Diadromous Fish Behavior, Movement, and Project Interaction Study, Phase 1

Lawrence Project (FERC No. 2800)

Prepared For
Essex Company, LLC
A subsidiary of Patriot Hydro, LLC

Normandeau Associates, Inc.
25 Nashua Road
Bedford, NH 03110
www.normandeau.com

And

Profish Technology
Chemin des Pêcheurs 114
5100 NAMUR
Belgium

April 2025

Table of Contents

List of Tables

List of Figures

1 Introduction

Essex Company, LLC (Essex), a subsidiary of Patriot Hydro, LLC, is the Licensee, owner, and operator of the Lawrence Hydroelectric Project (Project or Lawrence Project), which is Federal Energy Regulatory Commission (FERC or Commission) Project No. 2800. The Project was licensed by the Commission on December 4, 1978 (with an effective date of December 1, 1978), and the license expires on November 30, 2028. The Lawrence Project is located on the Merrimack River in the City of Lawrence in Essex County, Massachusetts.

In accordance with 18 C.F.R. § 5.15, Essex has initiated studies and information gathering activities as provided in the study plan and schedule approved by the Commission. Among the studies initiated during 2024 was the Diadromous Fish Behavior, Movement, and Project Interaction Study (Project Interaction Study), the methodologies of which were outlined in the Revised Study Plan (RSP) filed by Essex with the Commission on April 10, 2024, and approved with modifications by FERC in their May 10, 2024, Study Plan Determination (SPD). This report describes the Licensee’s implementation of the study plan and schedule, the data collected, and any variances from the study plan and schedule.

2 Goals and Objectives

The goal of this study was to assess Project-related effects on the behavior of diadromous fish species in and around the Lawrence Project. As described in the RSP, the Project Interaction Study design is a two-phase approach whereby Phase 1 sought to:

(1) determine the appropriate acoustic telemetry tool to address the study goal when considering the hydromorphological conditions of the Merrimack River and the downstream study area as influenced by the Project facilities and its operations, and

(2) validate the detection ranges obtained using acoustic telemetry receivers with the aim of being able to inform the technical and cost aspects of an adequate study design to address the overall goal and objectives to inform on fish behavior downstream of the Project.

Data collection during 2024 focused on information required to meet the objectives for Phase 1 of the Project Interaction Study.

The RSP provides a basic framework for Phase 2 of the Project Interaction Study, and Essex indicated that the information collected during the 2024 Phase 1 assessment will be used to inform the overall study design for the latter phase. As a result, the Phase 2 methodology has been updated based on findings from the 2024 observations and the revised Phase 2 study plan is provided herein as Appendix A.

3 Project Description and Study Area

The Lawrence Project works consist of: (1) the 35-foot-high by 900-foot-long gravity Essex Dam of stone masonry construction (also known as the Great Stone Dam), with a five-foot-high pneumatic crest gate system mounted on the spillway crest; (2) a 9.8-mile-long impoundment having a surface area of 655 acres at a normal water elevation of 44.17 feet National Geodetic Vertical Datum of 1929 at the top of the crest gates, and gross storage capacity of approximately 19,900 acre-feet; (3) a powerhouse located at the end of a small forebay adjacent to the south abutment of the Essex Dam containing two 8.4 megawatt generating units and a tailrace channel extending into the Merrimack River channel; (4) fish passage facilities integral with the powerhouse, including a fish lift, downstream fish bypass, an eel lift at the left abutment of the dam, and an eel ladder at the right abutment of the dam; (5) the North Canal, approximately 5,300 feet long by 95 feet wide by 15 feet deep, originating at the north abutment of the dam and paralleling the Merrimack River downstream of the Essex Dam; (6) the South Canal, approximately 2,750 feet long by 35 feet wide by 10 feet deep, originating at the south abutment of the Essex Dam and generally paralleling the Merrimack River downstream of the Essex Dam; (7) a single-circuit, underground/underwater 23.0-kilovolt transmission line to the Massachusetts Electric Company's Lawrence No. 1 substation; and (8) appurtenant facilities.

The study area for Phase 1 of the Project Interaction Study included the Project forebay area in the vicinity of the outlet from the upstream fish lift exit flume and the section of the Merrimack River located immediately downstream of the Essex Dam, extending downstream towards the I-495 Bridge in Lawrence.

4 Phase 1: Field Methodology

Phase 1 sought to determine the feasibility of utilizing the Juvenile Salmon Acoustic Telemetry System (JSATS) to monitor tagged fish in the riverine environment downstream of the Lawrence Project. The JSATS technology was developed by the Pacific Northwest National Laboratory (PNNL) and National Oceanic and Atmospheric Administration to monitor the behavior, movement, habitat use, and survival of juvenile salmonids migrating out from freshwater in the Pacific Northwest. PNNL notes that JSATS has been previously used to (1) estimate route-specific dam passage, (2) observe predator–prey interactions, and (3) evaluate fish behavior in dam tailraces using high-accuracy, high-efficiency 3-D tracking.

The JSATS system is comprised of three major components: acoustic transmitters, receivers, and the associated management/processing software. Each transmitter produces a signal at a fixed interval by inducing high-frequency (416.7 kHz) vibrations (signals) in the water. Submerged hydrophones will receive the signals and convert to an electrical impulse which is relayed to the receiver. The receiver identifies the signal as a unique identification code and then logs them along with the ID of the receiving hydrophone, time and date of the detection, and any other information relayed by the transmitter (e.g., pressure).

When a tagged fish swims within the detection range of multiple JSATS receivers, each receiver will record the unique identifier of the tag and the time of detection. By analyzing the time it takes for the signal to travel from the transmitter to multiple receivers, a technique known as Time of Arrival (TOA), the system can triangulate the position of a tagged fish. Data from multiple receivers can be collected and processed to reconstruct a fish's travel path over time. This data can then be used to inform on behavior, movement patterns, and response to environmental changes. This requires that multiple receivers within the study array can detect the same emitted pulse by the transmitter, while each receiver can have a variable detection capacity due to the background noise existing at its position.

Two separate Phase 1 study components were evaluated during the 2024 field season and their methodologies are provided in Sections 4.1 and 4.2.

4.1 River Herring Tag Retention and Survivability Assessment

During development of the RSP, the Merrimack River Technical Committee (MRTC) requested that two species of river herring, alewife and blueback herring, be targeted as test species for evaluation of behavior downstream of Lawrence. Previously conducted radio-telemetry studies on the Merrimack River have relied on the use of alewife as a surrogate for both river herring species (Normandeau 2021). To better evaluate the feasibility of testing both river herring species, Essex evaluated post-tagging transmitter retention and survival for both river herring species.

Two acoustic transmitter models were evaluated during the Phase 1 assessment: Advanced Telemetry Systems (ATS) model SS300 and ATS model SS400 (Figure 4-1). The SS300 transmitter used for this evaluation weighed 300 mg and measured 10.7 x 5.0 x 2.8 mm and the SS400 transmitter weighed 200 mg and measured 15.0 x 3.3 mm. When incorporating the smallest battery available, these two tag models will have a tag life of approximately 23 and 48 days, respectively, when set at a 3 second pulse rate interval (PRI)[1].

The RSP required a total of 50 adult alewife and 50 adult blueback herring to be obtained to evaluate tagging feasibility (tag retention and survivability). A total of 25 individuals of both species were to be tagged using dummy SS300 transmitters and 25 individuals of both species were to be tagged using dummy SS400 transmitters. An equal number of the two species were to be netted from the upstream fish lift and maintained as handling controls in the holding tank. All individuals (test and control) were marked with a uniquely identifiable Floy tag so that individual fish could be tracked through the hold period.

[1] The two ATS transmitter models can each be equipped with a larger battery which will extend transmitter life for the two models out to 81 and 302 days for the SS300 and SS400 tags, respectively and when set at a 3-second PRI. Incorporation of the larger battery will increase the physical dimensions and weight of the tag. At present, ATS can only incorporate pressure sensors into the SS300 model.

Insertion techniques differed for the two transmitter models. The SS300 transmitters were inserted gastrically by affixing each tag to the custom shaped end of a hollow flexible tube (Figure 4-2). The transmitter and leading edge of the flexible tube were inserted into the mouth and gently guided down to the stomach. Once in place, a flexible rod was inserted through the hollow tube to dislodge the transmitter and then the tube was removed leaving the transmitter in place. A hollow needle was used to insert SS400 transmitters into the body cavity of a (Figure 4-2). Following methodology described by Deng et al. (2017), the needle was inserted into the skin of the fish, with bevel facing up, at an angle of 30–40 degrees. The insertion point was at the end of the pectoral fins, offset from the ventral midline. Once the abdominal tissue was cut, the needle/syringe combination was twisted 90° and the acoustic tag was inserted. Care was taken to ensure the needle did not enter the body cavity beyond the bevel of the needle. Once the tag was injected, the needle was removed. No sutures were used to close the insertion cut.

Following tagging, fish were maintained in large, circular tanks continuously supplied with ambient Merrimack River water. Fish in the tank were observed once daily for a period of five days. Any instances of tag loss (as determined by visual search for loose tags on the bottom of the tank) or mortality were recorded. At the completion of the five-day holding period, all fish (test and controls) were netted from the tank and their total lengths (to the nearest mm) were recorded. Fish were sacrificed for a post-holding period necropsy to confirm tag retention and to assess positioning of the transmitters for each tagging methodology.

Figure 4–1. JSATS SS300 (lower) and SS400 (upper) transmitters manufactured by ATS and used in the river herring tag retention and survivability assessment as part of Phase 1 of the Project Interaction Study at Lawrence.

Figure 4–2. Insertion techniques for the JSATS SS300 (upper) and SS400 (lower) transmitters manufactured by ATS and used in the river herring tag retention and survivability assessment as part of Phase 1 of the Project Interaction Study at Lawrence.

4.2 JSATS Receiver Evaluation

The RSP identified six different pilot deployment locations covering a range of flow and channel/infrastructure morphology in the vicinity of the Project powerhouse and dam which included the (1) powerhouse forebay upstream of the outlet from the fish lift exit flume, (2) powerhouse tailrace, (3) river left downstream of the spillway and adjacent to the Route 28 Bridge, (4) river right in the vicinity of the Route 28 Bridge, (5) center channel downstream of the confluence of spillway and powerhouse discharge, and (6) center channel at a point approximately

600 meters downstream of the spillway (Figure 4-3). Performance information was collected at each pilot deployment location with the specific methodologies used dependent on whether the area was determined in the field to be suitable for evaluation for the potential collection of 2D positional data or 1D presence/absence data.

To evaluate JSATS hydrophones for 2D positional pilot deployment locations, an array of five hydrophones were deployed in a manner which maximized the likelihood of successful triangulation of tag positions. This was accomplished by deploying receivers in a grid pattern to create multiple areas between receivers in the shape of triangles. The array of triangles was positioned in a way that would maximize the likelihood that theoretical tagged fish moving freely throughout the array would have signal transmissions detected by at least three receivers. The time of arrival of the tag transmission at each detecting receiver allowed for triangulation during processing of the data. All coordinates for the JSATS hydrophones were recorded using an EOS Arrow Global Navigation Satellite System (GNSS) receiver with accuracy within one centimeter (cm).

Following receiver deployment in the field, a pair of acoustic transmitters (one SS300 and one SS400) were maintained on a line alongside a boat and driven through the 2D array of five receivers for several minutes. Concurrently with passage of the test transmitters through the receiver array, high accuracy GPS points were collected once per second using an EOS Arrow GNSS receiver to create a continuous GPS track of the known position of the test tag over time. This process was repeated twice at each 2D array deployment. The resulting data sets consisting of detection information logged by each of the five receiver units and the positional data for the receiver locations and transmitter track were evaluated using the R-package YAPS (Yet Another Positioning Solver). YAPS uses maximum likelihood analysis of a state-space model applied directly to TOA data in combination with a movement model to estimate transmitter positions. Output presented for this Phase 1 assessment consists of the track duration (minutes), expected number of transmissions (based on a 3 second PRI), number of detections meeting the three-receiver criteria for determining position, and the corresponding percentage of all detections meeting the three-receiver criteria and providing a position. In addition, the YAPS estimated transmitter positions are compared to the GPS recorded transmitter track collected during the field survey. The performance of each individual receiver within the array was also evaluated with the intent of understanding placement effects on units in the vicinity of the Project and how that may impact the final study design proposed for Phase 2.

To evaluate JSATS hydrophones at each boat accessible 1D presence/absence pilot deployment location, a pair of acoustic receivers (one ATS and one Lotek[2]) were affixed to a mooring and pairs were deployed at two locations (four total hydrophones). The same pair of acoustic

[2] The RSP included a comparison between JSATS receivers manufactured by Lotek and ATS.

transmitters (one SS300 and one SS400) were maintained on a line alongside a boat and driven through the receiver area for a set of two passes, each several minutes in duration. Boat tracks were conducted to represent a range of distances and positions relative to the installed hydrophones. The test transmitter track was documented using high accuracy GPS points collected once per second using an EOS Arrow GNSS receiver to create a continuous GPS track of the known position of the test tag over time. The intent of this testing was to define the detection range as well as to evaluate the detection rate as a function of the distance from the hydrophone for both transmitter models. To accomplish this, the relative position of all tag transmission (including those detected and undetected by the receivers) was determined using the time-stamped GPS track, the known 3-second PRI, and the set of recorded detections. Distance from the receiver for each transmission was calculated as the straight line between the known receiver position and the transmitter track position at the time of signal. The full set of transmissions (detected and undetected) were then binned into distance categories and the rate of detection was evaluated. The detection rate was defined as the ratio of the number of detections recorded by a hydrophone to the number of transmissions from a transmitter during a known duration of time.

$$\text{Detection Efficiency (\%)} = \frac{No.Detections}{No.Transmissions}$$

Due to the lack of safe boat access into the Project forebay, a simpler binary approach to evaluate acoustic receiver performance in that area was used. With a set of four ATS receivers installed at locations around the forebay, active transmitters were placed in the water at known points and the coordinates for each location were recorded. Upon completion of tag positioning around the forebay, the set of receivers were removed from the water and all data was downloaded and reviewed. A matrix was developed to provide the detection status (i.e., valid detections present, or transmitter not detected) in each receiver file for transmitters at each test location.

Figure 4–3. Pilot deployment locations 1 through 6 identified for evaluation of JSATS acoustic receivers in the RSP for Phase 1 of the Project Interaction Study at Lawrence.

5 Phase 1: Study Results

5.1 River Herring Tag Retention and Survivability Assessment

A total of 122 adult river herring (94 alewife and 28 blueback herring) were obtained via collection at the trap and truck facility at Amoskeag Dam (Merrimack River Project, FERC No. 1893, Manchester, New Hampshire) and boat electrofishing in the Merrimack River immediately downstream of Essex Dam on May 21 (Table 5-1). Mean total length for alewives was 286 mm and for blueback herring was 257 mm.

Table 5–1. Source, count, and size of alewives and blueback herring collected as part of Phase 1 of the Project Interaction Study at Lawrence.

Species	Source	Count	Total Length (mm)		
			Min	Mean	Max
Alewife	Amoskeag	73	256	288	311
	Lawrence	21	244	276	313
	All	94	244	286	313
Blueback Herring	Amoskeag	-	-	-	-
	Lawrence	28	206	257	285
	All	28	206	257	285

When alewives from both sources were considered, 33 individuals were tagged gastrically with SS300 transmitters, 32 were tagged internally with SS400 transmitters, and 29 served as handling controls (Table 5-2). Of the 65 total alewives tagged as part of the tag retention assessment, only one transmitter was shed over the five-day holding period, resulting in transmitter retention rates for alewives of 97% for SS300 transmitters inserted gastrically and 100% for SS400 transmitters inserted internally. The five-day survival rate for alewives tagged gastrically was slightly lower than the survival rate for the set of handling controls (88% vs. 93%). Survival of adult alewives tagged internally was higher than that observed for the set of handling controls (97% vs. 93%) (Table 5-2).

Although the collected number of blueback herring was lower than that of alewives, individuals were available to at least provide an initial evaluation of transmitter retention and latent survival. Eight individuals were tagged gastrically with SS300 transmitters, 12 were tagged internally with SS400 transmitters, and eight served as handling controls (Table 5-2). Of the 20 total blueback herring tagged as part of the tag retention assessment, there were no observations of shed transmitters for either method (gastric or internal). The five-day survival rate for blueback herring tagged during this assessment was 88% for those receiving SS300 transmitters gastrically and 92% for those receiving SS400 transmitters internally. Survival of blueback herring serving as handling controls was relatively low; 63% for the five-day holding period.

Table 5–2. River herring sample sizes by tagging method and associated tag retention and five-day survival rates collected as part of Phase 1 of the Project Interaction Study at Lawrence.

Alewife									
Source	Count	Tag Method			Retention Rate		Survival Rate		
		Gastric	Internal	Control	Gastric	Internal	Gastric	Internal	Control
Amoskeag	73	26	25	22	96%	100%	85%	100%	95%
Lawrence	21	7	7	7	100%	100%	100%	86%	86%
All	94	33	32	29	97%	100%	88%	97%	93%
Blueback Herring									
Source	Count	Tag Method			Retention Rate		Survival Rate		
		Gastric	Internal	Control	Gastric	Internal	Gastric	Internal	Control
Amoskeag	-	-	-	-	-	-	-	-	-
Lawrence	28	8	12	8	100%	100%	88%	92%	63%
All	28	8	12	8	100%	100%	88%	92%	63%

5.2 JSATS Receiver Evaluation

Evaluation of JSATS receivers downstream of Lawrence took place between October 7-10, 2024. Operating conditions at the time of data collection at each pilot deployment locations are presented in Table 5-3. In all cases, of the two available generating units (G1 and G2), only Unit G2 was online and passed between 1,240 and 1,750 cfs. The downstream bypass operated continuously (160 cfs) and there was no spill over Essex Dam during the field data collection period.

Table 5–3. Summary of Project operations at the time of test transmitter data collection at each pilot deployment location evaluated in the vicinity of Lawrence during Phase 1 of the Project Interaction Study.

Pilot Deployment Location	Tag Evaluation		Unit(s) Online	Mean Discharge (cgs)		
	Date	Time		Turbine	Bypass	Spill
1	10/7/2024	1500	G2	1,500	160	0
2	10/9/2024	1500	G2	1,750	160	0
3	-	-	-	-	-	-
4	10/10/2024	1100	G2	1,300	160	0
5	10/10/2024	1700	G2	1,250	160	0
6	10/10/2024	1800	G2	1,300	160	0

Of the six pilot deployment locations identified in the RSP, two were determined suitable for assessment of 2D positional data and three were evaluated for 1D presence/absence data. Conditions at one location were unsuitable for evaluation and no test data was collected (Figure 5-1). Field judgements were made based on available water depths, velocity conditions, and line of sight considerations. Table 5-4 provides positional and receiver information for each location associated with the set of pilot deployment locations.

Figure 5–1. Shallow site conditions for pilot deployment location 3 during the field evaluation portion of Phase 1 of the Project Interaction Study at Lawrence.

Table 5–4. Receiver information for the five pilot deployment locations evaluated in the vicinity of Lawrence during Phase 1 of the Project Interaction Study.

Pilot Deployment Location	Evaluation Methodology	Receiver ID	Receiver Type	Latitude	Longitude
1	1D	1A	ATS	42°41'57.08"N	71° 9'56.44"W
		1B	ATS	42°41'57.13"N	71° 9'56.64"W
		1C	ATS	42°41'56.45"N	71° 9'55.97"W
		1D	ATS	42°41'57.31"N	71° 9'55.24"W
2	2D	2A	ATS	42°41'58.94"N	71° 9'54.66"W
		2B	ATS	42°41'59.18"N	71° 9'55.65"W
		2C	ATS	42°41'59.61"N	71° 9'55.14"W
		2D	Lotek	42°42'0.09"N	71° 9'55.66"W
		2E	ATS	42°42'0.40"N	71° 9'54.68"W
4	2D	4A	ATS	42°42'0.54"N	71° 9'54.73"W
		4B	Lotek	42°42'0.17"N	71° 9'55.74"W
		4C	ATS	42°42'0.91"N	71° 9'55.70"W
		4D	ATS	42°42'1.30"N	71° 9'56.54"W
		4E	ATS	42°42'1.38"N	71° 9'54.98"W
5	1D	5A	ATS	42°42'5.50"N	71° 9'53.45"W
		5B	ATS	42°42'5.04"N	71° 9'54.91"W
		5C	Lotek	42°42'5.50"N	71° 9'53.45"W
		5D	Lotek	42°42'5.04"N	71° 9'54.91"W
6	1D	6A	ATS	42°42'12.47"N	71° 9'38.13"W
		6B	ATS	42°42'11.26"N	71° 9'37.42"W
		6C	Lotek	42°42'12.47"N	71° 9'38.13"W
		6D	Lotek	42°42'11.26"N	71° 9'37.42"W

Note: Pilot deployment location 3 not accessible due to river conditions during testing

5.2.1 Pilot Deployment Location No. 1

Pilot deployment location 1 was located in the powerhouse forebay upstream of the outlet from the fish lift exit flume (Figure 4-3) and was targeted for the collection of 1D data during the Phase 1 evaluation. Due to the lack of boat access into the powerhouse forebay, receiver installation and transmitter tests were conducted from shore. The deployment at this location consisted of four ATS receivers (Figure 5-2). Transmitters were positioned at six test locations (Figure 5-2) and the detection status for each location at each receiver is summarized in Table 5-5. Transmitters positioned in areas within the upstream exit from the forebay were detected by receivers positioned towards the upstream end of the forebay (i.e., 1A, 1B, and 1C) but not by the receiver positioned at the downstream end of the forebay (i.e., 1D). Conversely, the transmitter positioned near the intake racks within the forebay was detected by the receiver at the downstream end of the forebay but due to line-of-site limitations were not detected by the receivers near the exit from the upstream fishway.

Table 5–5. Summary of transmitter detection information collected at pilot deployment location 1 during Phase 1 of the Project Interaction Study at Lawrence.

Receiver ID	Receiver Type	Transmitter Test Location					
		US1	US2	US3	US4	US5	US6
1A	ATS	Y	Y	Y	N	N	N
1B	ATS	Y	Y	Y	N	N	N
1C	ATS	Y	Y	N	Y	N	Y
1D	ATS	N	N	N	Y	Y	Y

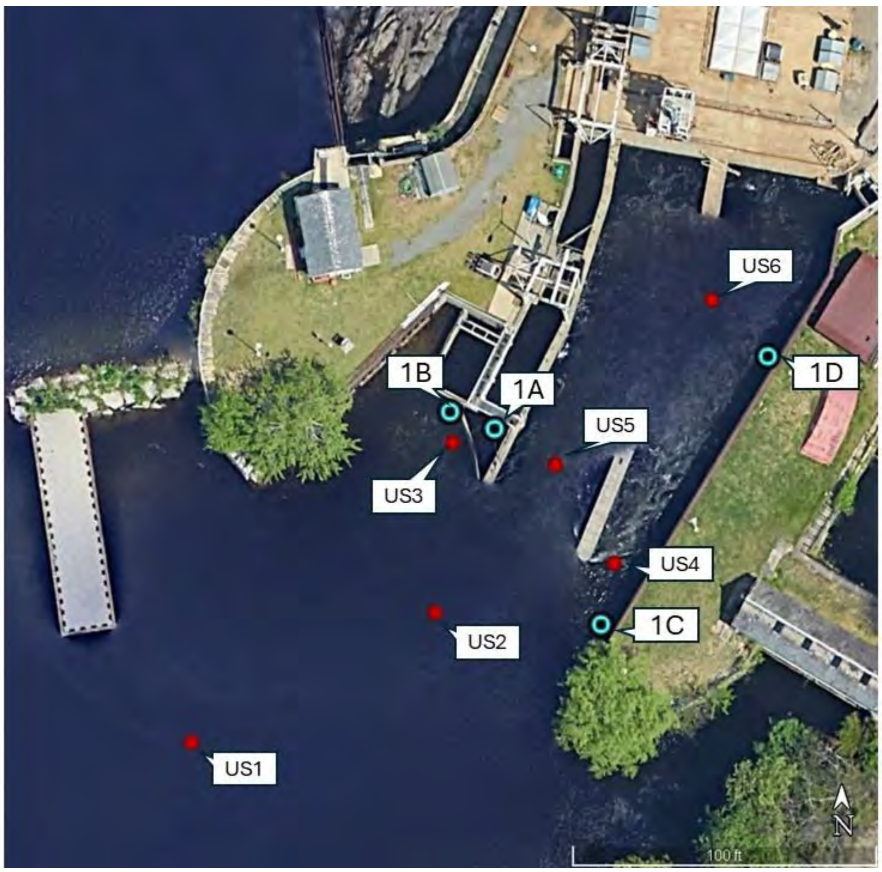


Figure 5–2. Receiver (1A-1D) and transmitter (US1-US6) placement during field evaluation at pilot deployment location 1 during Phase 1 of the Project Interaction Study at Lawrence.

5.2.2 Pilot Deployment Location No. 2

Pilot deployment location 2 was located at the powerhouse tailrace (Figure 4-3) and was targeted for the collection of 2D data during the Phase 1 evaluation. The array at this location consisted of five independent receivers: four manufactured by ATS and one manufactured by Lotek (Figure 5-3). The Lotek receiver (Receiver 2D) was positioned at the downstream end of the historic upstream fishway structure along the left-hand side of the powerhouse discharge (looking downstream). Figures 5-4 and 5-5 provide a visual comparison of the full GPS track recorded during each of the two transmitter tests with the points and corresponding travel path derived from the receiver detections as estimated using YAPS for the subset of transmissions detected by three or more receivers. Receivers at pilot deployment location 2 were installed near to the riverbed at depths of 9.4 (2A), 8.3 (2B), 7.6 (2C), 3.7 (2D) and 2.7 (2E) meters.

When compared to the calculated number of transmissions for the duration of the two separate transmitter tests (assuming one transmission every three seconds), the positioning percentage (i.e., the rate at which three or more receivers detected an individual transmission) ranged between 33-43% for the SS300 transmitter and 50-62% for the SS400 transmitter, equivalent to 7 to 12 detections per minute, respectively (Table 5-6). Note that these detection rates represent the full duration of each transmitter test (i.e., the periods of time when the tag was either within or outside/adjacent to the targeted 2D detection zone as defined by the outer perimeter of the installed array).

The mean distance error (i.e., the measured linear distance from the known transmission location [as measured by GPS] and the estimated transmission position [as calculated using YAPS]) from the full GPS track ranged from 1.8 to 2.1 meters when the full track length is considered (i.e., the full length of the track, both inside and outside of the primary detection area as defined by the perimeter of the receiver array). When the subset of the GPS track occurring within the primary detection area at location 2 was considered, the mean error distance for estimated positions was reduced to a range between 1.4 and 1.6 meters. It should be noted that in both cases, an unquantified degree of error was introduced into the test tag positions due to (1) flow effects which deflected the test transmitters out of a vertical position with the GPS unit on the boat, and (2) a degree of horizontal movement for the fixed hydrophones on the temporary anchor systems employed during this study.

The contribution and detection rate for the full GPS track associated with each individual receiver installed as part of the test array at pilot deployment location 2 is summarized in Table 5-7. The detection rates for ATS receivers installed at 2A, 2B, and 2C averaged around 9% higher for the SS400 transmitter than was observed for the SS300 transmitter during both tag tests. For pilot deployment location 2, across all tests and considering both tag types, ATS receiver detection rates at 2A, 2B, and 2C ranged from 66.3% to 92.1%. The ATS receiver installed at 2E had the lowest detection rate: ranging between 30-32% for the SS300 transmitter and 39-45% for the SS400 transmitter. Based on the pattern of detected versus undetected observations for the ATS receiver at 2E, it is suspected that the discharge from the downstream bypass reduced that receiver's line of sight detecting transmissions from closer to the downstream face of the powerhouse. The detection rate for the Lotek receiver installed at 2D was poor for both transmitter types and during both tag tests, detecting between 3 and 10% of transmissions. Images depicting the spatial distribution of transmissions detected versus not detected at each receiver location within the array at pilot deployment location 2 are provided in Appendix B.

Table 5–6. Summary of 2D detection testing at pilot deployment location 2 during Phase 1 of the Project Interaction Study at Lawrence.

Pilot Deployment Location No.	2			
Transmitter Test No.	1		2	
Test Duration (minutes)	8.92		8.25	
Calculated No. Transmissions	178		165	
Transmitter Type	SS300	SS400	SS300	SS400
Full Track - No. YAPS Positions	58	89	71	103
Full Track - Positioning Percent	32.5%	49.9%	43.0%	62.4%
Estimated No. Detections Per Minute	7	10	9	12
Full Track - Mean Error Distance from GPS (m)	2.12	2.00	2.01	1.84
Inner Array - Mean Error Distance from GPS (m)	1.41	1.56	1.64	1.42

Table 5–7. Transmission detection percentages for individual JSATS receivers installed as part of the 2D array at pilot deployment location 2 during Phase 1 of the Project Interaction Study at Lawrence.

Receiver ID	Receiver Type	Transmitter Test 1		Transmitter Test 2	
		SS300	SS400	SS300	SS400
2A	ATS	71.8	80.1	66.3	78.9
2B	ATS	82.9	92.1	72.3	84.9
2C	ATS	81.4	89.2	77.1	82.5
2D	Lotek	3.4	6.2	4.8	10.2
2E	ATS	29.9	44.6	32.5	38.6

Figure 5–3. Receiver placement during field evaluation at pilot deployment location #2 during Phase 1 of the Project Interaction Study at Lawrence.

