UPPER OHIO NAVIGATION STUDY, PENNSYLVANIA
ENVIRONMENTAL APPENDIX

Benthic Substrate Characterization

<u>Riverbed Substrate Characterization Ground-Truthing of Side Scan Acoustic Signatures, Ohio River Mile 0.0 – 40.0</u>
November 2009

Note to Reader:

The District undertook studies of the Upper Ohio River study area to update bathymetric data and characterize benthic substrates. These studies supported a Corps' commitment from the Ohio River Mainstem System Study to identify, describe, and quantify riverine habitat of the Ohio River.

Benthic substrates over the 40-mile study area were characterized using a staged approach. The first stage during 2008 consisted of the collection and analysis of multi-beam and side-scan sonar data, resulting in seven discrete acoustic classes thought to be associated with discrete benthic substrate types. The second stage during 2009 consisted of ground-truthing the seven acoustic classes to refine associations between acoustic classes and actual riverbed substrate types, and portray them in GIS for use in river habitat evaluations. The District selected 248 sampling stations and used a modified VanVeen grab-sampler with supplemental weight to collect samples. This sampler was selected to penetrate deeper into sediments than other similarly-sized grab sampler types, and to provide better representation of larger particle-size classes. Overall grab-sampler performance was assessed.

This study confirmed that different substrate types had different acoustic signatures and identified three broad groupings: acoustic classes 1, 2, and 3 (largely coarse-grained sediments); acoustic class 5 (fine-grained over rock bottom); and acoustic classes 4, 6, and 7 (distinctly fine-grained sediments). Generally, based on grain-size distributions, samples from Emsworth Pool (the uppermost pool in our study area) were almost entirely fine-grained substrates, while New Cumberland Pool (the lowermost pool in our study area) was skewed toward coarse-grained substrates, and the spread of particle sizes observed in samples from Dashields and Montgomery pools were wider than observed at the other two pools.

Further analyses from the existing data could be performed to refine the apparent correlations. It was recommended by the surveyor that more surveys be performed with more substrate data collected, upon which more complex statistical analyses would be necessary if stronger correlation between the acoustic sonar survey data and the sediment data is desired.

Riverbed Substrate Characterization Ground-Truthing of Side Scan Acoustic Signatures Ohio River Mile 0.0 - 40.0 W911WN-07-D-0001-014

U.S. Army Corps of Engineers
Pittsburgh District

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Executive Summary

The acoustic sonar survey produced broad maps of substrate classes in the study area. Ground-truthing was conducted to test associations between sediment collected in the field and the acoustic classes. Based on examination of grain size distributions in undisturbed samples, most samples were fines (157/258 = 61percent) and other grain sizes with substantial fines content (45/258 = 17 percent). Sand dominant samples comprised a small proportion of the total (35/258 = 14 percent). Just 15 percent of total number of samples (39/258 = 15 percent) were comprised of coarse-grained sediments as the dominant fraction *and* had fines comprising less than 10 percent of the total sample. Cobbles were dominant in 5 percent of the samples and only one boulder dominant sample was found.

Based on grain size, there are three groups of acoustic classes that are significantly different:

- Classes 1, 2, and 3 are distinct from the others and have coarse-grained sediments;
- Classes 4, 5, 6, and 7 are distinct from classes 1, 2, and 3 and have fine-grained sediments; and
- Class 5 is distinct from classes 4, 6, and 7 and lacks the medium sand found in classes 4, 6, and 7.
- When examined individually, each acoustic class has the following distinguishing characteristics: Acoustic class 1 is coarse-grained with samples that are cobble and samples that are fines. This class may have the “hardest” bottom of the coarse-grained substrates;
- Acoustic class 2 is coarse-grained with samples that are fines;
- Acoustic class 3 is coarse-grained with samples that are medium sand and fines. It has the deepest sampling depths, highest frequency of laminate structure and the widest range of substrate types;
- Acoustic class 4 is fine-grained with the most samples comprised of fines and some samples comprised of medium sand. It is the deepest of the fine-grained acoustic classes;
- Acoustic class 5 is fine-grained with most samples comprised of fines. Medium sand was absent from this class. Acoustic class 5 is distinct from the other classes and is hypothesized to be a “skin” of fine-grained sediment over hard pan or bedrock;
- Acoustic class 6 is fine-grained with most samples comprised of fines and other samples that are medium sand or coarse gravel. This acoustic class is primarily restricted to shallower depths; and

- Acoustic class 7 is fine-grained with most samples comprised of fines and other samples that are coarse gravel or medium sand. The shallower depth of penetration suggests AC7 is a "harder" bottom substrate than acoustic class 6.

