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CYLINDRICAL WEDGEWIRE SCREEN PILOT STUDY & ENTRAINMENT MONITORING FOR GREENIDGE GENERATING FACILITY 2019

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1. INTRODUCTION

Section 316(b) of the Clean Water Act (CWA) (33 U.S.C. § 1326(b)) requires that the location, design, construction and capacity of cooling water intake structures reflect the best technology available (BTA) for minimizing adverse environmental impact. The State of New York similarly requires that cooling water intake structures reflect the best technology available for minimizing adverse environmental impact (6 NYCRR §704.5). The process for reaching BTA decisions, and the standards for BTA in New York are described in the New York State Department of Environmental Conservation (NYSDEC) Commissioner's Policy 52, (CP-52), which was adopted in 2011.

The BTA for Greenidge, as determined by NYSDEC in accordance with CP-52, is included in the Greenidge SPDES permit (NY0001325), which was renewed on October 1, 2017. The 2017 SPDES permit includes the following BTA requirements:

> Best Technology Available
>
> 1. The Department has determined that the best technology available (BTA) for the Greenidge Station cooling water intake structure is the use of cylindrical wedge-wire intake screens (slot size 0.5 mm < 1.0 mm) and variable speed drive pumps (VSPs) at Unit 4. A pilot study is necessary to confirm that the facility can operate reliably with wedge wire screens in this slot range. If the Department determines that the 0.5 mm to 1.0 mm slot-width screens are problematic at this facility, a contingency plan to meet the performance requirements contained in this permit must then be submitted for Department review and approval (see Biological Monitoring Requirement No. I3)
>
> Variable Speed Drives on Cooling Water Pumps
>
> 2. Within six (6) months of the effective date of the permit (EDP + 6 months), the permittee must provide a full description (including drawings) and schedule for installing and operating variable speed drives on the cooling water pumps at the Greenidge Station.
>
> 3. Within two (2) years of the effective date of the permit (EDP + 2 years), the permittee must complete the installation of the variable speed drives on the cooling water pumps at the Greenidge Station.
>
> Cylindrical Wedge Wire Screen Pilot Study
>
> 4. Within six (6) months of the effective date of the permit (EDP + 6 months), the permittee must submit an approvable Cylindrical Wedge-Wire Screen (CWWS) Pilot Study Plan that includes:
>
> > a. Details on CWWS dimensions and operational specifications [i.e., capacity, through-slot velocities (no greater than 0.5 fps), frequency of operation, proposed air burst cleaning frequencies];
> >
> > b. Frequency of screen operation;
> >
> > c. A detailed schedule for the study, plans, drawings, and description of all work to be done for the installation, testing and determination of the efficacy of the intake screens;
> >
> > d. Six-month progress reporting, and final report to be submitted within 6 months of the pilot study completion; and
> >
> > f. Description of all data analyses, calculations, models, and statistics that may be used to optimize the operations of CWWS. Upon receipt of Department

approval, the permittee must implement the Cylindrical Wedge-Wire Screen Pilot Study in accordance with the approved plans. The Cylindrical Wedge-Wire Screen Pilot Study Plan will become an enforceable condition of this SPDES permit.

Verification Monitoring Plan

6. Within three (3) months of Department approval of the Technology Installation and Operation Plan, the permittee must submit an approvable Verification Monitoring Plan. This plan must include details of procedures to confirm that the necessary reductions in impingement and entrainment required by this permit are being achieved, and must include the following:

a. At a minimum two years of in-plant entrainment monitoring over a five-year averaging period to verify the full-scale performance of BTA measures;

b. A description of the frequency and duration of monitoring, the parameters to be monitored, and the basis for determining the parameters and the frequency and duration for monitoring;

c. A schedule of implementation; and

d. A draft proposed Standard Operation Procedure (SOP) that describes the sampling protocols for these monitoring studies.

The plan and SOP must be updated as required by the Department. Upon receipt of Department approval, the permittee must complete the Verification Monitoring Plan in accordance with the approved schedule. The Verification Monitoring Plan and approved schedule will become an enforceable condition of this SPDES permit.

The Variable Speed Drives were installed in June 2019 in accordance with a NYSDEC-approved plan. The Cylindrical Wedge-Wire Screen (CWWS) Pilot Study, the results of which are provided herein, was conducted in accordance with the CWWS Pilot Study plan and schedule approved by NYSDEC on April 18, 2018. This CWWS Pilot Study Report provides information on screen fouling, debris clogging, and entrainment reduction efficacy for the two slot widths (0.5 and 1.0 mm) specified in the SPDES permit. Because the most recent facility-specific entrainment data were collected in 2006, the first year of Verification Monitoring required by Biological Monitoring Requirement 6.a was conducted in combination with the CWWS Pilot Study. This allows for the information on the types and sizes of aquatic organisms currently subject to entrainment at the Greenidge Generating Facility (Greenidge or the Facility) to be available to inform the slot width and other design aspects of the CWWS system.

2. GREENIDGE GENERATION

2.1 GENERAL

Greenidge is located in Yates County, New York on the western shoreline of Seneca Lake (Figure 2-1). The Facility formerly consisted of six coal-fired boilers and four turbine generators. Units 1 and 2 were removed from service in 1985. Unit 3, which operated from 1950 through 2009, had a capacity of 54 MW and used 34.2 kgpm cooling water. Unit 4, which began operation in 1953 and is the only unit still in existence, has a generating capacity of 107 MW, and has a total calculated circulating water pump flow rate of 68.0 kgpm. Unit 4 has been converted to burn primarily natural gas (with up to 19% biomass co-firing).

Cooling water for Unit 4 enters the station from Seneca Lake via a 7-ft diameter suction pipe extending from the pumphouse to a point 650 feet offshore). The intake pipe is elevated above the lake on wood pilings (Figure 2-2) and angled down at the lake end. The pipe withdraws water from a 27-ft x 27-ft steel intake structure composed of 3/16-inch bars on 6-inch centers in about 11 feet of water. The approach velocity at the bar rack is about 0.14 fps. There are no traveling screens on Unit 4. Reversing valves on the condenser automatically wash out any debris that might accumulate on the condenser tube face.

The three Unit 4 circulating water pumps (Figure 2-3) are horizontal, single stage, double suction centrifugal pumps manufactured by Westinghouse Electric Corporation. The pumps have 42-inch diameter suction connections and 36-inch diameter discharge connections. Flows are 22.67 kgpm for one pump operation, 45.3 kgpm for two pump operation, and 68.0 kgpm for three pump operation. Outside of the summer months, usually only two of the three pumps are operated simultaneously. In 2019, Variable Frequency Drive units were installed in accordance with Biological Monitoring requirements (2) and (3) of the SPDES permit.

The Unit 4 condenser, manufactured by the Westinghouse Electric Corporation, has 50,000 square feet of cooling surface made up of 9098 3/4" 0.D. No. 18 BWG Admiralty metal tubes. The tubes have an effective length of 28 feet. The condenser has parallel upper and lower chambers that can be operated independently. Each tube bank is approximately circular in cross section, with the tubes arranged in radial lines, and is entirely surrounded by a zone of exhaust steam. The air off-take is located at the center of the condenser so that steam will flow radially inward from the exhaust steam zone to the central core which is connected to the air ejector. The circulating water inlet manifold is fitted with two motor operated backwash valves to permit the water flow through the tubes to be reversed as necessary to remove debris and impinged organisms.

After passing through the Unit 4 condenser, cooling water discharges into a common 54" diameter steel pipe which connects to a concrete tunnel 41" x 61" in cross-section which extends to the north wall of the turbine room basement. At this point the tunnel divides into two 42" diameter steel pipes connecting to the temperature activated circulating water backwash valves. Water then flows through a 7 x 10-foot tunnel to the discharge cannel. The discharge canal, which is approximately 900-feet long, empties into the Keuka Outlet about 700 feet upstream from Seneca Lake.

Service water is supplied to Greenidge by four house service water pumps (rated at 550 gpm per pump), two hydrogen cooling pumps (rated at 120 gpm per pump), and a dual Hydro-jet pump (rated at 1,300 gpm). All service water is withdrawn from the Unit 3 intake downstream of the traveling screens. The Unit 3 intake also supplies water to a fire pump that is for emergency use only. No service water pump withdraws water from the Unit 4 intake. Intermittent operation of the traveling screens is required as a part of the service water supply.