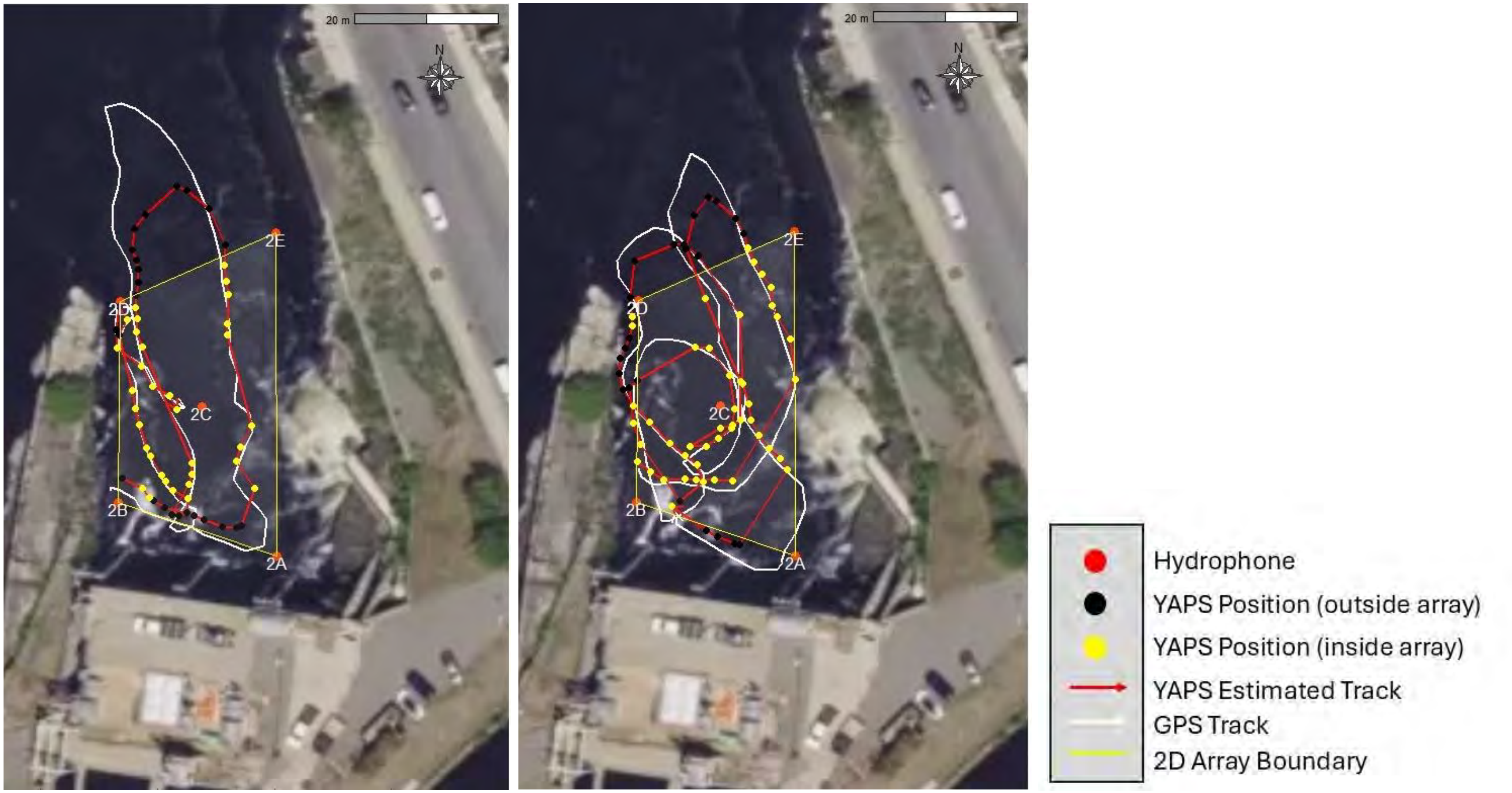
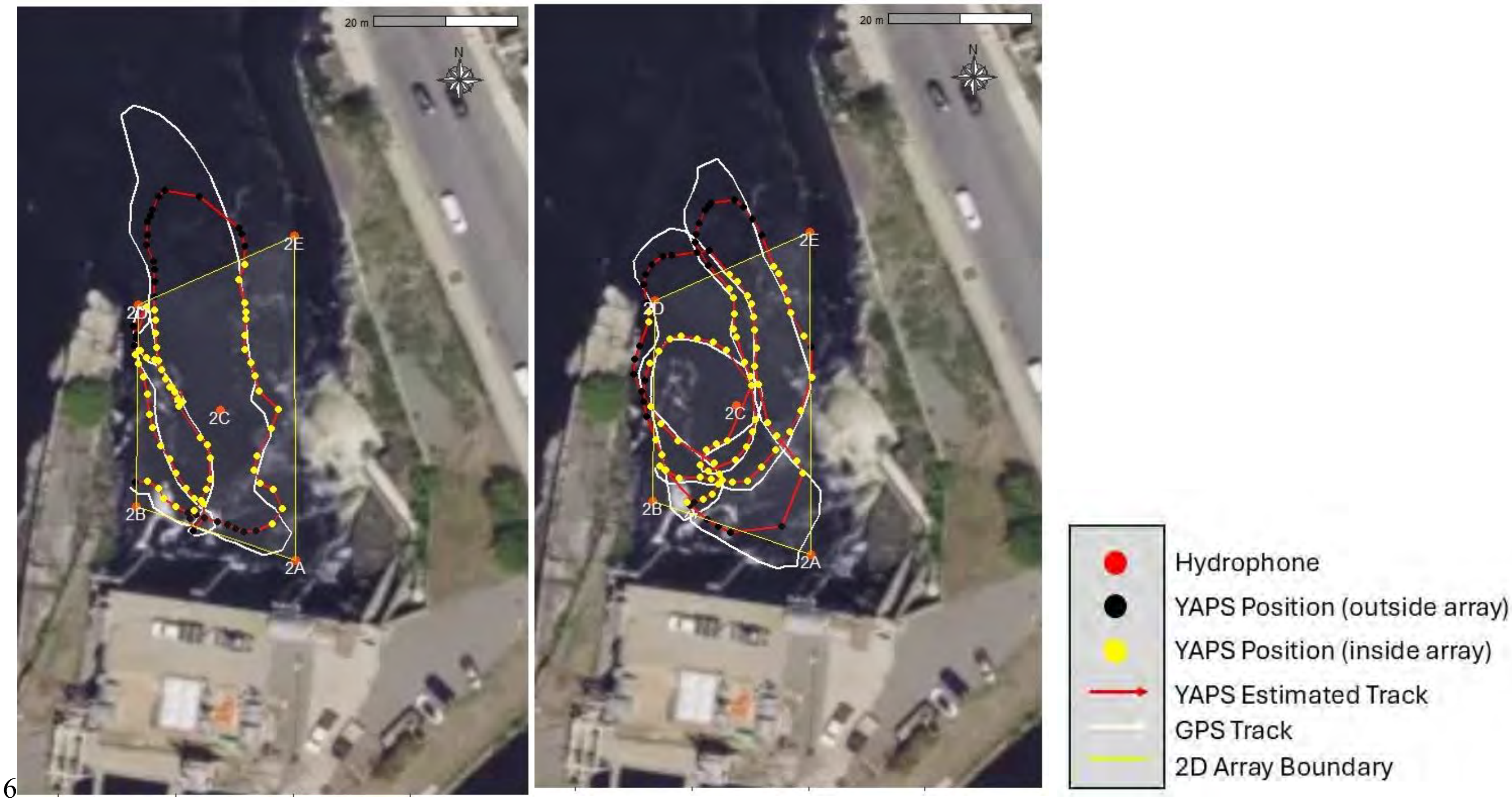


Figure 5–4. Test transmitter position and resulting YAPS positional estimates for the ATS SS300 tag during two transmitter tests at pilot deployment location #2 during Phase 1 of the Project Interaction Study at Lawrence. YAPS positions are identified as those associated with GPS/transmitter track within the boundary of the targeted 2D detection area (yellow) and those associated with GPS/transmitter track outside the boundary of the targeted 2D area (black).



6

Figure 5–5. Test transmitter position and resulting YAPS positional estimates for the ATS SS400 tag during two transmitter tests at pilot deployment location #2 during Phase 1 of the Project Interaction Study at Lawrence. YAPS positions are identified as those associated with GPS/transmitter track within the boundary of the targeted 2D detection area (yellow) and those associated with GPS/transmitter track outside the boundary of the targeted 2D area (black).

5.2.3 Pilot Deployment Location No. 4

Pilot deployment location 4 was located on the river right in the vicinity of Route 28 Bridge (Figure 4-3) and was targeted for the collection of 2D data during the Phase 1 evaluation. The array at this location consisted of five independent receivers: four manufactured by ATS and one manufactured by Lotek (Figure 5-6). The Lotek receiver (Receiver 4B) was positioned at the downstream end of the historic upstream fishway structure along the left-hand side of the powerhouse discharge (looking downstream). Figures 5-7 and 5-8 provide a visual comparison of the full GPS track recorded during each of the two transmitter tests with the points and corresponding travel path derived from the receiver detections as estimated using YAPS for the subset of transmissions detected by three or more receivers. Receivers at pilot deployment location 4 were installed near to the riverbed at depths of 2.4 (4A), 3.6 (4B), 3.5 (4C), 2.1 (4D) and 2.0 (4E) meters.

When compared to the calculated number of transmissions for the duration of the two separate transmitter tests (assuming one transmission every three seconds), the positioning percentage (i.e., the rate at which three or more receivers detected an individual transmission) ranged between 20-25% for the SS300 transmitter and 19-25% for the SS400 transmitter, equivalent to 4 or 5 detections per minute (Table 5-8). Note that these detection rates represent the full duration of each transmitter test (i.e., the periods of time when the tag was either within or outside/adjacent to the targeted 2D detection zone as defined by the outer perimeter of the installed array).

The mean error distance from the full GPS track ranged from 3.4 to 8.5 meters when the full track length is considered (i.e., the full length of the track, both inside and outside of the primary detection area as defined by the perimeter of the receiver array). When the subset of the GPS track occurring within the primary detection area at location 4 was considered, the mean error distance for estimated positions was reduced slightly to a range between 3.5 to 7.2 meters. It should be noted that in both cases, an unquantified degree of error was introduced into the test tag positions due to (1) flow effects which deflected the test transmitters out of a vertical position with the GPS unit on the boat, and (2) a degree of horizontal movement for the fixed hydrophones on the temporary anchor systems employed during this study.

The contribution and detection rate for the full GPS track associated with each individual receiver installed as part of the test array at pilot deployment location 4 is summarized in Table 5-9. The detection rate for the Lotek receiver installed at 4B was poor for both transmitter types and during both of the tag tests, detecting between 2 and 7% of transmissions. With a few exceptions, detection rates for ATS receivers installed at the other four positions were generally higher for the SS400 transmitter than the SS300 transmitter. Among the ATS receivers installed at pilot deployment location 4, the units at 4A, 4C, and 4D had detection rates ranging from 42 to 71%. The unit at 4E had the lowest detection rate: ranging between 27-35% for the SS300 transmitter and 29-36% for the SS400 transmitter. Based on the pattern of detected versus undetected observations for the ATS receiver at 4E, detection efficiency at that location was poor in the upstream direction with most detections occurring in the main channel adjacent to that position or just downstream. Images depicting the spatial distribution of transmissions detected versus not detected at each receiver location within the array at pilot deployment location 4 are provided in Appendix B.

Table 5–8. Summary of 2D detection testing at pilot deployment location 4 during Phase 1 of the Project Interaction Study at Lawrence.

Pilot Deployment Location No.	**4**			
Transmitter Test No.	**1**		**2**	
Test Duration (minutes)	9.4		6.4	
Calculated No. Transmissions	188		128	
Transmitter Type	SS300	SS400	SS300	SS400
No. YAPS Positions	37	35	32	32
Positioning Percent	19.7%	18.6%	25.0%	25.0%
Estimated No. Detections Per Minute	4	4	5	5
Full Track Mean Error Distance from GPS (m)	3.42	5.32	3.93	8.5
Inner Array Mean Error Distance from GPS (m)	3.57	4.7	4.54	7.16

Table 5–9. Transmission detection percentages for individual JSATS receivers installed as part of the 2D array at pilot deployment location 4 during Phase 1 of the Project Interaction Study at Lawrence.

Receiver ID	**Receiver Type**	**Transmitter Test 1**		**Transmitter Test 2**	
		SS300	**SS400**	**SS300**	**SS400**
4A	ATS	50.5	56.4	60.8	56.9
4B	Lotek	2.1	1.6	6.2	6.9
4C	ATS	67.6	70.7	68.5	56.9
4D	ATS	52.1	50.5	42.3	50.8
4E	ATS	35.1	36.2	26.9	28.6

Figure 5–6. Receiver placement during field evaluation at pilot deployment location 4 during Phase 1 of the Project Interaction Study at Lawrence.

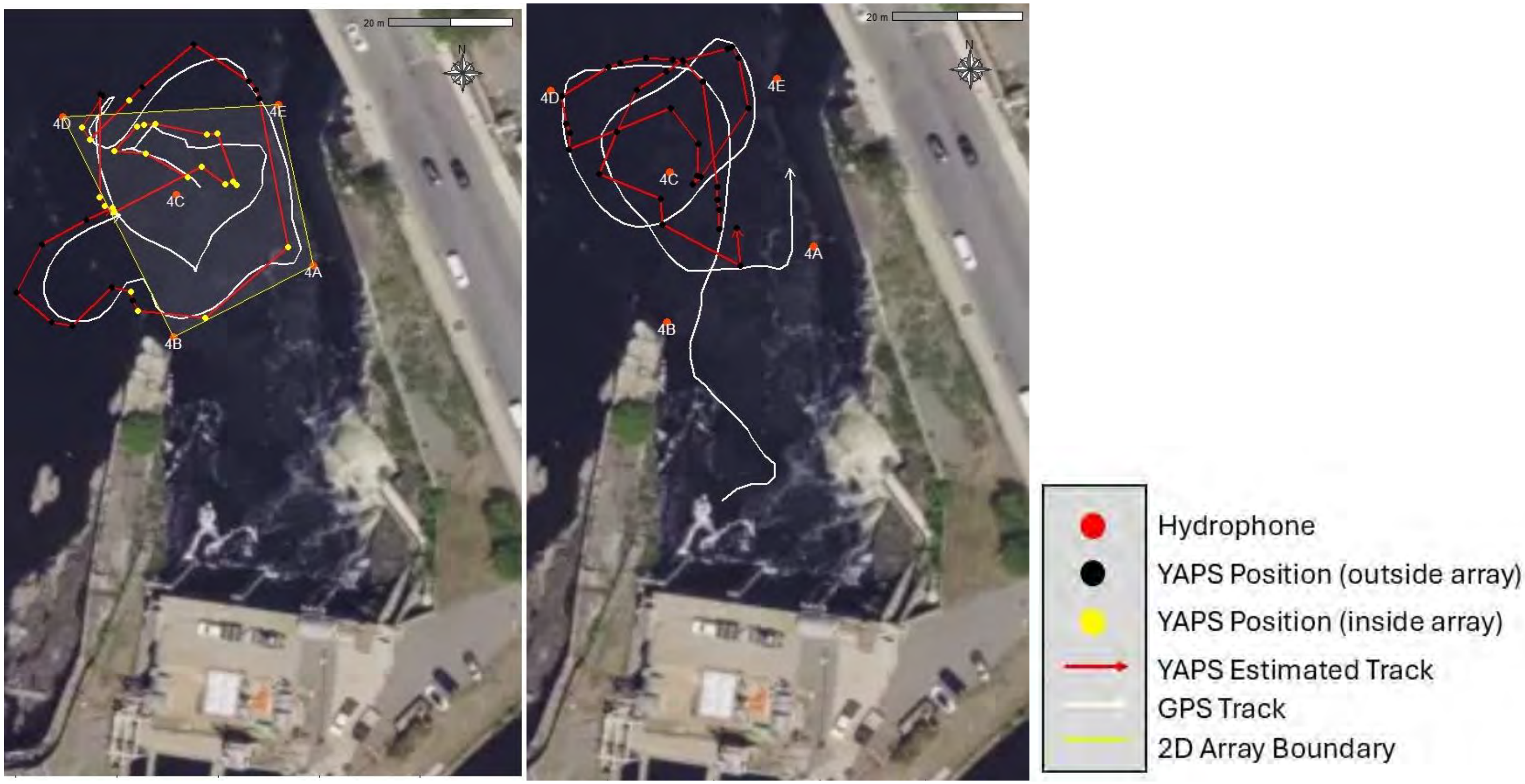


Figure 5–7. Test transmitter position and resulting YAPS positional estimates for the ATS SS300 tag during two transmitter tests at pilot deployment location 4 during Phase 1 of the Project Interaction Study at Lawrence. YAPS positions are identified as those associated with GPS/transmitter track within the boundary of the targeted 2D detection area (yellow) and those associated with GPS/transmitter track outside the boundary of the targeted 2D area (black).

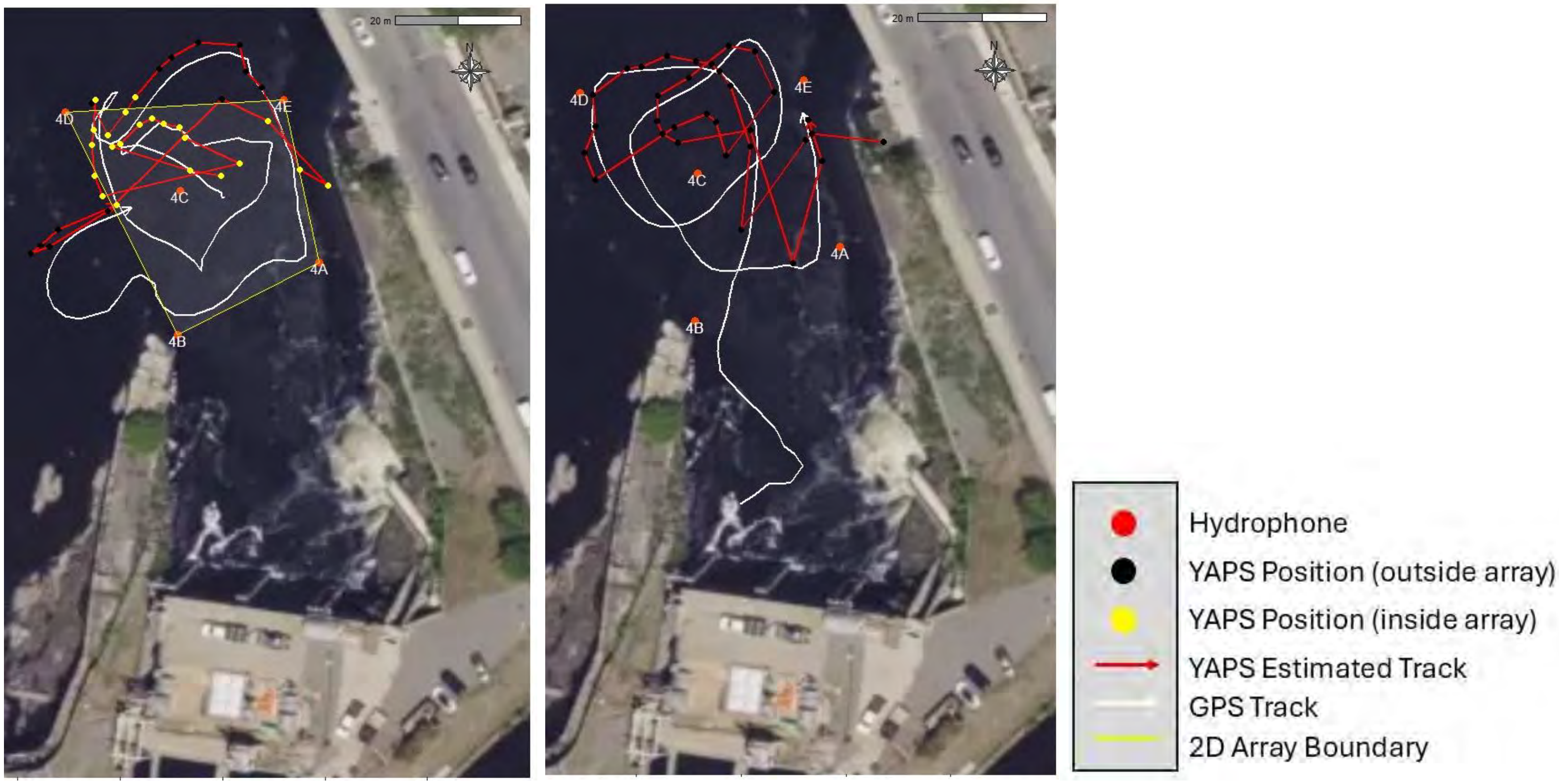


Figure 5–8. Test transmitter position and resulting YAPS positional estimates for the ATS SS400 tag during two transmitter tests at pilot deployment location 4 during Phase 1 of the Project Interaction Study at Lawrence. YAPS positions are identified as those associated with GPS/transmitter track within the boundary of the targeted 2D detection area (yellow) and those associated with GPS/transmitter track outside the boundary of the targeted 2D area (black).

5.2.4 Pilot Deployment Location No. 5

Pilot deployment location 5 was located at the center channel downstream of the confluence of spillway and powerhouse discharge (Figure 4-3) and was targeted for the collection of 1D data during the Phase 1 evaluation. Pilot deployment location 5 was characterized by relatively shallow water conditions (1-4 feet in depth) with higher flow rates in the range of 1-3 ft/s and some surface turbulence (Figure 5-9).

The deployment at this location consisted of four receivers: two manufactured by ATS (identified as 5A and 5B) and two manufactured by Lotek (identified as 5C and 5D; Figure 5-10). Figures presenting the GPS-recorded boat/transmitter track for the two test events and the relative location of each confirmed transmitter detection (by receiver and transmitter type) are included in Appendix C. Table 5-10 provides a summary of tag transmission locations during the two test events as well as the range and average tag position relative to each receiver. Test events were approximately 3-4 minutes in duration and covered a range of straight-line distances from the receivers ranging from 1 up to 208 m. It is important to understand that acoustic detections rely on the line-of-sight between the receiver and transmitter and so in-water obstructions related to bottom topography or other natural or engineered in-water features will influence detection rates for a particular receiver.

Tables 5-11 and 5-12 provide a summary of the observed detection ranges and rates for the ATS receivers installed at pilot deployment location 5 (Stations 5A and 5B, respectively). Although Lotek receivers were deployed alongside the ATS units at pilot deployment location 5, they were ineffective for detecting either the SS300 or SS400 transmitters given conditions at that test site. For the ATS receivers, detection rates varied among test runs and transmitter types with a general pattern of decreasing rates given an increase in distance between the tag and receiver (Figure 5-11). When considered for both ATS receivers during the pair of test runs, the SS300 transmitter was detected only within a distance of 40 m of the receiver and at a median detection rate of 10-25%. The detection range for the SS400 transmitter was slightly further with some detections in the 40-60 m range from the receiver but the overall median detection rates across the range of detectable distances were comparable (5-25%). At a three second PRI, detection efficiency rates of 5%, 10%, and 25% would correspond to 1, 2, and 5 detections per minute, respectively. The overall performance of the Lotek receivers was poor for both transmitter types.

Table 5–10. Summary of transmitter tests conducted at pilot deployment location 5 to evaluate the 1D detection range and during Phase 1 of the Project Interaction Study at Lawrence. (n = total number of test transmissions)

Transmitter Test No.	Receiver ID	Test Transmitter Positions			
		n	Max Distance (m)	Min Distance (m)	Mean Distance (m)
1	5A/5C	76	173	3	72
	5B/5D	76	208	4	74
2	5A/5C	65	180	1	110
	5B/5D	65	165	32	105

Table 5–11. Detection range and rate for the 1D evaluation using the ATS receiver installed at Station 5A during Phase 1 of the Project Interaction Study at Lawrence. Results presented by transmitter test (number 1 or 2) and type (SS300 or SS400).

Transmitter Test No.	Distance to Receiver (m)	SS300 Transmitter		SS400 Transmitter	
		% Detect	No. Detects/Min	% Detect	No. Detects/Min
1	0-20	8%	2	25%	5
	20-40	0%	0	6%	1
	40-60	0%	0	0%	0
	>60	0%	0	0%	0
	Total	1%	0	5%	1
2	0-20	33%	7	0%	0
	20-40	20%	4	0%	0
	40-60	0%	0	0%	0
	>60	0%	0	0%	0
	Total	5%	1	0%	0

Table 5–12. Detection range and rate for the 1D evaluation using the ATS receiver installed at Station 5B during Phase 1 of the Project Interaction Study at Lawrence. Results presented by transmitter test (number 1 or 2) and type (SS300 or SS400).

Transmitter Test No.	Distance to Receiver (m)	SS300 Transmitter		SS400 Transmitter	
		% Detect	No. Detects/Min	% Detect	No. Detects/Min
1	0-20	24%	5	35%	7
	20-40	25%	5	25%	5
	40-60	0%	0	14%	3
	>60	0%	0	0%	0
	Total	9%	2	13%	3
2	0-20	-	-	-	-
	20-40	0%	0	20%	4
	40-60	0%	0	11%	2
	>60	0%	0	0%	0
	Total	0%	0	3%	1

Figure 5–9. Site conditions for pilot deployment location 5 during the field evaluation portion of Phase 1 of the Project Interaction Study at Lawrence.

Figure 5–10. Receiver placement during field evaluation at pilot deployment locations 5 and 6 during Phase 1 of the Project Interaction Study at Lawrence.

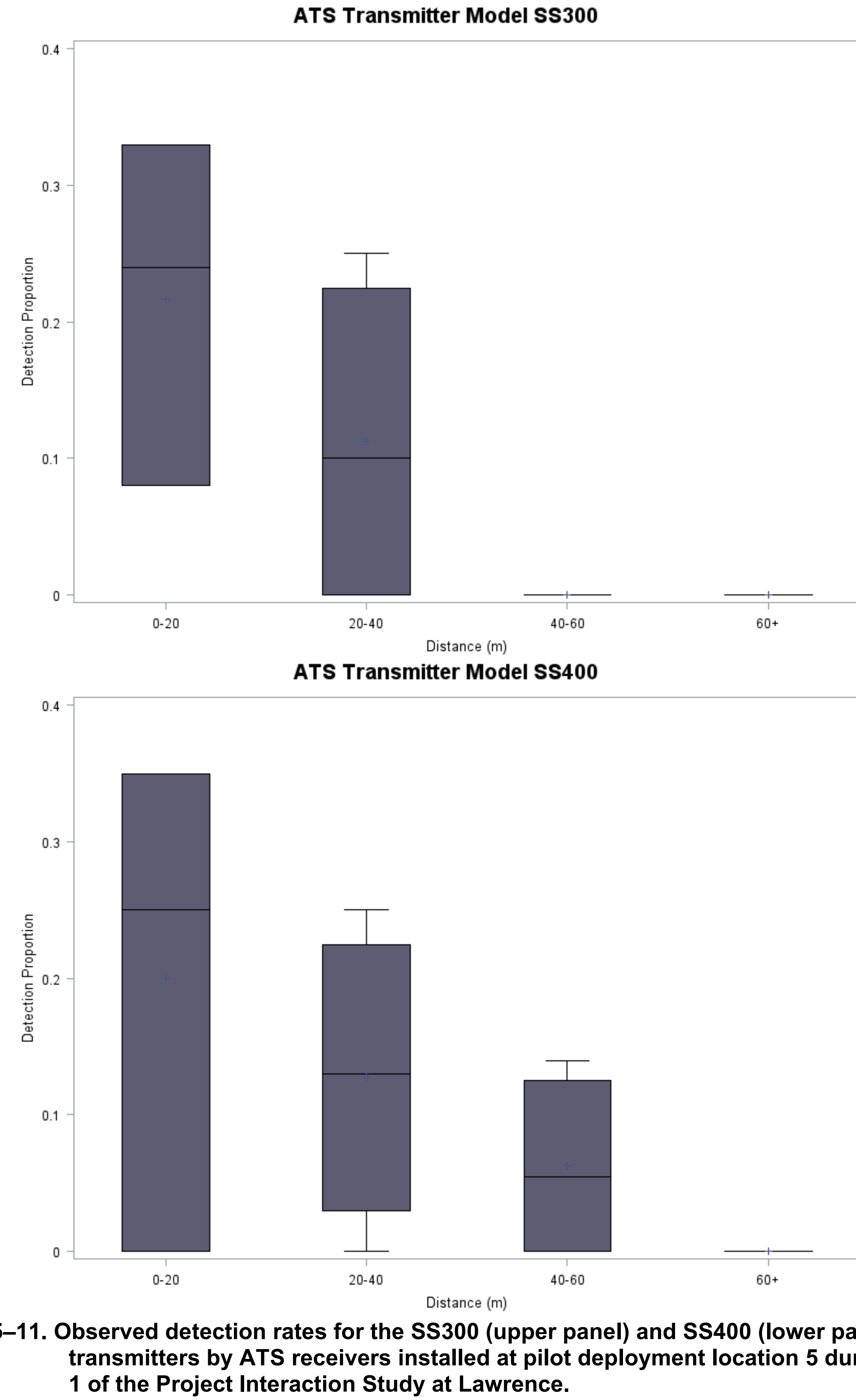


Figure 5–11. Observed detection rates for the SS300 (upper panel) and SS400 (lower panel) transmitters by ATS receivers installed at pilot deployment location 5 during Phase 1 of the Project Interaction Study at Lawrence.

5.2.5 Pilot Deployment Location No. 6

Pilot deployment location 6 was located at the center channel at a point approximately 600 meters downstream of the spillway (Figure 4-3) and was targeted for the collection of 1D data during the Phase 1 evaluation. Pilot deployment location 6 was characterized by relatively deeper water conditions (~6 feet in depth) with low flow rates near 0.5 ft/s (Figure 5-12).

The deployment at this location consisted of four receivers: two manufactured by ATS (identified as 6A and 6B) and two manufactured by Lotek (identified as 6C and 6D) (Figure 5-10). Figures presenting the GPS-recorded boat/transmitter track for the two test events and the relative location of each confirmed transmitter detection (by receiver and transmitter type) are included in Appendix C. Table 5-13 provides a summary of tag transmission locations during the two test events as well as the range and average tag position relative to each receiver. Test events were approximately 4-7 minutes in duration and covered a range of straight-line distances from the receivers ranging from 1 up to 149 meters[3].

Tables 5-14 through 5-17 provide a summary of the observed detection ranges and rates for the ATS and Lotek receivers installed at pilot deployment location 6 (Stations 6A, 6B, 6C, and 6D, respectively). For the ATS receivers, detection rates varied among test runs and transmitter types with a general pattern of decreasing rates given an increase in distance between the tag and receiver. When considering both ATS receivers during the pair of test runs, this pattern was slightly more pronounced for the SS300 transmitters. The median detection rate for this transmitter decreased from 62% at locations between 0-20 m from the receiver to 18% at locations greater than 60 m from the receiver, whereas the median detection rate for the SS400 transmitter ranged between 30-40% across the range of distances sampled (Figure 13). At a three second PRI, detection efficiency rates of 20%, 40%, and 60% would correspond to 4, 8, and 12 detections per minute, respectively. Similar to observations at pilot deployment location 5, the overall performance of the Lotek receivers was poor for both transmitter types.

Table 5–13. Summary of transmitter tests conducted at pilot deployment location 6 to evaluate the 1D detection range and during Phase 1 of the Project Interaction Study at Lawrence.

Transmitter Test No.	Receiver ID	Test Transmitter Positions			
		n	Max Distance (m)	Min Distance (m)	Mean Distance (m)
1	6A/6C	133	82	4	45
	6B/6D	133	89	14	46
2	6A/6C	81	149	40	88
	6B/6D	81	145	1	74

[3] It is important to understand that acoustic detections rely on the line-of-sight between the receiver and transmitter, so in-water obstructions related to bottom topography or other natural or engineered in-water features will influence detection rates for a particular receiver.

Table 5–14. Detection range and rate for the 1D evaluation using the ATS receiver installed at Station 6A during Phase 1 of the Project Interaction Study at Lawrence. Results presented by transmitter test (number 1 or 2) and type (SS300 or SS400).

Transmitter Test No.	Distance to Receiver (m)	SS300 Transmitter		SS400 Transmitter	
		% Detect	No. Detects/Min	% Detect	No. Detects/Min
1	0-20	62%	12	29%	6
	20-40	36%	7	28%	6
	40-60	47%	9	17%	3
	>60	24%	5	9%	2
	Total	38%	8	19%	4
2	0-20	-	-	-	-
	20-40	-	-	-	-
	40-60	14%	3	82%	16
	>60	12%	2	42%	8
	Total	12%	2	51%	10

Table 5–15. Detection range and rate for the 1D evaluation using the ATS receiver installed at Station 6B during Phase 1 of the Project Interaction Study at Lawrence. Results presented by transmitter test (number 1 or 2) and type (SS300 or SS400).

