Attachment 4

**THIS DOCUMENT CONTAINS PROPRIETARY, COMPANY CONFIDENTIAL INFORMATION SUBJECT TO BUSINESS CONFIDENTIALITY CLAIM UNDER 40 C.F.R. PART 2 AND COMPARABLE STATE LAW**

# WEDGEWIRE SCREEN CONFIRMATORY STUDY SCOPE DESCRIPTION

## PSNH MERRIMACK STATION UNITS 1 & 2
## BOW, NEW HAMPSHIRE

**Submitted to:**

Public Service Company of New Hampshire
D/B/A Eversource Energy

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## 1.0 INTRODUCTION

Enercon Services, Inc. (ENERCON) is pleased to provide this description of the confirmatory study for wedgewire screens at Merrimack Station, owned by Public Service Company of New Hampshire (PSNH). As described in the "Wedgewire Half Screen Technical Memo" submitted in December 2016 (Ref. 4.1), wedgewire half screens can provide significant entrainment benefits at a greatly reduced cost. As stated in that submittal, further design efforts and testing are planned to occur at Merrimack Station through the summer of 2017. The confirmatory study for the wedgewire screen is planned to begin in early May.

For the confirmatory study, ENERCON will work side-by-side with Normandeau Associates, Inc. (Normandeau). As a team, ENERCON and Normandeau provide decades of experience completing CWW screen design and effectiveness assessments. Below are several items demonstrating why ENERCON is uniquely qualified to perform the in-river testing for Merrimack Station.

- The team includes industry recognized technical experts on CWIS design assessments, and incorporates the expertise of several environmental scientists, engineers, and management professionals.

- The team has interfaced with both state and federal permitting agencies / regulators. The team has a thorough understanding of what is required to complete CWW screen testing, having performed a nearly identical scope of work previously.

- In the past decade of evaluating CWW screens, the team has accumulated extensive experience on their design, including their effectiveness at reducing entrainment via physical exclusion of organisms larger than the screen slot width, as well as via hydraulic bypass and behavioral avoidance due to the shape and hydrodynamic qualities of the screens (Reference 4.1, Attachment 1).

Finally, the ENERCON / Normandeau team is ideally suited to perform the Merrimack Station confirmatory testing because it has performed a nearly identical scope of work on the Hudson River in 2011. A 12-inch CWW screen was lowered from a barge to the appropriate depth within the water column, and a pump was used to draw water through the screen into a sampling tank. A control port was used that was designed to reduce larval avoidance based on the lessons learned from previous field testing, and near field tucker trawl samples were collected over a portion of the testing period. Barge-mounted pumps independently drew water from the CWW screen and control port. Two independently placed Acoustic Doppler Current Profilers (ADCPs) were used to measure the flow field and turbulence in the vicinity of the CWW screen and control port. The Merrimack Station confirmatory study will not use a barge but will capitalize on the experience gained during that successful study.

## 2.0 DESCRIPTION OF CONFIRMATORY STUDY

In 2011, the United States Environmental Protection Agency (EPA) issued a draft national pollutant discharge elimination system (NPDES) permit for Merrimack Station. Since the issuance of this draft permit, several engineering and biological assessments have been prepared by ENERCON and Normandeau and submitted by PSNH to the EPA. In December of 2016, PSNH submitted the “Wedgewire Half Screen Technical Memo” (2016 memo), which was prepared by ENERCON with an attachment provided by Normandeau (Reference 4.1). This technical memo provides a high-level design description for wedgewire half screen implementation at Merrimack Station, demonstrating that the technology provides significant entrainment benefits at a greatly reduced cost. The 2016 memo identified that a site-specific confirmatory study would be undertaken to validate the biological effectiveness of wedgewire half screens at Merrimack Station. Available literature supports that Merrimack Station should attain significant entrainment reduction benefits from the installation of wedgewire half screens (Reference 4.1, Attachment 1). The purpose of the study identified by the 2016 memo is to confirm the entrainment reduction that is expected given the high ratio of sweeping velocity to through-slot velocity present at Merrimack Station.

The preparation for the confirmatory study is currently underway. In order to provide the most relevant entrainment data, the testing will be conducted during the typical 13-week entrainment period, starting in early May of 2017 (Reference 4.1, Attachment 1). Due to the rapidly approaching start date for the testing, the preparation for the study is expedited in nature and has already started. As part of this preparation process, a preliminary test design has been developed that includes a list of long lead time items required to support the testing. These items will be procured in advance to avoid delays to the testing schedule.

This confirmatory study scope description includes:

- A description of the purpose and methods of the confirmatory study;
- Details for the major components of the study;
- An outline of how the study will be performed; and,
- Details on how the entrainment reduction will be evaluated.

## 2.1 CONFIRMATORY STUDY SCOPE

The scope of the confirmatory study is to provide empirical data that quantifies the entrainment benefit Merrimack Station would receive if the 96-inch diameter wedgewire half screen design presented in the 2016 memo was to be implemented. Although the confirmatory study is being designed to model 96-inch diameter half screens, it is expected that the test will provide results that represent similar large-diameter half screens (i.e., screens with comparable cone angles and withdrawal elevations). The study will be performed at Merrimack Station beginning in May of 2017, and will continue throughout the typical 13-week entrainment period. The study will be conducted near the Unit 1 intake structure, and it is expected that the results from the test will be applicable to wedgewire half screen installations at both units given their proximity to each other and to the test screen. The empirical data will be obtained by collecting biological samples drawn through a test wedgewire screen that models the proposed half screens. The eggs and larvae collected from these samples will then be identified and counted to quantify the entrainment data. The entrainment data gathered for flow through the test wedgewire screen will be compared to control entrainment data taken from the Unit 1 intake to determine an overall entrainment reduction for the test screen.

The test screen used for the confirmatory study will be a 12-inch diameter CWW screen with a slot width of 3 mm. The screen will be made out of Z-Alloy, and is currently being fabricated by Johnson Screens. Johnson Screens is also fabricating the screen support stand used to maintain the screen in the desired location. Although a CWW screen is being used as a model to represent the half screen solution presented in the 2016 memo, half screens remain the intended wedgewire solution for Merrimack Station. The CWW test screen is designed to match the parameters of the half screen as closely as possible, including the screen slot width, the through-slot velocity, the flow dynamics around the screen, and the screen elevation within the water column. A detailed evaluation for modeling the half screen with a CWW test screen is provided in Attachment 1.

Samples will be taken from the Unit 1 intake structure to provide control entrainment data. The control samples will be compared to samples taken through the test screen, which provide entrainment data representative of the proposed half screens. The test screen will be installed in the vicinity of the Unit 1 intake and a pump will be used to draw flow through the screen at a flow rate that provides a through-slot velocity of approximately 0.4 fps, matching the through-slot velocity of the proposed half screens. The control samples and test screen samples will be collected as near simultaneously as possible, and will be processed by Normandeau to provide detailed entrainment data. An ADCP study will be performed concurrently with the confirmatory study, and the current data will also be processed and reported by Normandeau.

## 2.2 TEST COMPONENTS

The parameters of the confirmatory study will match the parameters of the proposed half screen design as closely as possible to provide an accurate model. The major components of the test and the associated model parameters are described in the sections below.