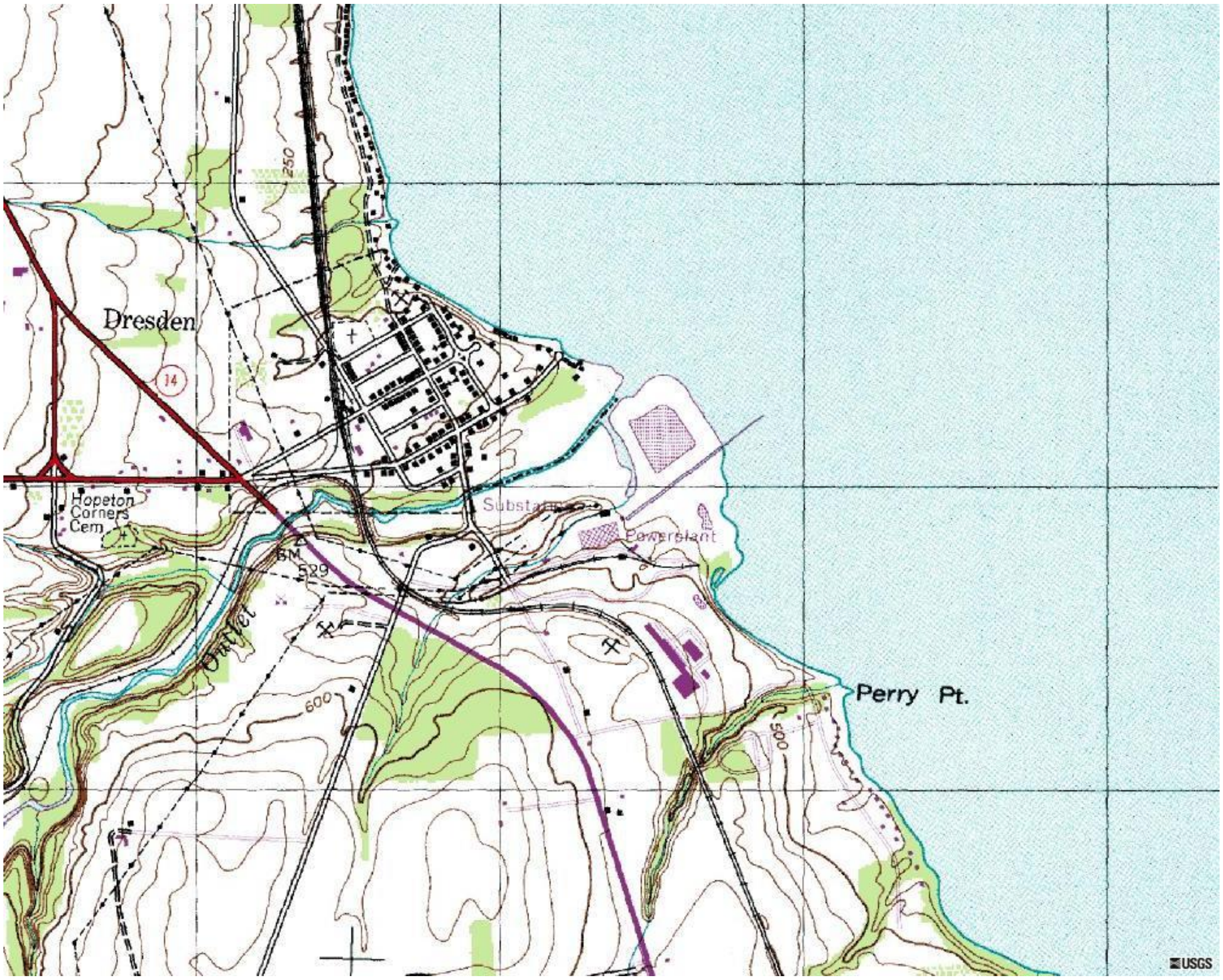

Figure 2-1 Topographic map of area surrounding Greenidge (USGS Dresden 7.5-minute quadrangle, 1978)

Figure 2-2 Greenidge Generation Unit 4 intake pipe

Figure 2-3 Greenidge Unit 4 circulating water pump A.

2.2 OPERATION

Greenidge has operated intermittently over the last 3 years with annual capacity factors of 18% in 2017, 20% in 2018, and 6% in 2019. Generation has typically been higher in summer months, although the winter of 2017-2018 was also a period of relatively high output (Figure 2-4).

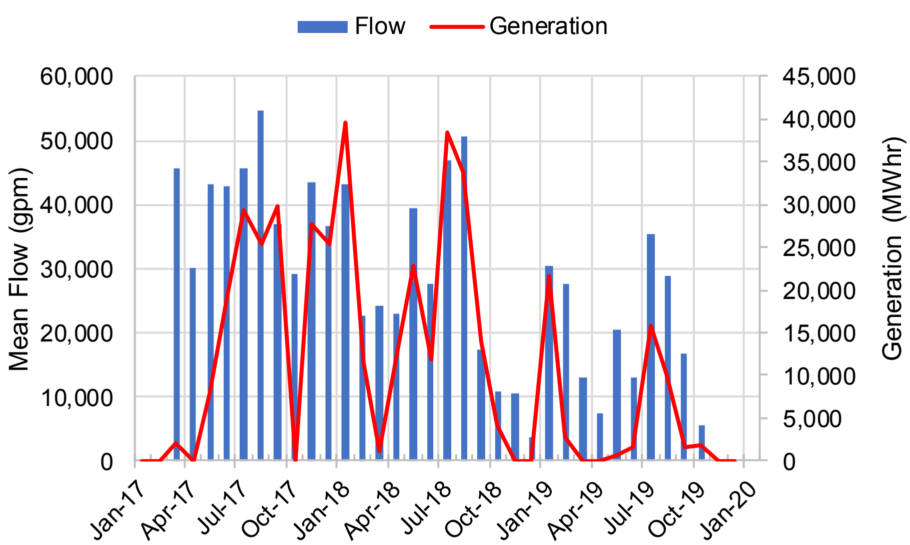

Figure 2-4 Mean monthly flow (gpm) and monthly generation (MWhr) at Greenidge Generation, 2017-2019.

3. CWWS PILOT STUDY

Cylindrical wedgewire screens, also called “V” screens or profile screens are a passive intake system. The typical design consists of wedge-shaped wires or bars welded to an internal cylindrical frame that is mounted on a central intake pipe, with the entire structure submerged in the source waterbody. When velocity through the slots between the wires is 0.5 fps or less, these screens exploit physical and hydraulic exclusion mechanisms to achieve consistently high reductions in impingement mortality. Significant entrainment reductions may also result from the phenomena of hydraulic bypass when there are prevailing water currents, active avoidance by motile life stages, and, when the screen slot size is smaller than limiting dimensions of egg and larval life stages, by physical exclusion.

CWWS for cooling water intakes are designed to have a low, uniform through-slot velocity (less than 0.5 feet per second). The velocity field quickly dissipates rapidly as distance from the screen increases due to the cylindrical shape, thus creating a relatively small flow field in the waterbody. This small flow field, together with optimal screen orientation, results in a small system profile and minimizes the potential for contact between the screen and any susceptible organisms that may come under the intake’s hydraulic influence. In addition, in flowing water, the ambient current crossflow carries most free-floating organisms and debris past the screen and removes organisms that are temporarily in contact with or pinned against the screen. CWWS may also employ cleaning and de-icing systems, such as brushes or air-burst sparging or may be constructed with nickel or copper alloys to discourage biofouling.

According to USEPA, CWWS can be successfully employed by large intake facilities under certain circumstances. The limiting factor for a larger facility may be the availability of sufficient accessible space near the facility itself because additional screen assemblies consume more space on the waterbody floor and might interfere with navigation or other uses of the waterbody. Consideration of the impacts in terms of space and placement must be evaluated before selecting CWWS for deployment.

As with any intake structure, the presence of large debris poses a risk of damage to CWWS if not properly managed. Apart from the damage that large debris can cause, smaller debris, such as household trash or organic matter, can build up on the screen surface, altering the through-slot velocity of the screen face and increasing the risk of entrainment and/or impingement of target organisms. Selection of the optimal location in the waterbody may reduce the collection of debris on the structure. Ideally, CWWS are located away from areas with high levels of submerged aquatic vegetation (SAV) and out of known debris channels. Proper placement alone may achieve the desired effect, although technological solutions also exist to physically remove small debris and silt. Automated air-burst systems can be built into the screen assembly and set to deliver a short burst of air from inside and below the structure, or mechanized brush systems can clean both the inside and outside of the screen. Biofouling, growth of biological organism on or inside the screen, can be reduced through use of nickel or copper alloys.

3.1 CWWS DESIGN ISSUES

A CWWS system for Greenidge will have to be properly sized, located, and constructed in order to function properly to deliver cooling water to Unit 4, while reducing fish entrainment and impingement. Some of the key design issues are:

- Slot width of the screen
- Alloy for screen
- Method of cleaning the screens (air burst or brush)

- Dimensions of the screens
- Orientation of the screens
- Number of screen units
- Mounting (fixed or movable) and array footprint
- Ice damage prevention
- Degree of overdesign required
- Screen failure bypass requirements
- Frazile/Anchor Ice preventative measures (thermal discharge, bubbles, circulation propellers)
- Intake pipe modifications
- Coatings and materials of pipes and structures (Silicone Epoxy, HDPE, etc.)
- Allowable hydraulics for existing intake system
- Access issues (via barge on lake, deck area, divers, etc.)
- Redundancy requirements for operations
- Emergency bypass

These design issues cannot be addressed without information on:

- Species, life stages, and sizes of organisms to be protected
- Nature, type, and severity of debris fouling
- Type and rapidity of biofouling
- Substrate type and depth
- Ambient water currents (direction and magnitude)
- Water temperatures (year-round)

As an example of the design decisions required, the simple question of number of screen modules could be addressed as follows, given that some other decisions have already been determined. If we assume that the system must be able to deliver 68,000 gpm, with a through-slot velocity of no more than 0.5 fps, and a slot width between 0.5 mm and 1 mm, using ISI brush-cleaned cylindrical T-screens (Figure 2-4) made with standard 1.75 mm width #69 wedgewire would be used.