Transmitter Test No.	Distance to Receiver (m)	SS300 Transmitter		SS400 Transmitter	
		% Detect	No. Detects/Min	% Detect	No. Detects/Min
1	0-20	64%	13	14%	3
	20-40	22%	4	27%	5
	40-60	31%	6	20%	4
	>60	56%	11	19%	4
	Total	44%	9	21%	4
2	0-20	31%	6	62%	12
	20-40	29%	6	57%	11
	40-60	33%	7	67%	13
	>60	10%	2	39%	8
	Total	19%	4	47%	9

Table 5–16. Detection range and rate for the 1D evaluation using the Lotek receiver installed at Station 6C during Phase 1 of the Project Interaction Study at Lawrence. Results presented by transmitter test (number 1 or 2) and type (SS300 or SS400).

Transmitter Test No.	Distance to Receiver (m)	SS300 Transmitter		SS400 Transmitter	
		% Detect	No. Detects/Min	% Detect	No. Detects/Min
1	0-20	0%	0	0%	0
	20-40	0%	0	0%	0
	40-60	0%	0	0%	0
	>60	0%	0	0%	0
	Total	0%	0	0%	0
2	0-20	-	-	-	-
	20-40	-	-	-	-
	40-60	0%	0	0%	0
	>60	0%	0	0%	0
	Total	0%	0	0%	0

Table 5–17. Detection range and rate for the 1D evaluation using the Lotek receiver installed at Station 6D during Phase 1 of the Project Interaction Study at Lawrence. Results presented by transmitter test (number 1 or 2) and type (SS300 or SS400).

Transmitter Test No.	Distance to Receiver (m)	SS300 Transmitter		SS400 Transmitter	
		% Detect	No. Detects/Min	% Detect	No. Detects/Min
1	0-20	0%	0	0%	0
	20-40	0%	0	2%	0
	40-60	0%	0	4%	1
	>60	0%	0	4%	1
	Total	0%	0	3%	1
2	0-20	0%	0	0%	0
	20-40	0%	0	14%	3
	40-60	0%	0	0%	0
	>60	0%	0	0%	0
	Total	0%	0	1%	0

Figure 5–12. Site conditions for pilot deployment location 6 during the field evaluation portion of Phase 1 of the Project Interaction Study at Lawrence.

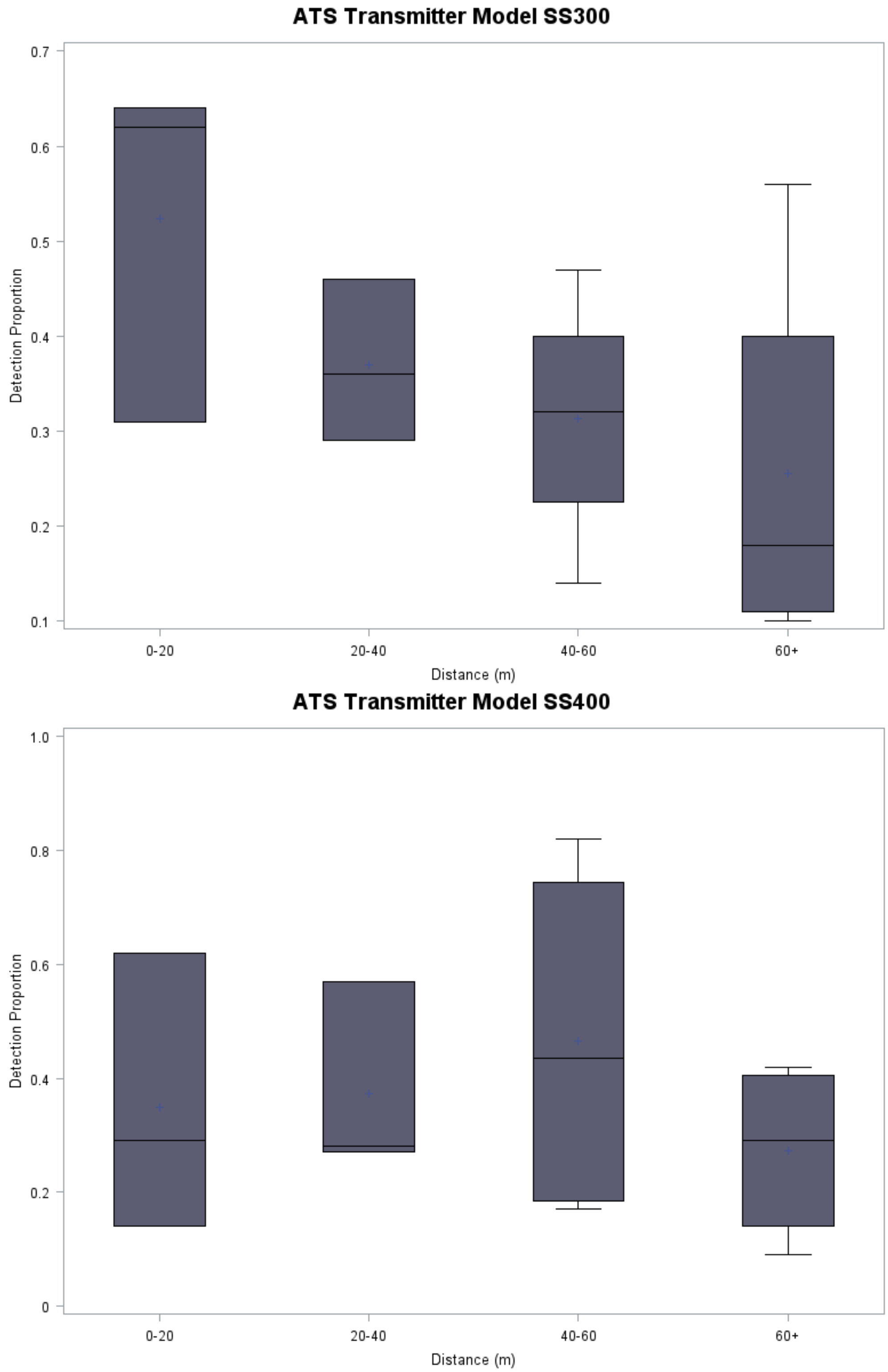


Figure 5–13. Observed detection rates for the SS300 (upper panel) and SS400 (lower panel) transmitters by ATS receivers installed at pilot deployment location 6 during Phase 1 of the Project Interaction Study at Lawrence.

6 Summary

A feasibility study to assess the use of JSATS telemetry transmitters and receivers for a future evaluation of diadromous fish movements in the areas upstream and downstream of Essex Dam was conducted in support of the ongoing FERC relicensing of the Lawrence Hydroelectric Project. This Phase 1 evaluation consisted of two primary components: a tank-based evaluation to examine transmitter retention and post-tagging survival rates of adult river herring (alewife and blueback herring) and a field evaluation to determine the functionality (as measured by detection range and rate) of JSATS receivers at different locations in the vicinity of the dam. The two Phase 1 components were each completed during the 2024 field season and findings from these studies have been used to update the Phase 2 methodology with respect to target fish species, transmitter selection, receiver selection, and the placement/anticipated resolution of receivers (see Appendix A of this report).

Collection and tagging of adult river herring took place during late May 2024. A blend of sampling techniques was employed and although they produced enough alewives to meet the RSP sample size, the total number of blueback herring for evaluation was lower than targeted. Despite that, two transmitter types manufactured by ATS were evaluated (SS300 and SS400). The transmitters differed from one another in their size (weight and dimensions) and the methodology by which they were affixed to a fish. The SS300 transmitter is slightly larger and due to its rectangular-like shape was inserted gastrically into both herring species. The SS400 is slightly smaller and due to its cylindrical shape was inserted into the abdominal cavity of both species using a hollow needle. In general, both herring species demonstrated high transmitter retention rates for the SS300 tag (97% in alewife and 100% in blueback herring) and the SS400 tag (100% in both species). Latent (5-day) survival was higher in alewife for fish tagged internally using the SS400 transmitter (97%) than those tagged gastrically using the SS300 transmitter (88%). The latent survival rates observed for both test groups did not differ greatly from the latent survival rate observed for adult alewives maintained in the same tank as handling controls (93%). Latent survival for blueback herring was slightly lower than that observed for alewife (92% for those tagged internally and 88% for those tagged gastrically). Similar to the observations for alewife, the latent survival estimates for tagged fish were comparable (in this case better) than that observed for control fish (63% survival). All blueback herring used in this evaluation (test and control fish) were subjected to collection by electrofishing, netting/transport to the holding tanks, and the five-day holding period. It is likely that this involved process to acquire those fish for the holding study caused a stress response, easily detected due to the relatively small samples sizes for blueback herring.

Based on these observations, it appears that the adults of both alewife and blueback herring are compatible with the two ATS transmitters assessed during this study. Both retention and latent survival rates were relatively high and did not show any strong differences between the two transmitter methods. That said, the capabilities of the transmitters themselves will need to be considered during the design of Phase 2. Based on anecdotal observations from staff biologists during this study, the cylindrical shape and ease of inserting via a hollow needle make the use of the SS400 transmitter for marking adult herring a quick process. In addition, the life span of the SS400 transmitter at a comparable transmission rate is longer than that of the SS300. However, the SS400 does not currently support additional sensor information to be included in each tag transmission. The SS300 allows for the collection of pressure information with each tag detection, allowing the user to determine fish depth for each recorded transmission.

Numerous factors are identified in the literature which may influence acoustic detection range variability including turbidity, temperature, surface conditions, depth, water flow, bathymetry and substrate obstruction (Kessel et al. 2013). The RSP identified a total of six locations representing a cross section of conditions under which the performance of JSATS receivers was to be evaluated (identified in this report as pilot deployment locations 1 through 6). Field conditions at the time of data collection prevented sampling at pilot deployment location 3.

Figure 6-1 delineates six general regions upstream and downstream of the Lawrence Dam. Table 6-1 provides a general characterization of each region relative to in-river conditions (depth, flow, etc.).

- Regions A (lower impoundment) and F (downstream reach) can be characterized as relatively deep and low velocity areas with limited surface turbulence which remain relatively steady under a range of inflow conditions. Phase 1 data collection at pilot deployment location 6 is most representative of these regions.
- The powerhouse forebay (Region B) and tailrace (Region C) are both relatively deep and flow conditions range from moderate to high depending on the level of generation. There is a larger degree of surface turbulence present in Region C due to the downstream bypass discharge. These two regions are generally steady with regards to water depth and flow under a range of inflow conditions. Phase 1 data collection at pilot deployment location 1 is representative of the powerhouse forebay and pilot deployment locations 2 and 4 are most representative of the powerhouse tailrace.
- The dam spill zone (Region D) is relatively shallow and characterized by high flow conditions and surface turbulence. Conditions in this region range tremendously depending on river conditions from periods of no spill , shallow depths and a lack of connectivity to periods of high velocity and turbulent conditions. This region was not suitable for collection of Phase 1 data due to no flow.
- The downstream confluence zone (Region E) is also relatively shallow and characterized by high flow conditions and surface turbulence. As this area receives flow from both the powerhouse tailrace and spillway, conditions in the downstream confluence zone are fairly consistent (relative to the dam spill zone). Phase 1 data collection at pilot deployment location 5 is most representative of this region.

A preliminary assessment of all six regions was conducted by project staff at the onset of the Phase 1 evaluation. Based on general conditions as well as consideration of Phase 2 study needs, it was determined that evaluation of receiver range and rates would be conducted in a manner that would inform on the potential collection of detection data appropriate for 2D data resolution at pilot deployment locations 2 and 4 and 1D data resolution at pilot deployment locations 1, 5, and 6. The approaches taken for the 1D sites varied slightly due to a lack of safe boat access at deployment location 1. The 1D and 2D evaluations considered both transmitter models (SS300 and SS400) as well as receivers manufactured by Lotek and ATS. Based on the higher detection rates observed for the ATS receivers, the Lotek receivers will not be discussed any further in this report or considered for inclusion in Phase 2.

Region C (Figure 6-1) provided the best combination of field conditions to support an array suitable for providing the data resolution required to facilitate the collection of 2D positional data for tagged fish (relative water depth, relatively consistent hydraulic conditions, and shore/boat accessibility). Findings from the 2D test arrays deployed in Region C (i.e., pilot deployment locations 2 and 4) support the use of that approach at that location. Transmitter detection tests from the two pilot arrays resulted in a percentage of transmissions providing positions (i.e., detected by 3 or more receivers) ranging between 20-47% for the SS300 transmitter and 19-62% for the SS400 transmitter. At a three second PRI this equates to four positions per minute at 20% detection efficiency and 10 positions per minute at 50% detection efficiency. When evaluated at a receiver level, detection efficiency was higher for units installed in the deeper water conditions closer to the powerhouse (e.g., receiver sites 2A, 2B, 2C) and lower for units installed towards the downstream end of Region C (e.g., receiver sites 4D, 4E). Similarly, the error around the YAPS-estimated transmitter locations in the lower end of Region C (i.e., from pilot deployment location 4) were higher than those observed for the upstream end of the region. It is important to note that for the Phase 1 evaluation, a sizable percentage of the measured error between known and estimated transmitter positions is likely attributable to (1) flow effects which deflected the test transmitters out of a vertical position with the GPS unit on the boat, and (2) a degree of horizontal movement for the fixed hydrophones on the temporary anchor systems employed during this study. Hydrophones deployed for the purposes of collecting 2D data in future evaluations will be installed using a more permanent and robust mooring system to reduce horizontal movement as well as positional error.

Results from pilot deployment locations assessed for 1D detection during Phase 1 supported previously reported findings for acoustic receivers deployed in areas characterized by greater depth and less flow (e.g., pilot deployment locations 1 and 6) producing better results than those characterized by shallower and faster current velocities (e.g., pilot deployment location 5). In general, the detection rate for acoustic transmitters decreased with distance from the receiver. The impact of in-water obstructions restricting line-of-sight between transmitter and receiver was obvious at pilot deployment location 6 (i.e., bridge abutments). When detection rates for both receivers during the pair of transmitter tests conducted at pilot deployment location 6 are considered as a whole, the detection rate inside of 40 m was 45% versus 25% outside of 40 m for the SS300 transmitter. There was not a difference in the detection rate for the SS400 transmitter (31% inside 40 m and 32% outside of 40 m).

Based on observations made during the Phase 1 evaluation of JSATS transmitters and receivers at Lawrence, it appears that the installation of a 2D array in the area downstream of the powerhouse (i.e., Region C; Figure 6-1) is feasible and likely to produce meaningful positional information for fish carrying either the SS300 or SS400 transmitters. Phase 1 field testing of these units occurred during October 2024 when powerhouse discharges were around 1,500 cfs. It is anticipated that powerhouse discharge during the spring migration period will be closer to the station capacity of 8,000 cfs and as a result, the potential impact on receiver detection range due to the additional noise associated with river flow should be considered when developing a final receiver array design (i.e., tighter spacing). The use of the SS300 transmitters on a subset of study fish will allow for the collection of depth information for those individuals which may enter the Region C array. Given the relatively poor detection rates for acoustic receivers evaluated during Phase 1 from areas characterized by shallower water depths and higher flow velocities, collection of viable 2D positional data has a low probability of success in the area immediately downstream of the dam spillway and in downstream confluence zone (i.e., Regions D and E). Careful positioning of receivers in these areas may still yield meaningful 1D detections of tagged fish to inform on presence/absence. Findings from the Phase 1 evaluation confirmed that deployment of acoustic receivers within the forebay (Region A) and at locations in the mainstem downstream reach (Region F) will provide sufficient detection rates of either transmitter model to indicate fish presence.

The RSP identified the inclusion of several cross-river downstream checkpoints to inform on passage of tagged fish to and from the upstream 2D array. Observations from the pilot deployment location 6 suggest that a maximum receiver spacing of 40 m should allow for 6-9 detections per minute (depending on transmitter type and at an assumed 3-second PRI) for fish passing through those areas.

Table 6–1. Characteristics summary for general regions in the vicinity of the Lawrence Project.

General Region	Region ID	Relative Depth	Relative Flow Condition	Surface Turbulence	Steady Conditions	Boat Access
Lower Impoundment	A	Deep	Low	No	Yes	Yes
Powerhouse Forebay	B	Deep	Moderate-High	No	Yes	No
Powerhouse Tailrace	C	Deep	Moderate-High	Yes	Yes	Yes
Dam Spill Zone	D	Shallow	None to High	Yes	No	No
Downstream Confluence Zone	E	Shallow	High	Yes	Yes	Yes
Downstream Reach	F	Deep	Low	No	Yes	Yes

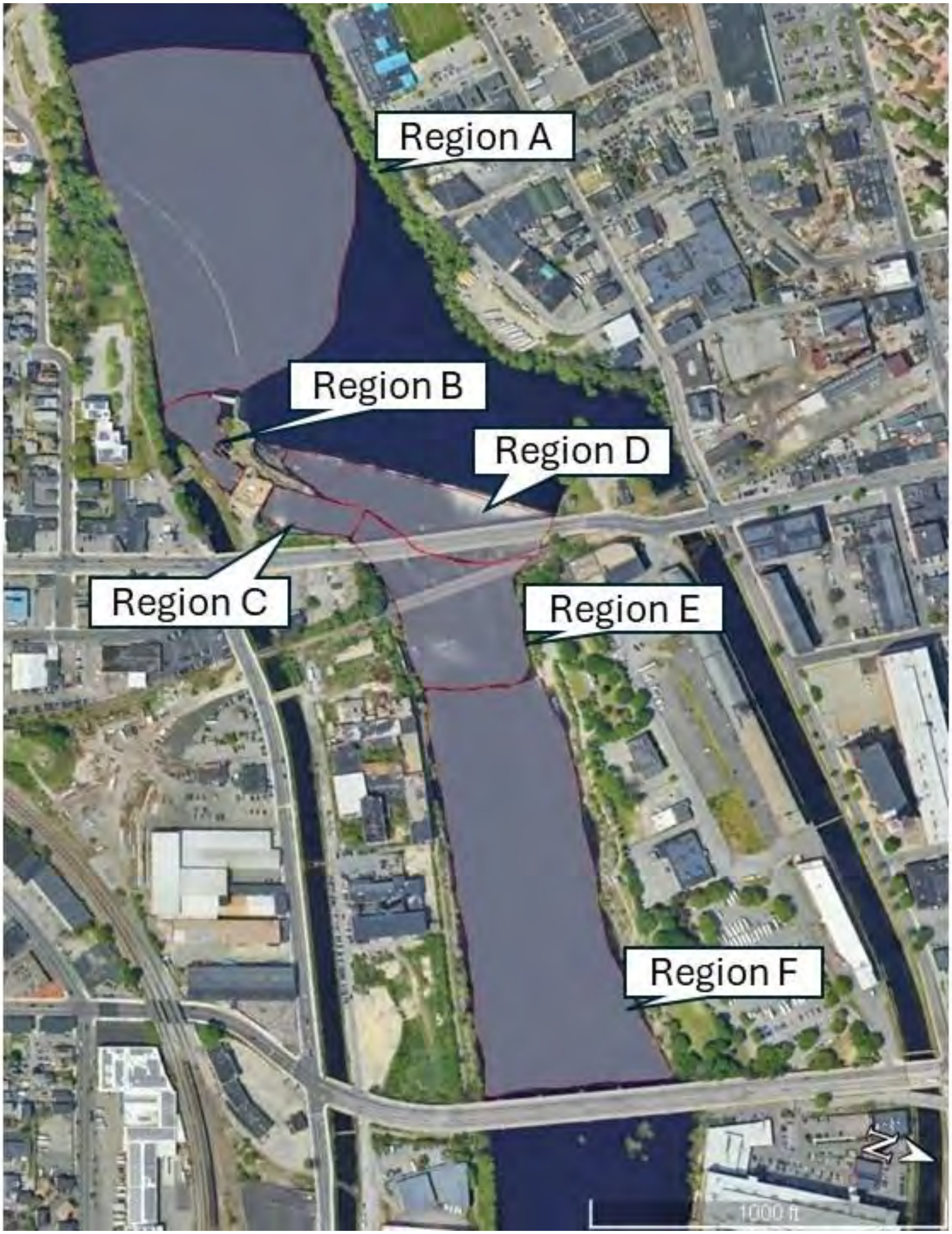


Figure 6–1. General regions based on hydraulic and bathymetric conditions in the vicinity of the Lawrence Project.

7 Variances from the FERC Approved Study Plan

Phase 1 of the Project Interaction Study was conducted following the methodologies identified in the RSP. A few discrepancies between the proposed and final study approach are noted here:

- The RSP indicated that adult alewife and blueback herring for the tank evaluation of transmitter retention would be collected at the Lawrence upstream fishway and would total 50 test fish of each species. Since herring passage at the Lawrence fish lift at the time of collection was insufficient to provide an adequate number of test fish, Essex coordinated with the state fisheries agencies (Massachusetts and New Hampshire) to obtain samples via boat electrofishing downstream of Essex Dam and at the fish ladder trap and truck facility at Amoskeag Dam in Manchester, NH. Alewife collections met the minimum sample sizes identified in the RSP. Although blueback herring collections did not meet the minimum sample sizes identified in the RSP, enough individuals were obtained to evaluate both tagging methods and maintain some control fish to understand potential collection and handling effects.
- The methodology identified in the RSP to assess the detection range and rate relied on the deployment of transmitters at fixed locations for a duration of time. In lieu of that, geo-referenced transmitter locations were recorded as tags were actively moved around the receiver area to better simulate the active swimming of live fish. The same methodology (i.e., the percentage of detected transmissions relative to the total number of known transmissions for a set period of time) was used to estimate the detection efficiency of the two transmitter models during the Phase 1 analysis. Transmitters used for this testing were affixed to a weighted fishing line to facilitate moving them through the test areas.
- The RSP identified a total of six pilot deployment locations for the collection of Phase 1 receiver performance data. One of the six locations (i.e., pilot deployment location 3) was inaccessible by boat and also had inadequate water depth for the installation and testing of acoustic receivers. Data was collected at the other five locations and is reported here.

8 References

Deng, Z.D., J.J. Martinez, H. Li, R.A. Harnish, C.M. Woodley, J.A. Hughs, X. Li, T. Fu, J. Lu, G.A. McMichael, M.A. Weiland, M.B. Eppard, J.R. Skalski, and R.L. Townsend. 2017. Comparing the survival rate of juvenile Chinook salmon migrating through hydropower systems using injectable and surgical acoustic transmitters. Scientific Reports 7:42999 | DOI: 10.1038/srep42999.

Kessel, S.T., S.J. Cooke, M.R. Heupel, N.E. Hussey, C.A. Simpfendorfer, S. Vagle, and A.T. Fisk. 2013. A review of detection rang testing in aquatic passive acoustic telemetry studies. Reviews in Fisheries Biology and Fisheries. DOI 10.1007/s11160-013-9328-4

Normandeau Associates, Inc. (Normandeau). 2021. Technical Report for the Upstream and Downstream Adult Alosine Passage Assessment – Lowell Hydroelectric Project (FERC No. 2790). Report Prepared for Boott Hydropower, LLC

.

Appendix A: Updated Revised Study Plan for Lawrence Project Interaction Study

Essex filed their Revised Study Plan with FERC on April 10, 2024, which included the proposed methodologies for Phase 1 and a framework for the eventual fish tagging and movement study to be conducted during Phase 2 of the Diadromous Fish Behavior, Movement, and Project Interaction Study. In the RSP, Essex indicated that following the completion of Phase 1 (and assuming the JSATS technology proves fit for evaluating fish movement in the conditions downstream of the Lawrence Dam) Essex would consult with the Merrimack River Technical Committee (MRTC) to finalize study details for Phase 2.

A draft of the updated study plan was provided to the MRTC on January 16, 2025 and Essex met with the MRTC on January 23, 2025 to review the proposed Phase 2 study methods. Discussion during and immediately following the January 23 consultation meeting resulted in final resolution on the number and types of transmitters as well as the final field design for installation of JSATs receivers. The methodologies provided here have been updated to reflect consultation with the MRTC and will be used during the execution of Phase 2 of the Project Interaction Study anticipated to be completed during spring 2025.

Phase 2: Goals and Objectives

The goal of the Project Interaction Study is to assess Project-related effects on the behavior of diadromous fish species (alosines and striped bass) in and around the Lawrence Project. Specific objectives originally identified by Essex in the RSP have been updated to reflect recommendations provided by FERC in their May 10, 2024, SPD. Phase 2 of this study specifically seeks to:

- Assess tagged fish distribution and movement in the Project tailrace and proximal downstream reach (striped bass, alewife, blueback herring, and American shad).
- Evaluate the overall passage effectiveness of the existing fish lift for alewife and blueback herring[4] given the extent of alosine behavioral modification due to predator presence and passage related delay.
- Evaluate alosine movement through the Project (i.e., through the Project forebay and into the impoundment) following alosine behavioral modification as it relates to predator presence downstream of the dam.

Phase 2: Geographic Scope

The geographical area of coverage for this study runs from the lower extent of the Project impoundment upstream of the dam and downstream of the Lawrence powerhouse to the I495 bridge in Lawrence.

Phase 2: Acoustic Equipment and Deployment Approach

The field evaluations conducted during Phase 1 of the Project Interaction Study provided insight into transmitter and receiver performance at Lawrence. The proposed transmitter and receiver study design presented here has considered all information collected during the Phase 1 evaluation conducted during 2024.

Transmitters

The Phase 1 evaluation assessed two acoustic transmitter models manufactured by ATS: model SS300 and model SS400 (Table A-1). The SS300 transmitter weighs 300 mg and measures 10.7 x 5.0 x 2.8 mm and the SS400 transmitter weighs 200 mg and measures 15.0 x 3.3 mm. When incorporating the smallest battery available, these two tag models will last approximately 23 and

[4] Note that the overall and internal fishway effectiveness for American shad will be evaluated using radio telemetry as part of the Upstream Anadromous Fish Passage Assessment.

48 days, respectively, when set at a 3-second PRI[5]. At present, ATS can only incorporate pressure sensors into the SS300 model.

The retention and post-tagging latent (i.e., 5-day) survival of adult river herring marked with the two transmitter models were evaluated during Phase 1 of the Project Interaction Study. Tagging methods were different for each transmitter type with the SS300 transmitters inserted gastrically and the SS400 transmitters inserted into the body cavity via a hollow needle. Transmitter retention was high for both evaluated tagging methods: 97-100% for the gastric approach using the SS300 transmitters and 100% for the internal injection approach using the SS400 transmitters on alewife and blueback herring, respectively. Post-tagging survival appeared slightly higher for individuals of both species tagged using the internal injection approach and the SS400 transmitters (97% vs. 88% for alewife and 92% vs. 88% for blueback herring).

Based on observations from the Phase 1 transmitter retention and survival test and the attributes of each tag type (i.e., sensor capabilities and battery duration), both will be incorporated into the Phase 2 study design.

Table A-1. Attribute summary for the ATS SS300 and SS400 acoustic JSATS transmitters.

Transmitter Parameter	Transmitter Model	
	SS300	SS400
Weight (mg)	300	200
Dimensions (mm)	10.7x5.0x2.8	15.0x3.3
Duration (days)		
@ 3 seconds	23	48
@ 5 seconds	37	71
@ 10 seconds	68	111
Pressure Sensor	Yes	No
Fish Attachment	Gastric or Abdominal Incision	Abdominal Injection

Receivers

The Phase 1 evaluation assessed the performance of two JSATS compatible receiver types: the Lotek WHS 4250 and ATS SR3001. As detailed in the Phase 1 report, the field performance of the Lotek WHS 4250 was inadequate for the conditions tested downstream of Lawrence. The ATS SR3001 receiver provided viable estimates of detection range and rate across a suite of deployment

[5] The two ATS transmitter models can each be equipped with a larger battery which will extend transmitter life for the two models out to 81 and 302 days for the SS300 and SS400 tags, respectively and when set at a 3-second PRI. Incorporation of the larger battery will increase the physical dimensions and weight of the tag.

conditions. The results of the Phase 1 evaluation support the use of the ATS SR3001 receiver for evaluation of fish movement downstream of Lawrence. Physical conditions downstream of the dam will determine the spatial extent of resolution types (i.e., 2D versus 1D [present/absent]).

Deployment Approach

A minimum of 30 ATS receivers will be installed at Lawrence to evaluate the movement and behavior of tagged diadromous fish species during spring 2025. Receivers will be installed during late-April or early-May, dependent on river conditions and prior to the release of any tagged fish. The full receiver set will be maintained through June.

Receivers will be strategically placed throughout the Project area, with gate receivers (used to determine if fish are entering/leaving the study area) covering points upstream and downstream of the dam, and a concentrated region with significant overlap to provide 2D positioning in the powerhouse tailrace reach where river conditions are suitable for that type of data acquisition. For the purposes of proposed receiver placement, a detection range of 50 m was assumed based on observations recorded during the Phase 1 assessment. To ensure receiver coverage in the 2D zone will meet the study needs (i.e., high probability of simultaneous detection of a tag transmission by three or more receivers), range testing will be conducted prior to fish release. Additional receivers may be added to the 2D zone based on results of the pre-study range test findings.

Figures A-1 and A-2 present the proposed receiver locations. Receivers comprising the 2D array (Figure A-1) will be installed in a manner which limits their ability to change position during the study and also provides overlap among all units to maximize the likelihood of multiple detections of any single tag transmission. Where appropriate, ATS model SR3017[6] receivers will be used and hydrophones will be affixed to project structures. Receivers acting as gates or providing presence/absence information from areas outside of the 2D array (Figure A-2) will be tethered to a standard anchor/buoy system as receiver position is not critical for detecting transmissions at these locations.

[6] ATS model SR3017 is equivalent to the ATS model SR3001 evaluated during Phase 1. The difference is that the hydrophone component of the SR3017 is cabled, allowing the user to deploy it fixed to an in-water structure and power/interact from shore. The SR3001 is autonomous.

Figure A-1. Proposed acoustic receiver installation for the 2D component of the Project Interaction Study at Lawrence.

Figure A-2. Proposed acoustic receiver installation for the 1D component of the Project Interaction Study at Lawrence.

Phase 2: Target Fish Species, Sample Size Determination, and Tagging

The target fish species, sample sizes for each, and the proposed methodology for procuring and releasing study fish during Phase 2 of the Project Interaction Study are summarized here.

Target Fish Species

Four anadromous fish species will be included in Phase 2 of the Project Interaction Study. Striped bass and river herring were identified by Essex in the RSP as target fish species with the inclusion of alewife and/or blueback herring being dependent on observations made during the tank evaluation component of Phase 1 which was designed to evaluate their compatibility with available transmitter models (i.e., retention and post-tagging survival). Findings from the river herring tank evaluation component of Phase 1 support the inclusion of both river herring species in the Phase 2 study component. In their May 10, 2024, Study Plan Determination, FERC recommended that Essex include American shad as a target species in the Phase 2 study. As a result, striped bass, alewife, blueback herring, and American shad will be included in Phase 2 of the Project Interaction Study.