### 2.2.1 Test Wedgewire Screen and Location

The proposed wedgewire screen solution presented in the 2016 memo includes the installation of 96-inch diameter half screens with a slot width of 3 mm. Due to cost, engineering, and schedule restrictions, it is not practical to use a full 96-inch diameter half screen for the confirmatory study. Therefore, a smaller and readily available wedgewire screen will be used during testing as a model for the proposed half screens. In order for the smaller screen to serve as an accurate model for the proposed half screens, it must match the primary parameters of the half screen as closely as possible. These parameters include the screen's slot width, the through-slot velocity, the flow dynamics around the screen, and the screen elevation within the water column.

A 12-inch diameter CWW T-shaped screen has been selected as the model screen for testing. A detailed evaluation for why a 12-inch cylindrical wedgewire screen will provide similar hydraulic bypass characteristics to the proposed half screen design is provided in Attachment 1. In addition, Attachment 1 discusses why the use of a cylindrical screen is preferred to a half screen for the testing. It is critical that the flow profile over the 12-inch test screen be as similar as reasonably possible to the anticipated flow profile over the 96-inch half screen while maintaining the required height within the water column. The use of a full cylinder and a simple, unobtrusive support system provides this. See Attachment 1 for further information. As described in Attachment 1, the analysis provided is applicable for the 12-inch diameter CWW screen and support stand that will be placed in the Merrimack River under typical river flow conditions (i.e. laminar flow).

The 3 mm slot width screen will have a design through-slot velocity of approximately 0.4 feet per second (fps), matching the half screen design presented in the 2016 memo. Designing the model screen to match the through-slot velocity of the proposed half screens is important because the ratio of sweeping velocity to through-slot velocity has been shown to have a large impact on the amount of entrainment reduction observed due to hydraulic bypass (Reference 4.1, Attachment 1). Testing a through-slot velocity that matches that of the proposed half screen design is important so that the hydraulic bypass effects observed during the test are applicable to the full-scale design.

Although the construction drawings for the test screen are currently being finalized by Johnson Screens as part of the on-going procurement process, it is expected that the screen will have an overall length of approximately 35 inches. This length includes two 3-inch long cones attached to each end of the screen, intended to improve the hydraulic flow pattern around the screen. These cones will be fabricated with the same angle as the cones included in the proposed half-screen design, so that a similar flow pattern will occur around the test screen. The screen will have a 6-inch diameter outlet which will be connected to the test pump by piping and/or flexible hosing.

The test screen is being fabricated out of Z-Alloy, matching the design presented in the 2016 memo. This allows the amount of biofouling that could occur on the proposed half screens to be modeled during the testing. The amount of biofouling that occurs during the confirmatory study could help to inform the design of the air burst system (ABS) that is currently included in the half screen design to help dislodge debris and prevent biofouling. It is important to note, however, that due to the brief duration during which the screen will be placed in the river, the test screen used in the confirmatory study will not be equipped with an ABS. Therefore, although the test screen is made out of the same material as the proposed half screens and is constructed with the same slot width, increased biofouling may be observed due to the lack of an ABS.

Due to the head loss through the wedgewire screens and associated piping, it is likely that the water level in the intake bay would decrease if the proposed half screen design were to be implemented. This intake bay drawdown could be amplified if significant blockage of the screens due to biofouling or debris were to occur. To help inform any potential impacts on drawdown within the intake structure due to biofouling and debris blockage, the head loss through the screen assembly will be monitored throughout the test. If the head loss across the screen becomes too high, it is possible that the screen could be damaged by the suction force of the pump. Therefore, if the head loss across the screen increases unexpectedly then the screen will be inspected and cleaned as required.

In addition to drawdown concerns, biofouling and debris blockage could also cause the screen to have higher localized through-slot velocities than designed, potentially reducing the effectiveness. If excessive biofouling were to occur due to the lack of an ABS on the test screen, the results of the test could under-predict the actual entrainment reduction that would occur for the full half screen design. Although the head loss measurement will help assess potential drawdown issues caused by the screens, it is not a direct indicator of screen blockage, as it is expected that over 50% of the screen would need to be blocked before the head loss would be noticeably impacted. Therefore, the possibility of using divers to visually monitor the screens periodically for biofouling and blockage will be reviewed during the detailed design of the study and included as appropriate.

In order to serve as a model for the half screens, the test screen will be located as close to the proposed location of the half screens as practical. The test screen will be placed in the vicinity of the Unit 1 intake structure, which is shown in the figure below. The screen will be placed at a distance from the shore that is representative of the expected location of the proposed half screens, and will be at an elevation in the water column that matches that of the half screens. Section 2.2.2 provides more details on how this elevation is determined and achieved.

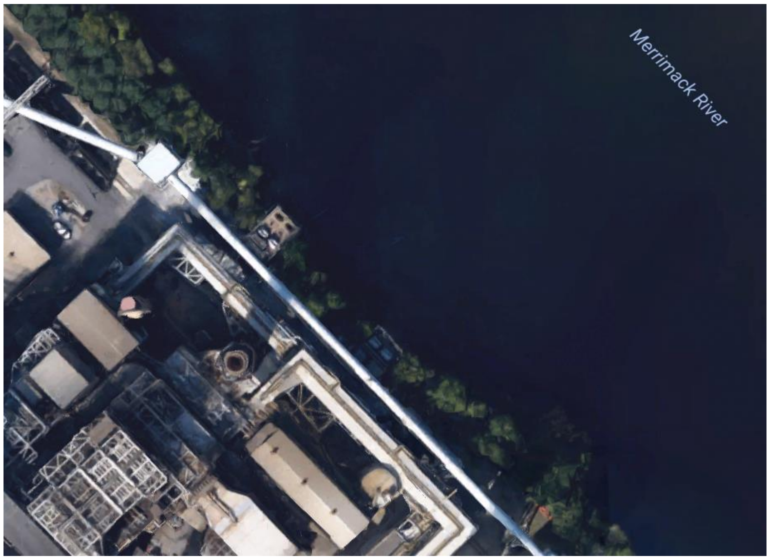

**Figure 1: Intakes 1 and 2 at Merrimack Station**[1]

When the screen location is finalized during the detailed design, the hydraulic zone of influence (HZOI) of the Unit 1 intake will be analyzed and considered. To analyze the HZOI of the Unit 1 intake, a 90° arc that extends outward from the intake mouth is considered. For a given radius of this arc, R, the velocity of water at the perimeter of the arc caused by the intake flow can be estimated (see Figure 2). This intake velocity is estimated by dividing the intake flow rate by the entire flow area, or the area of the arc.