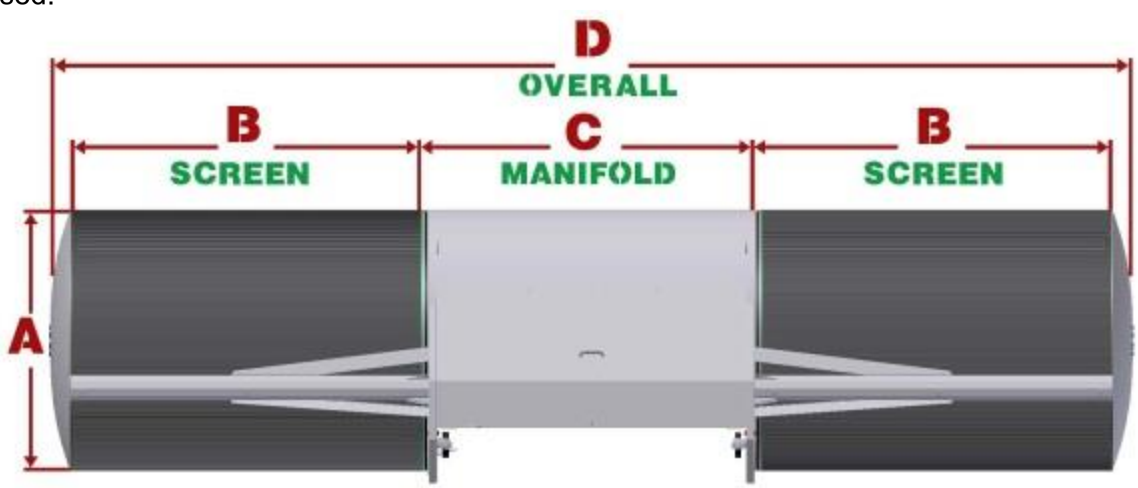

Figure 3-1 General design of standard ISI brush-cleaned cylindrical wedgewire T-screen modules. (From SI website).

A flow of 68,000 gpm, the maximum rated flow at Unit 4, with through-slot velocity no greater than 0.5 fps would require 25 of the T 30-42 screens with slot width of 0.5 mm, but only 16 screens with slot width of 1.0 mm (Table 3-1). At the other end of the screen size scale, the required flow rates could be achieved with five T 72-96 screens with slot width of 0.5 mm, or three screens with 1.0 mm slot width.

The screen size decision must accommodate the depth of the withdrawal site, which limits the size of screen that can be used without withdrawing too close to the lake surface, and also the need to over-design the system to account for higher velocities when screens are partially clogged. The number and size of screens required will determine the size and design of the footprint for the system on the lake bottom, and the construction methods required.

Table 3-1 Number of T-screen modules required to meet 0.5 fps through-slot velocity at 68,000 gpm flow.

ISI Model[a]	Surface Area per module (ft^2)	Slot width 0.5 (mm)		Slot width 0.75 (mm)		Slot width 1.0 (mm)	
		Open Area 22%		Open Area 30%		Open Area 36%	
		Velocity (fps)	# Screens	Velocity (fps)	# Screens	Velocity (fps)	# Screens
T 30-42	55	0.50	**25**	0.48	**19**	0.48	**16**
T 36-54	85	0.48	**17**	0.50	**12**	0.50	**10**
T 42-66	121	0.47	**12**	0.46	**9**	0.50	**7**
T 48-72	151	0.46	**10**	0.48	**7**	0.47	**6**
T 60-90	236	0.49	**6**	0.43	**5**	0.45	**4**
T 72-96	302	0.46	**5**	0.42	**4**	0.47	**3**

[a] First number in model name is the screen diameter (dimension A in Figure 2-1) in inches, and second number is the length of the screen section (dimension B in Figure 2-1) in inches.

3.2 STUDY DESCRIPTION

The CWWS pilot study included sampling at the location of the cooling water intake in Seneca Lake using 0.5 mm and 1.0 mm slot width wedgwire screens, and sampling of entrainment through the cooling system at a location downstream of the circulating pumps (Figure 3-2).

3.2.1 Nature, type, and severity of debris fouling

Due to the location of the intake, debris (primarily biological in nature) fouling of CWWS could be severe. The severity determines the type of cleaning technology to be employed, and the frequency with which it must be used. Debris fouling was monitored on a bi-weekly/weekly basis concurrent with the entrainment study.

For the debris fouling test, on each sampling event water was pumped through two test screens for 24 hours. Screens and sampling apparatus were those used during the CWWS test studies conducted by EPRI in 2005 and 2006 (EPRI 2005), with a 0.5 mm slot screen and a 1.0 mm slot screen (Figure 3-3 Figure 3-4, Figure 3-5).

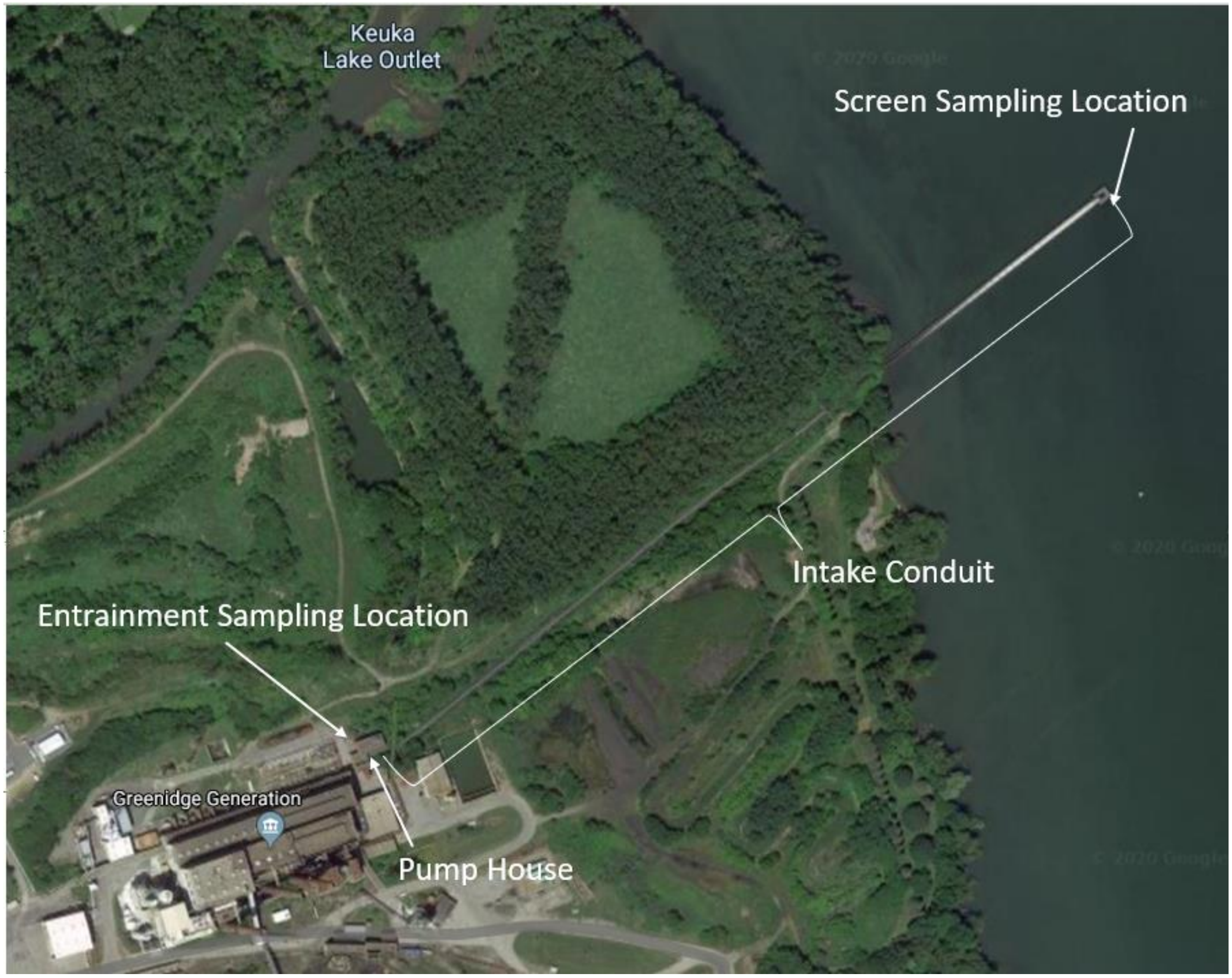

Figure 3-2 Aerial view of Greenidge Generation, Unit 4 intake conduit, and sampling locations for the 2019 CWWS Pilot Study.