Sample Sizes

Sample sizes for the four target fish species vary based on species-specific objectives identified for each as part of the Phase 2 study.

River Herring (alewife and blueback herring):

In the RSP, Essex proposed to tag and release up to 345 individuals of each river herring species. Using a binomial model, sample sizes were calculated for various effectiveness levels ranging from 30% to 80% using the formula:

$$n = \frac{Z_{\alpha/2}^2 x\ p\ x(1-p)}{E^2}$$

Where:

n = the required sample size

$Z_{\alpha/2}$ = the Z-value for the desired level of confidence (i.e., 1.96 for a 95% confidence level)

p = the estimated proportion or success rate of passage (i.e., fish passes upstream or does not pass upstream)

E = the desired margin of error

For a passage effectiveness of 50%, a sample size of 96 fish is required to obtain a precision of ± 10% at a probability level of 0.95 (Table A-2). In the Lawrence Project PSP[7], Essex incorporated estimated rates of adult river herring fallback and predation at 0.21 and 0.5. Application of those adjustments to the range of sample size estimate from the binomial approach was performed to adjust the sample sizes (S_{adj}) as follows:

$$S_{adj} = (\text{target minimum sample size}) / [1- (\text{predation rate} + \text{fallback rate})].$$

When the most robust calculated sample size is adjusted to account for downstream losses associated with fallback or predation, a total of 331 adult herring should be tagged. For the purposes of Phase 2 of the Project Interaction Study, Essex will tag and release the 345 individuals of each river herring species identified in the RSP.

Table A-2. Calculated and adjusted sample sizes under range of assumed passage effectiveness rates required to obtain a precision of ± 10% at probability levels of 0.9 or 0.95 when corrected to account for a post-tagging rate of loss of 0.71.

Passage Rate (p)	1-α		S_{adj}	
	0.9	0.95	0.9	0.95
0.3	57	81	196	278
0.4	65	92	224	318
0.5	68	96	233	331
0.6	65	92	224	318
0.7	57	81	196	278
0.8	43	61	149	212

American shad:

As defined in the Upstream Anadromous Fish Passage Assessment, proposed by Essex in the April 10, 2024, RSP and approved with modifications by FERC in the May 10, 2024, SPD, Essex will evaluate the upstream approach, tailrace residence duration, internal and overall fishway effectiveness, and subsequent upstream movement using a total of 430 radio tagged adult American shad. To provide a more robust assessment of movement in the Project tailrace and proximal downstream reach, Essex will dual tag (i.e., one radio telemetry tag and one acoustic JSATS tag) 200 of the adult American shad already proposed to be marked and released downstream of the dam during the Upstream Anadromous Fish Passage Assessment.

[7] FERC Accession No. 20231128-5122

Striped bass:

As stated in the RSP, Essex will collect and tag up to 100 striped bass downstream of the Lawrence Dam as part of the Phase 2 of the Project Interaction Study.

Fish Collection and Tagging

Adult American shad and river herring collected for tagging as part of Phase 2 of the Project Interaction Study will be collected in the Merrimack River downstream of the Project, likely from the reach between the Union Street Duck Bridge and the Lawrence crossing of Route 495. Boat electrofish collections of adult alosines from this reach will be made following the approach used by Gahagan and Bailey (2020) for collection of adult shad in the Charles River. Essex assumes that the required permits will be authorized by the state and federal resource agencies to conduct boat electrofish sampling in this reach for collection of test fish given its designation as critical habitat for the federally listed Atlantic sturgeon[8] and known presence of the federally listed shortnose sturgeon. Striped bass targeted for tagging as part of the Phase 2 component of the Project Interaction Study will be opportunistically collected during boat electrofish sampling for adult alosines or targeted directly by rod and reel.

Following capture, fish will be immediately placed in a large, onboard, flow-through live well and the crew will navigate the boat to a safe shoreline location for tagging. Each fish will be visually assessed to ascertain their suitability for tagging. Any individuals exhibiting excessive scale loss or other signs of significant stress will not be considered and will be released back into the river untagged. Individuals deemed acceptable for tagging will be quickly measured (total length, nearest mm), and sex will be determined (when possible) by gently expressing eggs or milt from running-ripe fish. Species will be recorded at the time of tagging. Following tagging, study fish will be immediately released back into the Merrimack River and the coordinates and date/time of release will be recorded.

The target total number of transmitters by species and type are presented in Table A-3. A percentage of individuals will be tagged using the ATS model SS400 transmitter which exhibited high retention and post-tagging survival for adult river herring and can quickly and effectively be injected into any of the target species using a hollow needle. This will minimize the duration of time test fish are out of the water and subjected to handling and tagging. A subset of each fish species will be tagged using the ATS model SS300 transmitter for the purpose of collecting pressure readings associated with each detection record. The use of these transmitters in a subset of test fish will allow for the evaluation of depth and provide a more robust evaluation of fish positions for individuals which ascend upstream into the receiver array within the Project tailrace

[8] As defined in 82 Federal Register 39160 as "*Merrimack River from the Essex Dam (also known as the Lawrence Dam) downstream to where the main stem river discharges at its mouth into the Atlantic Ocean*".

and proximal downstream reach. Tagging methodologies will likely mirror those employed during the Phase 1 river herring assessment with the SS300 transmitters being inserted gastrically and the SS400 transmitters being injected via hollow needle.

Table A-3. Sample sizes by target fish species and transmitter type for Phase 2 of the Project Interaction Study.

Target Species	Total No. Tagged	Transmitter Model	
		SS300	SS400
Alewife	345	145	200
Blueback Herring	345	145	200
American Shad	200	100	100
Striped Bass	100	50	50

Phase 2: Data Analysis and Reporting

Following the completion of data downloads from each individual hydrophone, data analysis will proceed in two different ways, depending on whether the hydrophone is included in the 2D array or one of the several 1D checkpoints

Data files from hydrophones representing the 1D detection locations will be grouped as appropriate with any other hydrophones included in a particular "gate" location and then filtered to leave only the relevant information. Any detections for transmitter identification codes not included in the study will be removed as erroneous data. Additionally, detections will be filtered based on the release time of each fish to ensure that only valid detections are only retained representing the time after a particular fish was released. Data will then be arranged chronologically to provide insight into how individual fish moved up or down the river over time following initial release. For the subset of fish determined to have moved upstream to a point inside the bounds of the 2D array in the tailrace, a more robust analysis will be initiated to determine fish positions via the 2D analysis. For the subset of tagged fish that enter the fish lift and exit upstream, the set of forebay receivers will be used to determine whether that individual successfully continued upstream or was entrained through the powerhouse and returned downstream, which could be via the turbines or downstream bypass.

Data files from hydrophones comprising the 2D array in the powerhouse tailrace will be imported into R statistical software for analysis using a "time of arrival" methodology which will determine the X-Y position of a fish for each of the pings that are emitted from its transmitter at a three second PRI. For the full duration of residence time for a fish present within the bounds of the 2D array in the powerhouse tailrace, a latitude and longitude will be determined as long as three or more receivers successfully detected a single transmission. For each fish that spends time within the 2D array, positions over time will be determined and available for mapping within predetermined subsections of the tailrace. For individuals carrying the SS300 transmitter with pressure sensor, fish depth will be estimated based on the recorded pressure reading associated with each tag transmission. For this subset of fish, data will be available to evaluate based on X-Y-Z positions. The full set of successfully determined positions of tagged fish representing the four species will be assessed to reveal patterns of movement and/or zones of preferred residency within the tailrace.

Acoustic data will be presented in two formats: bin densities and density plots. Bin densities will provide the percentage of tagged fish that were detected in each of the bins of space in the 2D array region. Bins will be provided by dividing the 2D array area into a uniform square grid (Figure A-3 provides an example 3m square grid). The exact grid spacing will be determined following review of the positional error of tag positions estimated during pre-study tag testing during spring 2025. The percentage of tagged fish detected in each bin will be recorded (by species) over the duration of the study and the percentage will be displayed on a color scale overlaid on the grid map. The use of bins will reduce the potential for a single fish to skew the results as its presence in an area is only counted a single time. This will provide insight into the spatial use of the 2D array area by test fish, rather than the amount of time spent in a particular area.

Density plots will be developed to present positions of tagged fish in the 2D array area and incorporate a temporal component of the detection data. Since these will include multiple detections for an individual, there is potential for data presented in this manner to be skewed by individual fish which may spend long periods of time in certain areas. Data will be examined and presented by species in this manner.

Phase 2: Schedule, Level of Effort, and Estimated Cost

Phase 2 of the Project Interaction Study will be conducted during spring 2025. Findings will be compiled and provided as part of the Updated Study Report filing on April 26, 2026. The cost for Phase 2 of the Project Interaction Study as currently designed is approximately $560,000.

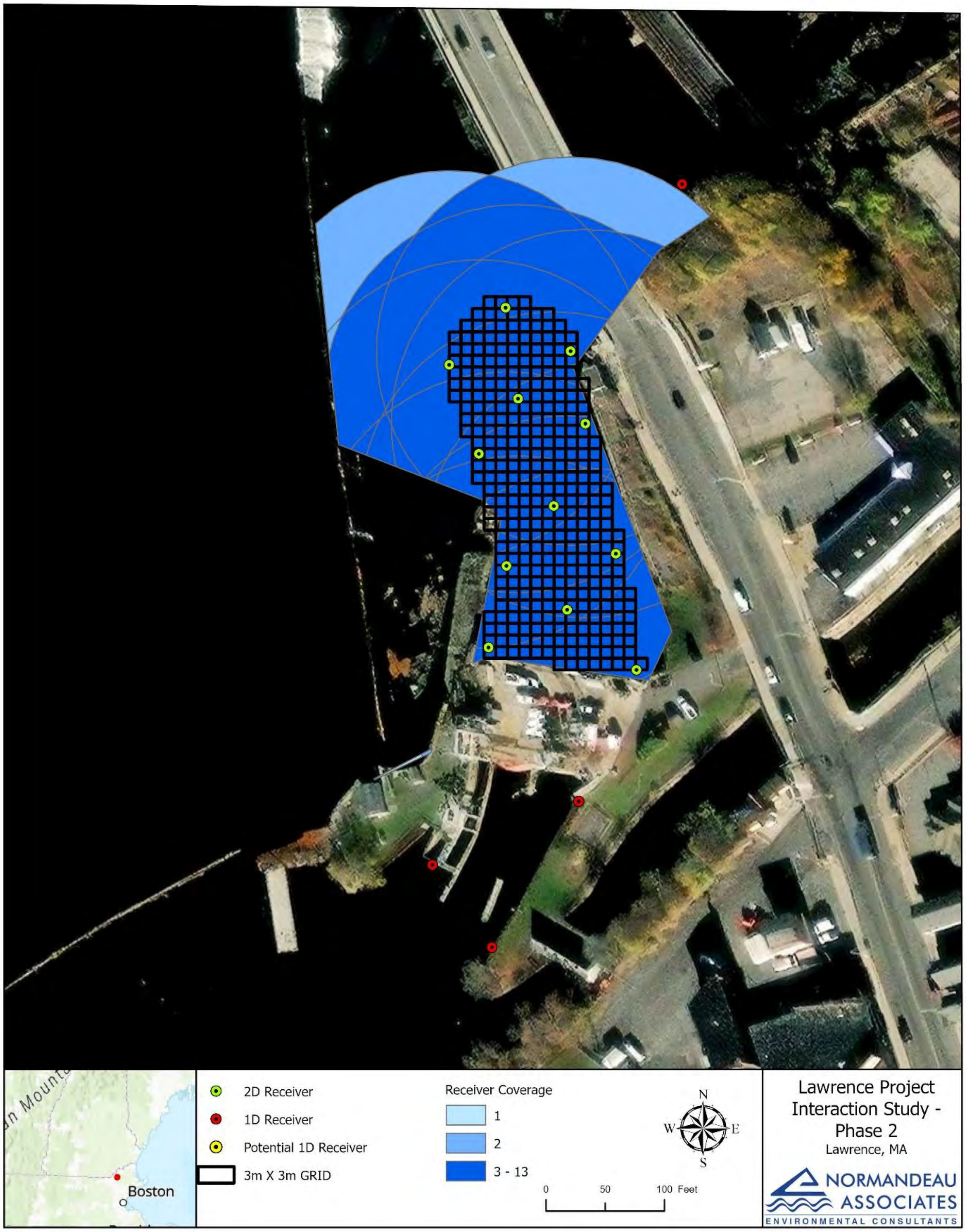
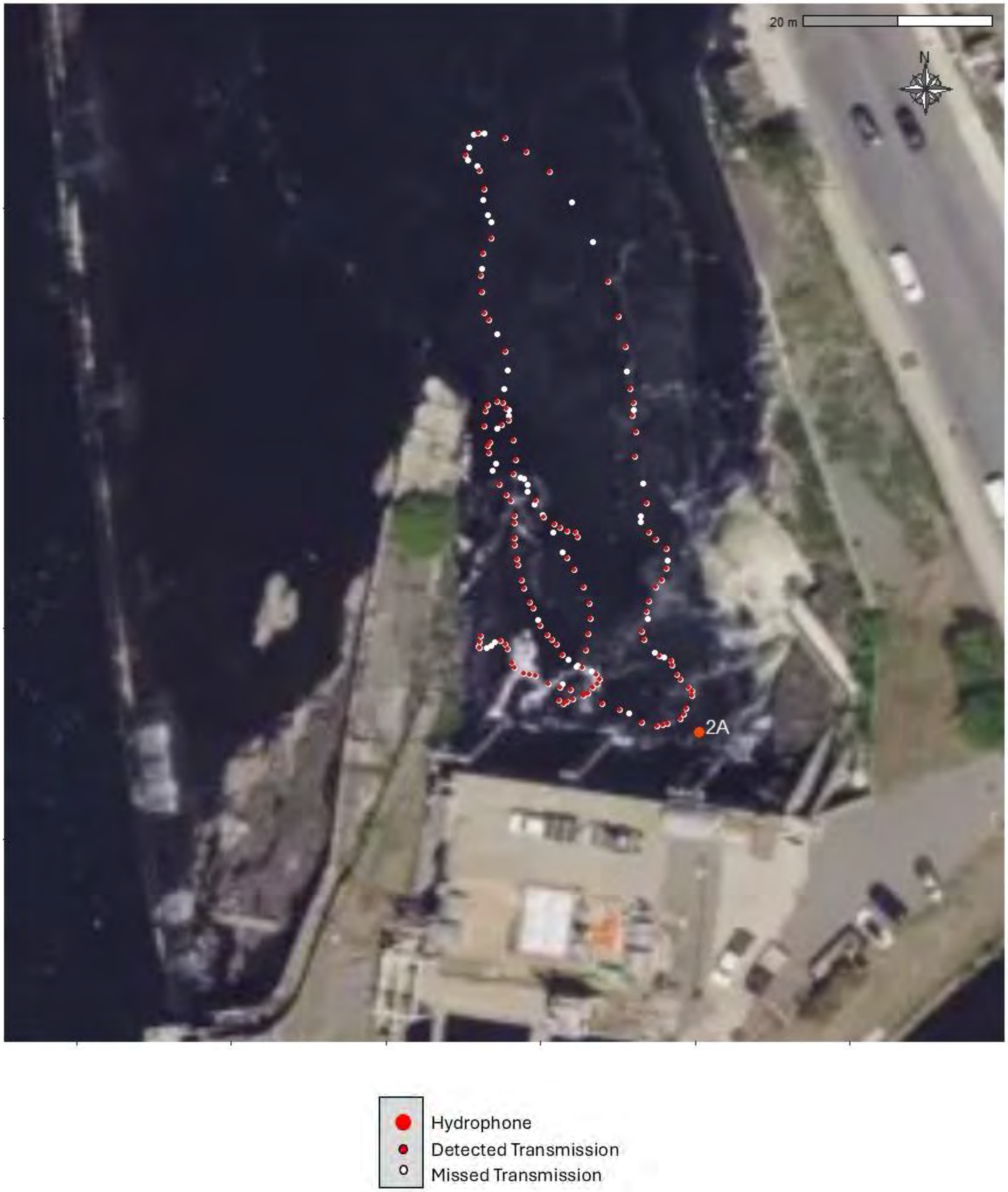


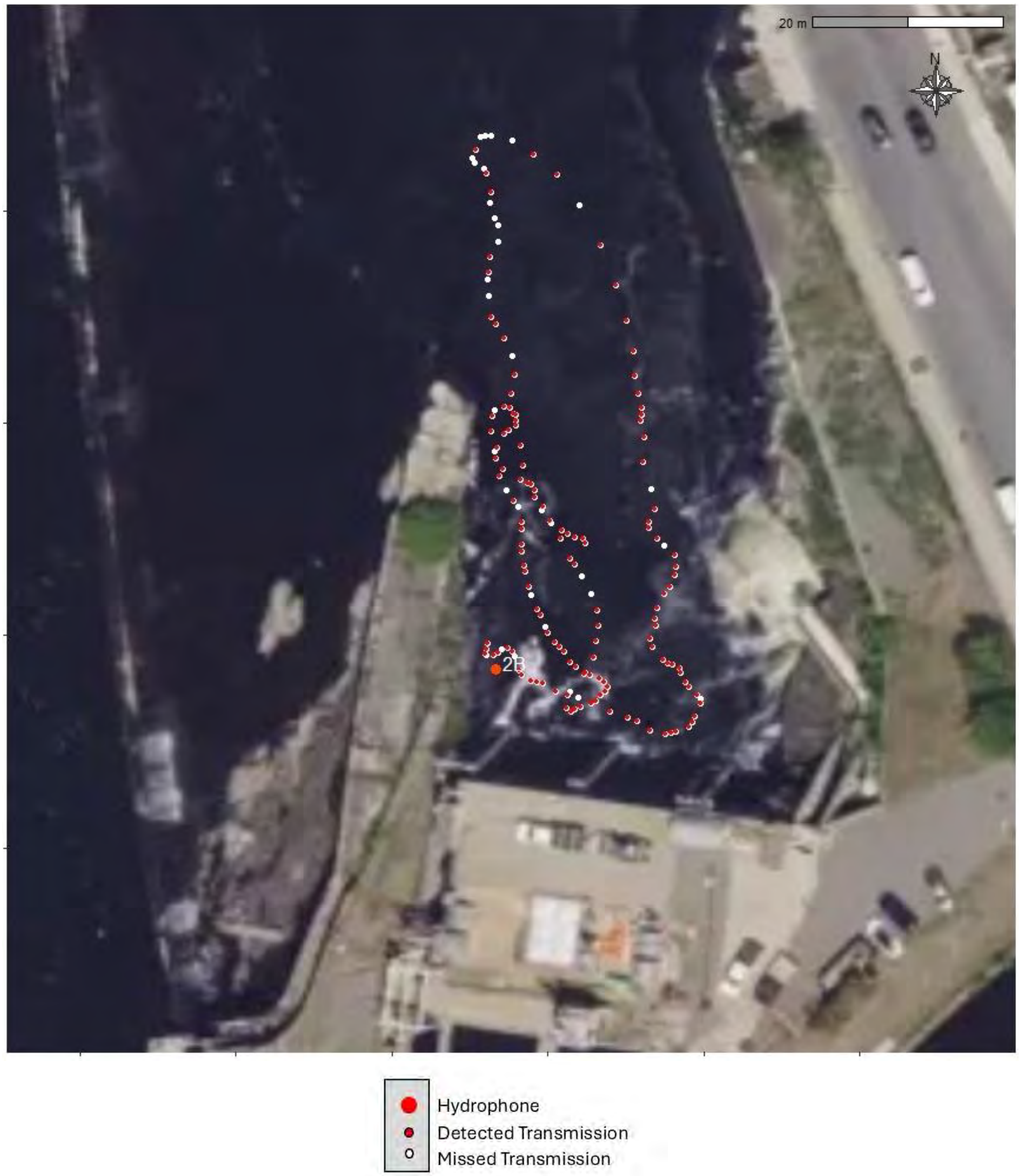
Figure A-3. Example three-meter square grid design for evaluation of positional bins and density plots for tagged diadromous fish species as part of Phase 2 of the Interaction Study at Lawrence.

Appendix B: 2D Array Receiver Detection Coverage

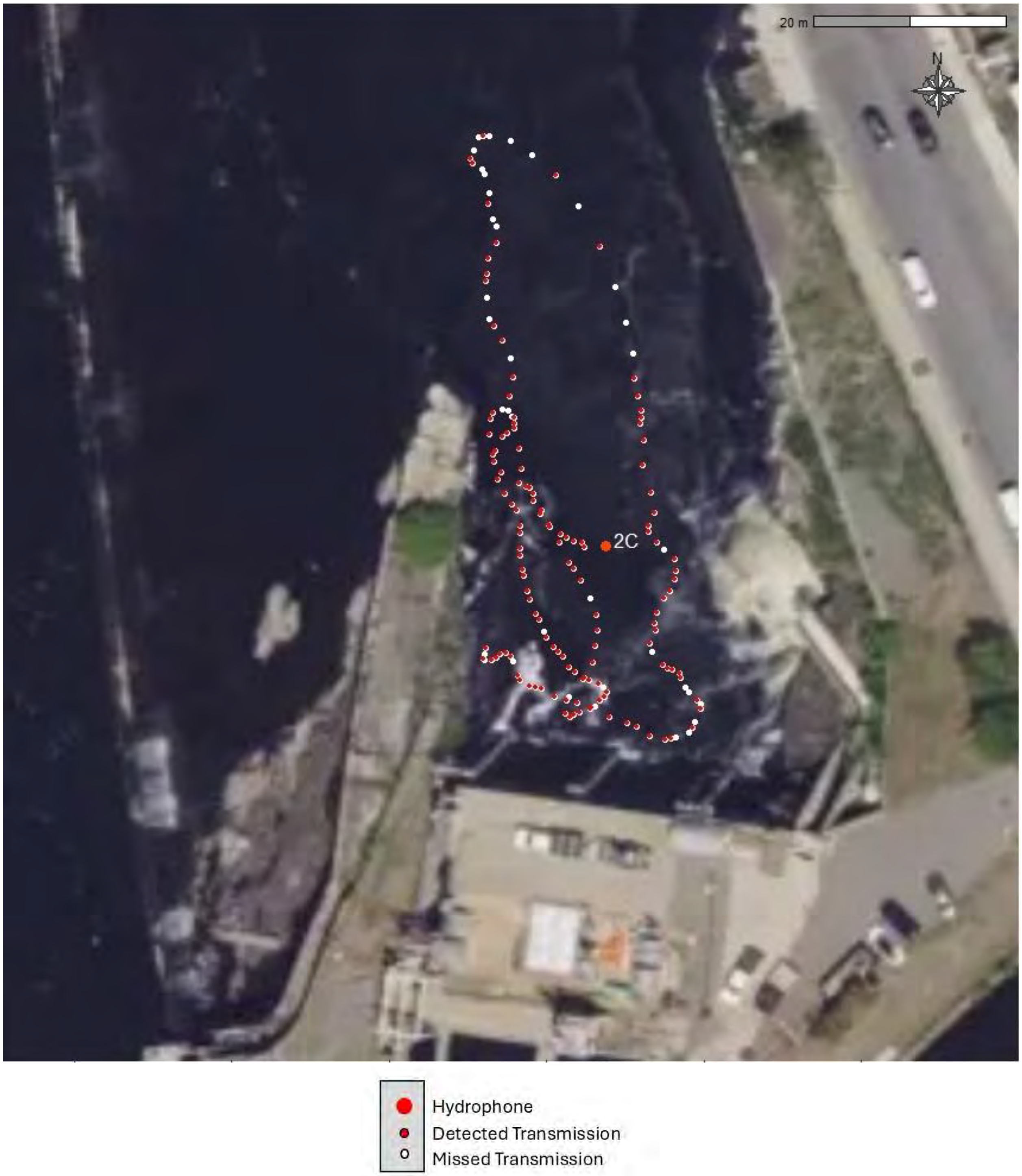
Pilot Deployment Location	2
Receiver Type	ATS
Receiver ID	2A
Transmitter Model	SS300
Transmitter Test No.	1



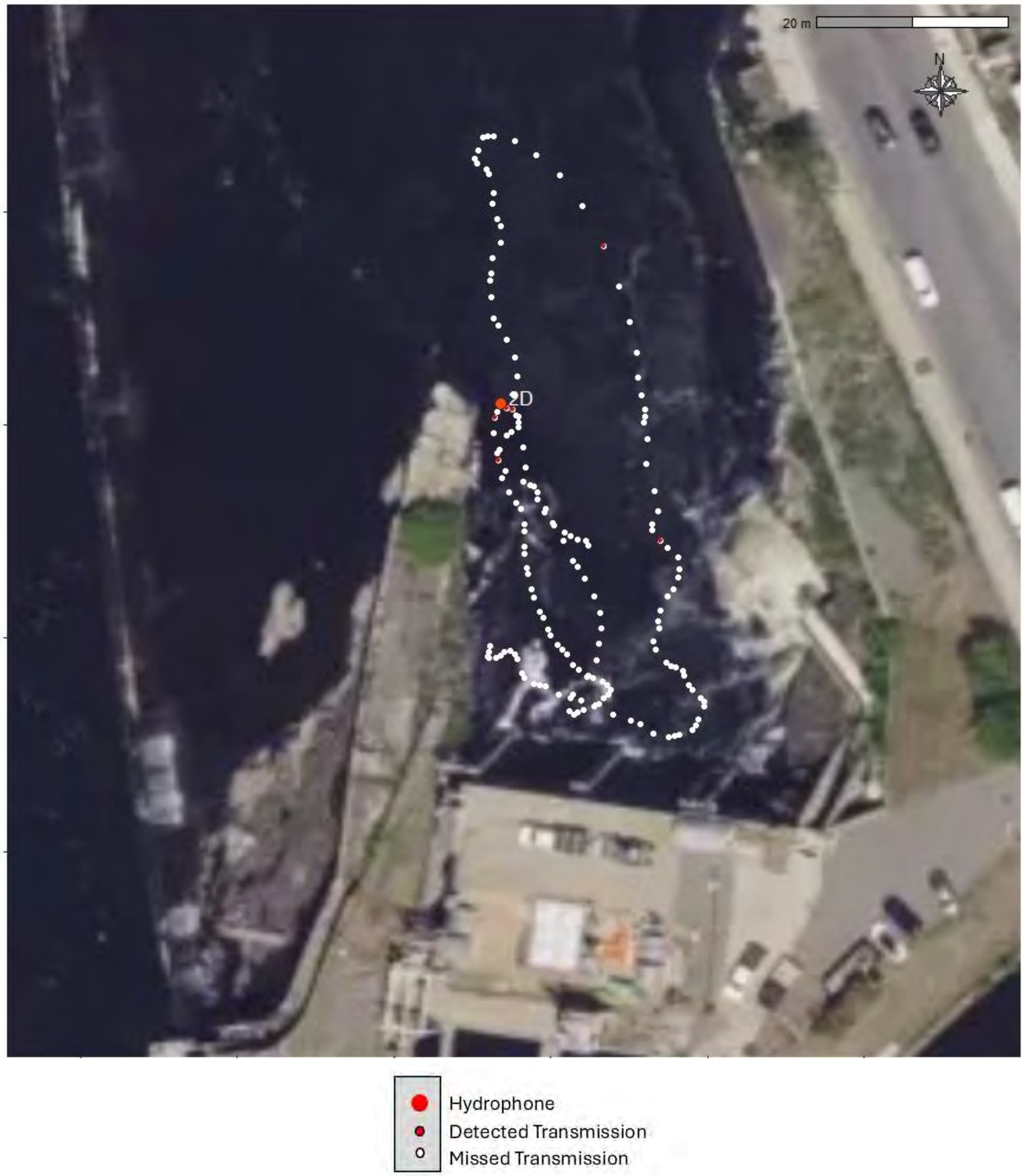
Pilot Deployment Location	2
Receiver Type	ATS
Receiver ID	2B
Transmitter Model	SS300
Transmitter Test No.	1



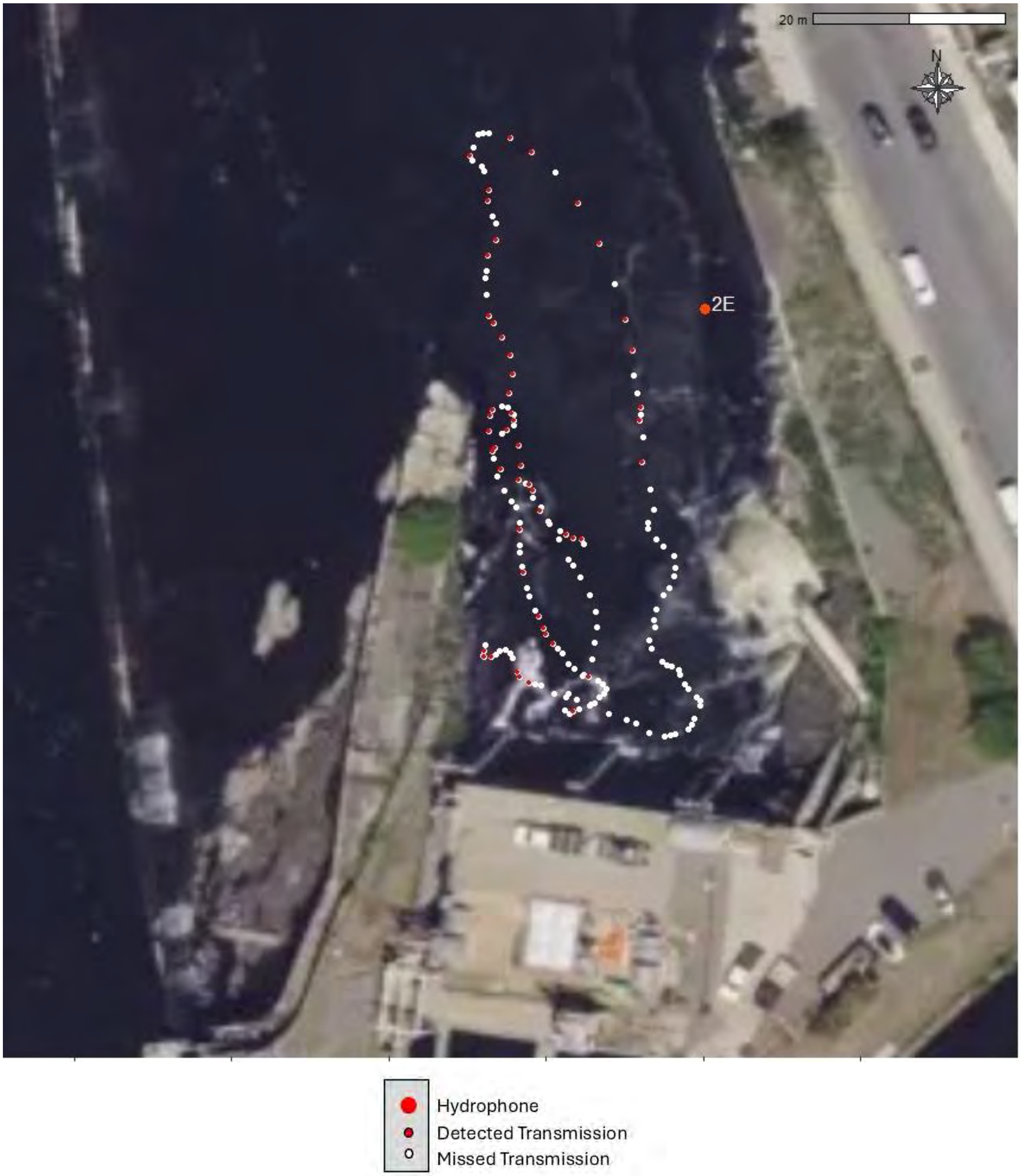
Pilot Deployment Location	2
Receiver Type	ATS
Receiver ID	2C
Transmitter Model	SS300
Transmitter Test No.	1