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[1] Image courtesy of Imagery ©2017 Google, Map data ©2017 Google

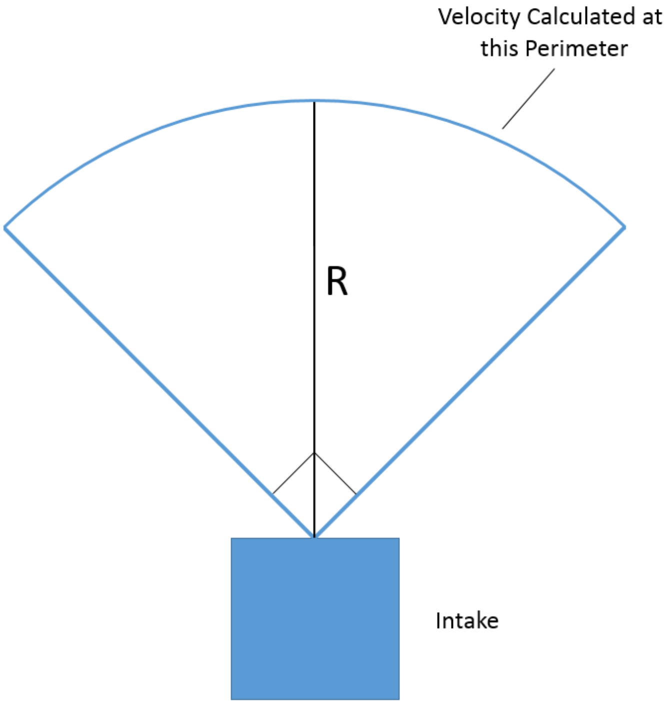

**Figure 2: Example HZOI Analysis Figure**

To determine how far from the intake the test screen must be placed, the radius of this arc will be extended until the estimated velocity due to the intake flow is acceptably small compared to the sweeping velocity of the river. In addition to the HZOI analysis, a team of divers will also be used to inspect the river bottom and assist in finding a suitable location to place the test screen. The screen will be located as close to the proposed half screen location as possible, but may need to be moved further upstream based on the diver observations or to avoid the hydraulic influence of the Unit 1 intake operation. As part of the HZOI analysis, it will also be confirmed that any discharge returned to the river will be returned in a location where it does not have an appreciable impact on the test or control samples.

### 2.2.2 Test Screen Support Stand

In order to support the test CWW screen and assure that it is maintained at the proper elevation in the water column, a custom support system has been designed and procured along with the screen itself. The support is being fabricated by Johnson Screens, and it is designed so that the screen will be at an elevation in the water column that is representative of the proposed half screen installation. The proposed half screens are 96 inches in diameter and would be placed flush with the river bottom. The centroid of a half-circle with respect to the vertical direction (y-bar) is defined as 4r/3π (Reference 4.2), which would be a height of approximately 20-3/8 inches.

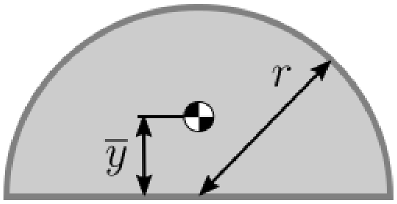

**Figure 3: Centroid of a Semicircle**

Therefore, the centerline of the cylindrical test screen will be elevated approximately 20-3/8 inches above the river bottom to match the centroid of the half screens that it is modeling. In order to adequately support the screen at this elevation, the support stand is designed as a tripod system that will be welded onto the outlet pipe of the screen. The use of a tripod allows for a more stable, wobble-free configuration. Each leg of the tripod is comprised of a 3/4-inch pipe and a 1-¼ inch rod that are joined together by a bushing, and welded to the wedgewire screen approximately halfway down the outlet pipe, extending below the screen. The legs are sized and cut at angles such that the centerline of the screen is located at a height of approximately 20-3/8 inches above the river bottom.

The screen will be oriented so that the axis of the screen is parallel to the predominant direction of the river current. The orientation of the screen and the centerline height will be confirmed by divers when the screen and support stand are installed in the river during construction. Although the orientation and centerline height of the screen may vary slightly during the test due to the dynamic nature of the river, these variations are expected to be small and not impact the validity of the test results. The possibility of using divers to visually monitor the screens periodically for significant changes to the screen orientation or centerline height will be reviewed during the detailed design of the study and included as appropriate.

Each of the three legs of the tripod will connect to a footing sized so that the downward force on the soil is evenly distributed. This will help to support the screen in the event that it is placed on softer soil. Each of the three footings will have a size of 6 inches by 6 inches. This results in a total affected area of 108 square inches for the entire support stand, or less than 1 square foot.

The proposed half screen solution is anticipated to be placed up to 80 feet into the river from the existing face of the screen house. A detailed evaluation of the zone of influence (ZOI) of the Unit 1 intake flow has not yet been completed. It is possible that the ZOI extends beyond the proposed half screen location, causing the test screen to be placed further upstream along the shoreline. Assuming that the length of hose in contact with the river bottom does not exceed 80 feet, and that the hose has a diameter of 6 inches and lays flat, approximately 40 square feet of area would be affected. Therefore, the affected area for the entire test setup is expected to be 41 square feet or less.

### 2.2.3 Test Pump

Based on testing experience, Normandeau has recommended an electric solids handling pump with an open type impeller to be used for the confirmatory study. This type of pump has been used in previous in-river testing performed by Normandeau, and has successfully provided the required flow with very limited damage to the entrained eggs and larvae. Initial investigations into the availability of this type of pump have indicated that it is readily available.

Solids handling pumps, like the one recommended by Normandeau, are often used for pumping fluids with concentrations of solid materials, including applications where the suspended solids must be handled with a minimum amount of breakage or degradation (Reference 4.3, Page 6-6). These pumps have a substantial clearance between the impeller and pump casing, allowing solids up to the size of the clearance to be passed through the pump without impact. This type of design minimizes the damage that eggs and larvae experience when passing through the pump.

Based on input from Johnson Screens, a flow of approximately 400 gallons per minute (gpm) is required to create a through-slot velocity of approximately 0.4 fps (see Section 2.2.1) for the test screen. Therefore, the pump will be sized to provide a flow of at least

400 gpm at the expected system head loss. The system head loss is estimated by considering pipe/hose losses, losses associated with valves and orifices, as well as losses due to elevation changes between the screen and the sampling nets.

The test setup will allow flows from both the test screen and control to be throttled to match each other, so that both samples can be taken at the same time and collect approximately the same volume of water. Any bypass flow that occurs as a result of throttling will be returned to the immediate shoreline of the river.

### 2.2.4 Acoustic Doppler Current Profiler

An ADCP will be used during the study to record continuous three-dimension water velocity measurements. ADCPs use the Doppler effect to measure water velocity by transmitting sound at a fixed frequency and listening to echoes that return from sound scatterers in the water. These sound scatterers are solids floating in the water, such as small particles, and, on average, move at the same horizontal velocity as the water (Reference 4.4, Page 6). The deployed ADCP will measure the current velocity in depth cell layers by internally solving the Doppler shift in frequency of the acoustic echo return signal from each depth cell. The velocity will be measured at a depth approximately equal to the centerline of the test screen. Retrieval of the ADCP for data download will be scheduled to occur approximately monthly from May 1st through August 31st to represent the typical entrainment period.

## 2.3 TESTING APPROACH AND ANALYSIS

Both the control and testing samples will be taken in the vicinity of the Unit 1 intake structure. The testing samples will be drawn through the test wedgewire screen, which will be located at an elevation in the water column representative of the proposed half screen design. The type of pump used for these samples is based on Normandeau's operating experience, and will be sized such that the through-slot velocity in the test screen matches that of the proposed half screen design. As detailed in the Normandeau memo in Attachment 2, the control sample will be taken in accordance with the sampling design and methods used to collect data for the May 2006 through June 2007 Normandeau entrainment abundance and survival study. The samples will be collected as simultaneously as possible, ensuring that the control samples are representative for the obtained testing samples.