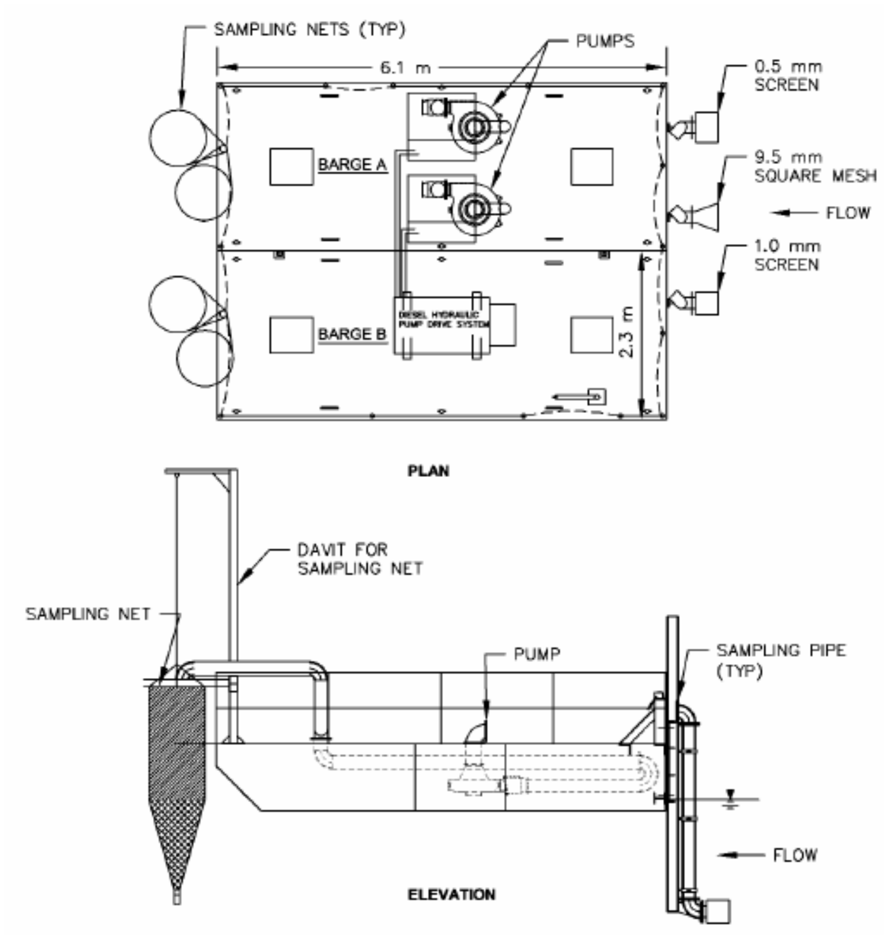

Figure 3-3 Schematic view of sampling barge and apparatus to be used in entrainment and debris fouling aspects of Greenidge pilot study.

Figure 3-4 Two test screens (near and far), with control intake (mid) used in EPRI wedgewire screen testing.

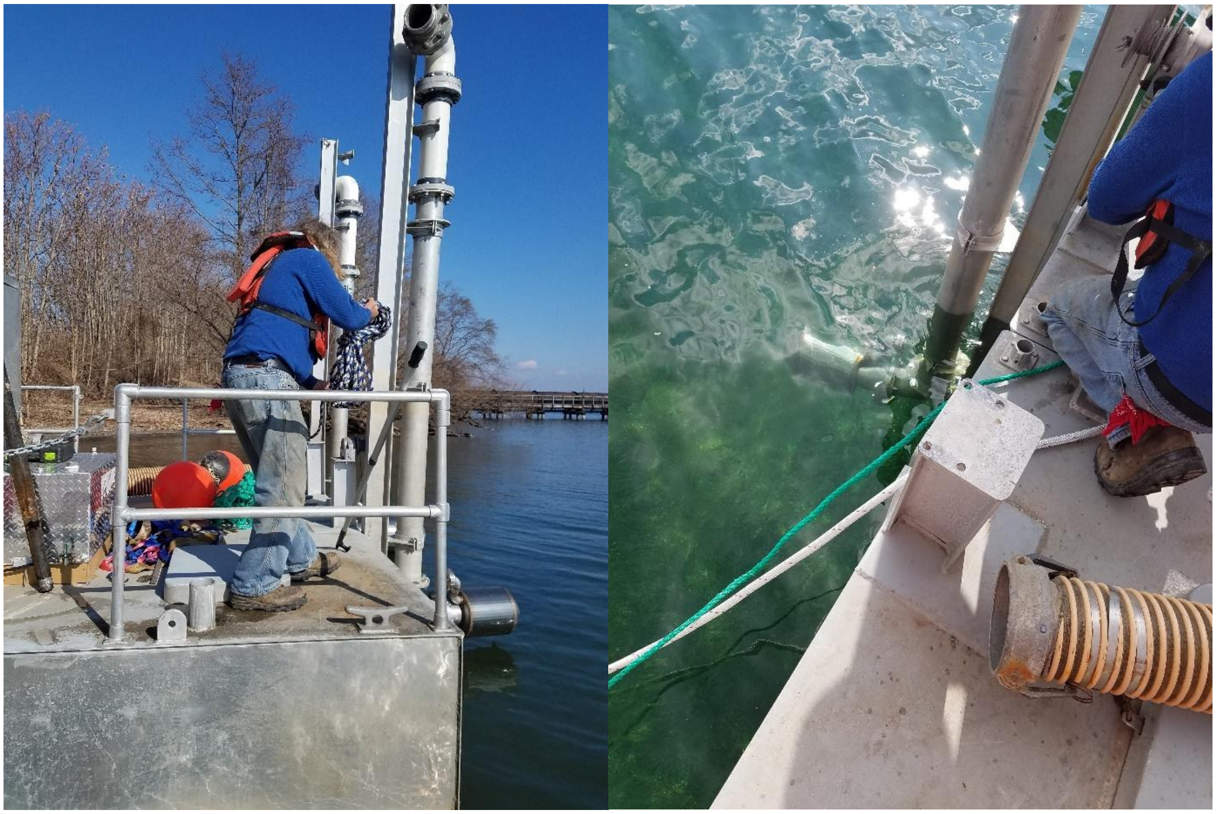

Figure 3-5 Intake end of barge showing intake screens raised (left), and with screens deployed, showing clarity of water in Seneca Lake at time of deployment in March, 2019.

The flow rates were selected so that through-slot velocity for clean screens would be approximately the same and not exceed 0.5 fps. The 0.5 mm screen is a standard S-16 screen with a diameter of 16 inches, a length of 18 in, and a discharge diameter of 8 in. The porosity of the 0.5 mm screen was 23.8 percent, which makes the limiting flow rate of 335 gpm. The 1.0 mm screen was a standard S-12 screen, 12 inches in diameter, 14 in long, and with a discharge diameter of 6 in. The porosity of the 1.0 mm screen was 38.5 percent, and limiting flow rate 316 gpm. The control intake on the sampling barge was not used.

At the start of each sampling event (Figure 3-6) flow through the screens was adjusted to be approximately 0.5 fps for each screen, to the ability of the control system. At the conclusion of 24-hour sampling event, the debris on each screen was collected, preserved, categorized (aquatic vegetation, terrestrial vegetation, etc.), and weighed.

Figure 3-6 Sampling barge in position at south side of Greenidge Generation intake structure in Seneca Lake. Nets are raised because biological sample was not occurring at the time.

3.2.2 Type and rapidity of biofouling

In addition to the debris loading samples taken from the outside of the screens, biofouling of the screens was examined through use of screen coupons (small samples of actual screen material) inserted into a collection box (Figure 3-7). Water was pumped through the box continuously from May through the end of the CWWS Pilot Study on October 15, except during inspections, at a nominal flow rate of approximately 0.5 fps through the coupon slots. Coupons were removed, examined, and photographed weekly during each entrainment sampling event. At the end of the study, coupons were thoroughly cleaned, and the material from the screens was preserved and examined at the ECSI laboratory in Middletown, DE, to determine the magnitude and type of biological growth on the screens.

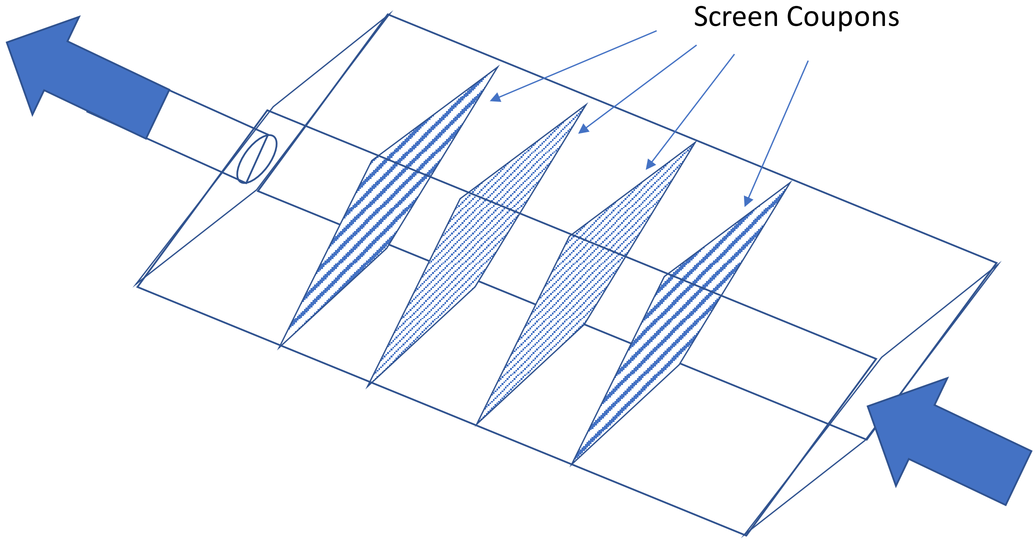

Figure 3-7 Conceptual design of apparatus to test screen biofouling.

3.2.3 Entrainment monitoring

Entrainment at Greenidge was monitored during each 24-hour event. A 100-m^3 sample was taken from a tap installed in the main cooling water conduit downstream of the cooling water pumps. Samples were collected with a typical net-in-barrel system with a conical 0.3 mm mesh Nytex net (Figure 3-8). One sample was collected in each period (12:00 to 18:00, 18:00 to 00:00, 0:00 to 06:00, and 06:00 to 12:00) over the course of the study.

Samples were preserved in 5% formalin and transferred to the ECSI laboratory facility in Middletown, DE, for analysis. Fish eggs and larvae were identified to the lowest taxonomic classification possible, counted, and larvae were measured to the nearest 0.1 mm.