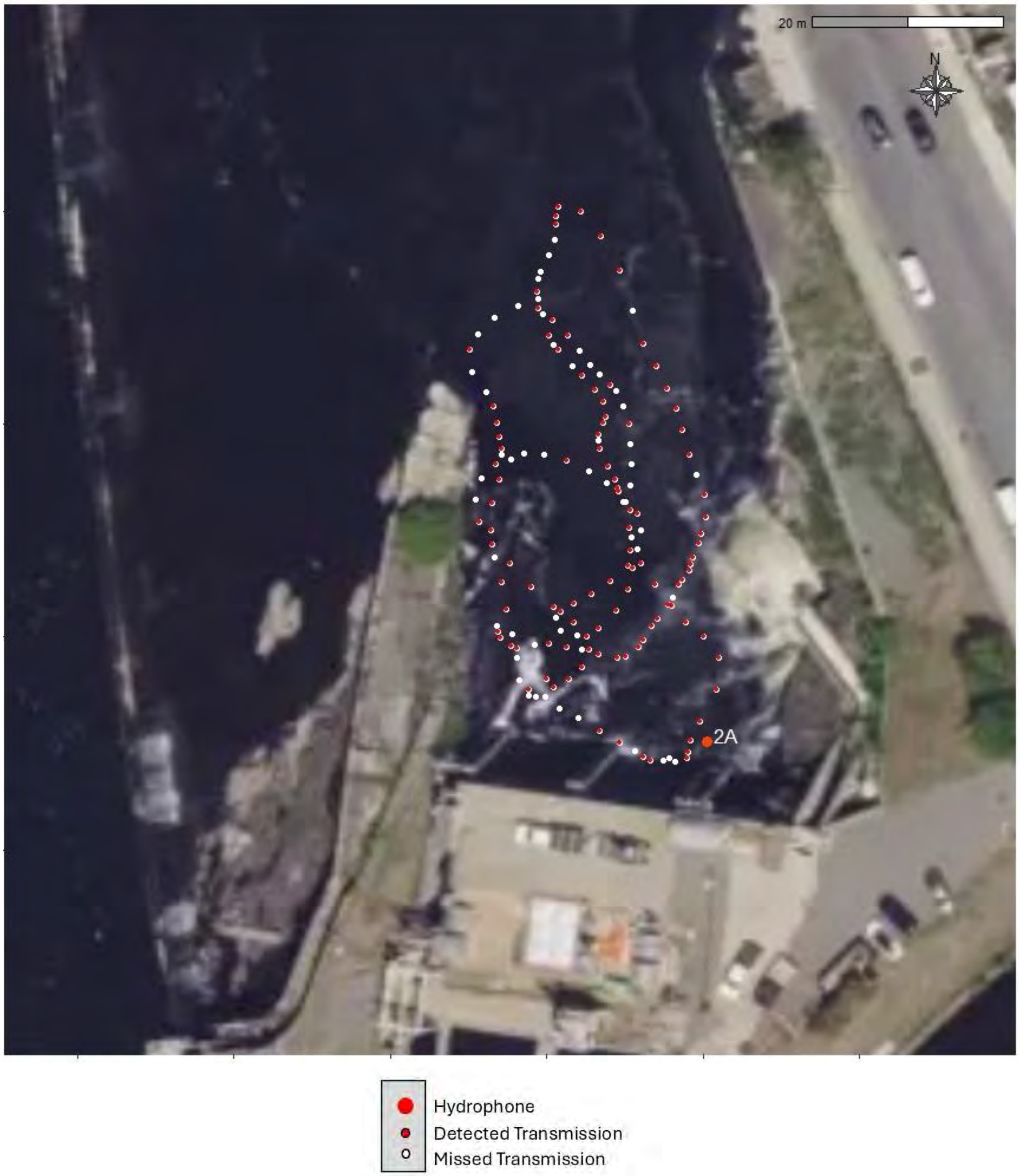
Pilot Deployment Location	2
Receiver Type	Lotek
Receiver ID	2D
Transmitter Model	SS300
Transmitter Test No.	1



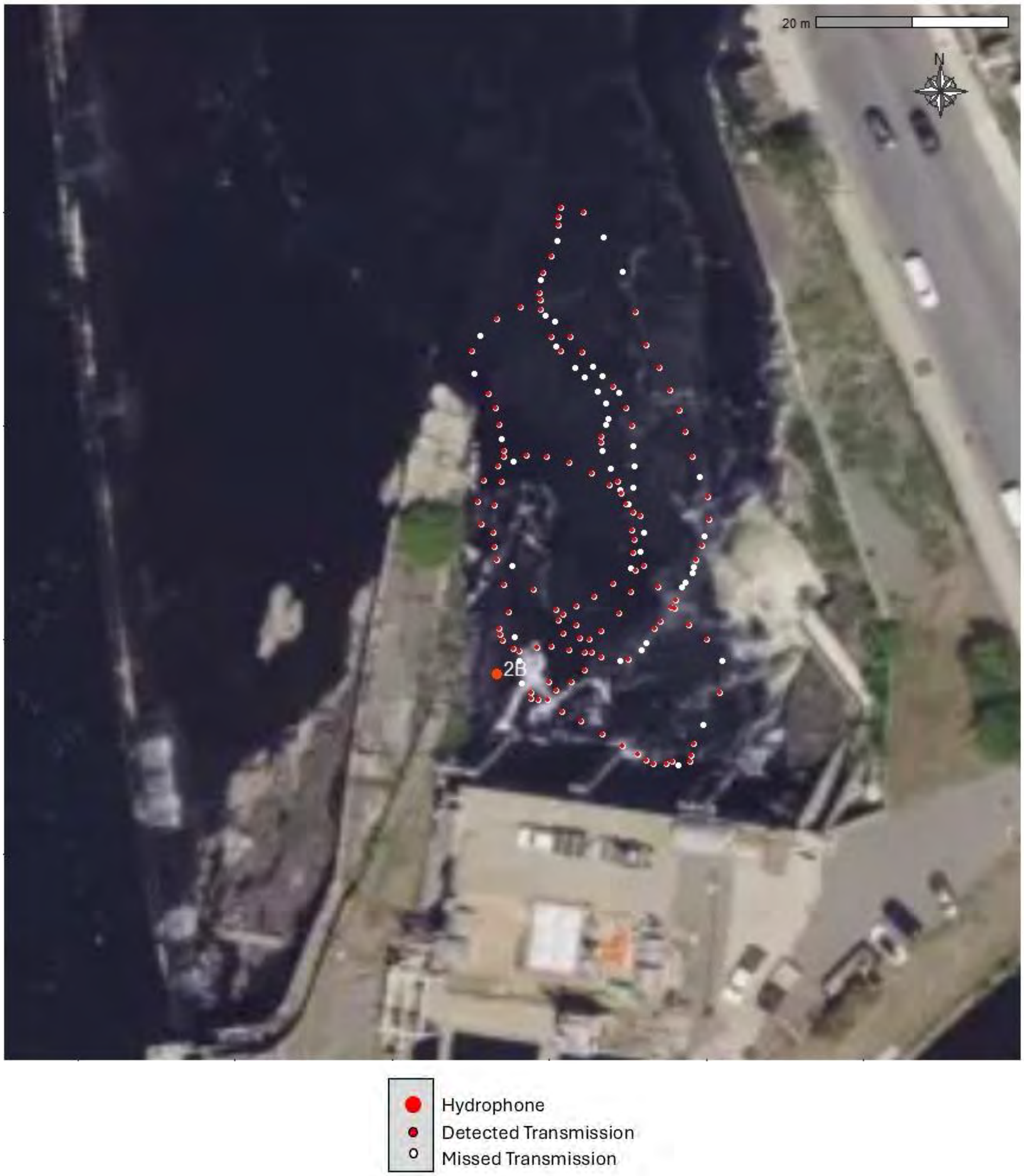
Pilot Deployment Location	2
Receiver Type	ATS
Receiver ID	2E
Transmitter Model	SS300
Transmitter Test No.	1



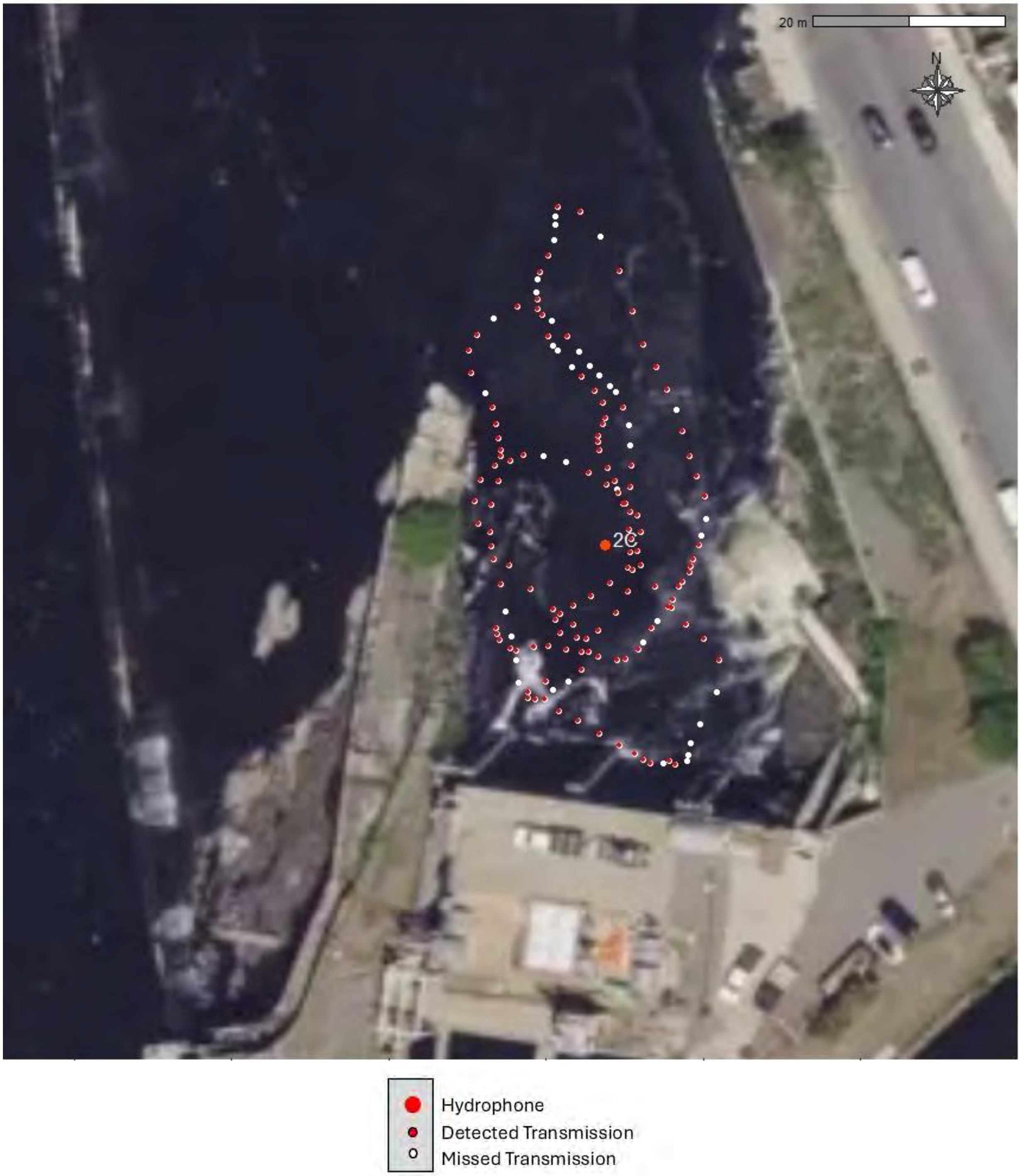
Pilot Deployment Location	2
Receiver Type	ATS
Receiver ID	2A
Transmitter Model	SS300
Transmitter Test No.	2



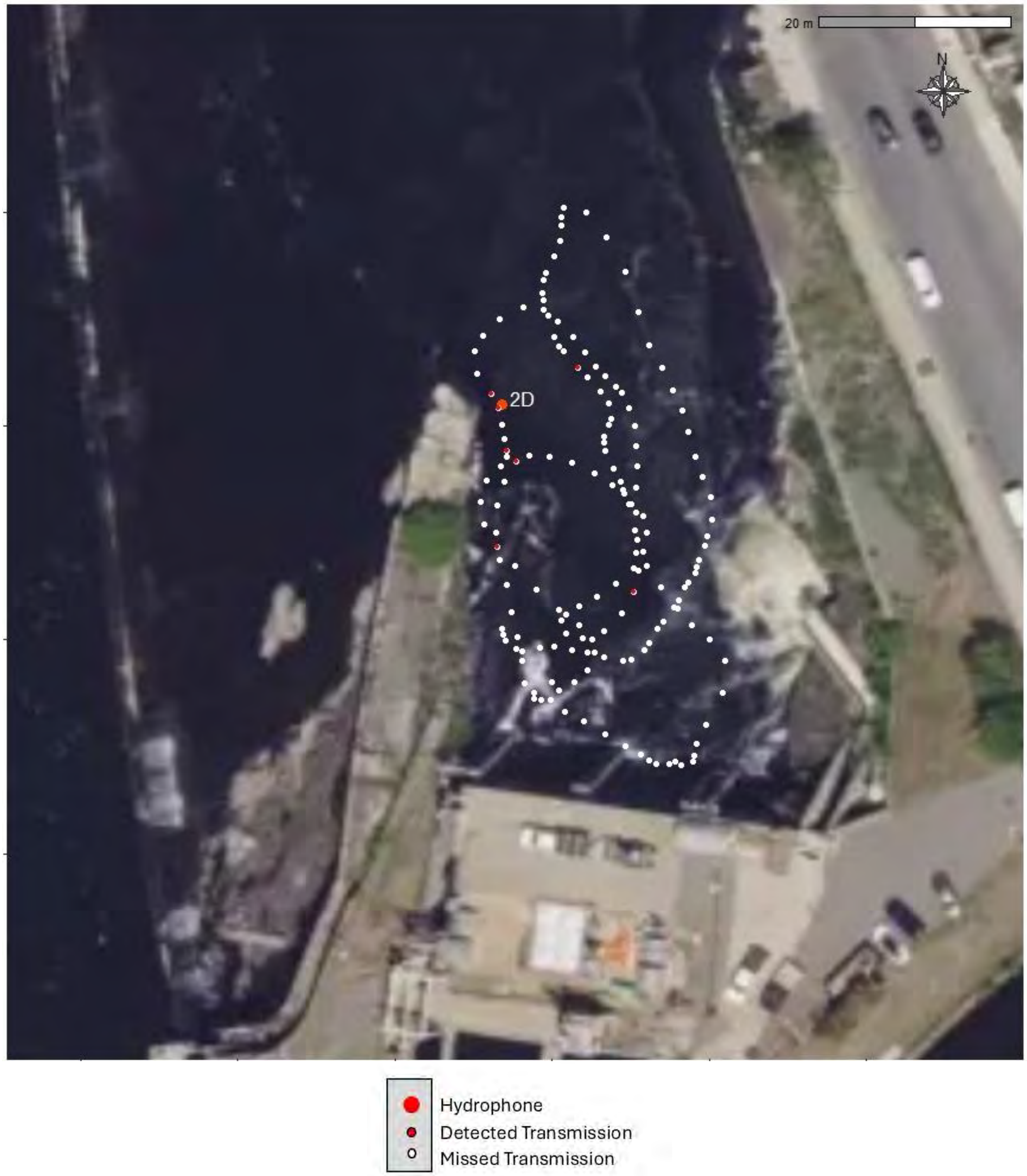
Pilot Deployment Location	2
Receiver Type	ATS
Receiver ID	2B
Transmitter Model	SS300
Transmitter Test No.	2



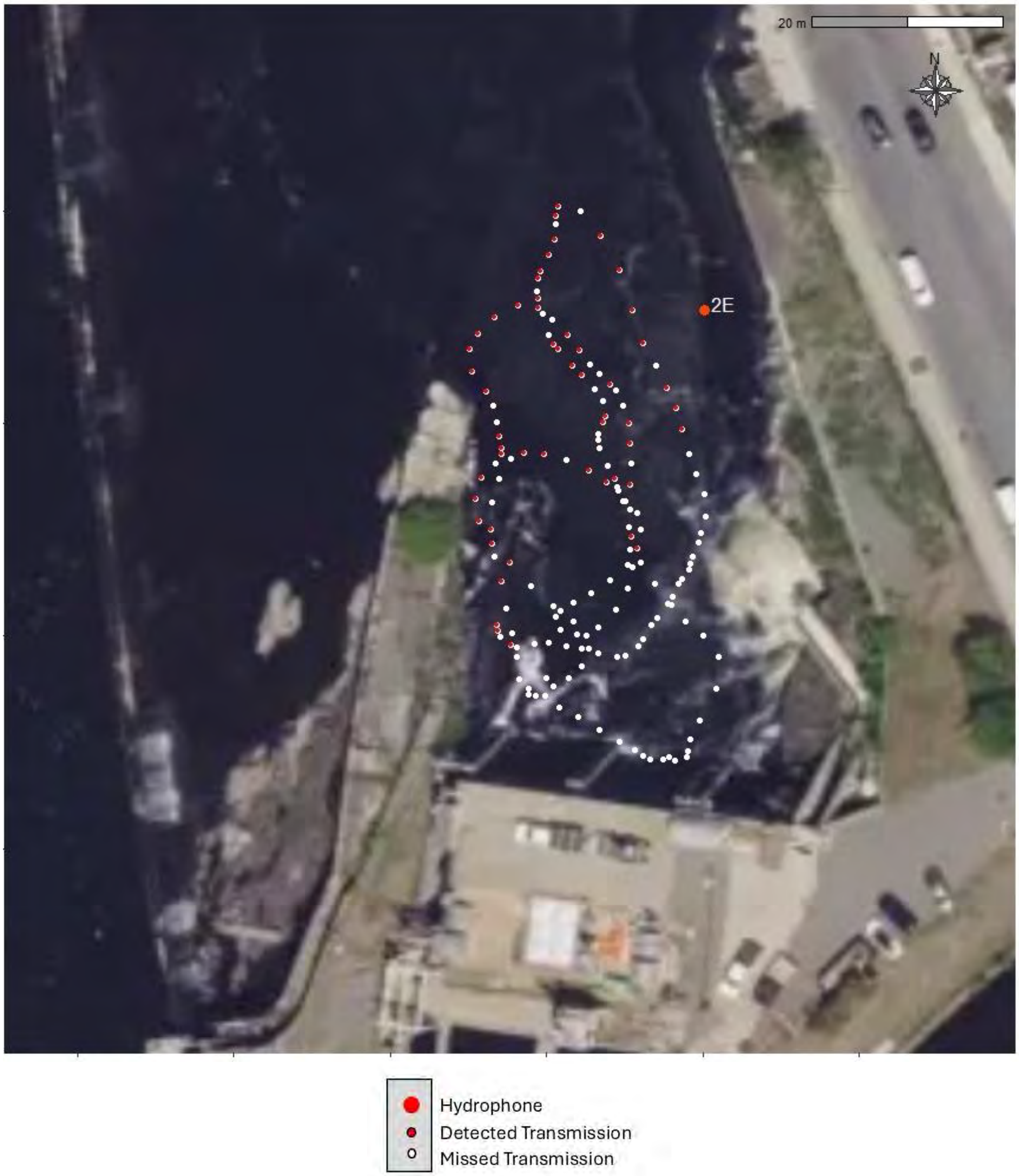
Pilot Deployment Location	2
Receiver Type	ATS
Receiver ID	2C
Transmitter Model	SS300
Transmitter Test No.	2



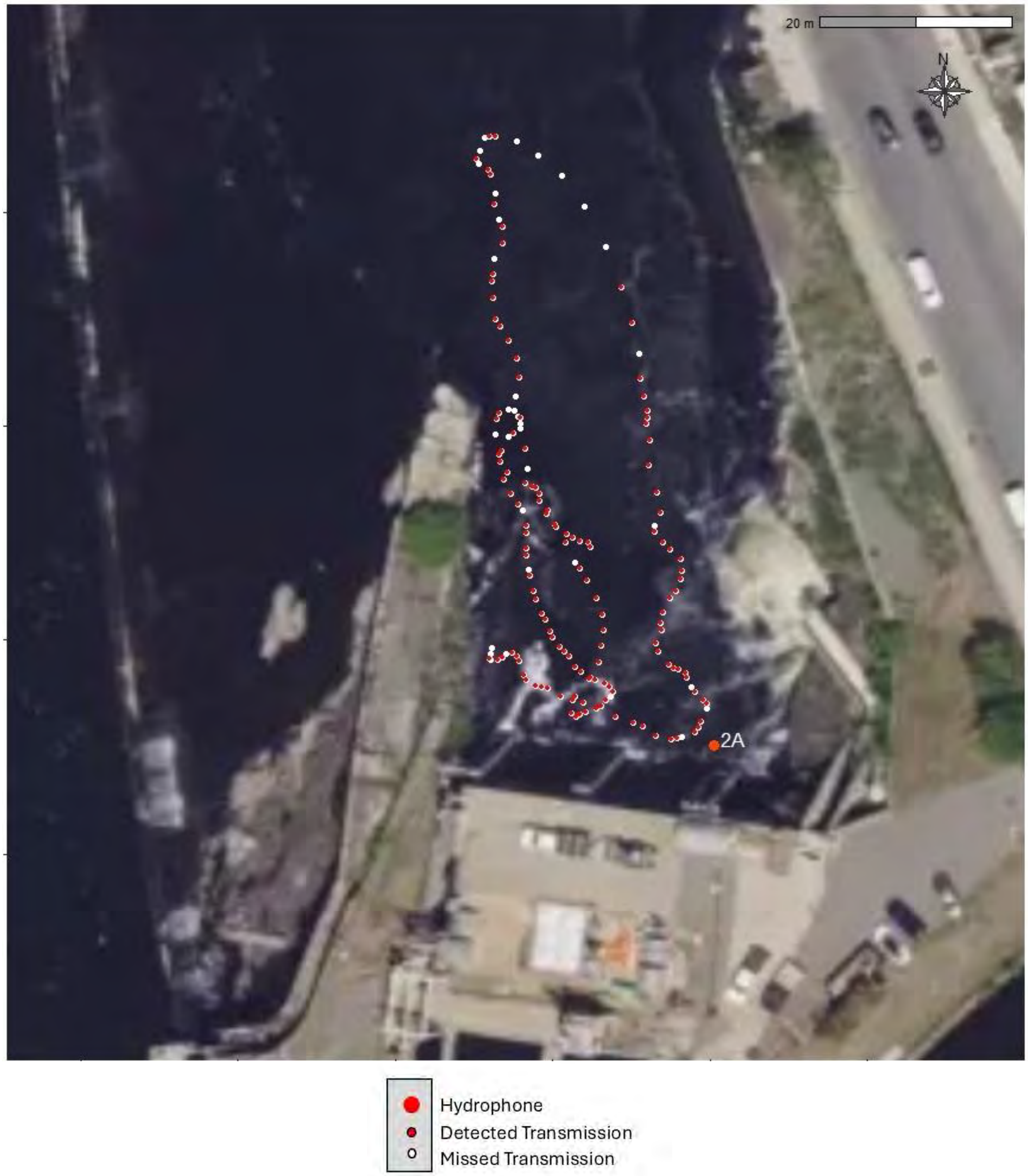
Pilot Deployment Location	2
Receiver Type	Lotek
Receiver ID	2D
Transmitter Model	SS300
Transmitter Test No.	2



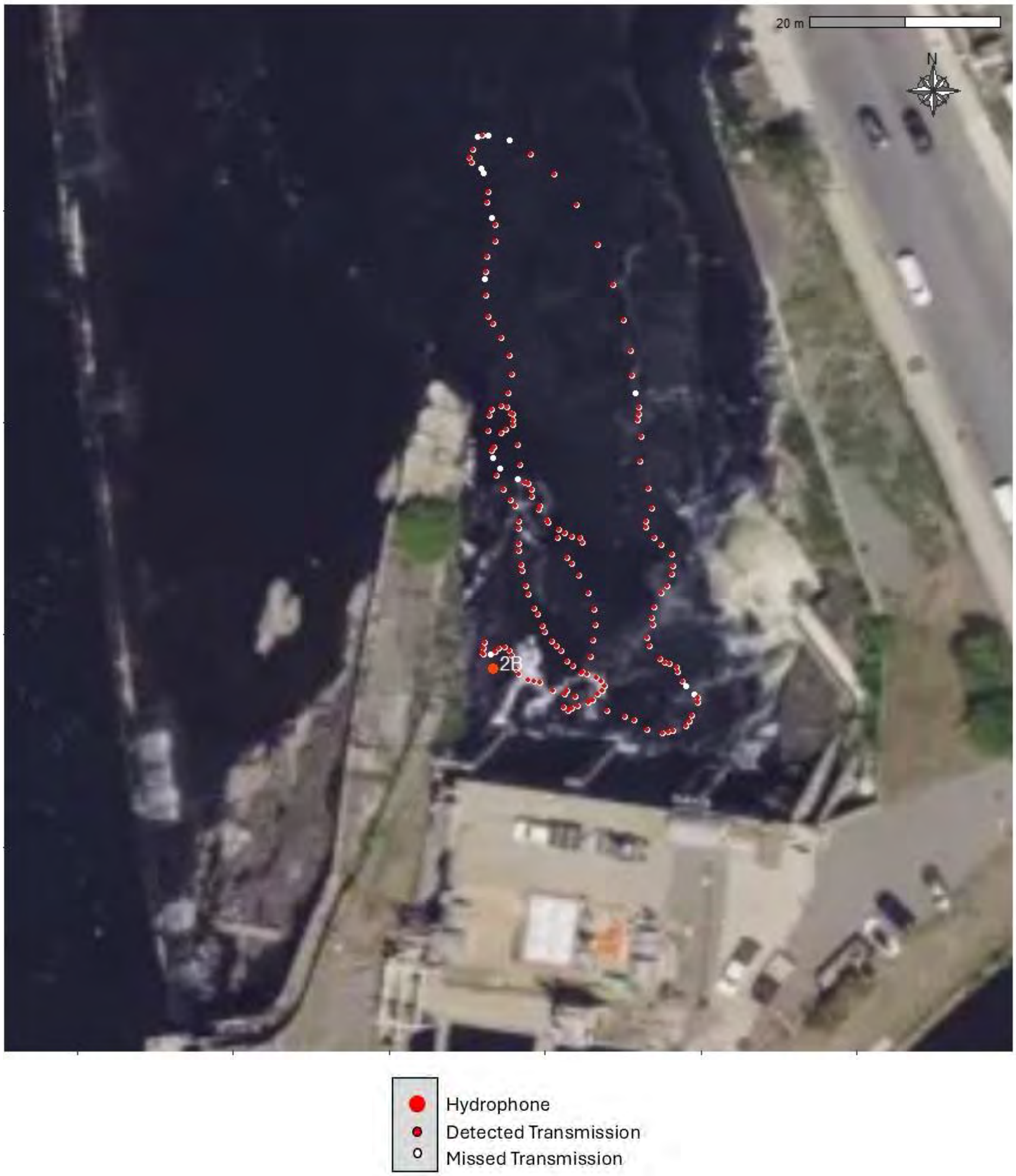
Pilot Deployment Location	2
Receiver Type	ATS
Receiver ID	2E
Transmitter Model	SS300
Transmitter Test No.	2



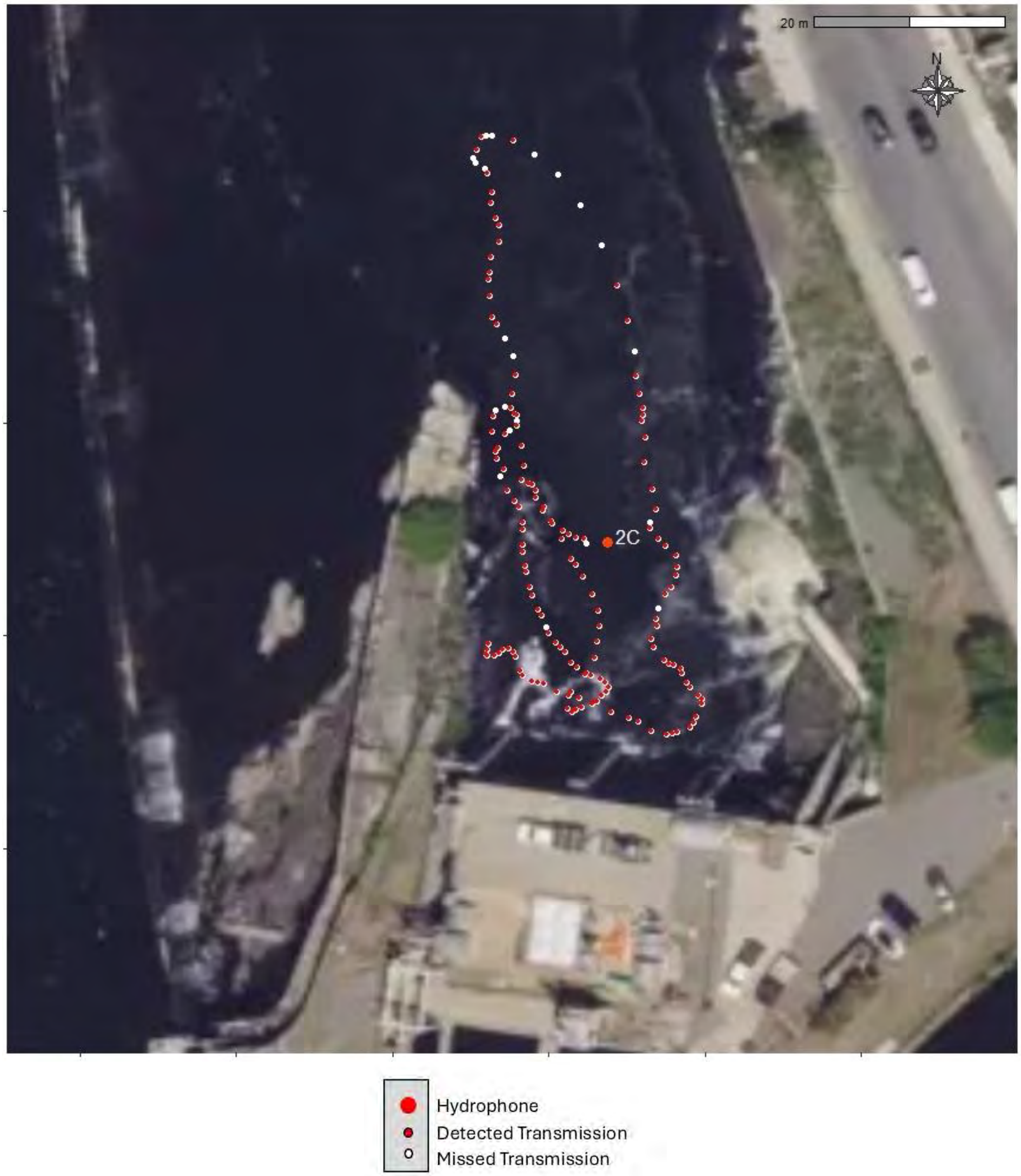
Pilot Deployment Location	2
Receiver Type	ATS
Receiver ID	2A
Transmitter Model	SS400
Transmitter Test No.	1



