4.

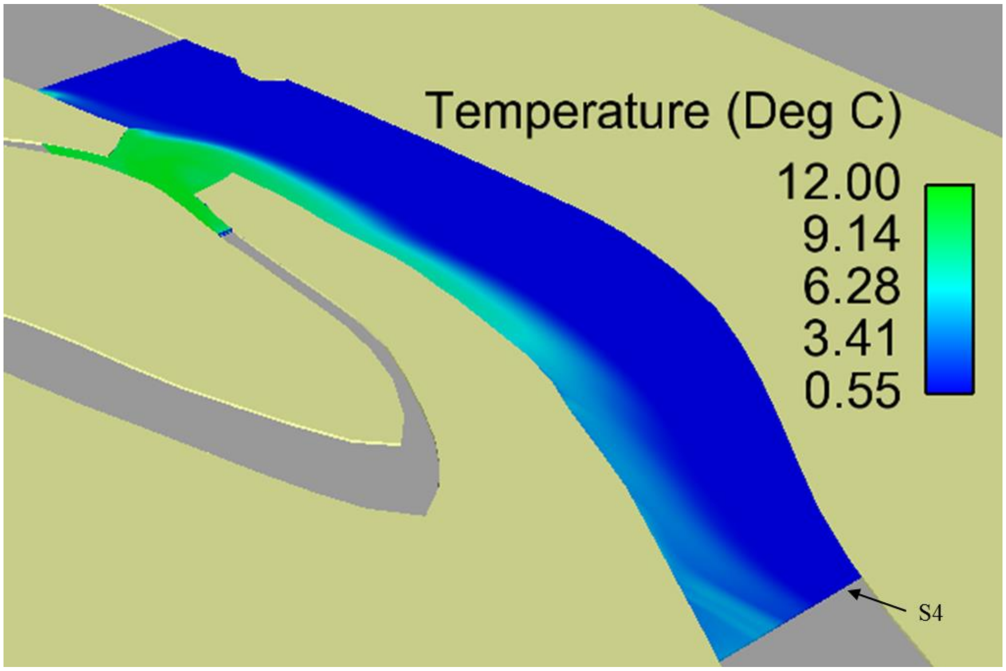


Figure 6: Isometric View of January Results

A cross-sectional view of the thermal plume at S4 is provided in Figure 7 for the January case. The cross-sectional view starts from the western bank on the left side of the graph and traverses the width the river to the eastern bank, shown on the far-right side of the graph. The x-axis shows the distance from the western bank, in feet. Black temperature contours lines for the temperatures 3.77°C, 2.00°C, and 1.63°C are shown on the output, and the 2.00°C contour is designated by white shading. The maximum water temperature at the riverbed is approximately 4.85°C, and, as shown in the figure below, approximately 55% of the river bottom remains at a temperature below 2°C.

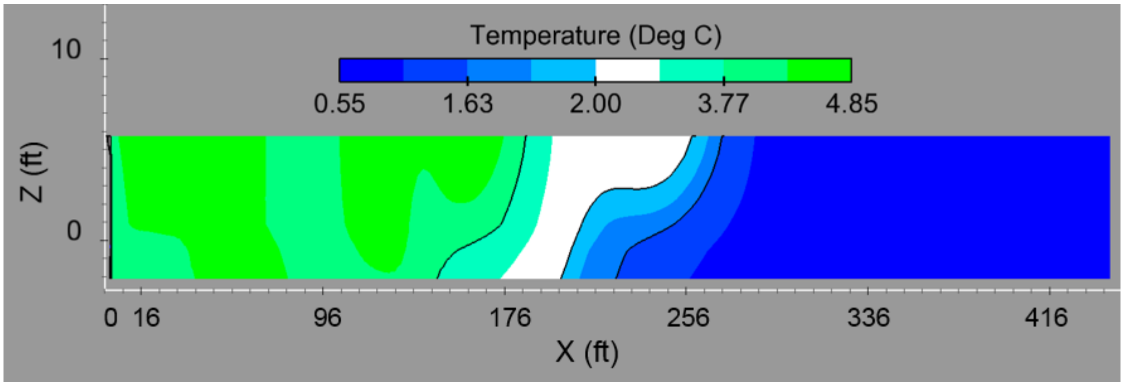


Figure 7: Cross-Sectional View of January Results at S4

Note that although the contours shown in the figure above are displayed in a relatively coarse gradient, the temperature results are calculated for every cell within the CFD model. With a total of 400 cells in the X-direction, the computational mesh was sufficiently fine to provide a detailed resolution of the model and an accurate characterization of the thermal plume. The contours in Figure 7 are shown in a coarser gradient for the purpose of simplifying the presentation of the model results and allowing them to be easily interpreted.