3.2.4 Biological effectiveness of wedgewire screens

During the period between 18:00 and 06:00, two 100 m^3 samples of entrainable organisms were collected from the water drawn through each of the screens. If any cooling water pumps were operating, the samples were timed to correspond with the entrainment samples collected from the condenser tap (See 3.2.4). Samples occurred at night (Figure 3-9) due to the higher entrainment density typically seen at night to facilitate comparison of organism densities and size frequencies between entrainment and screen samples. The simultaneous collections provide an empirical demonstration of the efficacy of the wedgewire screens.

Figure 3-8 Entrainment monitoring equipment (barrel sampler) with net removed for sample extraction.

Figure 3-9 Biological sampling of the flow through CWWS screens during nighttime. Nets are positioned to receive the flow and capture entrainable organisms.

4. PILOT STUDY RESULTS

4.1 SCREEN DEBRIS ACCUMULATION

At the start of each 24-hour sample, flow through the 0.5 and 1.0 mm slot wedgewire screens was adjusted to approximately 0.5 fps using valves to each water pump from the common hydraulic system. Flow rate was then monitored hourly during the pumping period. Adjustments were made only if flow rates departed significantly from the target rates.

If debris accumulation was significant during the sampling event, then it would be expected that 1) flow rates would tend to decline through time, 2) flow through the 0.5 mm screen would decline more rapidly than through the 1.0 mm screen, 3) flow rates would decline more severely when aquatic vegetation begins to die off in the fall or after storm events bring debris into the water column.

None of these expected patterns were observed in the flow data. There was not a typical pattern of declining flows during sampling events. During some events, flow rates declined during sampling, but in other events, flow rates increased (Figure 4-1). The changes in flow during an event, as measured by the estimated linear slope of the trend, generally were similar for the two screens (Figure 4-2), and the flow trends were not seasonally influenced.

According to the study design, at the conclusion of 24 hours, the accumulated debris on each screen was to be collected by fitting a mesh “sock” over each screen prior to cessation of pumping. The debris was to be preserved, described (aquatic vegetation, terrestrial vegetation, etc.), and quantified. However, the amount of debris retrieved from the screens at the conclusion of pumping was negligible throughout the entire study.

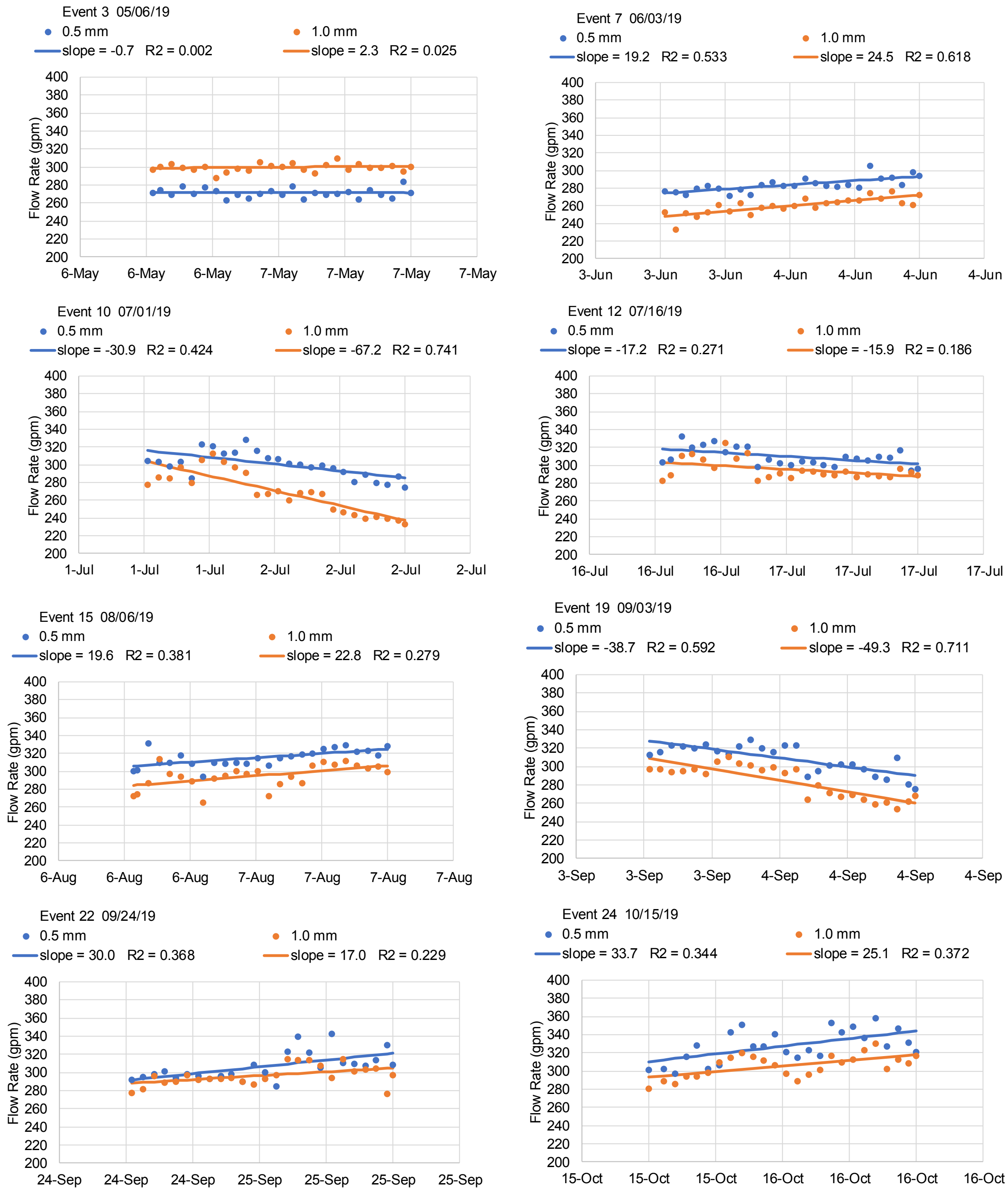

Figure 4-1 Hourly flow rates (gpm) and linear trend in flow through 0.5 and 1.0 mm slot wedgewire screens during sampling events 3, 7, 10, 12, 15, 19, 22, and 24, shown as illustrative examples of typical patterns, during 2019 CWWS pilot study.

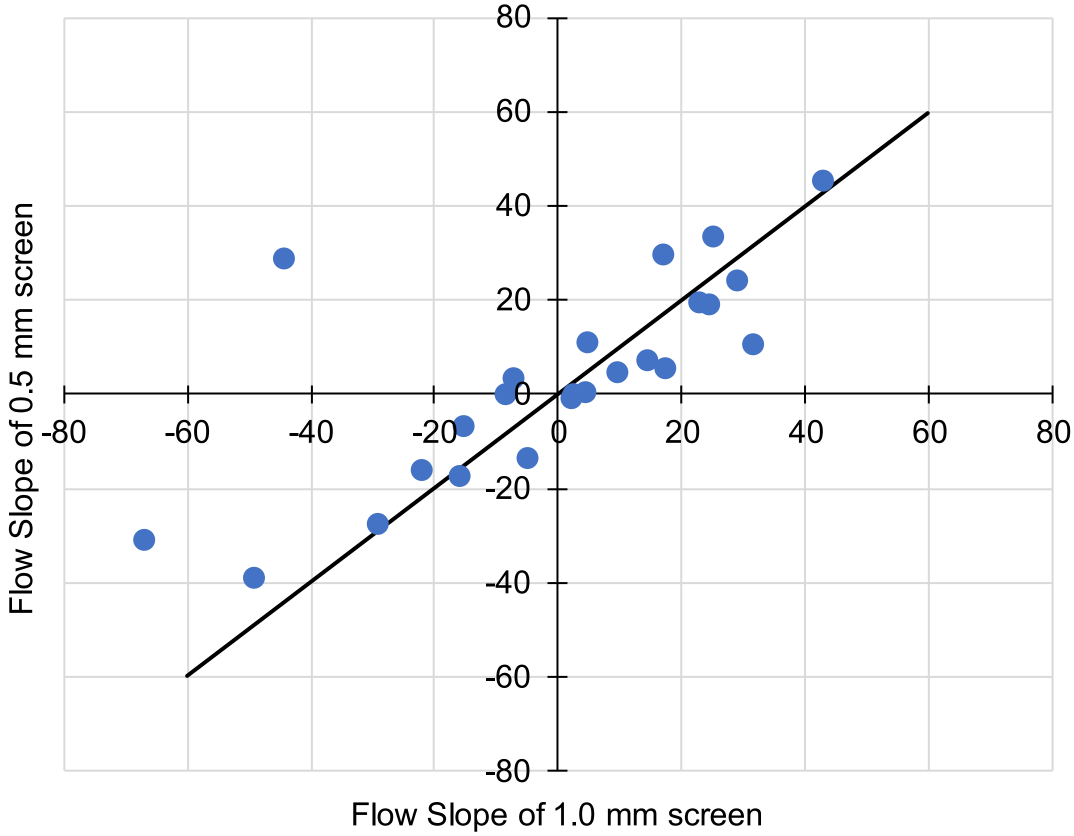

Figure 4-2 Correspondence of slopes for linear trend of flow for 0.5 and 1.0 mm slot wedgewire screens during 2019 CWWS pilot study.

4.2 SCREEN BIOFOULING

The screen coupon samples maintained in continual flow-through (except during an electrical shortage between events 17 and 18) provided information on rates and severity of screen biofouling. A gradual buildup of material and growth on the coupons was observed during the sampling season, but the amount of material on the screens appeared to peak around event 12, and then remain the same or decline afterwards (Figure 4-3, Figure 4-4, Figure 4-5). The 1.5 mm slot coupon, which occupied the first position in the sampler, accumulated larger zebra mussels and debris as would be expected. The 0.75 mm slot copper-nickel alloy coupon in the last position appeared to accumulate more biofouling and loose material than the stainless steel coupons in intermediate positions.