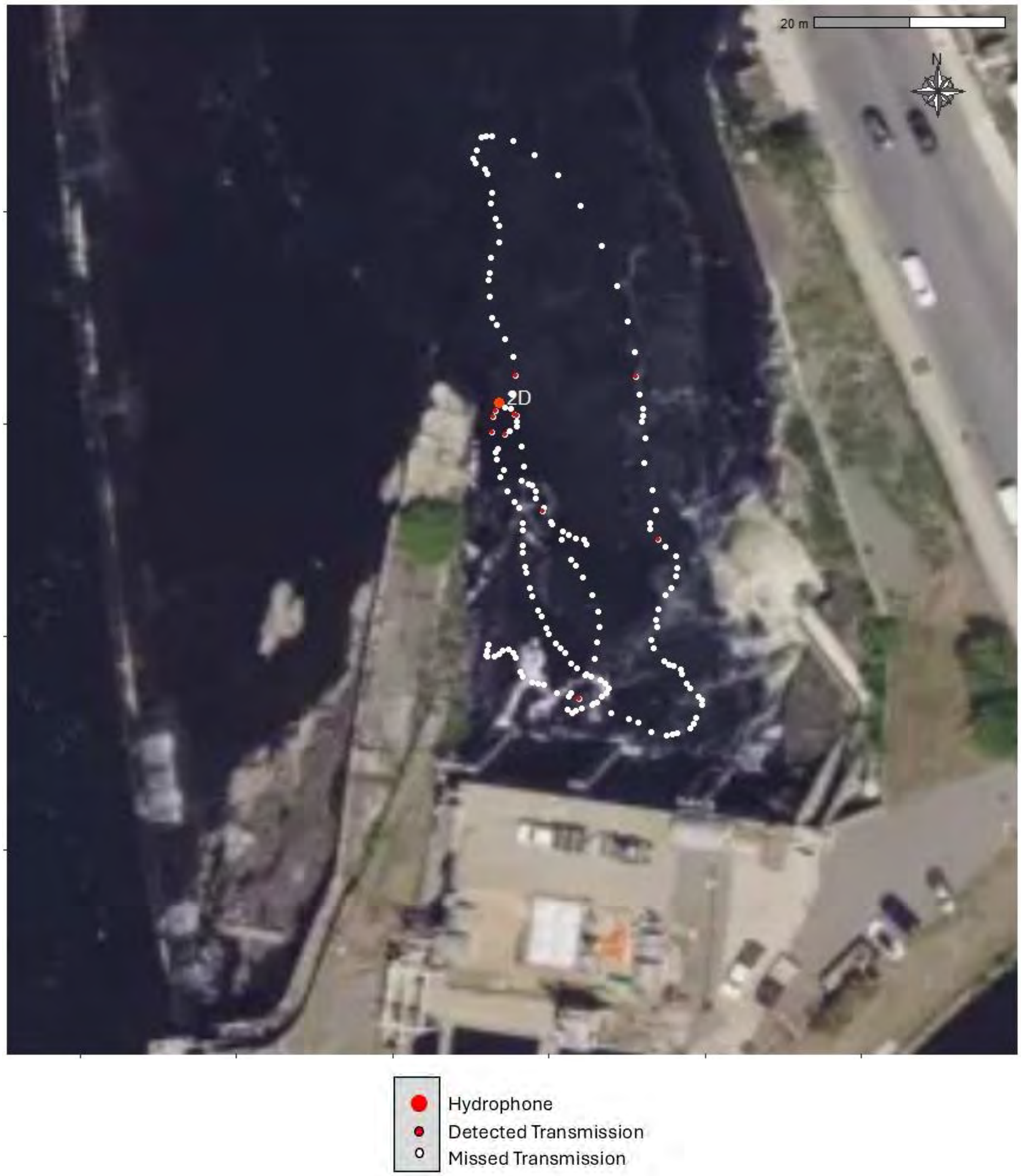
Pilot Deployment Location	2
Receiver Type	ATS
Receiver ID	2B
Transmitter Model	SS400
Transmitter Test No.	1



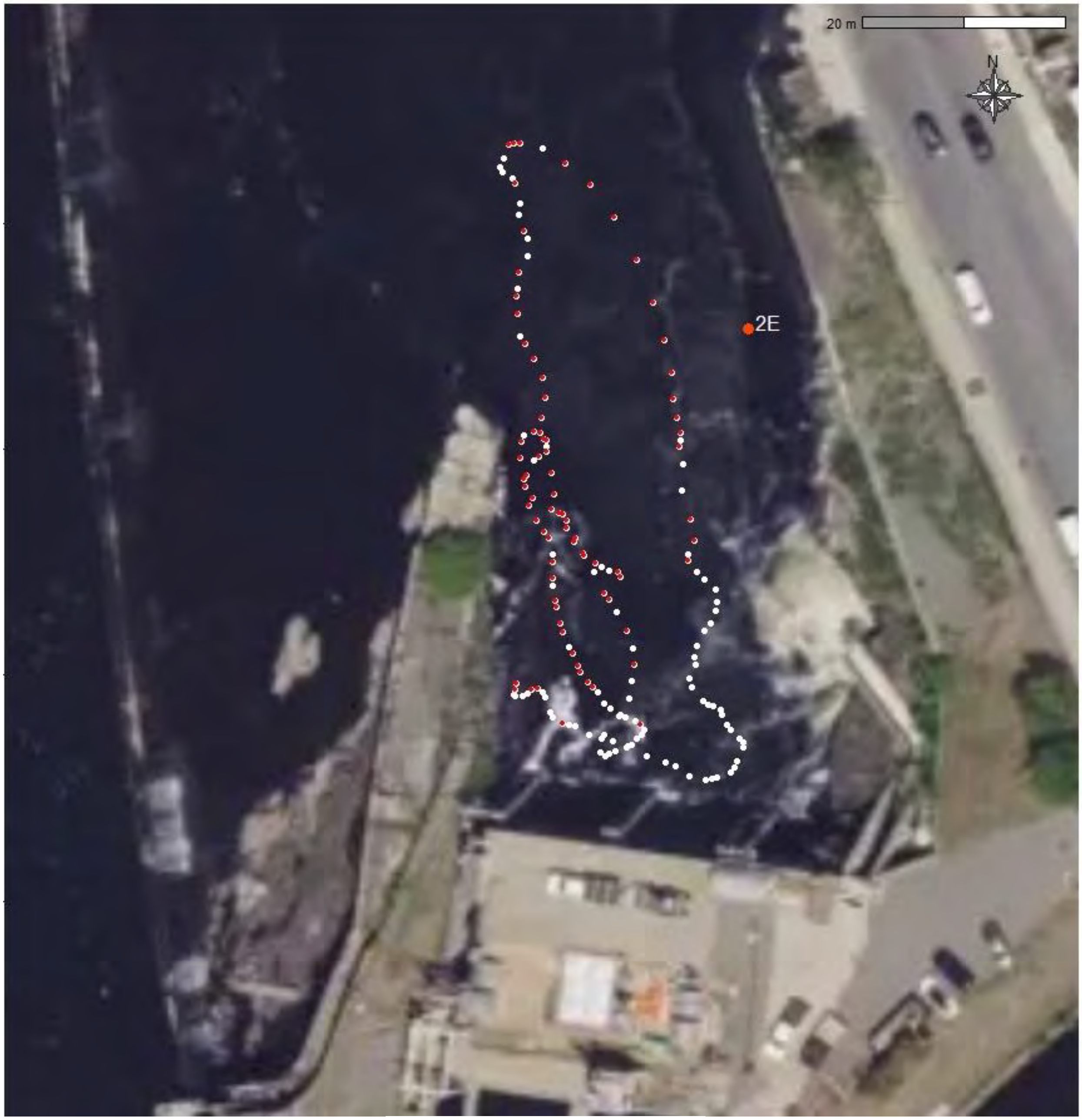
Pilot Deployment Location	2
Receiver Type	ATS
Receiver ID	2C
Transmitter Model	SS400
Transmitter Test No.	1

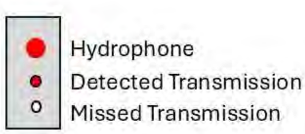


Pilot Deployment Location	2
Receiver Type	Lotek
Receiver ID	2D
Transmitter Model	SS400
Transmitter Test No.	1

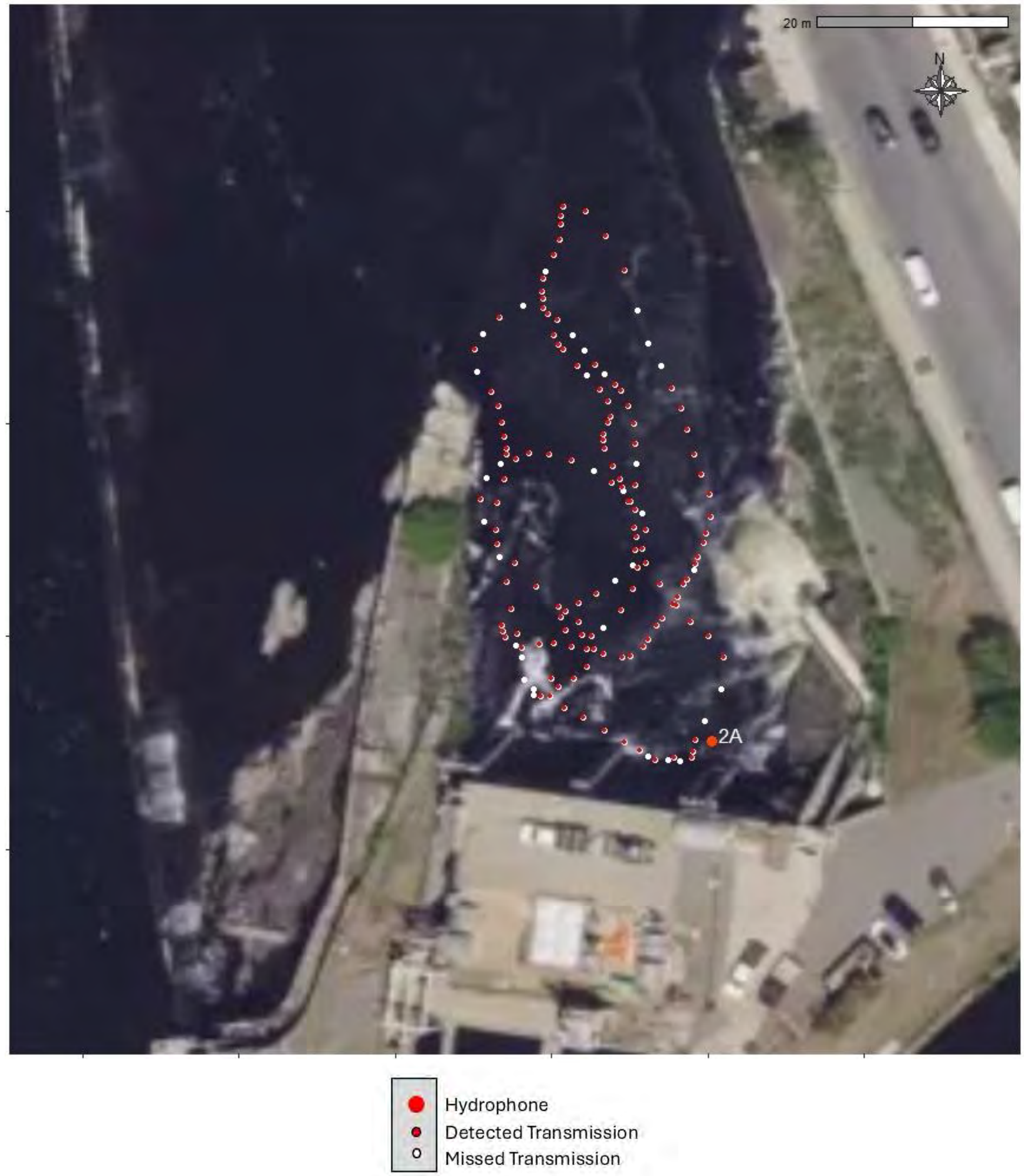


Pilot Deployment Location	2
Receiver Type	ATS
Receiver ID	2E
Transmitter Model	SS400
Transmitter Test No.	1



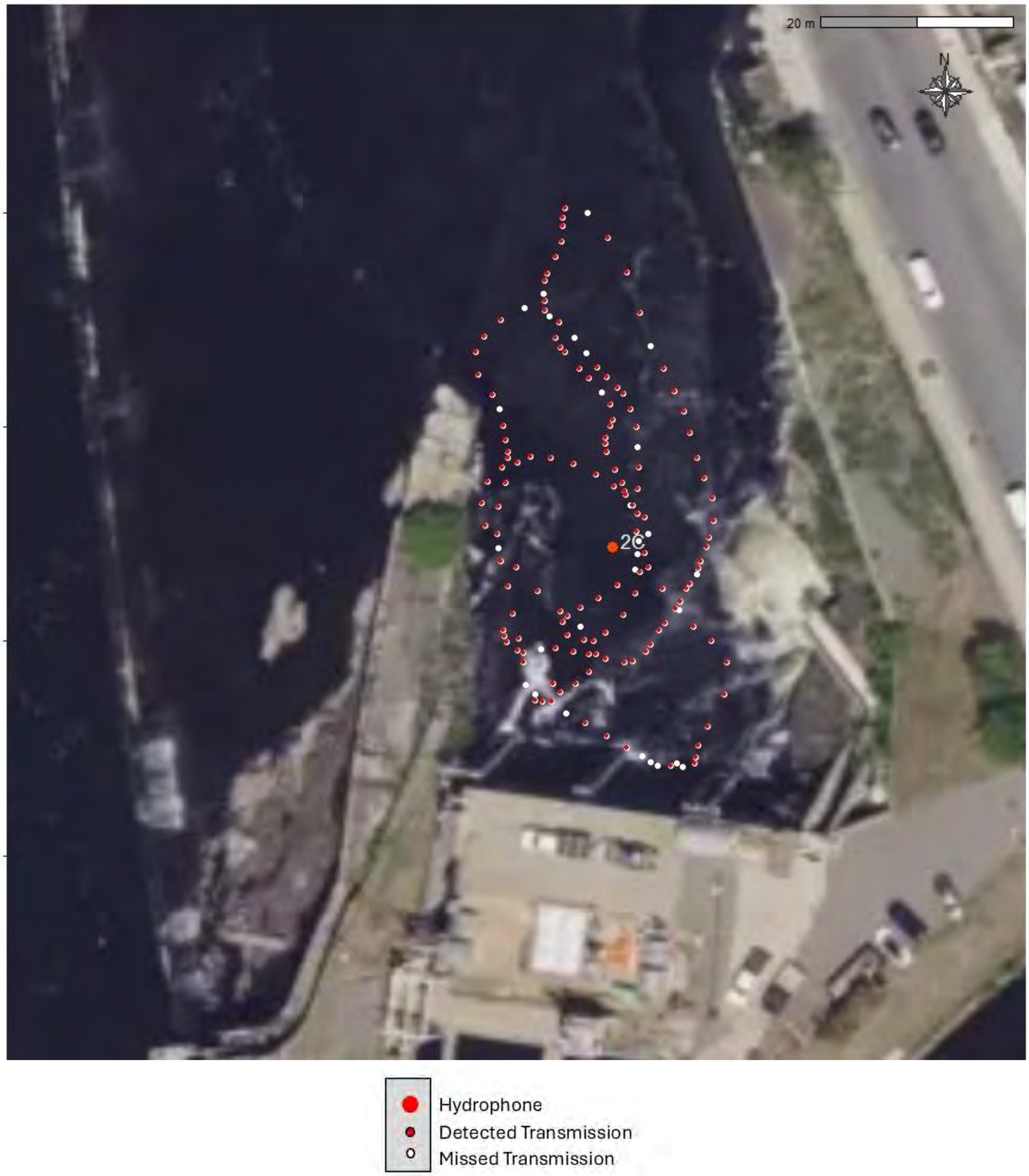


Pilot Deployment Location	2
Receiver Type	ATS
Receiver ID	2A
Transmitter Model	SS400
Transmitter Test No.	2

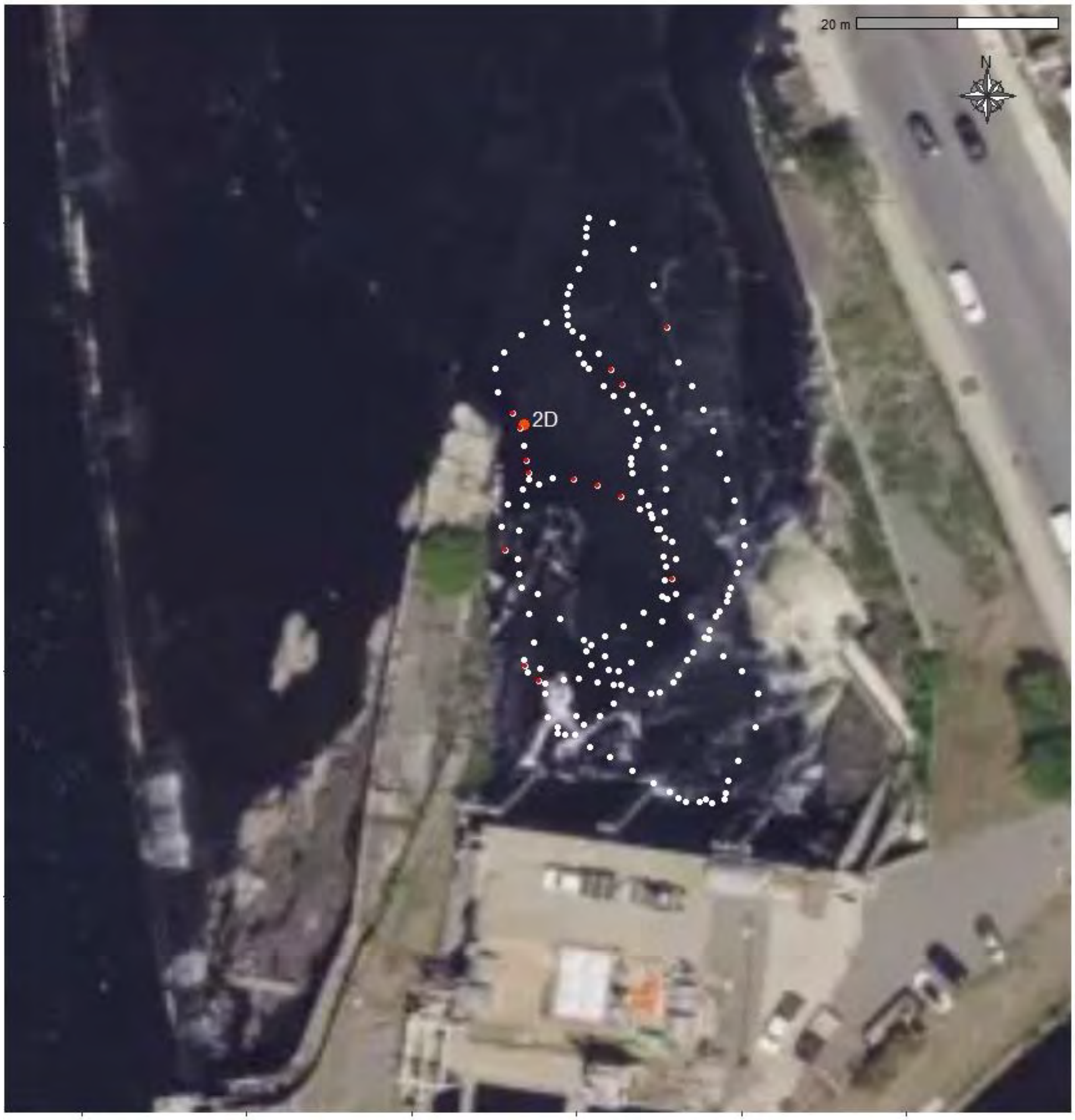


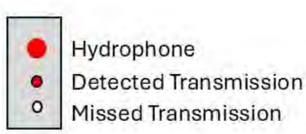
Pilot Deployment Location	2
Receiver Type	ATS
Receiver ID	2B
Transmitter Model	SS400
Transmitter Test No.	2

Pilot Deployment Location	2
Receiver Type	ATS
Receiver ID	2C
Transmitter Model	SS400
Transmitter Test No.	2

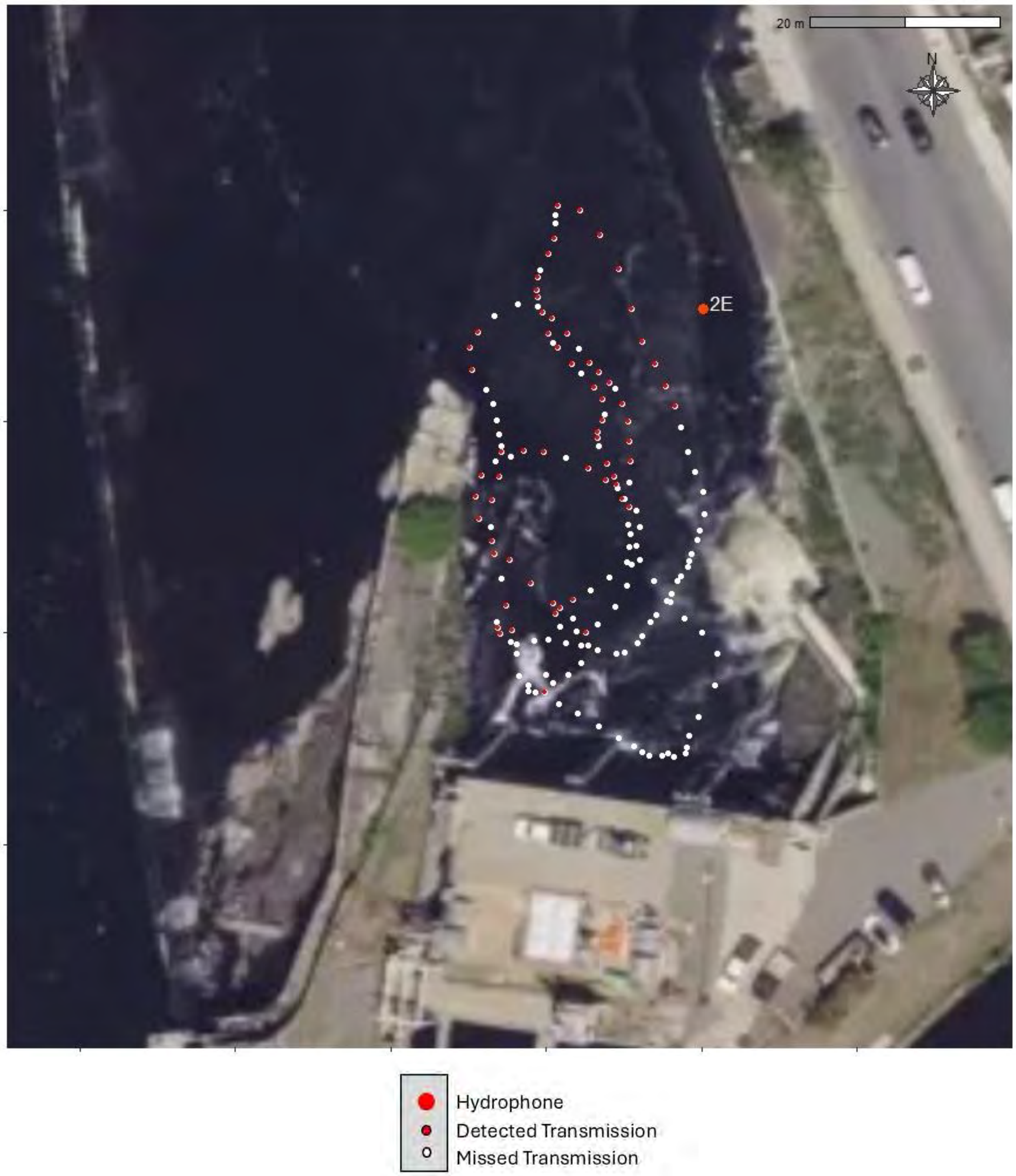


Pilot Deployment Location	2
Receiver Type	Lotek
Receiver ID	2D
Transmitter Model	SS400
Transmitter Test No.	2

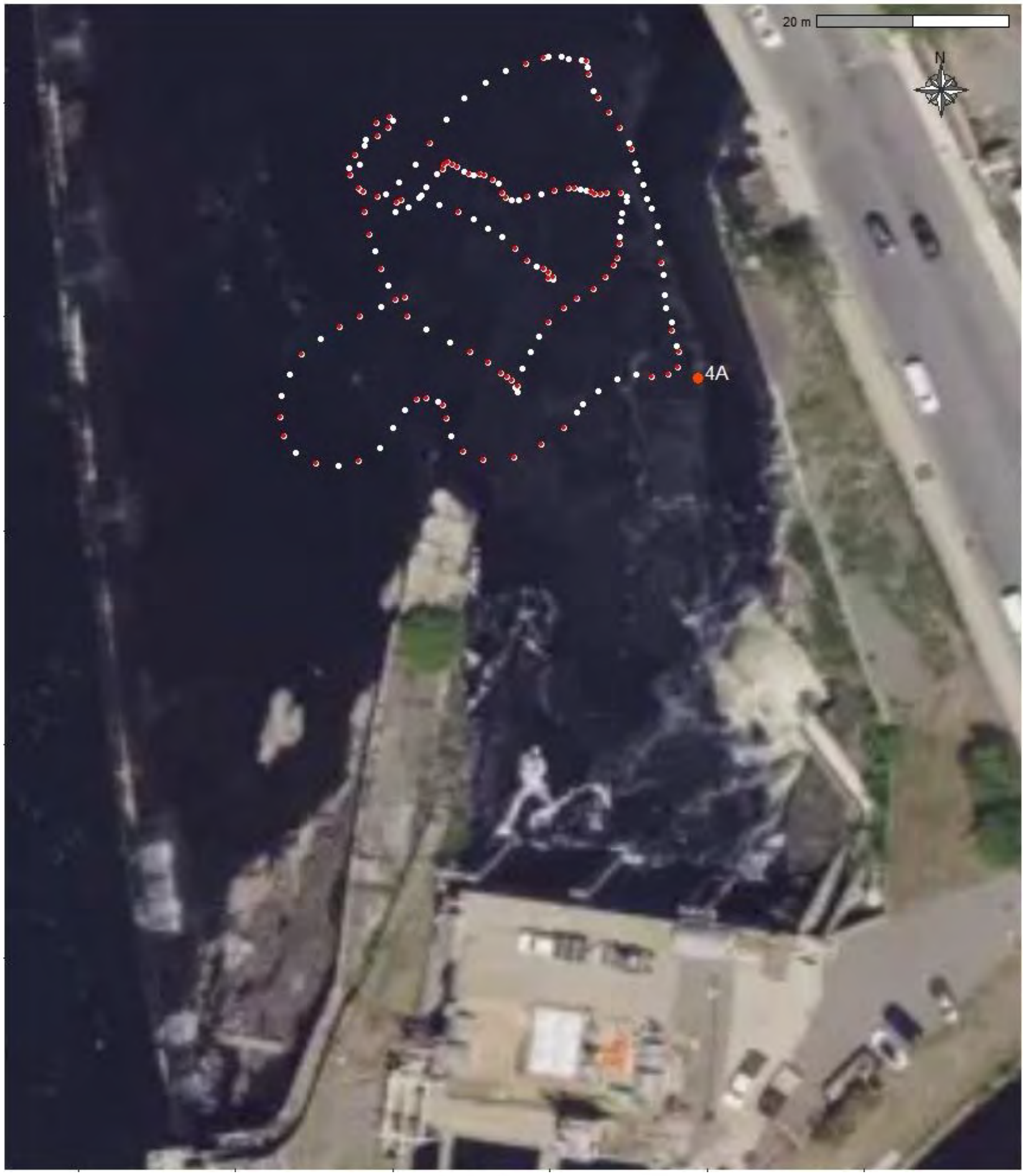




Pilot Deployment Location	2
Receiver Type	ATS
Receiver ID	2E
Transmitter Model	SS400
Transmitter Test No.	2

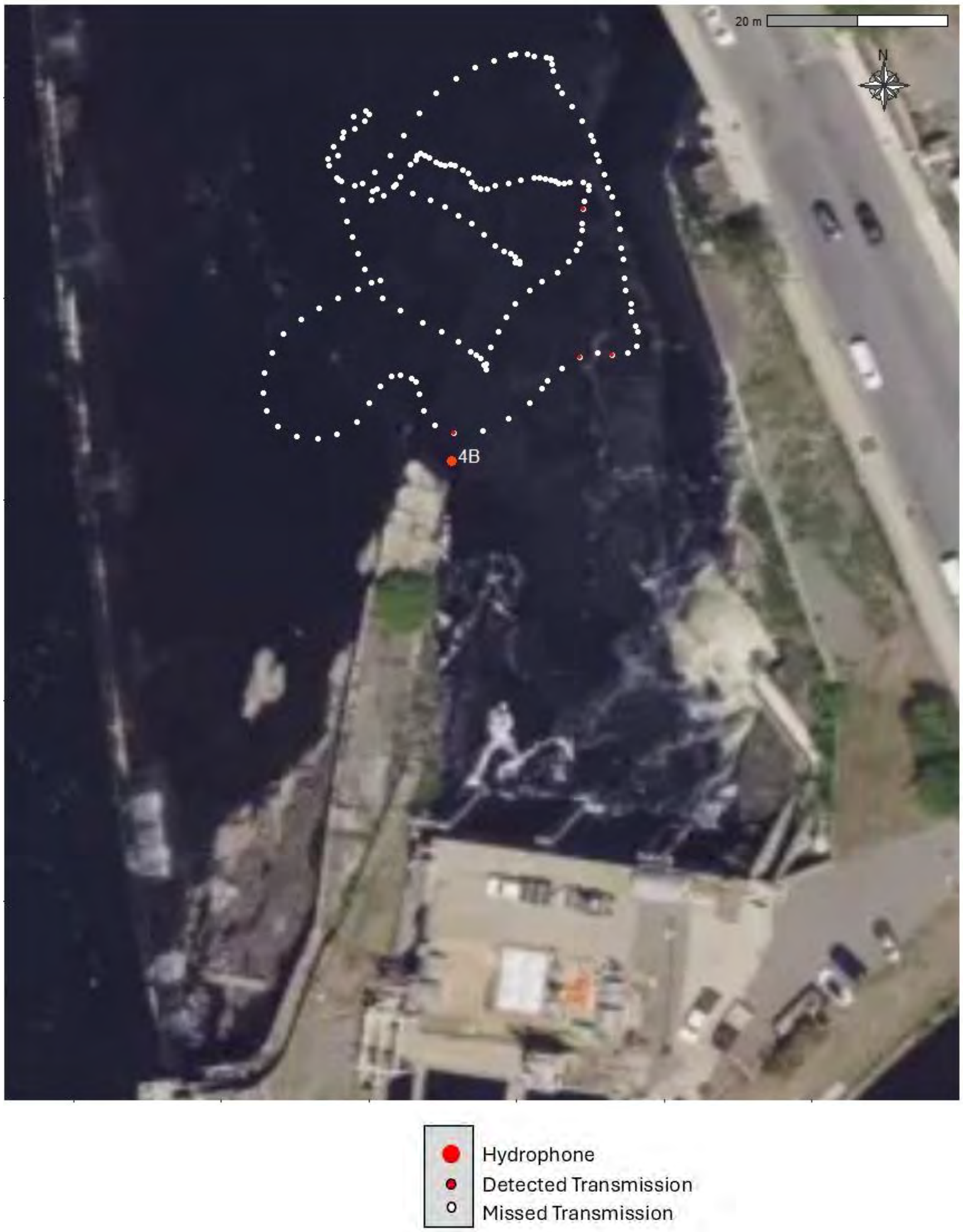


Pilot Deployment Location	4
Receiver Type	ATS
Receiver ID	4A
Transmitter Model	SS300
Transmitter Test No.	1