As described by Normandeau in Attachment 2, the samples will be taken during various parts of the day during a 13-week sampling period, and each collected sample will be approximately 100 cubic meters. Each sample will be filtered through a 0.300 mm mesh net and into a collection tank. The collection tanks will be filled with river water to help buffer the flow and ensure that the eggs and larvae remain in good condition. The nets will be changed out frequently and washed with filtered water to collect the sampled material into labeled jars. The captured eggs and larvae will then be collected, preserved, and transported to a laboratory for analysis. More detail on the procedure and schedule for collecting samples is provided in Attachment 2.

Once the samples have been filtered, the water is pumped to the Unit 1 fish handling and return system, which discharges to Outfall 004. Any excess flow that is not filtered is re-routed and also discharged to Outfall 004. The flow rate required for the test screen to achieve a through-slot velocity of 0.4 fps is approximately 400 gpm (Section 2.2.3). The control sample flow will be throttled to 240 gpm, meaning that a total of 640 gpm of flow could be discharged when samples are being taken. Therefore, it is estimated that approximately 921,600 gallons per day of discharge to Outfall 004 could be required when samples are actively being collected.

The analysis of the samples will consist of identifying and counting the collected eggs and larvae, for both the control and test samples. According to Normandeau's Attachment 2, only ichthyoplankton that were alive at the time of collection will be identified and counted. The analysis will be subject to quality controls that dictate which samples are to be subsampled, how measurement equipment will be calibrated, and the percentage of allowable counts in the final data that exceed tolerance. Attachment 2 provides detailed information on the analysis processes and the quality controls that will be implemented. The processed data for the sample sets will then be compared, and an entrainment reduction due to the wedgewire screen will be calculated. The analysis will also incorporate the current flow data acquired through the ADCP, and will investigate the relationship between the velocity of the sweeping flow and the observed reduction in entrainment.

Once the analysis is complete, the processed data and calculated entrainment reduction results will be presented in a test report document prepared by Normandeau. These results will then be available for use to help fully inform the best technology available (BTA) evaluation at Merrimack Station and the potential implementation of the half screen design presented in the 2016 memo.

## 3.0 SCHEDULE

The table below presents a preliminary schedule for the confirmatory study preparation and sample collection. Note that the test design and preparation have already begun, and the long lead time items are being constructed so that the testing schedule is not delayed. The testing is scheduled to begin in early May, and will last approximately three months to fully encompass the typical 13-week entrainment season.

**Table 1: Preliminary Confirmatory Study Schedule**

| Milestones | Target Start | Duration |
|---|---|---|
| Procurement and Construction | 1/23/17 | ~3 months |
| Sample Collections | Early May | ~3 months |

## 4.0 REFERENCES

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

4.2 Hibbeler, R.C., "Engineering Mechanics Statics", 10th Edition.

4.3 Perry & Green, "Perry's Chemical Engineers' Handbook", 6th Edition.

4.4 "Acoustic Doppler Current Profiler Principles of Operation A Practical Primer," RD Instruments, 2nd Edition.

4.5 Blevins, Robert D., "Applied Fluid Dynamics Handbook," Van Nostrand Reinhold Company, Inc., 1984.

4.6 Lindeburg, Michael R., "Mechanical Engineering Reference Manual for the PE Exam," 13th Edition.

## Attachment 1: Wedgewire Screen Hydraulic Evaluation

As discussed in the 2016 memo (Ref. 4.1), two 96-inch half screens are proposed for installation at Unit 1, and five such screens are proposed for Unit 2. Due to cost, engineering, and schedule restrictions, it is not practical to use a full 96-inch diameter half screen for the confirmatory study. A 96-inch screen is very large – for reference, a smaller 84-inch half screen is shown below in Figure 4.

**Figure 4: Johnson Screens Half T-84HCE screen**

To preclude the need to purchase a 96-inch half screen for the confirmatory test, a smaller screen will be used. A 12-inch screen manufactured by Johnson Screens is analyzed for acceptability within this attachment. A small screen is necessary for the in-river testing due to the limitations on the size of the confirmatory study equipment that can be readily procured and installed and the requirement that this equipment produce a through-slot velocity of approximately 0.4 fps.

Based on input from Normandeau and previous entrainment studies, the entrainment density can vary substantially with location in the water column, and with location from shore. In order to appropriately replicate the conditions that the proposed 96-inch half screen would experience, the test screen should be located and supported in a way that matches as many of these parameters as possible. In order for the test 12-inch screen to be located at a representative height within the water column, a support system is required to elevate the 12-inch test screen above the river bottom. This tripod support system is described in Section 2.2.2.

Half screens can be manufactured that are 12 inches in diameter, but a 12-inch half screen would still need to be supported above the river bottom to achieve the correct height within the water column. In addition to matching the location within the water column, the 12-inch test screen should be installed in such a way that the flow profile is similar to that of the proposed 96-inch half screen. The anticipated flow profile over a 96-inch half screen, with cone deflectors on each end of the screen, is smooth and includes no abrupt changes in direction of the flow near the screen. This is shown in Figure 5 below.

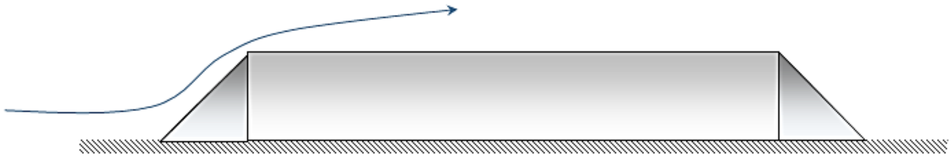

**Figure 5: Anticipated flow profile over the 96-inch half screen, mounted flush to the river bottom**

A variety of configurations using a 12-inch half screen were investigated to determine which, if any, can provide a similar flow profile over the screen. The goal was to support the screen in a way that achieved the proper water column height and provided a smooth flow profile without any abrupt changes in direction. See Figure 6 for several configurations that were investigated.