The amount of material removed from the screens at the end of the study was relatively small, ranging from 0.2 gm on the 0.75 mm stainless steel coupon, to 1.4 gm on the 0.75 mm copper-nickel coupon in the last position (Table 4-1). Biological growth on the screen was primarily algae. *Gammarus*, Gastropoda, and zebra mussels (*Driessena polymorpha*) were found on all of the coupons throughout the study and in the final quantification.

When the screens were raised during demobilization of the study, the biological growth on the screens was primarily on the top of the screens where sunlight would be the strongest (Figure 4-6).

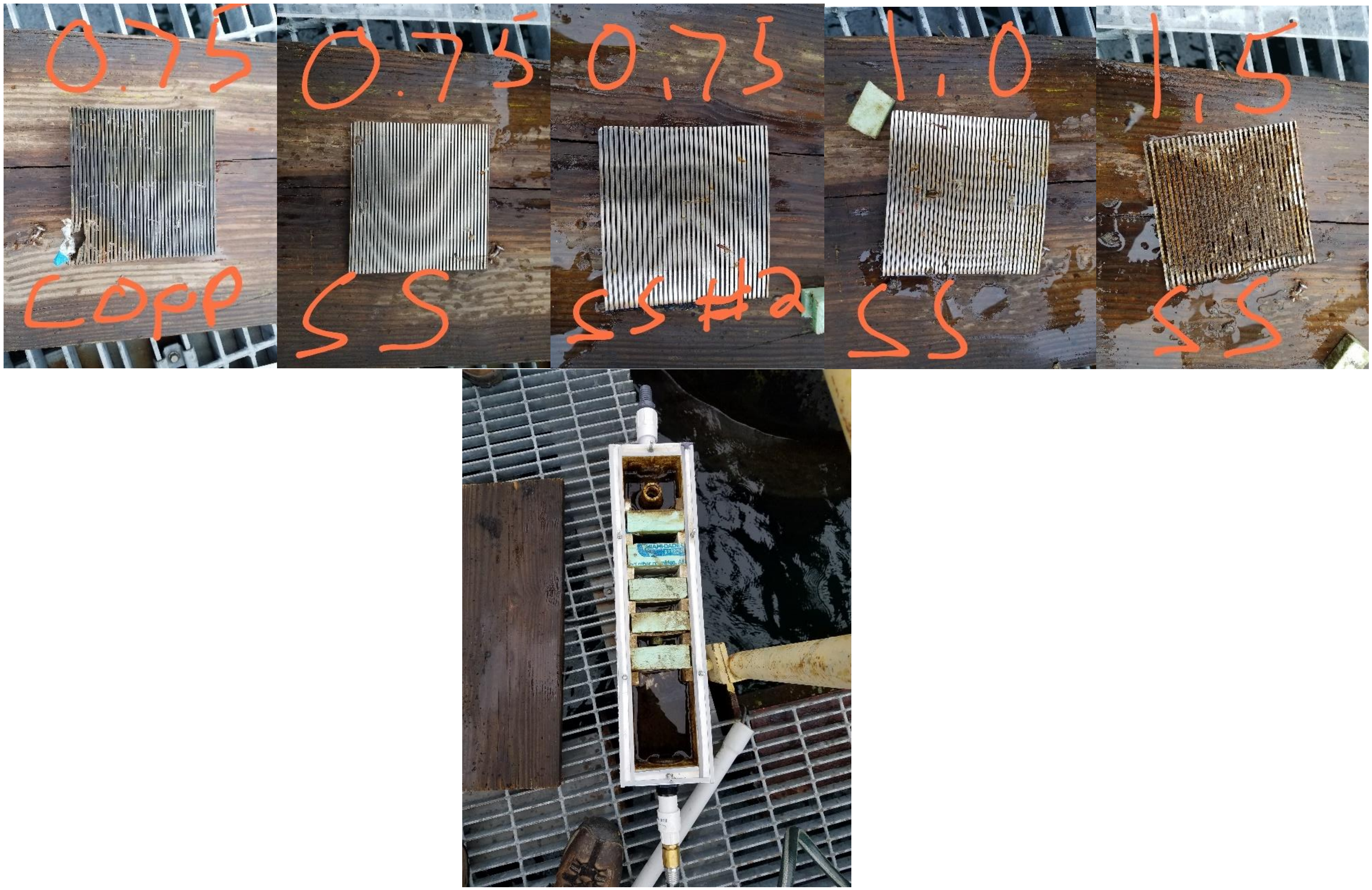

Figure 4-3 Biological fouling of screen coupons after 4 weeks of flow (Event 4). Screen coupons are 0.75 mm slot copper-nickel allow, 0.75 mm slot stainless steel (#1 and #2), 1.0 mm slot stainless steel, and 1.5 mm slot stainless steel. Bottom photo is the flow-through chamber used to hold the screen coupons in order of decreasing slot width.

Figure 4-4 Biological fouling of screen coupons after 12 weeks of flow (Event 12). Screen coupons are 0.75 mm slot copper-nickel allow, 0.75 mm slot stainless steel (#1 and #2), 1.0 mm slot stainless steel, and 1.5 mm slot stainless steel.

Figure 4-5 Biological fouling of screen coupons after 24 weeks of flow (Event 24). Screen coupons are 0.75 mm slot copper-nickel allow, 0.75 mm slot stainless steel (#1 and #2), 1.0 mm slot stainless steel, and 1.5 mm slot stainless steel.

Table 4-1 Organisms and material collected from screen coupon samples at conclusion of 2019 CWWS Pilot Study.

Item	Screen				
	0.75 Cu-Ni	0.75 SS #1	0.75 SS #2	1.0 SS	1.5 SS
Gammarus	48	136	28	40	122
Gastropoda	1		25		6
D. polymorpha		4		13	6
Arachnida	2				
Algae	X	x	X	X	X
Shell fragments	X				
Weight (gm)	1.4	0.8	0.2	0.3	1.2

Figure 4-6 State of intake screens when raised for demobilization at end of the 2019 CWWS Pilot Study.

4.3 ENTRAINMENT MONITORING

Entrainment monitoring was conducted during every planned event, except during the week of June 10, when the facility was shut down during installation of the Variable Speed Drives. During each event, four standard 100-m^3 samples were collected from the tap in the water line to the condensers (Table 4-2). In addition, during the two night sampling periods between 18:00 and 06:00 two 100-m^3 samples were taken from the water pumped through each of the wedgewire screens.

Table 4-2 Entrainment sample dates and volume of water sampled during Greenidge Generation 2019 CWWS Pilot Study.

Event	Date	Entrainment		0.5 mm WWS		1 mm WWS	
		Samples	Volume (m^3)	Samples	Volume (m^3)	Samples	Volume (m^3)
1	8-Apr	4	413.4	2	207.4	2	207.3
2	22-Apr	4	424.7	2	208.5	2	208.6
3	6-May	4	415.2	2	208.1	2	213.4
4	13-May	4	445.2	2	205.5	2	205.5
5	20-May	4	419.5	2	213.0	2	204.8
6	28-May	4	432.7	2	205.2	2	217.7
7	3-Jun	4	421.6	2	217.6	2	205.6
8	17-Jun	4	410.7	2	204.9	2	205.0
9	24-Jun	4	424.4	2	215.6	2	205.1
10	1-Jul	4	424.2	2	218.6	2	205.5
11	8-Jul	4	434.0	2	210.7	2	205.1
12	16-Jul	4	424.5	2	207.9	2	204.8
13	22-Jul	4	425.1	2	206.9	2	207.7
14	30-Jul	4	430.7	2	206.8	2	226.8
15	5-Aug	4	428.4	2	207.9	2	208.2
16	12-Aug	4	417.9	2	209.8	2	205.0
17	19-Aug	4	452.2	2	207.9	2	213.9
18	26-Aug	4	448.9	2	219.4	2	213.2
19	3-Sep	4	433.7	2	212.0	2	218.9
20	10-Sep	4	441.5	2	208.2	2	206.3
21	17-Sep	4	425.2	2	207.3	2	217.1
22	24-Sep	4	436.7	2	207.3	2	205.3
23	1-Oct	4	429.2	2	205.2	2	212.4
24	15-Oct	4	436.9	2	214.3	2	205.9

Lake temperatures, as measured at Greenidge Generation, followed a typical season cycle, ranging from 5 °C at the beginning of April, to 28.3 °C in early August (Figure 4-7).