Hydrophone
Detected Transmission
Missed Transmission

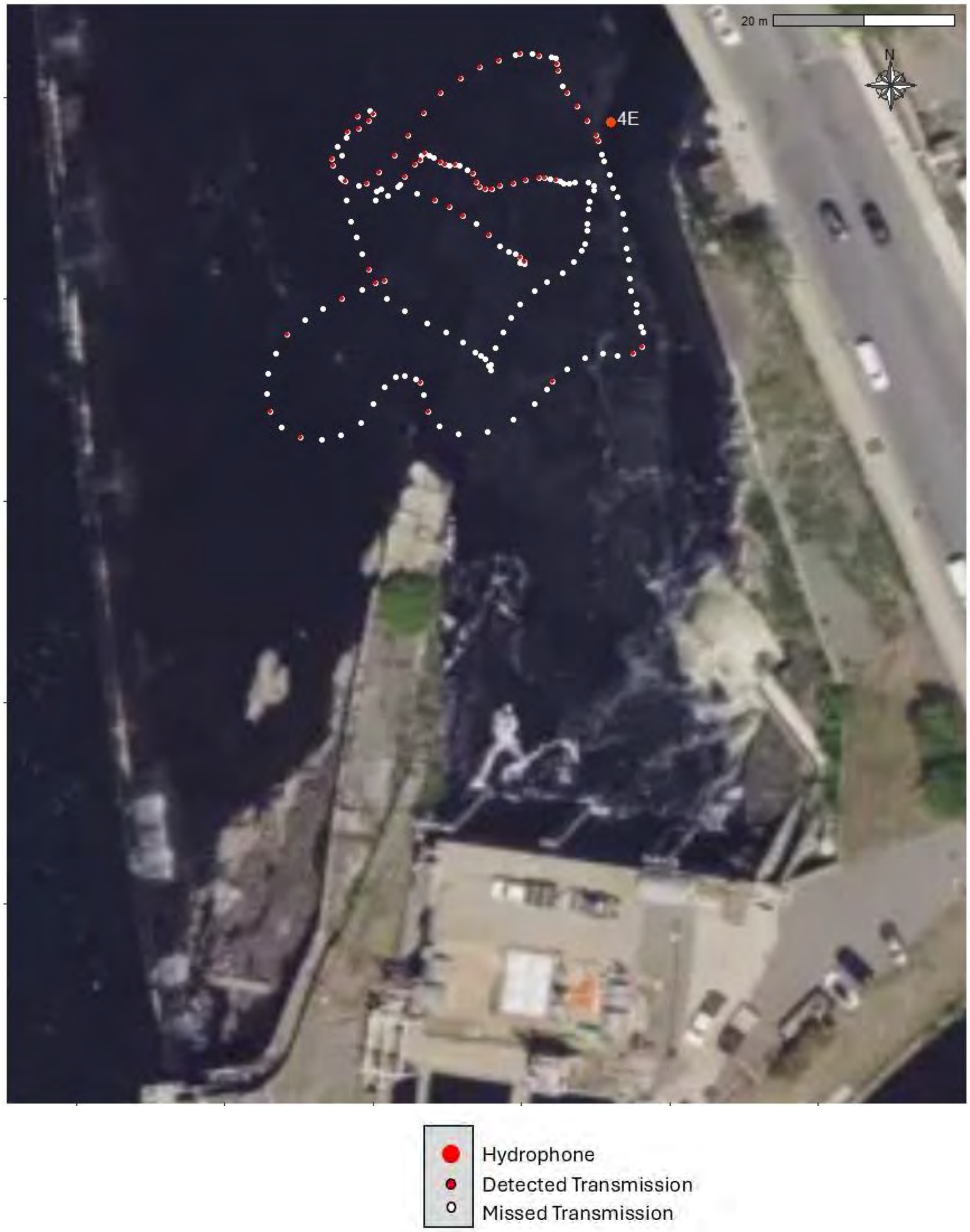
Pilot Deployment Location	4
Receiver Type	Lotek
Receiver ID	4B
Transmitter Model	SS300
Transmitter Test No.	1



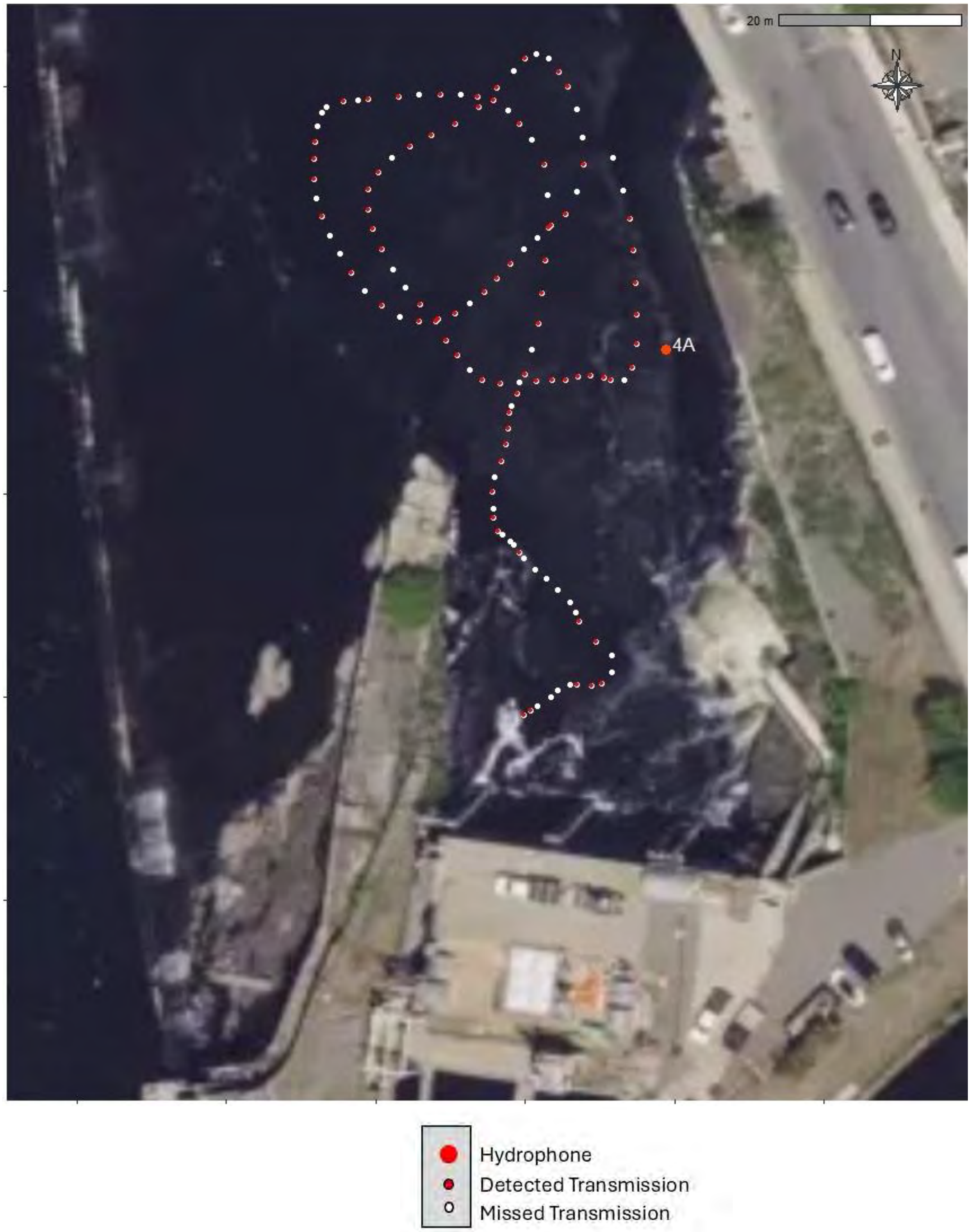
Pilot Deployment Location	4
Receiver Type	ATS
Receiver ID	4C
Transmitter Model	SS300
Transmitter Test No.	1

Pilot Deployment Location	4
Receiver Type	ATS
Receiver ID	4D
Transmitter Model	SS300
Transmitter Test No.	1

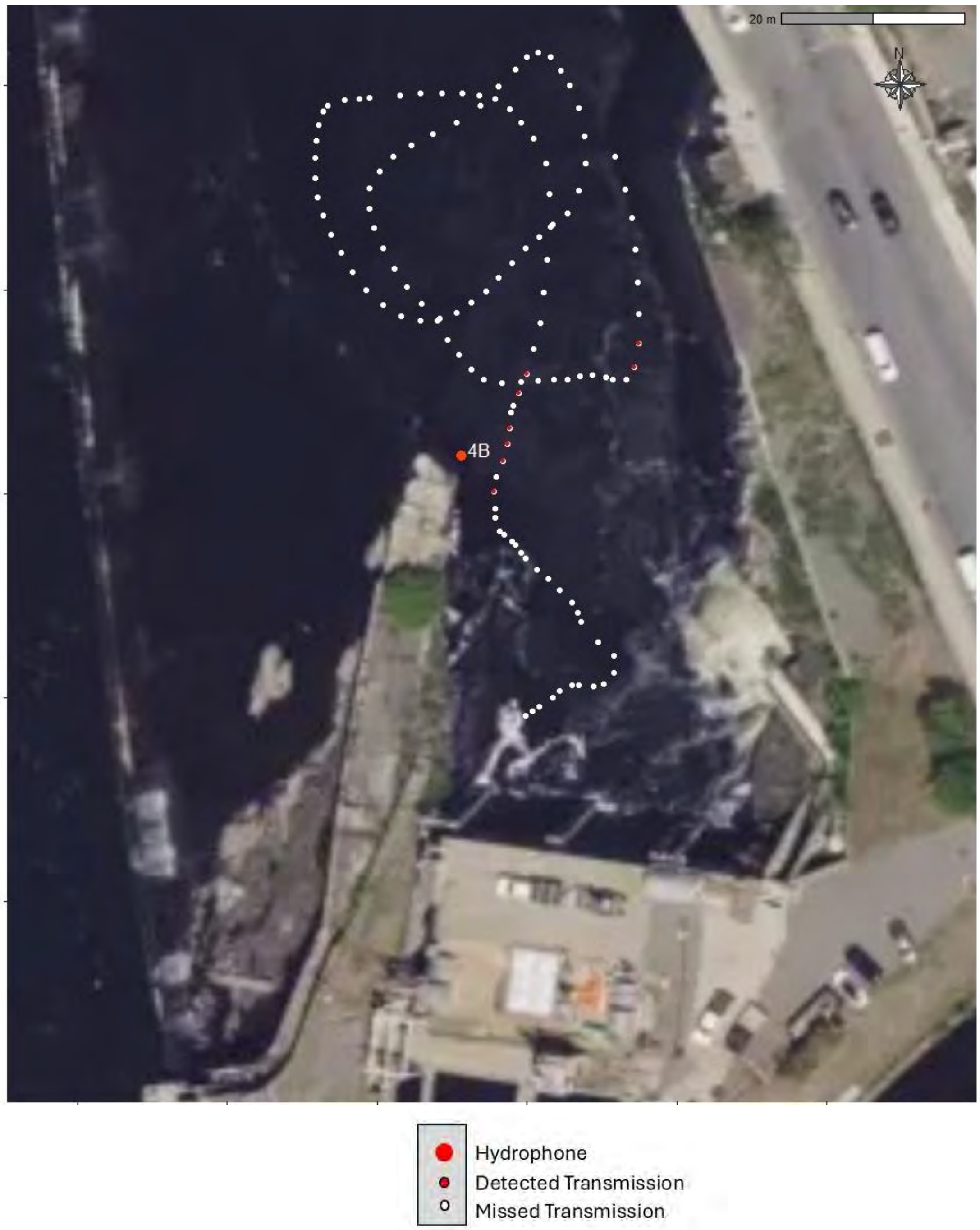
Pilot Deployment Location	4
Receiver Type	ATS
Receiver ID	4E
Transmitter Model	SS300
Transmitter Test No.	1



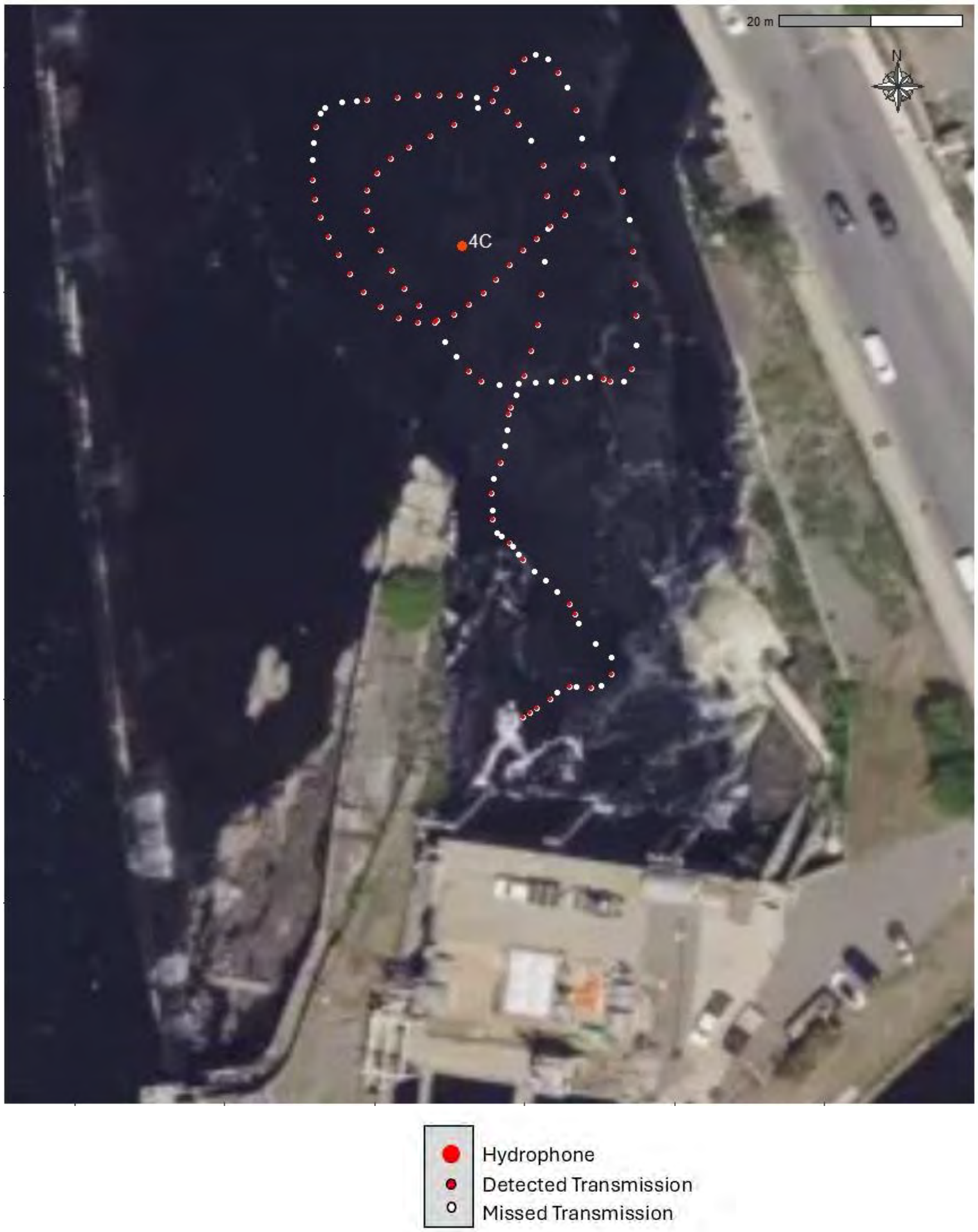
Pilot Deployment Location	4
Receiver Type	ATS
Receiver ID	4A
Transmitter Model	SS300
Transmitter Test No.	2



Pilot Deployment Location	4
Receiver Type	Lotek
Receiver ID	4B
Transmitter Model	SS300
Transmitter Test No.	2

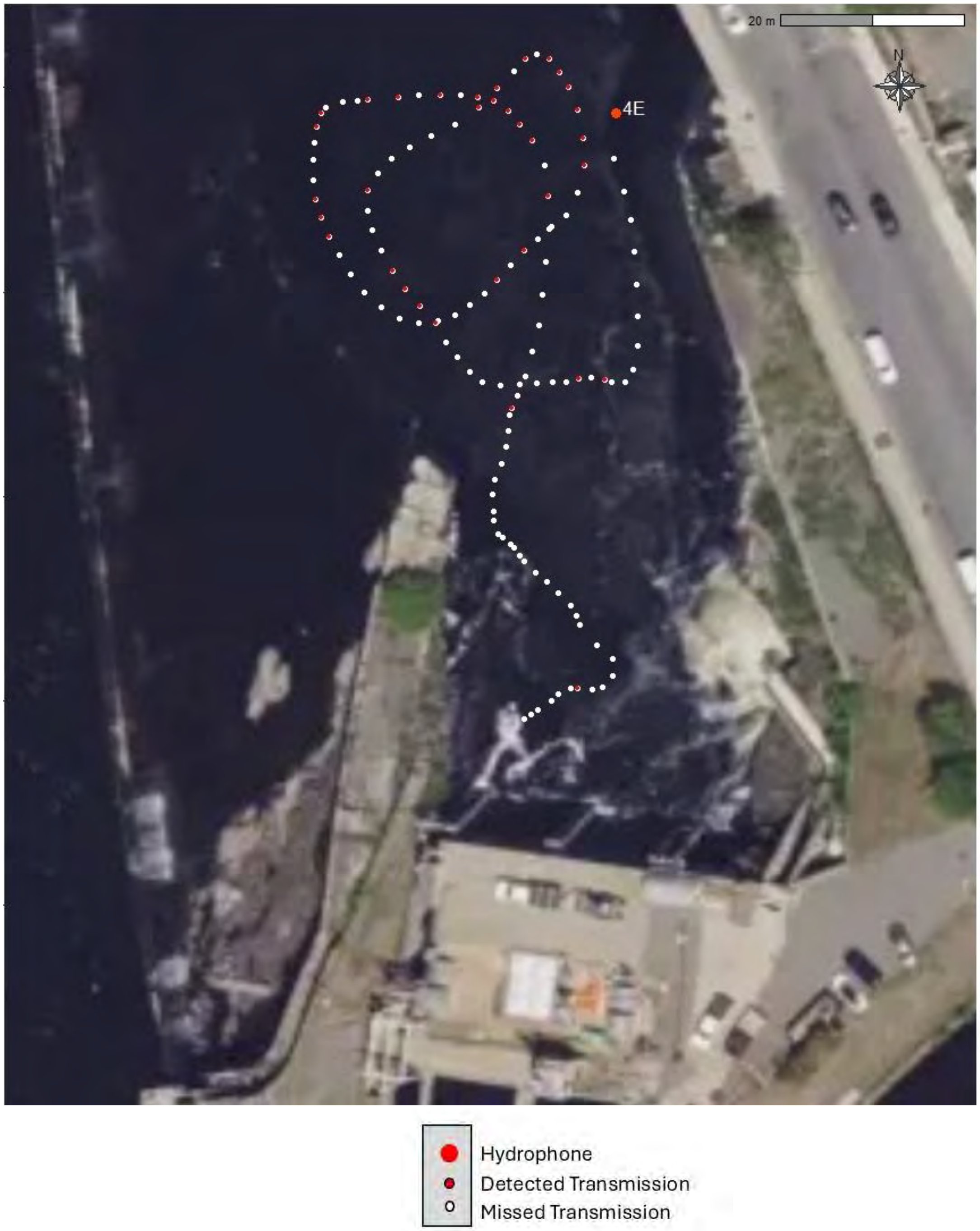


Pilot Deployment Location	4
Receiver Type	ATS
Receiver ID	4C
Transmitter Model	SS300
Transmitter Test No.	2



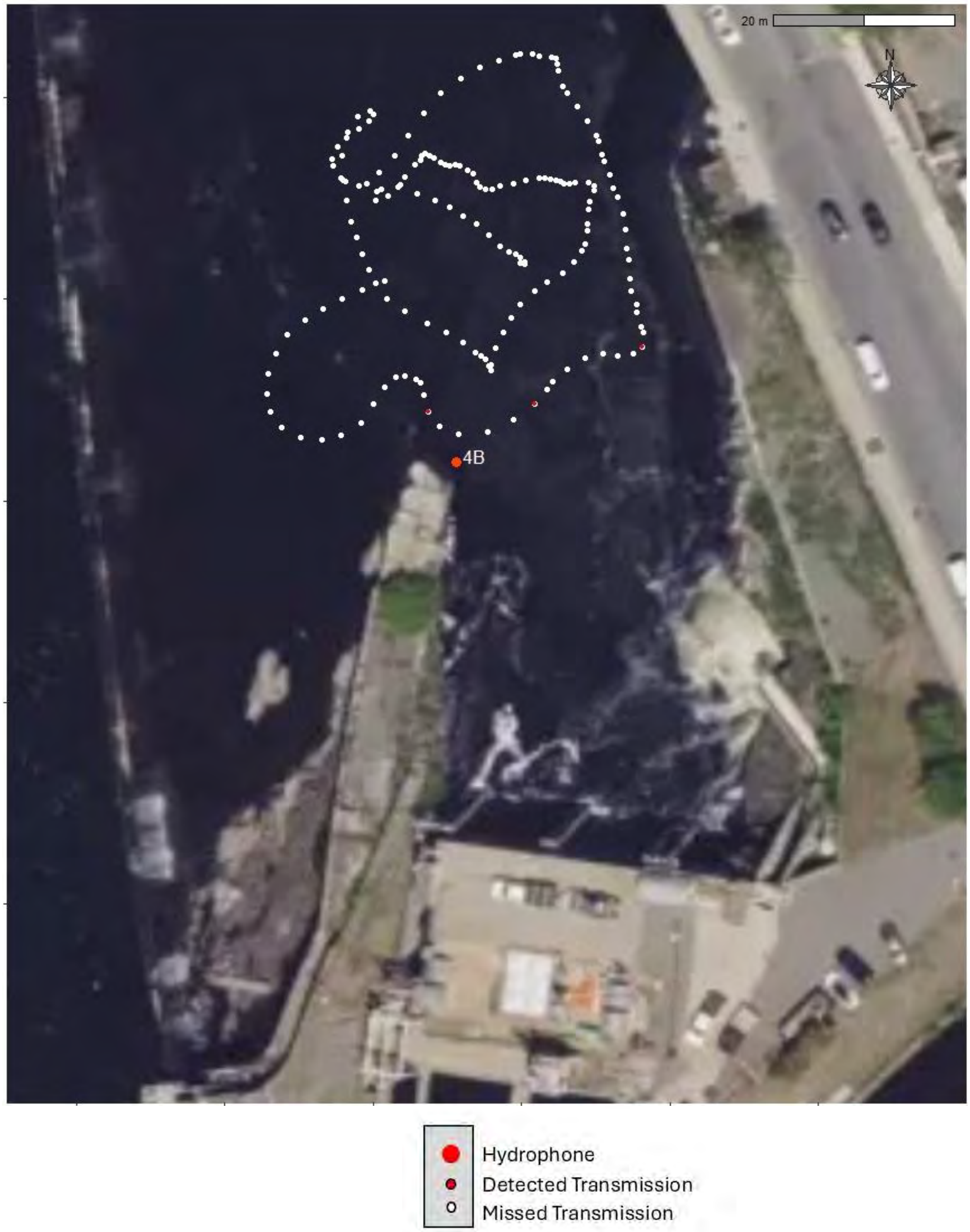
Pilot Deployment Location	4
Receiver Type	ATS
Receiver ID	4D
Transmitter Model	SS300
Transmitter Test No.	2

Pilot Deployment Location	4
Receiver Type	ATS
Receiver ID	4E
Transmitter Model	SS300
Transmitter Test No.	2

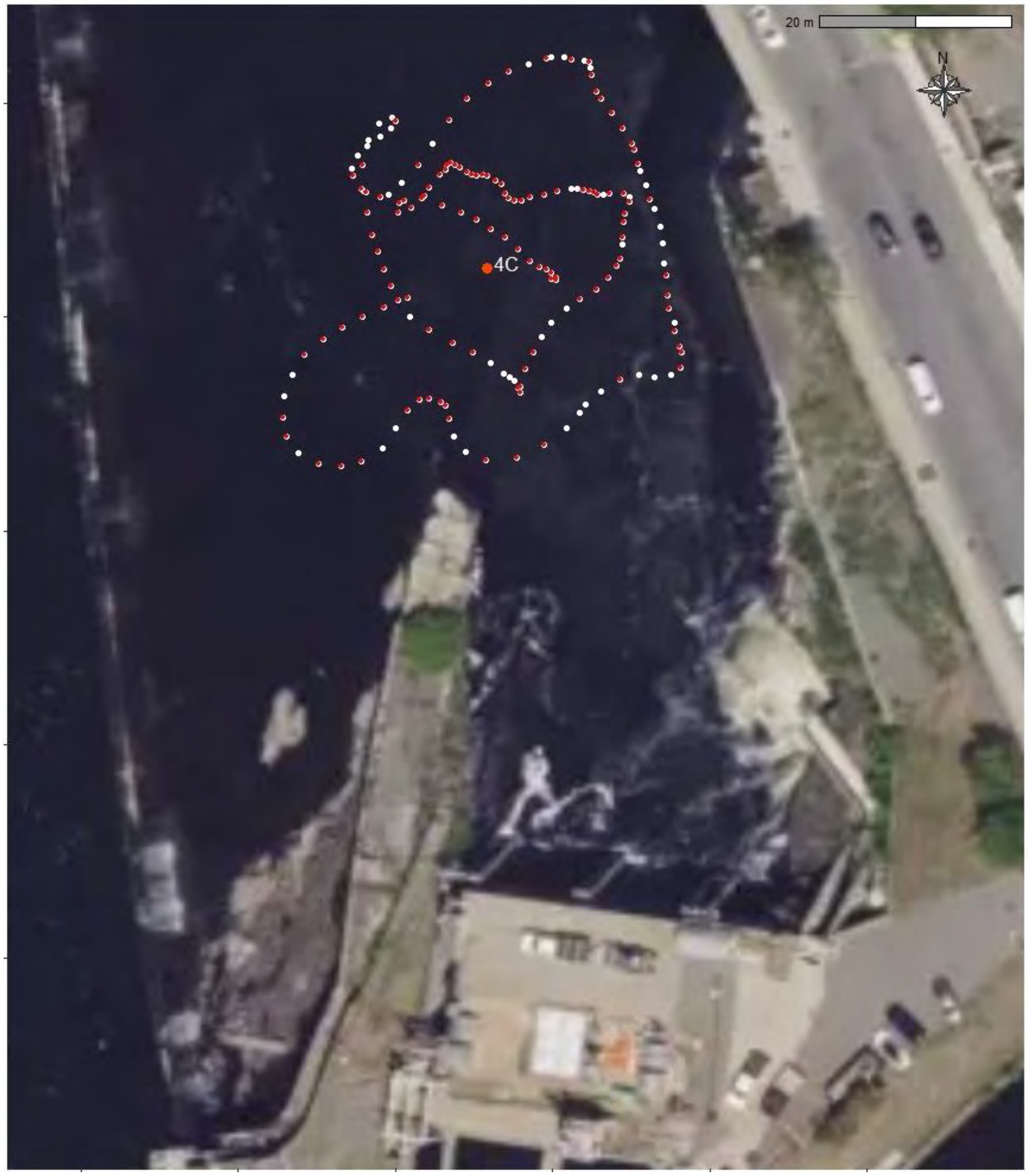


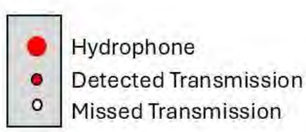
Pilot Deployment Location	4
Receiver Type	ATS
Receiver ID	4A
Transmitter Model	SS400
Transmitter Test No.	1

Pilot Deployment Location	4
Receiver Type	Lotek
Receiver ID	4B
Transmitter Model	SS400
Transmitter Test No.	1



Pilot Deployment Location	4
Receiver Type	ATS
Receiver ID	4C
Transmitter Model	SS400
Transmitter Test No.	1