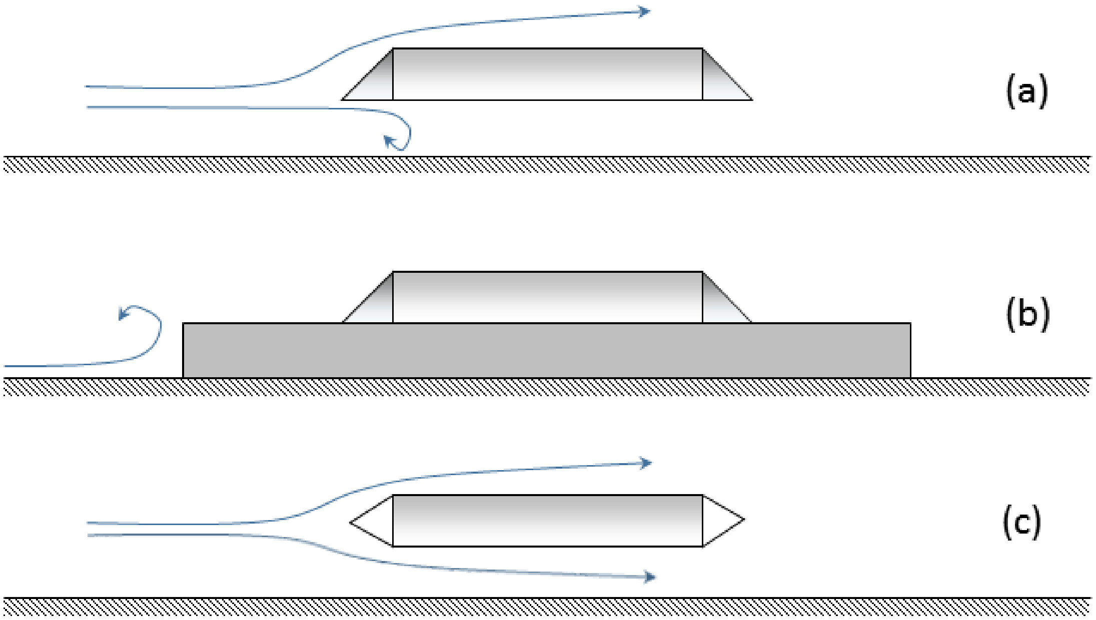

**Figure 6: Flow profiles for various wedgewire screen configurations**

Arrangement A: If a 12-inch half screen were to be supported above the river bottom, the flat surface on the bottom of the screen has the potential to create a wake zone beneath the screen, depending upon the exact flow direction and approach angle. The wake zone beneath the screen could potentially disrupt the flow dynamics around the screen, and alter the hydraulic bypass behavior of the screen. This could lead to a condition in which the flow behavior is non-representative of the proposed 96-inch half screen.

Arrangement B: Installation of a solid body beneath a half-screen would resolve the wake zone beneath and/or near the screen. However, the blunt body beneath the screen could create a significant flow disturbance upstream of the screen. It is unknown how this would affect the flow dynamics near the screen. A gradual ramping-up, instead of a step, was also considered. However, this design may have the potential to create a region of accelerated flow in the area of the screen (similar to a venturi). This may create a non-representative condition.

Arrangement C: Installation of a cylindrical screen would allow the screen to be elevated above the river bottom, and would allow for a smooth flow profile to be maintained on all sides of the screen, similar to the proposed 96-inch half screen. The method for supporting the 12-inch full cylindrical screen would need to be configured such that a large disturbance is not created upstream of the screen. For this reason, a small, unobtrusive support system would be recommended. The test screen support system is discussed further in Section 2.2.2.

As discussed above, a 12-inch cylindrical screen is best-suited to represent the expected flow profile over the proposed 96-inch half screens in a way that avoids having to install a full-scale screen in the river. Qualitatively, supporting the 12-inch cylindrical test screen with an unobtrusive support system allows a smooth flow profile to be achieved while elevating the screen centerline to the appropriate location within the water column. However, having a smooth flow profile does not in itself guarantee that the bypass characteristics of the two screens will be similar.

A study was conducted to examine the similarities between the anticipated flow profiles between the 12-inch and 96-inch screens with cone end deflectors. The purpose of the cone ends is to deflect flow around the screen in a more hydrodynamic manner to reduce drag and improve entrainment performance characteristics. The deflection of the flow is a key contributor to the hydraulic bypass effect of wedgewire screens. The size difference between the screens (12 inches versus 96 inches) and cone angle were investigated to determine if any adjustments should be made to ensure that the bypass flow characteristics would be similar between the two.

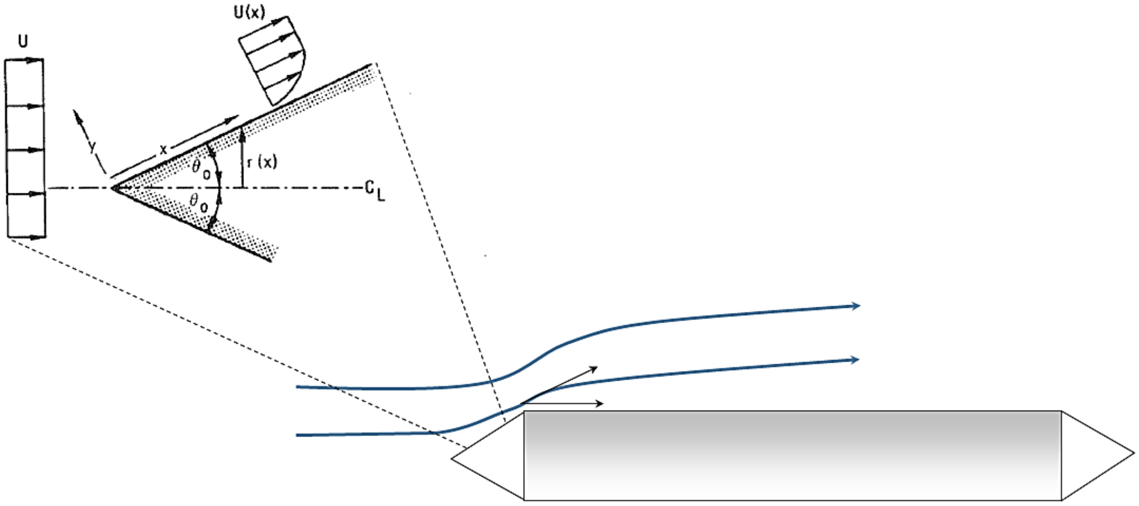

**Figure 7: Bypass flow characteristics around wedgewire screen: boundary layer separation angle (Ref. 4.5)**

For the study, the angle at which the flow is deflected from the screens by the cone deflector was studied in detail. This was investigated by calculating the boundary layer thickness using axisymmetric flow theory. When a free-flowing liquid interacts with a solid surface, a boundary layer forms near the interface in which there is less velocity and momentum than in the free stream. The angle at which this boundary layer forms relative to the screening surface is considered in this evaluation as an indicator of how entrainable organisms would bypass the screening surface. The momentum thickness is a measure of the boundary layer thickness, and is theoretically defined as the distance by which the solid body would have to be displaced into the flow to account for the loss of momentum due to the boundary layer formation.

The momentum thickness ($\delta_2$) is mathematically defined as follows (Ref. 4.5):

$$\delta_2 = \int_0^\infty \frac{u}{U}\left(1 - \frac{u}{U}\right) dy$$

Where:

$\delta_2$ = Momentum thickness
u = Local flow velocity parallel to the surface
U = Free stream velocity parallel to the surface
y = Distance perpendicular from the surface into the flow

The momentum thickness for flow over a cone was investigated (see left side of Figure 7). A solution to the boundary layer under this configuration is possible using a Mangler Transformation, which enables axisymmetric flow to be interpreted from an equivalent two-dimensional flow. The cone angle for the screens is custom for each installation and can be determined during detailed design. For the purposes of this investigation, a constant angle of 90° is assumed based on photographs and drawings of wedgewire screens. Based on this assumed input, a half-angle ($\Theta_0$) of 45° is utilized (see left side of Figure 7).

Based on the information provided in Table 10-6 of Reference 4.5, the following relationship was developed between the half-angle and the value *n* used in the Mangler Transformation.