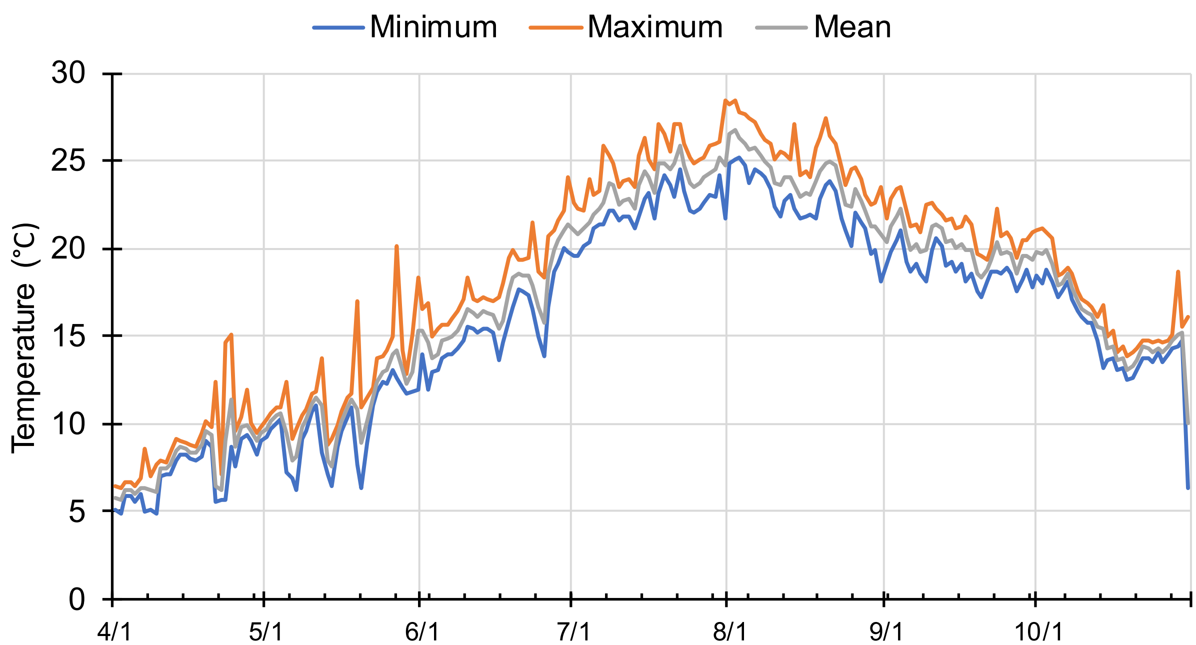

Figure 4-7 Daily minimum, maximum, and mean intake water temperature at Greenidge Generation during 2019 CWWS Pilot Study.

4.3.1 Species Compostion

Entrainment samples, in which a total of 219 organisms were collected, were dominated by alewife, primarily in the PYSL stage, but also approximately 10% eggs (Table 4-3). Other relatively common taxa were Cyprinidae (minnow family) as eggs, carp (also in family Cyprinidae) as eggs, and unidentified eggs. The taxa collected in larval stages included yellow perch (1 individual), and channel catfish (2 individuals).

Table 4-3 Species composition of entrainment, and 0.5 mm and 1.0 mm wedgewire screen samples collected during 2019 CWWS Pilot Study.

Taxon	Entrainment					0.5 mm					1.0 mm				
	Egg	YSL	PYS	Und	Total	Egg	YSL	PYS	Und	Total	Egg	YSL	PYS	Und	Total
Alewife	14	1	131	1	147	0	1	28	0	29	0	2	68	0	70
Unidentified	45	1	0	3	49	0	0	0	0	0	0	0	0	2	2
Cyprinid Unid	10	0	0	0	10	0	0	3	0	3	0	1	6	0	7
Carp	10	0	0	0	10	0	0	0	0	0	0	0	0	0	0
Yellow perch	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
Channel catfish	0	0	2	0	2	0	0	0	0	0	0	0	0	0	0
Tesselated darter	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0
Total	79	3	133	4	219	0	2	31	0	33	0	3	74	2	79

The species composition was relatively similar to that observed in 2006 in that alewife was the most abundant taxon (HDR 2007), but that study collected only 74 organisms. In the 2006 study, white sucker, banded killifish, bullhead (Ameiurus sp.), and brook silverside were also collected.

4.3.2 Seasonal Variation

Seasonal variation in entrainment densities was similar to that exhibited in 2006 (HDR 2007), with relatively low densities in April and May, peak densities in July, and low or zero densities in August and thereafter (Table 4-4). On the date of the single highest densities, July 8, densities were approximately 4 times as high as on any other date, with one third of all organisms captured during the study occurring during one sample period on that night.

Fish eggs were collected from the first sample on April 8, until August 12, with peak densities in mid-June through mid-July, and the highest single date density on July 1 (Table 4-4). Larval densities were overall about 2 times as high as egg densities. Peak larval density occurred on July 8, a week after the peak egg density.

4.3.3 Diel Variation

As expected, night-time densities exceeded day-time densities during most sampling events (Table 4-5). Overall, averaged over the entire program, mean daytime entrainment density was 14.48 organisms per 1000 m^3 withdrawn, and mean nighttime entrainment density was 28.10 (Table 4-5).

Table 4-4 Mean daily density of fish eggs and larvae collected in entrainment sampling at Greenidge Generation, 2019.

Event	Date	Entrainment		
		Eggs	Larvae	Total
1	4/8/2019	9.76	0.00	9.76
2	4/22/2019	0.00	0.00	0.00
3	5/6/2019	0.00	0.00	0.00
4	5/13/2019	0.00	0.00	0.00
5	5/20/2019	2.44	0.00	2.44
6	5/28/2019	6.92	0.00	6.92
7	6/3/2019	4.84	2.41	7.25
8	6/17/2019	14.61	12.15	26.75
9	6/24/2019	25.92	2.37	28.29
10	7/1/2019	47.26	11.85	59.12
11	7/8/2019	6.92	249.19	256.11
12	7/16/2019	2.35	21.33	23.68
13	7/22/2019	0.00	21.72	21.72
14	7/30/2019	40.44	23.73	64.17
15	8/5/2019	0.00	0.00	0.00
16	8/12/2019	4.79	0.00	4.79
17	8/19/2019	0.00	0.00	0.00
18	8/26/2019	0.00	0.00	0.00
19	9/3/2019	0.00	0.00	0.00
20	9/10/2019	0.00	0.00	0.00
21	9/17/2019	0.00	0.00	0.00
22	9/24/2019	0.00	0.00	0.00
23	10/1/2019	0.00	0.00	0.00
24	10/15/2019	0.00	0.00	0.00
	Mean	6.93	14.36	21.29

Table 4-5 Density (# per 1000 m^3) of fish eggs and larvae combined during entrainment and screen test sampling during 2019 CWWS Pilot Study.

Event	Date	Entrainment	
		Day	Night
1	4/8/2019	19.51	0.00
2	4/22/2019	0.00	0.00
3	5/6/2019	0.00	0.00
4	5/13/2019	0.00	0.00
5	5/20/2019	4.89	0.00
6	5/28/2019	9.23	4.61
7	6/3/2019	9.68	4.81
8	6/17/2019	34.05	19.46
9	6/24/2019	18.42	38.15
10	7/1/2019	46.75	71.49
11	7/8/2019	99.87	412.34
12	7/16/2019	23.97	23.40
13	7/22/2019	4.75	38.69
14	7/30/2019	66.79	61.55
15	8/5/2019	0.00	0.00
16	8/12/2019	9.58	0.00
17	8/19/2019	0.00	0.00
18	8/26/2019	0.00	0.00
19	9/3/2019	0.00	0.00
20	9/10/2019	0.00	0.00
21	9/17/2019	0.00	0.00
22	9/24/2019	0.00	0.00
23	10/1/2019	0.00	0.00
24	10/15/2019	0.00	0.00
	Mean	14.48	28.10

4.3.4 Length Frequency

Of 88 larvae collected in entrainment samples and measured in the laboratory, 78 were alewife larvae. Lengths of larvae, to nearest mm, ranged from 4 to 16 mm, with a mode of 5-6 mm (Figure 4-8). The lengths indicate that the majority of entrained organisms would be early life stages less than ½" long.

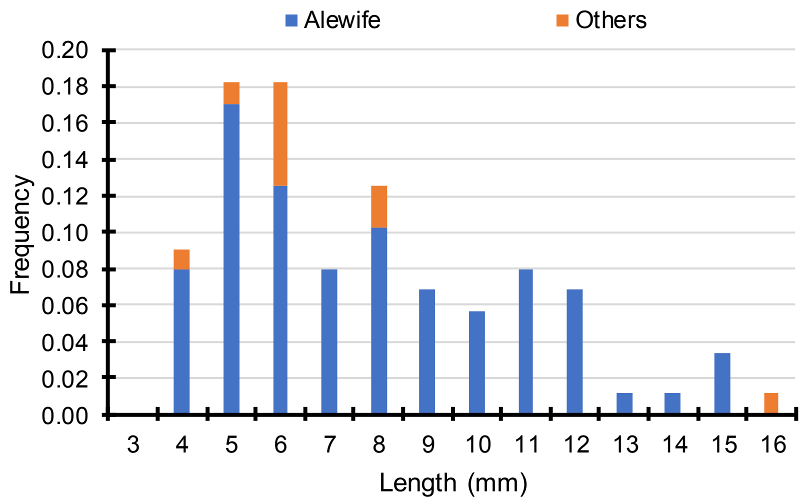

Figure 4-8 Length frequency of 78 alewife larvae and 10 other species larvae collected during entrainment sampling at Greenidge Generation, 2019.

4.3.5 Interannual Variation

The seasonal pattern of entrainment densities, and the overall mean monthly densities were similar in 2006 and in the current study in 2019, with the exception that density in July was much higher, approximately 7-fold, in the current study. However, the extreme magnitude of this peak was primarily the result of a single sample on July 8.