5.3 Case 3 – February

The February CFD case was characterized by relatively low ambient river flow (3,158 cfs) and relatively cold ambient air (24.2°F). The thermal plume at the water surface for this case is shown in Figure 8 and was observed to be attached to the western river bank and slightly irregular as it traveled downstream. Although the temperature of the plume dissipates as it traveled downstream, a small temperature increase over ambient was observed downstream of the discharge at sampling station S4.

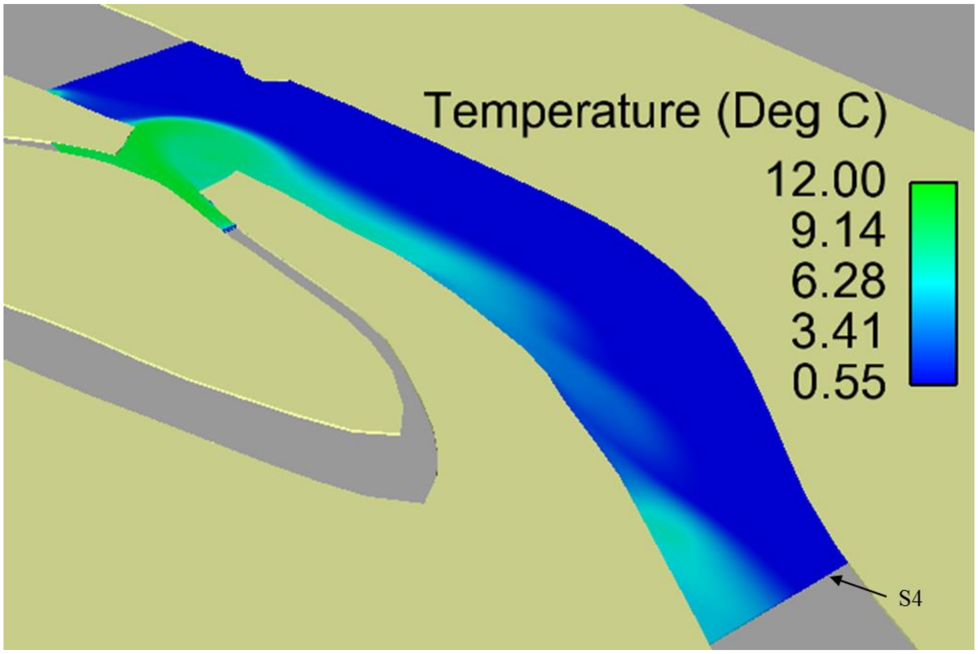


Figure 8: Isometric View of February Results

A cross-sectional view of the thermal plume at S4 is provided in Figure 9 for the February case. The cross-sectional view starts from the western bank on the left side of the graph and traverses the width the river to the eastern bank, shown on the far-right side of the graph. The x-axis shows the distance from the western bank, in feet. Black temperature contours lines for the temperatures 4.34°C, 2.00°C, and 1.81°C are shown on the output, and the 2.00°C contour is designated by white shading. The maximum water temperature at the riverbed is approximately 4.34°C, and, as shown in the figure below, approximately 52% of the river bottom remains at a temperature below 2°C.