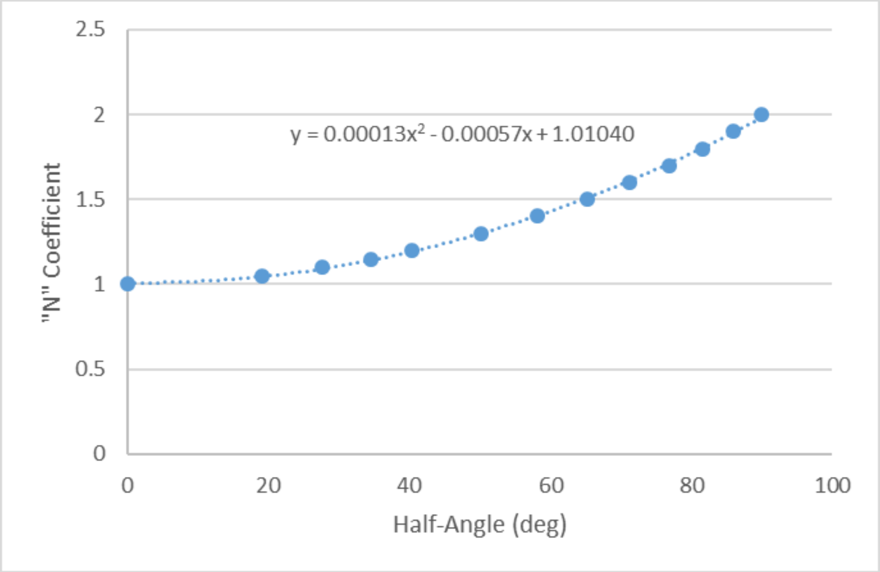

**Figure 8: Relationship between cone half-angle and the "n" coefficient used in the Mangler Transformation**

From the literature, a curve fit was created so that the two parameters could be quickly related. From the coefficient $n$, the equivalent two-dimensional flow parameter $\beta$ can be defined by the equation below (Ref. 4.5).

$$\beta = \frac{2\left(n-1\right)}{n+2}$$

Where:

$\beta$ = Two-dimensional flow coefficient

n = Dimensionless coefficient

The value of $\beta$ can be used as an input for the similarity solution for a two-dimensional boundary layer. Specifically, the similarity solution for a dimensionless momentum boundary layer profile

($\delta^*_2$) was utilized. Similar to the previous relationship, a curve fit was created from the values in Table 10-5 of Reference 4.5 to allow for a quick relationship to be defined.

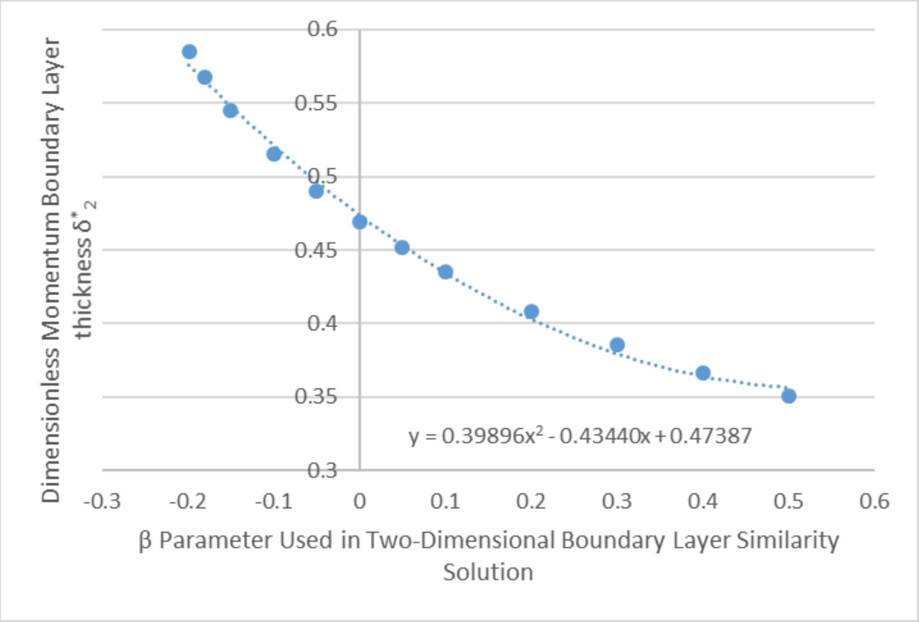

**Figure 9: Similarity solution for two-dimensional boundary layers**

Based on this relationship, a dimensionless momentum boundary layer thickness ($\delta^*_2$) can be determined from any two-dimensional flow parameter $\beta$. The final step is to apply the boundary conditions (i.e., geometry and velocity) to the solution. The solution for the momentum thickness ($\delta_2$) is determined using the following equation (Ref. 4.5).

$$\delta_2 = (2-\beta)^{1/2} x \left(\frac{\upsilon}{U\ x}\right)^{1/2} \delta_2^*$$

Where:

$\delta_2$ = Momentum boundary layer thickness (ft)

$\beta$ = Dimensionless two-dimensional flow coefficient

$x$ = Distance from edge of cone along inclined surface (ft)

$v$ = Kinematic viscosity (ft$^2$/sec)

U = Free stream velocity (ft/s)

$\delta^*_2$ = Dimensionless momentum boundary layer thickness

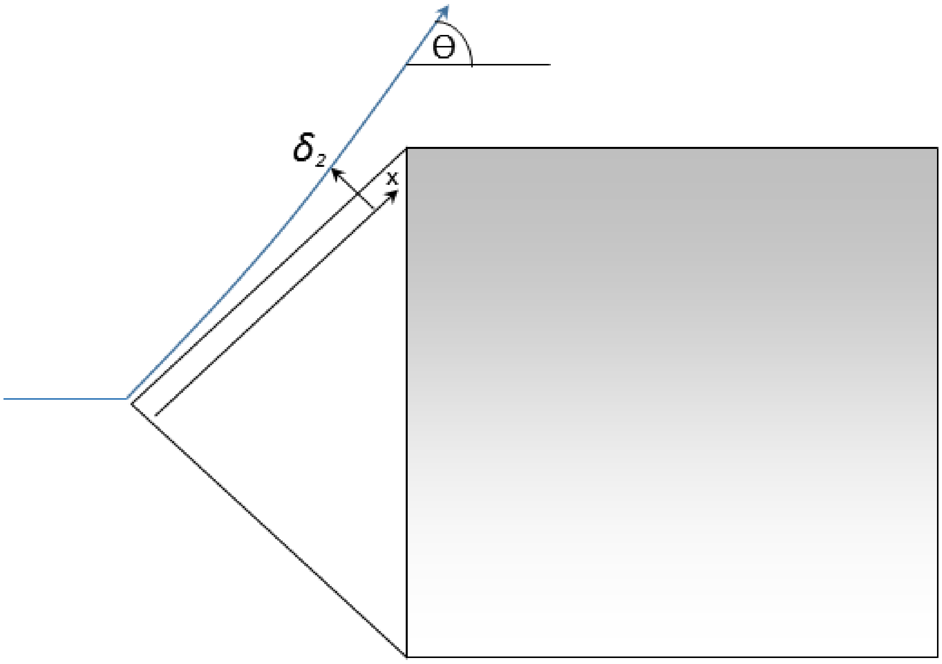

**Figure 10: Momentum boundary layer thickness visualization**

Based on the methodology described above, conditions for both the 12-inch cylindrical screen and the 96-inch half screen were used to determine the momentum boundary layer thickness at the location where the inclined surface (i.e., the cone) meets the flat surface (i.e., where the screening material begins). The inputs and results are presented below in Table 2.