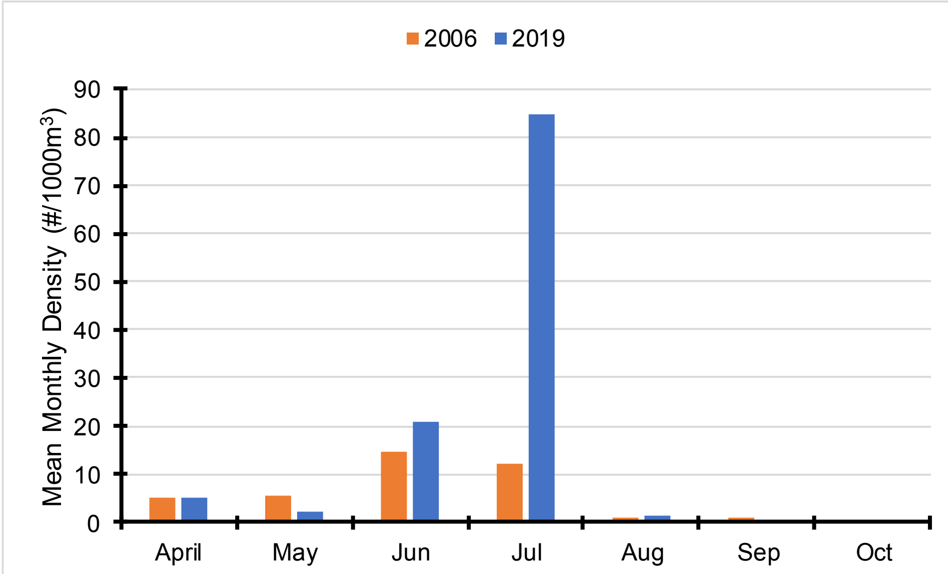

Figure 4-9 Comparison of mean monthly entrainment density at Greenidge Generation in 2006 and 2019.

4.4 ESTIMATED ENTRAINMENT

Annual entrainment estimates are typically done by summing the products of daily (or hourly) entrainment densities and the daily (or hourly) cooling water flows across all days when entrainment may occur:

$$Number\ Entrained = \sum_{i=1}^{T} D_i V_i$$

where T is the number of periods (days or hours), D_i is the entrainment density in period i, and V_i is the volume of cooling water withdrawn in period i. For periods in which there was no sample to calculate entrainment density, the density is linearly interpolated from the prior and subsequent entrainment samples.

Estimated entrainment in 2019, using actual cooling water flows from April through October was 0.49 million fish eggs and larvae. On many days during the entrainment sampling program, the cooling water pumps would not have been used except that flow was needed so that sampling could be conducted. If those flows are removed, the calculated entrainment would have been 0.23 million. If the cooling water pumps had operated at full capacity (68,000 gpm), estimated entrainment would have been 1.43 million.

4.5 WEDGEWIRE SCREEN EFFICACY

4.5.1 Density of organisms

Sampling through the wedgewire screens at the end of the intake conduit did not capture any fish eggs through either screen, but had a total of 33 larvae from the 0.5 mm slot screen and 79 from the 1.0 mm slot screen (Table 4-3). Because screen sampling occurred only at night, valid density comparisons of the wedgewire screens with entrainment can only be done for the night entrainment sampling. Total densities in the 1.0 mm screen samples were on average about 30%

lower than entrainment densities, and in the 0.5 mm screen samples about 77% lower. Larval densities were 12% lower for the 1.0 mm screen and 71% lower for the 0.5 mm screen.

Table 4-6 Mean night density (fish larvae and total fish) from entrainment and wedgewire screen samples at Greenidge Generation in 2019.

		Larval Density			Total Density		
Event	Date	Entrain-ment	0.5 mm	1.0 mm	Entrain-ment	0.5 mm	1.0 mm
1	4/8/2019	0.00	0.00	0.00	0.00	0.00	0.00
2	4/22/2019	0.00	0.00	0.00	0.00	0.00	0.00
3	5/6/2019	0.00	0.00	0.00	0.00	0.00	0.00
4	5/13/2019	0.00	0.00	0.00	0.00	0.00	0.00
5	5/20/2019	0.00	0.00	0.00	0.00	0.00	0.00
6	5/28/2019	0.00	0.00	0.00	4.61	0.00	0.00
7	6/3/2019	4.81	0.00	0.00	4.81	0.00	0.00
8	6/17/2019	0.00	19.54	9.74	19.46	19.54	9.74
9	6/24/2019	4.74	0.00	0.00	38.15	0.00	0.00
10	7/1/2019	19.03	22.85	34.00	71.49	22.85	34.00
11	7/8/2019	402.98	47.37	292.69	412.34	47.37	292.69
12	7/16/2019	18.69	0.00	0.00	23.40	0.00	0.00
13	7/22/2019	38.69	67.68	120.43	38.69	67.68	120.43
14	7/30/2019	47.45	0.00	0.00	61.55	0.00	0.00
15	8/5/2019	0.00	0.00	4.72	0.00	0.00	4.72
16	8/12/2019	0.00	0.00	0.00	0.00	0.00	0.00
17	8/19/2019	0.00	0.00	9.59	0.00	0.00	9.59
18	8/26/2019	0.00	0.00	0.00	0.00	0.00	0.00
19	9/3/2019	0.00	0.00	0.00	0.00	0.00	0.00
20	9/10/2019	0.00	0.00	0.00	0.00	0.00	0.00
21	9/17/2019	0.00	0.00	0.00	0.00	0.00	0.00
22	9/24/2019	0.00	0.00	0.00	0.00	0.00	0.00
23	10/1/2019	0.00	0.00	0.00	0.00	0.00	0.00
24	10/15/2019	0.00	0.00	0.00	0.00	0.00	0.00
	Mean	22.35	6.56	19.63	28.10	6.56	19.63

4.5.2 Length frequencies

Length frequency of alewife larvae from entrainment samples and from the 1.0 mm slot screens were nearly identical, but no larvae were observed above 9 mm in length from the 0.5 mm slot screen samples (Figure 4-10).

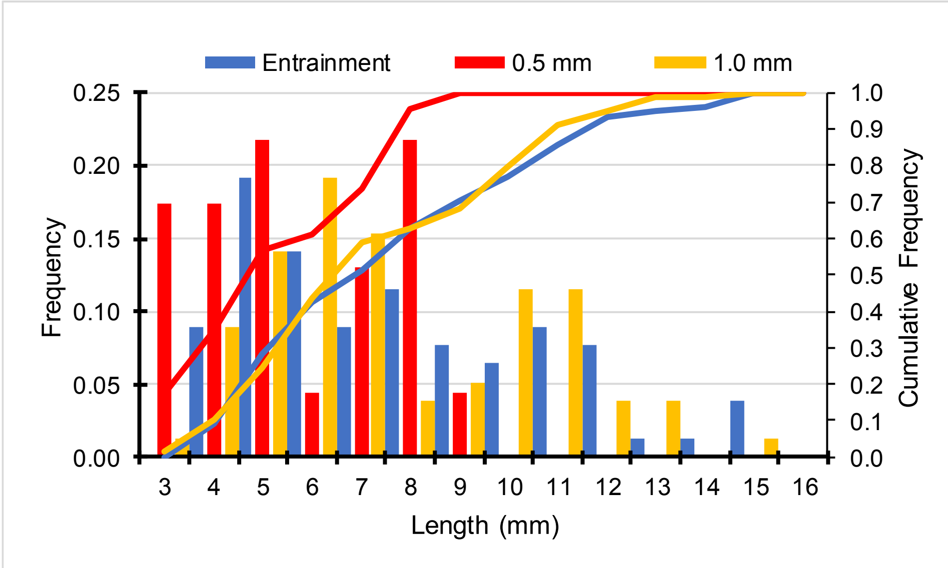

Figure 4-10 Length frequency of alewife larvae collected in entrainment samples, and in samples from 0.5 mm and 1.0 mm slot width wedgewire screens at Greenidge Generation in 2019.

5. CONCLUSIONS

The CWWS pilot study indicated no fatal flaw in implementing the wedgewire screen portion of the Best Technology Available for Greenidge Generation. Neither 0.5 mm nor 1.0 mm slot width screens appeared particularly susceptible to debris fouling, especially since some type of cleaning system would be incorporated into an actual screen installation.

Although biofouling of the screen coupons that were tested was not severe, stainless steel screens seemed to support fewer fouling organisms than copper-nickel allow screens. As would be expected, smaller slot widths, 0.5 and 0.75 mm, had more fouling organisms than 1 mm slots.

Total densities in the 1.0 mm screen samples were on average about 30% lower than entrainment densities, and in the 0.5 mm screen samples about 77% lower. Laval densities were 12% lower for the 1.0 mm screen and 71% lower for the 0.5 mm screen.

The length frequency of larvae collected from the 1.0 mm slot test screen was very similar to the unscreened sample, indicating little size selectivity of the 1.0 mm slot width. However, the 0.5 mm slot width screen did not sample larvae longer than 9 mm, indicating either exclusion or avoidance of the larger larvae.

Entrainment sampling from the cooling water demonstrated similar results to those found in 2006: entrainment was dominated by alewife larvae and occurred primarily in April through early July. Densities in 2019 were similar to those of 2006 in April-June, but the peak density in 2019 occurred in early July and was substantially higher than 2006 densities. This extreme peak in 2019 was strongly influenced by a single sample on July 8.

Actual entrainment was only 0.49 million fish eggs and larvae, and had pumping not been required for the monitoring program entrainment would have been 0.23 million. Estimated entrainment under full flow conditions in 2019 would have been 1.43 million fish eggs and larvae, primarily alewife.

REFERENCES

Electric Power Research Institute (EPRI). 2005. Field Evaluation of Wedgewire Screens for Protecting Early Life Stages of Fish at Cooling Water Intake Structure. Palo Alto, CA: Report 101011.

HDR 2007. 2006 Ichthyoplankton and Entrainment Studies. Prepared for AES Greenidge, LLC.