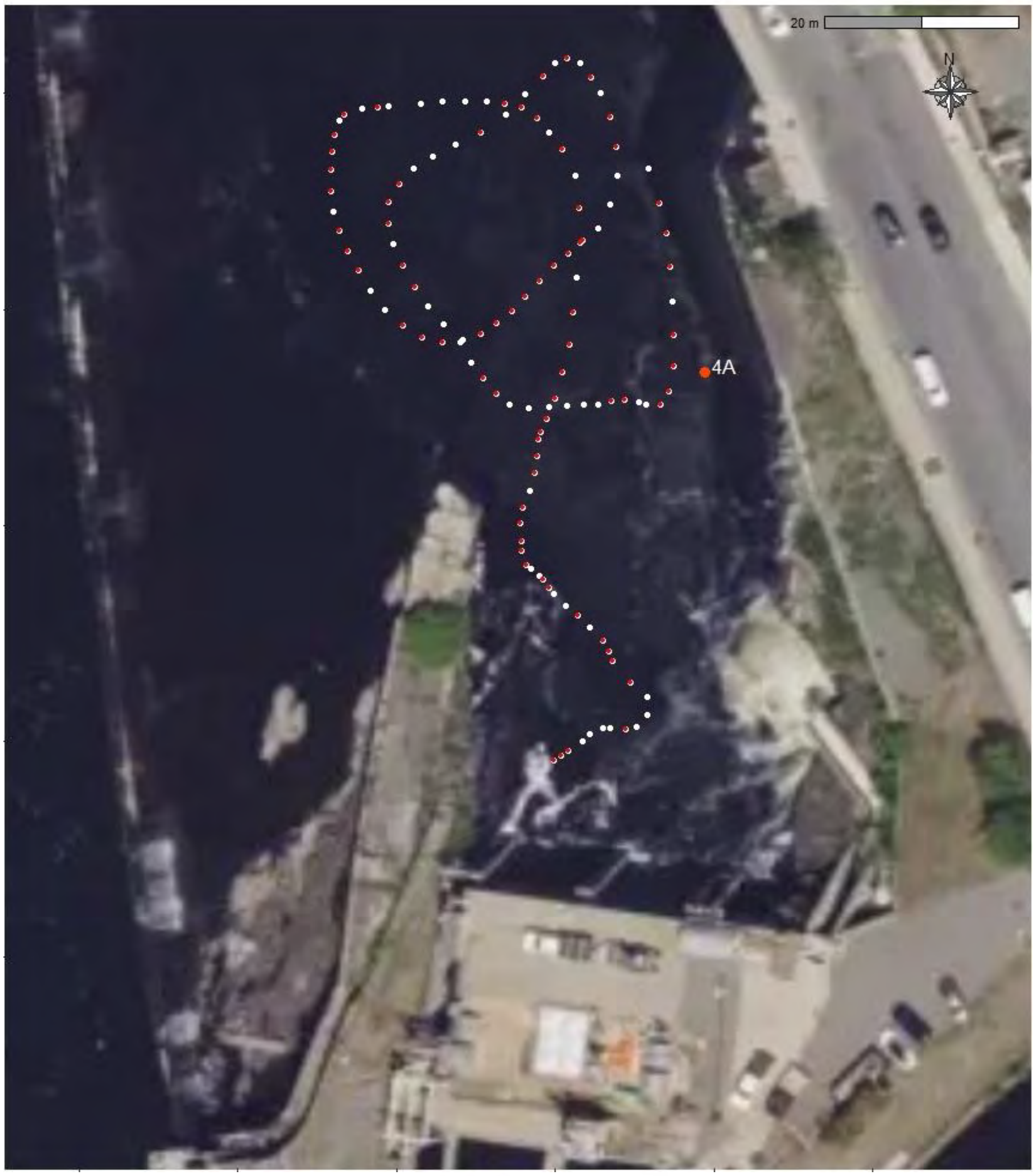


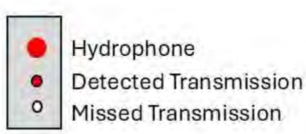


Pilot Deployment Location	4
Receiver Type	ATS
Receiver ID	4D
Transmitter Model	SS400
Transmitter Test No.	1

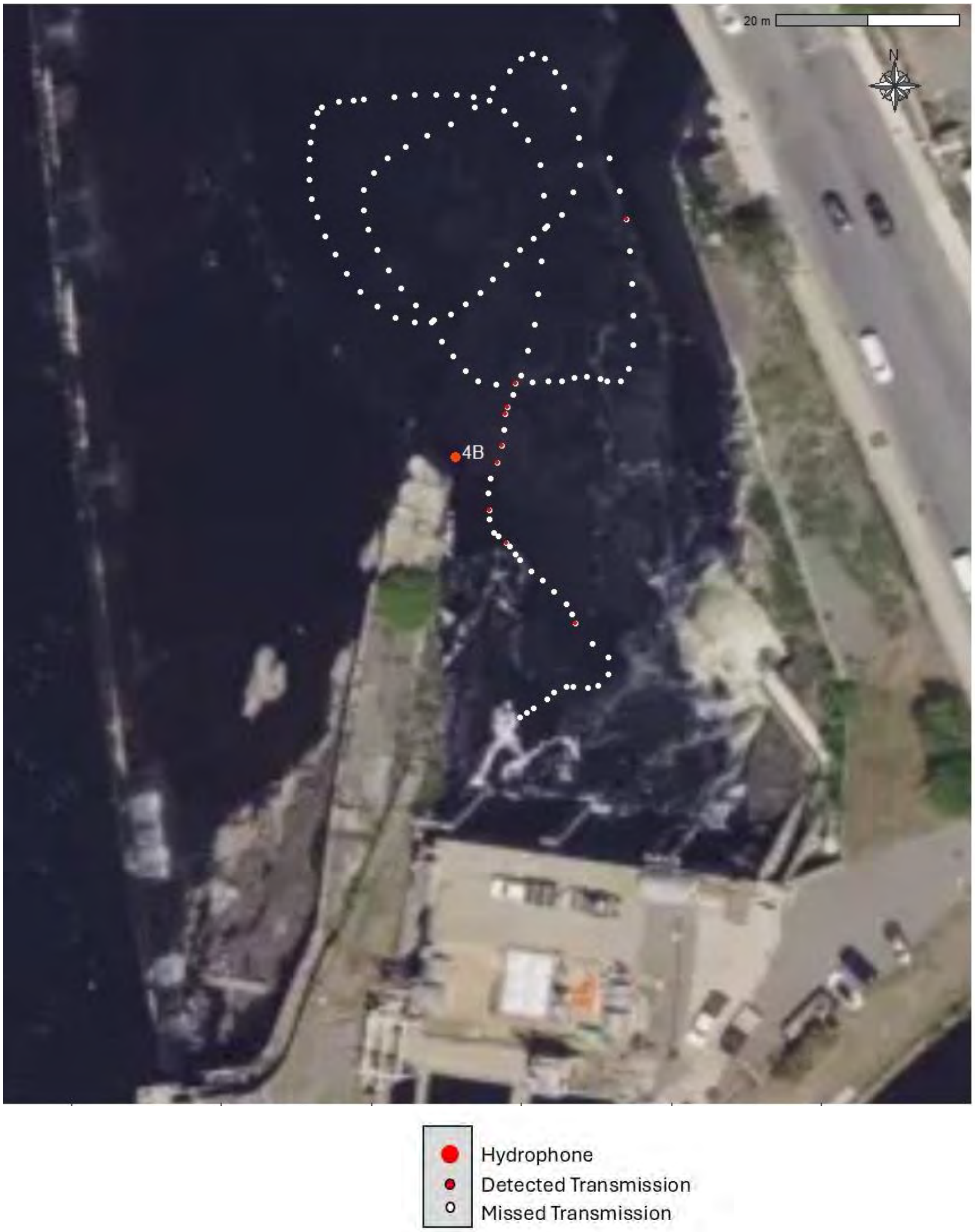
Pilot Deployment Location	4
Receiver Type	ATS
Receiver ID	4E
Transmitter Model	SS400
Transmitter Test No.	1

Pilot Deployment Location	4
Receiver Type	ATS
Receiver ID	4A
Transmitter Model	SS400
Transmitter Test No.	2

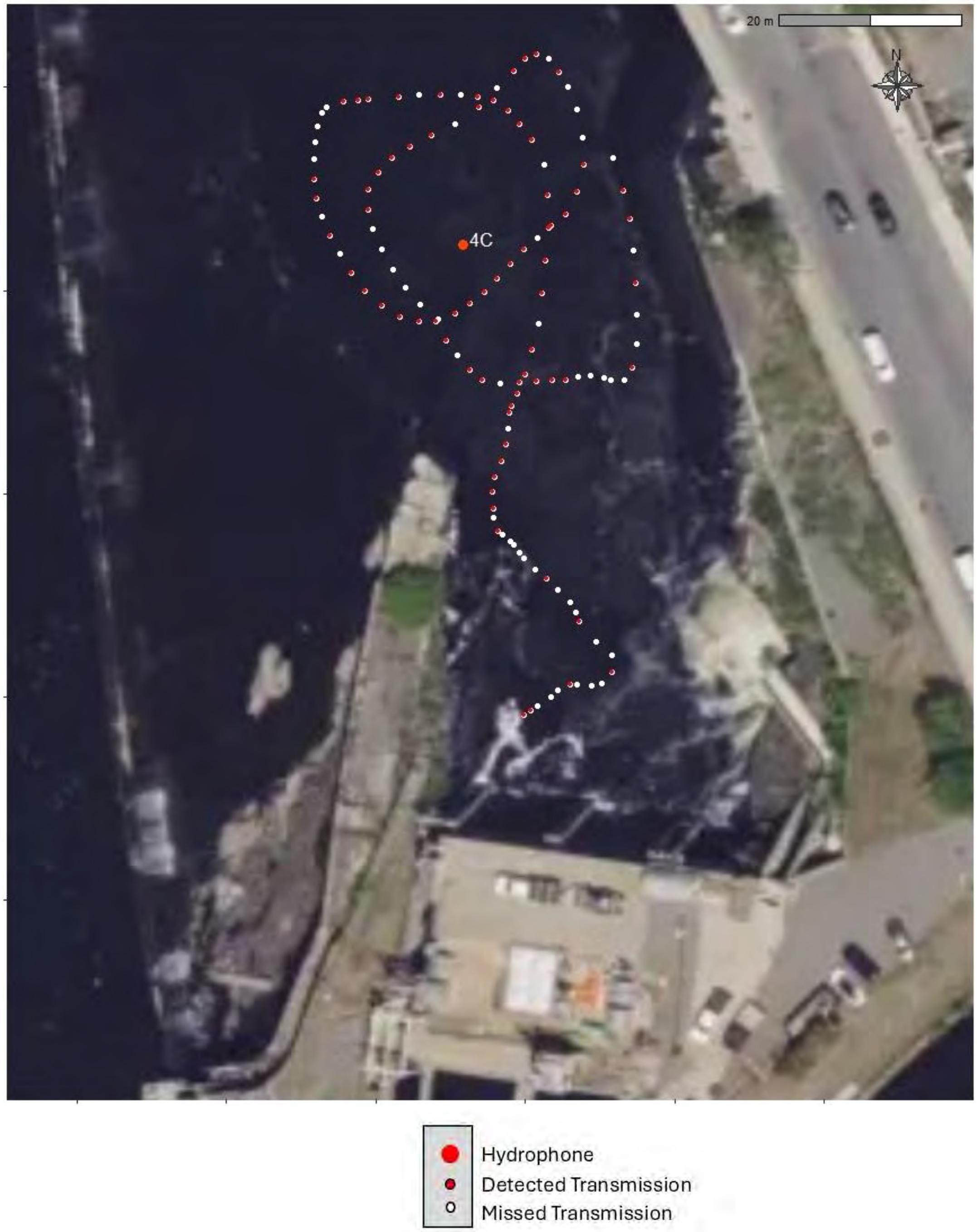




Pilot Deployment Location	4
Receiver Type	Lotek
Receiver ID	4B
Transmitter Model	SS400
Transmitter Test No.	2

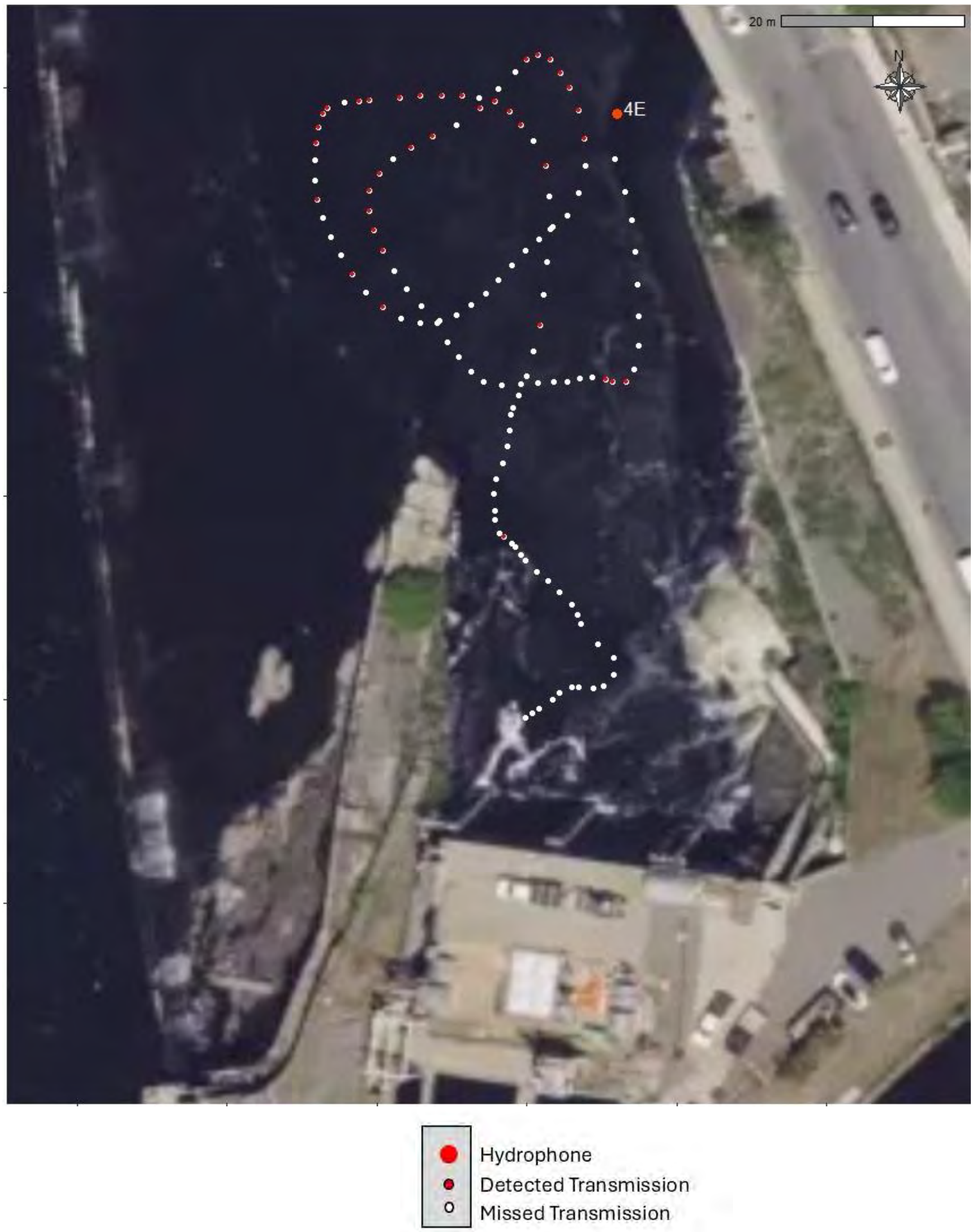


Pilot Deployment Location	4
Receiver Type	ATS
Receiver ID	4C
Transmitter Model	SS400
Transmitter Test No.	2



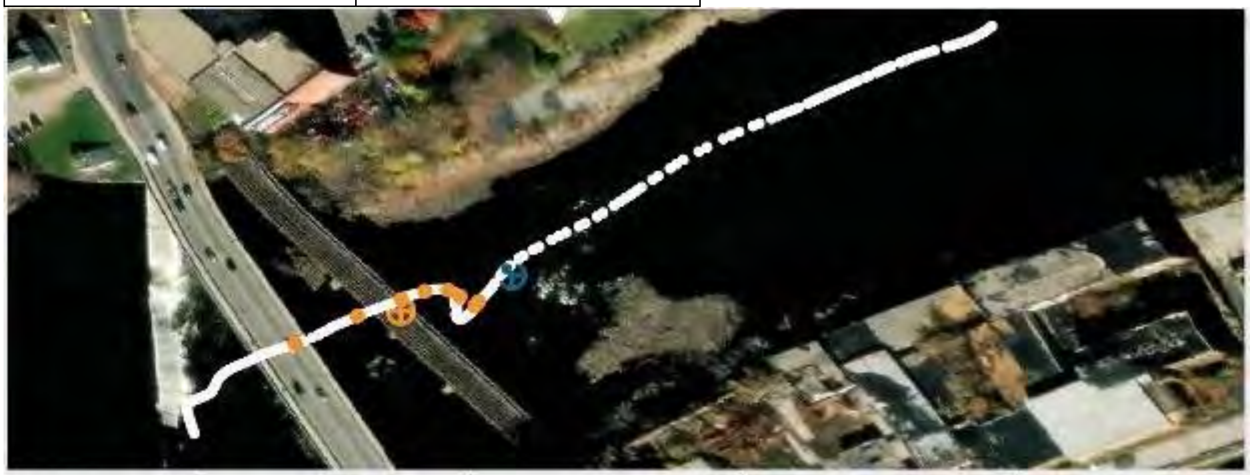
Pilot Deployment Location	4
Receiver Type	ATS
Receiver ID	4D
Transmitter Model	SS400
Transmitter Test No.	2

Pilot Deployment Location	4
Receiver Type	ATS
Receiver ID	4E
Transmitter Model	SS400
Transmitter Test No.	2



Appendix C: 1D Receiver Detection Coverage

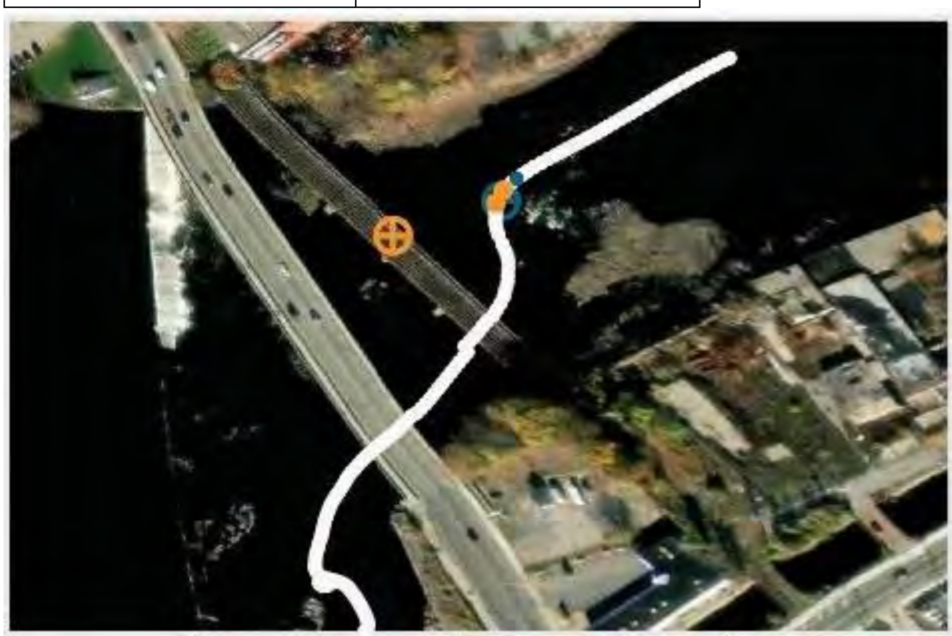
Pilot Deployment Location	5	
Receiver Type	ATS	
Receiver ID	5A (orange)	5B (blue)
Transmitter Model	SS300	
Transmitter Test No.	1	



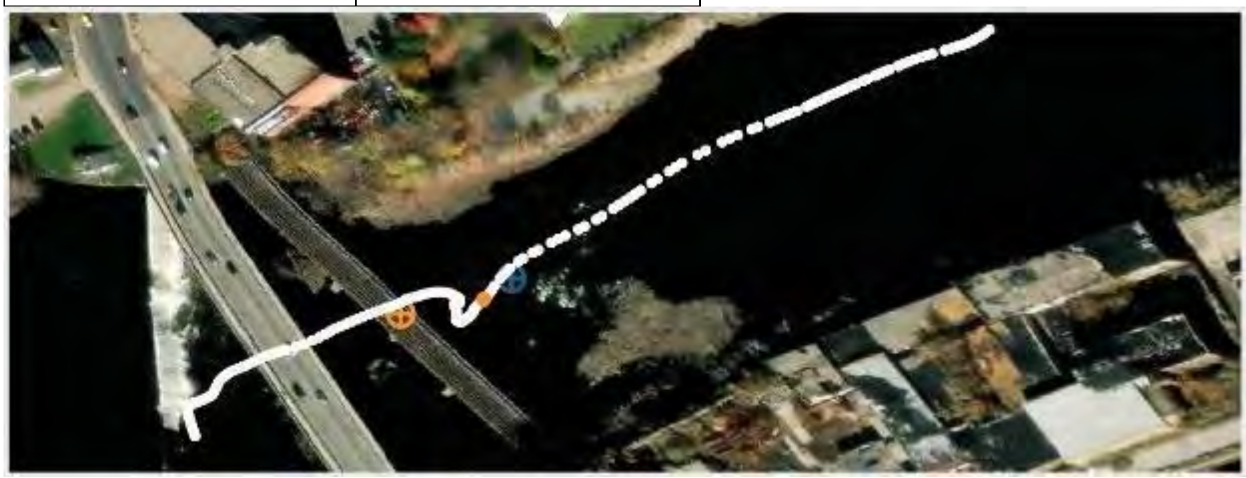
Pilot Deployment Location	5	
Receiver Type	ATS	
Receiver ID	5A (orange)	5B (blue)
Transmitter Model	SS400	
Transmitter Test No.	1	

Pilot Deployment Location	5	
Receiver Type	ATS	
Receiver ID	5A (orange)	5B (blue)
Transmitter Model	SS300	
Transmitter Test No.	2	

Pilot Deployment Location	5	
Receiver Type	ATS	
Receiver ID	5A (orange)	5B (blue)
Transmitter Model	SS400	
Transmitter Test No.	2	



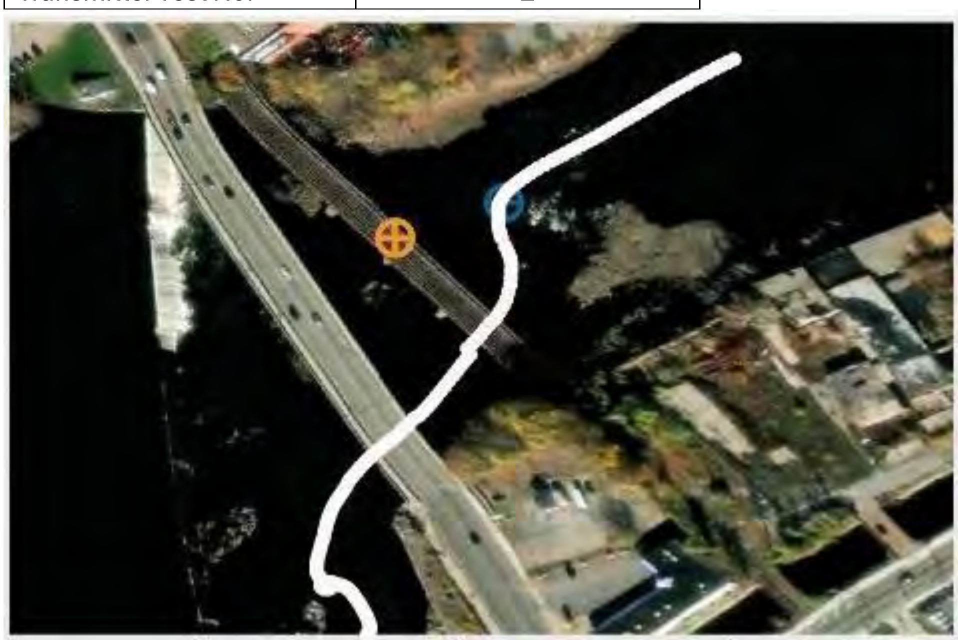
Pilot Deployment Location	5	
Receiver Type	Lotek	
Receiver ID	5C (orange)	5D (blue)
Transmitter Model	SS300	
Transmitter Test No.	1	



Pilot Deployment Location	5	
Receiver Type	Lotek	
Receiver ID	5C (orange)	5D (blue)
Transmitter Model	SS400	
Transmitter Test No.	1	

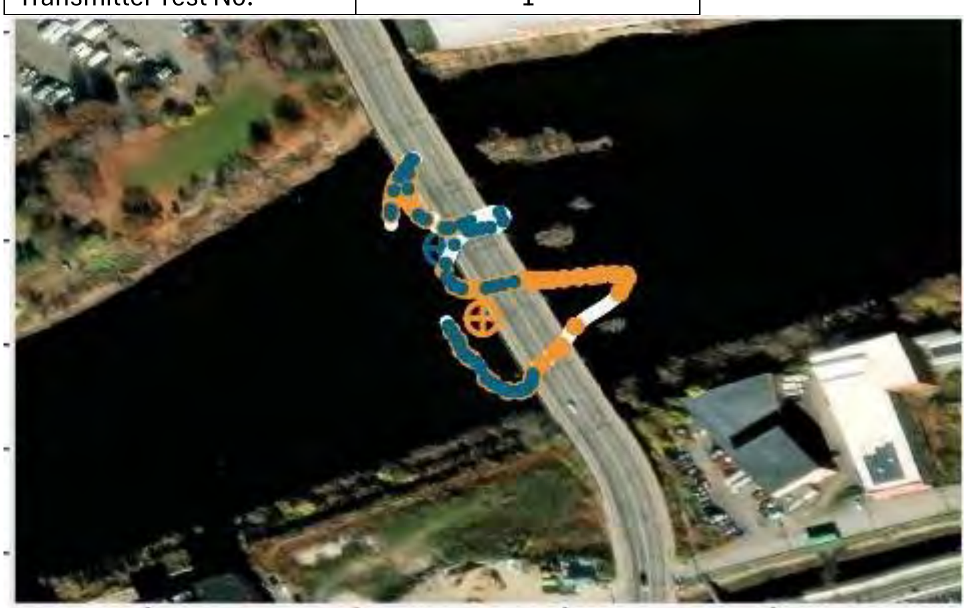
Pilot Deployment Location	5	
Receiver Type	Lotek	
Receiver ID	5C (orange)	5D (blue)
Transmitter Model	SS300	
Transmitter Test No.	2	

Pilot Deployment Location	5	
Receiver Type	Lotek	
Receiver ID	5C (orange)	5D (blue)
Transmitter Model	SS400	
Transmitter Test No.	2	



Pilot Deployment Location	6	
Receiver Type	ATS	
Receiver ID	6A (orange)	6B (blue)
Transmitter Model	SS300	
Transmitter Test No.	1	

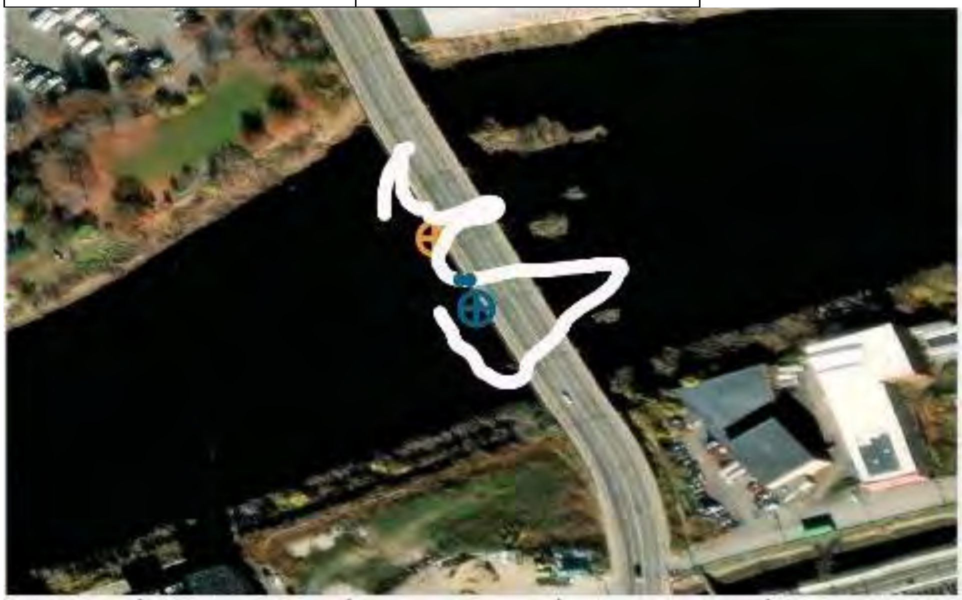
Pilot Deployment Location	6	
Receiver Type	ATS	
Receiver ID	6A (orange)	6B (blue)
Transmitter Model	SS400	
Transmitter Test No.	1	



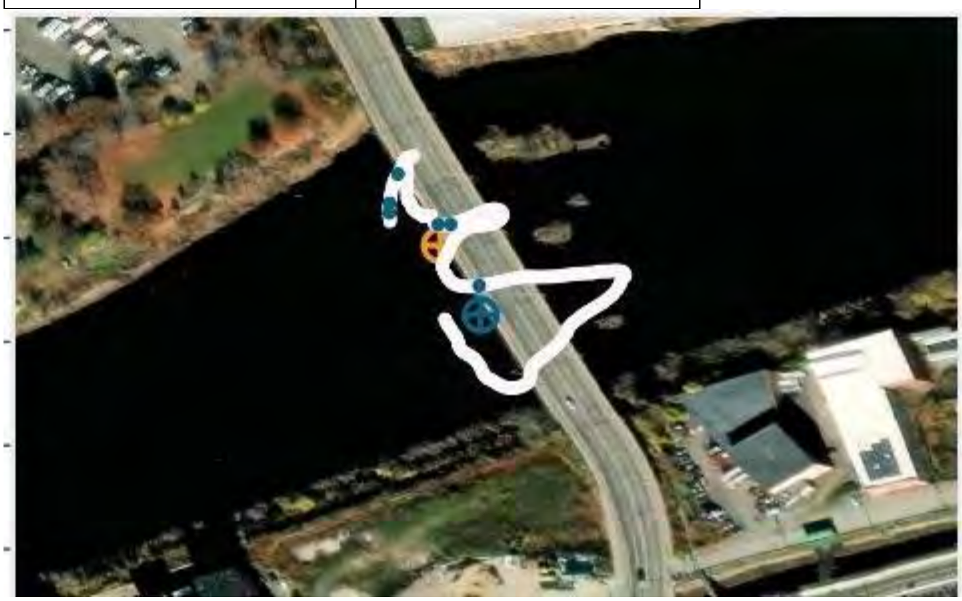
Pilot Deployment Location	6	
Receiver Type	ATS	
Receiver ID	6A (orange)	6B (blue)
Transmitter Model	SS300	
Transmitter Test No.	2	

Pilot Deployment Location	6	
Receiver Type	ATS	
Receiver ID	6A (orange)	6B (blue)
Transmitter Model	SS400	
Transmitter Test No.	2	

Pilot Deployment Location	6	
Receiver Type	Lotek	
Receiver ID	6C (orange)	6D (blue)
Transmitter Model	SS300	
Transmitter Test No.	1	



Pilot Deployment Location	6	
Receiver Type	Lotek	
Receiver ID	6C (orange)	6D (blue)
Transmitter Model	SS400	
Transmitter Test No.	1	



Pilot Deployment Location	6	
Receiver Type	Lotek	
Receiver ID	6C (orange)	6D (blue)
Transmitter Model	SS300	
Transmitter Test No.	2	

Pilot Deployment Location	6	
Receiver Type	Lotek	
Receiver ID	6C (orange)	6D (blue)
Transmitter Model	SS400	
Transmitter Test No.	2