**Table 2: Momentum boundary layer thickness analysis inputs and results**

| Parameter | Test Screen | Proposed Half Screen | Notes |
|---|---|---|---|
| Diameter (in.) | 12 | 96 | |
| Cone Angle (deg) | 90 | 90 | Estimated based on photographs |
| Kinematic Viscosity ($ft^2/s$) | 1.22E-5 | 1.22E-5 | Based on 60°F water (Ref. 4.6, P. A-122) |
| River Velocity (ft/s) | 2.9 | 2.9 | Based on average velocity reported in December 2016 Wedgewire Half Screen Technical Memo (Ref. 4.1) |
| Maximum "x" (ft) | 0.71 | 5.66 | Location at which boundary layer thickness is solved |
| Momentum Boundary Layer Thickness at Maximum "x" (in.) | 0.012 | 0.033 | |
| Angle of separation with respect to cone surface (deg) | 0.945 | 0.336 | |
| Angle of deflection with respect to horizontal ($\Theta$) (deg) | 45.945 | 45.336 | |

In summary, while the boundary layer thickness is greater for the 96-inch screen due to the greater length over which the boundary layer is able to develop, the angle of separation is not significantly different. Further, the angle of deflection $\Theta$ is dominated by the cone angle (90/2 = 45). Therefore, as long as the cone angles are equal, the angle of separation will be very similar between the two screens. It is critical that the cone angles of the test screen and proposed half screen match exactly. This will also help ensure that the flow disturbances between the conical and cylindrical surfaces are similar between the two screen types. Discussions with Johnson Screen have indicated that this angle can be custom for any installation. Therefore, this critical parameter can be matched between the two screens.

In conclusion, because the angle of deflection is similar between the 12-inch cylindrical and 96-inch half screen, the difference in size does not significantly affect the bypass flow characteristics of the screen. Therefore, the use of a 12-inch cylindrical screen supported by an unobtrusive support system is hydraulically acceptable to mimic the flow characteristics of the proposed 96-inch half screen system. Note that the above analysis does not apply to conditions where the incoming river flow is initially turbulent (i.e., non-laminar).

NORMANDEAU ASSOCIATES
Environmental Consultants

# Attachment 2 to the Wedgewire Screen Confirmatory Study Scope Description for PSNH Merrimack Station Units 1 & 2, Bow, New Hampshire

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## 1.0 Introduction

Public Service Company of New Hampshire doing business as Eversource Energy ("PSNH") operates Merrimack Station using a once-through cooling water intake structure ("CWIS") to obtain condenser cooling water from the Hooksett Pool section of the Merrimack River in Bow, New Hampshire under an existing National Pollutant Discharge Elimination System permit (NPDES Permit NH0001465) issued by the United States Environmental Protection Agency ("USEPA"). Enercon Services, Inc. ("Enercon") and Normandeau Associates, Inc. ("Normandeau") are preparing a scope description for a study to measure the entrainment reduction performance of narrow-slot wedgewire screens if designed, installed, and operated at Merrimack Station Units 1 & 2 ("the Scope Description"). Normandeau was requested to provide this Attachment 2 to provide an overview of the field equipment, sampling design, and laboratory procedures proposed for the biological evaluation portions of the Scope Description. Normandeau will prepare a project-specific Quality Assurance Plan and Standard Operating Procedures ("SOP") prior to the start of entrainment sampling at Merrimack Station once the Scope Description is approved.

## 2.0 Wedgewire Test Screens

A single 3-mm slot width wedgewire "test" screen will be deployed in the Merrimack River as described in the Scope Description. The discharge flow from the wedgewire test screen will enter the top of a water-filled tank containing a sampling net with 0.300-mm mesh. The collection net is cylindrical with a short conical section at the lower end tapering to the cod end collection cup. The net's shape is designed to maximize the filtering surface area (for low through-mesh velocity) and to allow the net to balloon outward away from the incoming stream of water (reducing the risk of net abrasion to the ichthyoplankton). Volume sampled by the test system will be measured by a factory-calibrated Signet flowmeter near the collection tank. A target test sample volume of about 100m$^3$ will be filtered and the contents collected in each two-hour interval at a flow rate of about 220 gallons per minute ("gpm") to 240 gpm.

## 3.0 Control Samples

In-plant control samples will be paired in two-hour time intervals with the test 3-mm wedgewire screen samples and collected from the Unit 1 CWIS using the same sampling equipment and procedures from the May 2006 through June 2007 entrainment study (Normandeau 2007). Volume sampled by the control system will be measured by a second factory-calibrated Signet flowmeter near the collection tank. As with the 3 mm test samples, a target control sample volume of about 100m$^3$ will be filtered and the contents collected in each two-hour interval at a flow rate of about 220 gpm to 240 gpm. Also as with the 3 mm test samples, control samples will be filtered through a 0.300-mm mesh cylindrical collection with a short conical section at the lower end tapering to the cod end collection cup.

## 4.0 Sampling Design and Schedule

The Merrimack Station wedgewire screen study will be scheduled for 13 consecutive weeks of sampling beginning during mid-May and continuing until early-August of 2017. This 13 week period was observed to represent 97% of the annual entrainment abundance at Merrimack Station, Units 1 and 2 combined (Normandeau 2007). Each matching set of samples will consist of one 100 $m^3$ sample taken from the 3 mm wedgewire test screen plus one 100 $m^3$ sample from the in-plant control (i.e., two samples in each two-hour set). A sampling "day" consists of 12 consecutive two-hour periods, and three sampling days will occur within each scheduled sampling week, representing 72 hours, and each pair of samples will be collected concurrently within a two-hour time period. Therefore, there will be 12 two-hour periods per sampling day, 36 two-hour periods sampled per week, and the entire 13 consecutive weeks of sampling consists of 468 matched pairs of one 3-mm test screen and one control sample (Table 4-1). The study design will total 936 samples collected if completed as planned.

## 5.0 Sample Collection Procedures

At the start of each scheduled weekly 96-hour sampling interval, the pumping systems for the wedgewire test screen will be started, the valve controlling the Unit 1 in-plant control sample discharge will be opened, and continuous constant flow will be established into each sampling tank. The pumping rate for the test wedgewire screen will be adjusted to provide the designed through slot velocity of 0.4 fps at the wedgewire test screen and allow a 100 $m^3$ sample to be delivered into the sampling net from each consecutive two-hour period. Similarly, the flow rate for the Unit 1 CWIS control sample will be adjusted to deliver a sampling flow of about 50 $m^3$/hour (220 gpm to 240 gpm) into the sampling net to obtain a 100 $m^3$ sample during each consecutive two-hour period of sampling.

The target test sample volume of about 100$m^3$ for each two-hour test or control sample will also be measured at the beginning and end of each week of sampling by a timed volumetric method of calculating flow volume to confirm the accuracy of the Signet flow meters. Each flowmeter check will be performed by filling an empty collection tank to the overflow ports of a measured and known volume (e.g., the outer barrel sampler tank). The time required to fill the tank with 320 gallons until it begins to overflow is recorded to the nearest 0.1 second and used to calculate the flow rate in gpm for comparison with the Signet flow meter reading for the same calibration period.