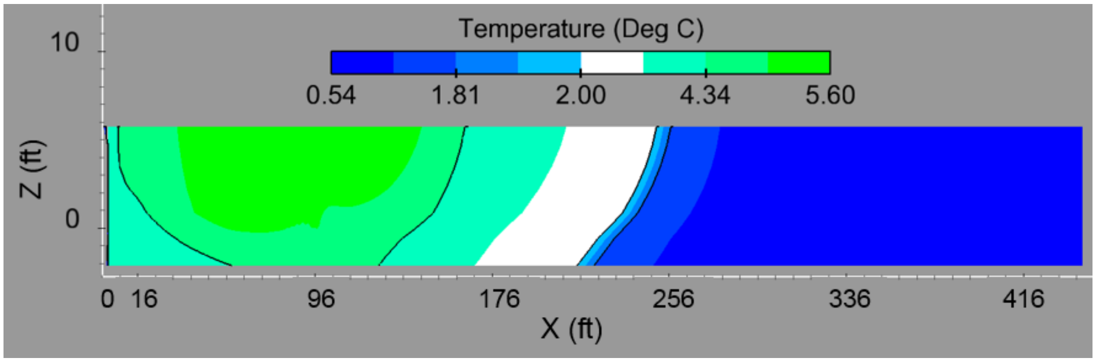


Figure 9: Cross-Sectional View of February Results at S4

Note that although the contours shown in the figure above are displayed in a relatively coarse gradient, the temperature results are calculated for every cell within the CFD model. With a total of 400 cells in the X-direction, the computational mesh was sufficiently fine to provide a detailed resolution of the model and an accurate characterization of the thermal plume. The contours in Figure 9 are shown in a coarser gradient for the purpose of simplifying the presentation of the model results and allowing them to be easily interpreted.

5.4 Case 4 – March

The March CFD case was characterized by relatively high ambient river flow (6,545 cfs) and relatively warm ambient air (33.9°F). The thermal plume at the water surface for this case is shown in Figure 10 and was observed to be attached to the western river bank and relatively thin, taking up a small overall percentage of the river. Although the temperature of the plume dissipates as it travels downstream, a small temperature increase over ambient was observed downstream of the discharge at sampling station S4.

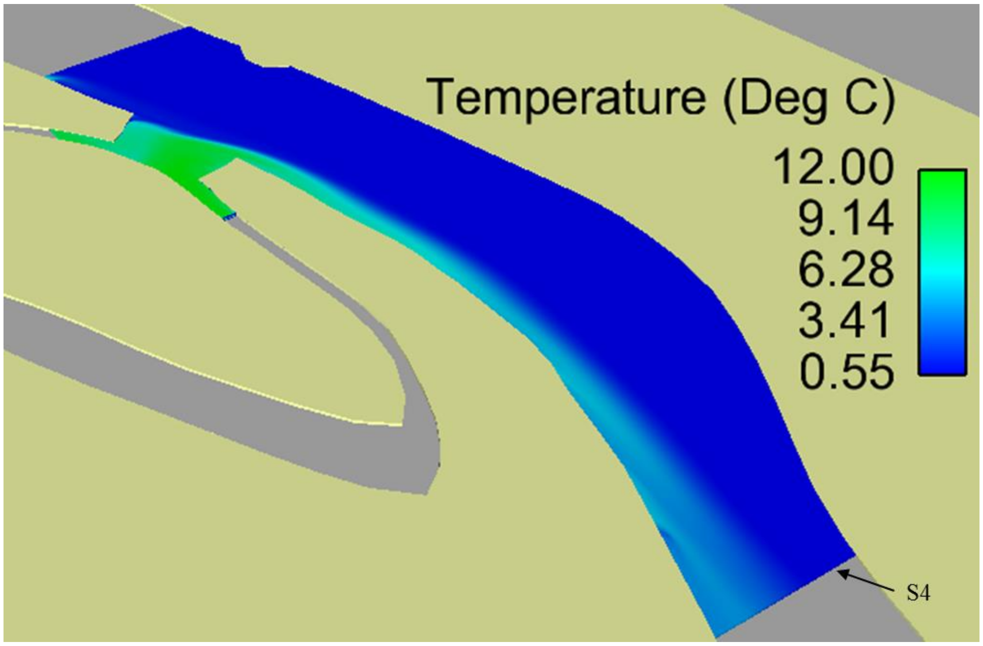


Figure 10: Isometric View of March Results

A cross-sectional view of the thermal plume at S4 is provided in Figure 11 for the March case. The cross-sectional view starts from the western bank on the left side of the graph and traverses the width the river to the eastern bank, shown on the far-right side of the graph. The x-axis shows the distance from the western bank, in feet. Black temperature contours lines for the temperatures 3.83°C, 2.00°C, and 1.64°C are shown on the output, and the 2.00°C contour is designated by white shading. The maximum water temperature at the riverbed is approximately 3.83°C, and, as shown in the figure below, approximately 60% of the river bottom remains at a temperature below 2°C.