Each 100 $m^3$ entrainment test or control sample will be pumped into a 0.300 mm mesh net suspended in a tank sampler filled with ambient water to buffer the flow and help ensure that ichthyoplankton will be in good condition for identification and enumeration, targeting an overall percentage of damaged eggs and larvae of less than 15%. Each net will be changed out frequently (about every 20 minutes) with a clean net and washed into a collection jar during each two-hour sample to help minimize damage to the collected ichthyoplankton due to turbulence in the net. At the end of each two-hour sampling interval, the remaining material in the collection net will be washed into the sample jar to terminate the two-hour sample, and replaced with clean nets to begin the next two-hour sample collection. The nets removed from the tanks will be washed down with filtered water from the outside to concentrate the sample material in the cod end collection cups, the samples will be rinsed into labeled jars, and the samples will be preserved with a final concentration of 6% buffered formalin. Sampling should be nearly continuous during each sampling day, with only about one minute needed to switch nets at the end of each two-hour sampling interval and the beginning of the next.

Ambient water temperature (nearest 0.1°C) and dissolved oxygen concentrations (nearest 0.1 mg/l) will be measured and recorded once during each two-hour sampling period in the water flow in both the wedgewire test screen sampling tank and in the in-plant control tank.

**Table 4-1. Weekly schedule and number of test and control samples proposed for the Merrimack Station Unit 1 Wedgewire Screen Study if conducted in 2017.**

| Week | Dates (2017) | Number of Samples Collected | |
|---|---|---|---|
| | | 3 mm Test Screen | In-Plant Control |
| 1 | 8-12 May | 36 | 36 |
| 2 | 15-19 May | 36 | 36 |
| 3 | 22-26 May | 36 | 36 |
| 4 | 29 May-1 Jun | 36 | 36 |
| 5 | 5-9 Jun | 36 | 36 |
| 6 | 12-16 Jun | 36 | 36 |
| 7 | 19-23 Jun | 36 | 36 |
| 8 | 26-30 | 36 | 36 |
| 9 | 4-8 Jul | 36 | 36 |
| 10 | 10-14 Jul | 36 | 36 |
| 11 | 17-22 Jul | 36 | 36 |
| 12 | 24-28 Jul | 36 | 36 |
| 13 | 31 Jul-4 Aug | 36 | 36 |
| **All** | | **468** | **468** |

## 6.0 Laboratory Analysis

Each entrainment sample represents the contents of about 100 m$^3$ of ambient water that has been withdrawn from Hooksett Pool of the Merrimack River and filtered through a 0.300 mm mesh net during about two-hours of sampling, washed into a one-liter sample container, and preserved at a final concentration of 6% buffered formalin (or 95% ethanol). Samples with high abundances (at least 400 eggs and 400 larvae) will be subsampled in the laboratory for eggs or larvae (or both). These quotas will apply to the total count of all species combined, not to individual species. If a sample contains low numbers of larvae but a high total volume of detritus and other plankton (more than 400 ml settled volume), a maximum of one-half of the sample will be sorted. The reliability of the selected splitting method will be documented by finding no statistically significant difference ($p \leq 0.05$) in a test of randomly selected split pairs, using a paired comparison method like a Chi-square test. The unanalyzed portion of any split sample, and the sorted and identified material from each sample processed, will be retained for a period of one year following delivery to, and acceptance of, the final report by PSNH. After one year all or some of the samples may be disposed of, with written permission from PSNH.

The enumeration of already dead organisms artificially inflates the densities of eggs and larvae found in entrainment samples. The exclusion of these dead organisms therefore is important when processing each ichthyoplankton sample, to provide the most accurate and representative estimates of entrainment densities and abundance. Fish eggs and larvae which were dead prior to capture and preservation exhibit changes in their physical characteristics that can be observed under microscopic examination and therefore used by Normandeau's Biological Laboratory in the sorting and identification procedures to distinguish ichthyoplankton eggs and larvae that were alive at the time of collection and preservation from those that were dead. Only ichthyoplankton that were alive at the time of collection will be identified to the lowest practical taxon and enumerated.

Eggs and larvae will be identified to the lowest practical taxon (Normandeau 2007) and counted by life stage (eggs, yolk-sac larvae, post yolk-sac larvae, or juvenile). Up to 30 eggs and 30 larvae per taxon will be measured from each sample (total length for eggs and larvae, greatest larval body depth and head capsule width and depth to the nearest 0.1 mm). The 30 eggs and 30 larvae measured per taxon will be selected randomly from all eggs and all larvae of that taxon regardless of life stage. Any damaged fragments of a larva will be counted only if it includes the head, to prevent double counting of any larvae broken during sample processing. The number and percentage of intact and damaged specimens will be determined by taxon and life stage and used to evaluate the ability of the field methods to provide samples with damaged specimens less than 15%. A voucher collection of ichthyoplankton eggs and larvae identified will be archived as a reference collection, retained along with the entrainment samples for one year, and disposed of as specified earlier for the unanalyzed portion of entrainment samples.

Each ocular micrometer used for total length or body depth measurements will be calibrated periodically (at least weekly) using a stage micrometer. After calibration of ocular micrometers on zoom microscopes, a calibration mark will be placed on the microscope so that measurement accuracy is maintained. Ocular micrometers on microscopes that have been adjusted or moved must be recalibrated before use. The calibrations will be documented in a log showing the dates and results of the calibrations.

Each technician's counts will be verified by a quality control ("QC") continuous sampling plan with a 10% Average Outgoing Quality Limit ("AOQL"), meaning that fewer than 10% of the counts in the final data could exceed tolerance (ASQC 1981). Tasks subject to QC are both sorting and identification. A sorted sample will fail the QC inspection if the QC inspector finds that 10% or more of the eggs and larvae in the sample had been missed by the sorter. All additional organisms found during sorting QC will be added to the sample vials before the identification phase. The identifications for a sample fails the QC inspection if the QC inspector finds that 10% or more of the eggs and larvae in the sample exceed the tolerance criteria for counting, identification, or life stage determination. Counts, identifications, and life stage determinations for all samples failing identification QC will be corrected on the data sheets before data entry.

Questionable measurement data are identified on an individual specimen basis by assigning a "valid" code, to allow analysts the option of excluding the questionable measurements without excluding the entire sample. Questionable measurement data, such as an unreasonable body depth to length ratio compared to the daily quartile values for the depth/length ratio, may be identified as either "outliers" inappropriate for analysis or "extreme values" invalid for analysis. Outliers will be defined as either more than 1.5 times the interquartile range ("IQR") below Q1 or more than 1.5 IQR above Q3; extreme values will be defined as either more than 3 IQR below Q1 or more than 3 IQR above Q3 (Tukey 1977).

Laboratory data will be double-keyed and verified by data entry software. Preliminary data files will be checked systematically by error-checking software and manual inspection, to identify and resolve questionable values. Final data files will be subjected to 1% AOQL inspection against the original data sheets.

## 7.0 Literature Cited

American Society for Quality control (ASQC). 1981. American national standard sampling procedures and tables for inspection by attributes. ANSIZI.4.1981. American Society for Quality Control, Milwaukee, Wisconsin.

Normandeau Associates, Inc. (Normandeau) 2007. Entrainment and impingement studies performed at Merrimack Generating Station from June 2005 through June 2007. Report prepared for Public Service of New Hampshire, October 2007.

Tukey, J.W. 1977. Exploratory Data Analysis. Addison-Wesley Publishing Company, Inc. Philippines. 506 p.