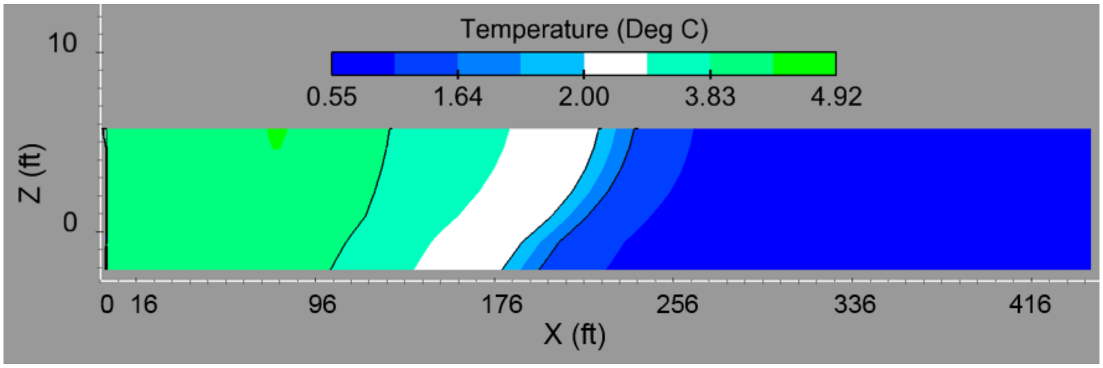


Figure 11: Cross-Sectional View of March Results at S4

Note that although the contours shown in the figure above are displayed in a relatively coarse gradient, the temperature results are calculated for every cell within the CFD model. With a total of 400 cells in the X-direction, the computational mesh was sufficiently fine to provide a detailed resolution of the model and an accurate characterization of the thermal plume. The contours in Figure 11 are shown in a coarser gradient for the purpose of simplifying the presentation of the model results and allowing them to be easily interpreted.

5.5 Discussion of Results

As described in Section 3, the ambient river temperature, discharge flow rate, and discharge temperature remained the same for all four cases. These parameters remained constant in order to model a “plant on” scenario, with both units operating at full design conditions, for each winter month of interest. Therefore, the parameters that were changed from case to case were the ambient river flow rate, ambient air temperature, and wind speed and direction.

The ambient river flow rate was the largest driver in the differences among the results of the four cases. Although the air temperature and wind properties did have an impact on the results, the impact of these parameters was secondary compared to the impact of the ambient river flow.

As shown in Section 2, December and March had the highest ambient flows at 6,030 cfs and 6,545 cfs, respectively. For these two cases, the relatively high ambient river flows had the effect of “pulling” the plume downstream, creating a relatively thin plume that was attached to the western bank. The relatively high ambient river flows also tended to dominate the mixing of the plume, rather than buoyancy effects created by the temperature differential, creating a well-mixed plume with little stratification in the water column.

In comparison, February had a relatively low ambient river flow (3,158 cfs) or less than half of the river flow in March. This low river flow allowed the temperature-driven buoyancy effects to play a larger role in the mixing of the plume, creating a more distinct stratification in the water column. This stratification showed the warmer, less dense portion of the plume rising towards the river surface. As described in Section 4.6, the low ambient river flow also created a periodic plume discharge pattern, with the plume building up at the mouth of the discharge canal and then releasing downstream at regular intervals.

For all cases, the thermal plume was observed to be attached to the western bank of the river, and was always more narrow at the river bottom than at the water surface. As shown by the contour lines, the 2°C threshold at the river bottom ranged from approximately 178 feet to 214 feet from the western bank. For all cases, the 2°C threshold was met well before the central S4 clam sampling location, which is 246 feet from the western bank (Reference 6.9).

5.6 Conclusion

This CFD analysis was performed to characterize the thermal plume in the Merrimack River for the winter months of December, January, February, and March with both units at the Station operating at design conditions. To do this, average ambient conditions (river flow, air temperature, wind speed and direction) were used to develop four different CFD cases. Each of the four cases was run until it reached steady-state, and then the results were post-processed to provide a characterization of the thermal plume. This analysis is provided for use as a screening tool to determine if any of the evaluated scenarios require further examination. These results are valid to inform the biological evaluations presented in AST's report regarding the Asian clam in the Hooksett Pool (Reference 6.1).

6 References

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6.7 Merrimack River Bathymetry Data, provided by Normandeau Associates, Inc. on 10/15/16.

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6.9 S4 Asian Sampling Locations GPS Coordinates spreadsheet, provided by AST on 9/21/17.

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6.11 River Flow 2012, Rafael Murillo Munoz, CRC Press, October 5, 2012.

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