The distribution of dominant grain sizes varies substantially both among and within pools. Samples from Emsworth pool were almost entirely fine-grained substrates while New Cumberland pool was skewed toward coarse-grained substrates. The spread of particle sizes observed in samples from Dashields and Montgomery were wider than observed at the other pools.

Even though coarse-grained sediment was dominant in acoustic classes 1, 2, and 3, fines or sand were observed at low frequency. Conversely, coarse-grained substrates were found in low frequencies in the fine-grained acoustic classes. The ground-truthing indicates that more complex statistical analyses will be necessary if stronger correlation between the acoustic sonar survey data and the sediment data is desired.

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1.0 Introduction

The U.S. Army Corps of Engineers, Pittsburgh District (hereafter "District") is collecting environmental baseline data in support of feasibility-level planning for modernization of the Emsworth, Dashields, and Montgomery Locks & Dams. The study area is the Upper Ohio River in Pennsylvania, from the origin at Pittsburgh to the Ohio state line (river miles: 0.0-40.0). As part of this effort, data were collected characterizing riverbed substrates in the study area. These data will support a number of Upper Ohio Navigation Study needs, as well as other District program interests, including those of the regulatory and navigation programs. For the Upper Ohio Navigation Study, needs include the identification of important habitat areas for fish and various invertebrates, evaluations of potential impacts on substrate and habitat by construction and operations, and the evaluation of potential impacts from changes in navigation patterns to be brought about by different modernization alternatives. Substrate data are also of interest to the District's ecosystem restoration program, and the identification of restoration needs and opportunities is dependent upon having accurate, updated baseline information.

Substrates over the 40-mile study area are being characterized in a staged approach. The first stage, which has been completed, was the collection of updated bathymetry and side scan sonar data and their incorporation into ESRI shape files. HYPACK/HYSWEEP 2008 and Quester Tangent Multiview software were used to delineate seven discrete acoustic classes, which may be associated with discrete riverbed substrate types. The objective of the second stage is ground truthing the acoustic classes to determine the degree of their association with substrate types. Depending upon the strength of correlations, a subsequent objective will be to refine the previously delineated acoustic classes to provide a stronger correlation, and ultimately link these refined acoustic classes to riverbed substrate types on existing ESRI shape files for use in river habitat evaluations.

This report addresses the second stage objective to ground truth the substrate types within each acoustic class identified previously. Here we describe the collection and analysis of sediment grab samples from seven acoustic classes and a set of candidate restoration sites.

2.0 Methods

2.1 STUDY AREA

The study area includes the reach of the Ohio River between the City of Pittsburgh (RM 0.0) and the Ohio state line (RM 40.0) (**Figure 1**). At the upstream end of the study area the Ohio River drains approximately 19,100 mi^2 and approximately 23,500 mi^2 at the downstream end (USGS 2009). The study area resides within the Pittsburgh Low Plateau physiographic province and the Western Allegheny Plateau ecoregion. The U.S. Army Corps of Engineers operates three lock and dam systems in the study area – Emsworth (RM 6.1), Dashields (RM 13.3) and Montgomery (RM 31.7). The three systems were built in 1922, 1929, and 1939 respectively. The City of Pittsburgh, located at the far eastern end of the study area, is the largest urban center and population density generally decreases with distance downstream.

Heavy industry is present throughout the length of the study area and includes steel and chemical manufacturing, electric power production, petroleum refining, and barge manufacturing and repair. Much of this industrial base is dependent upon the federal navigation system for the delivery of raw materials and the export of finished products.

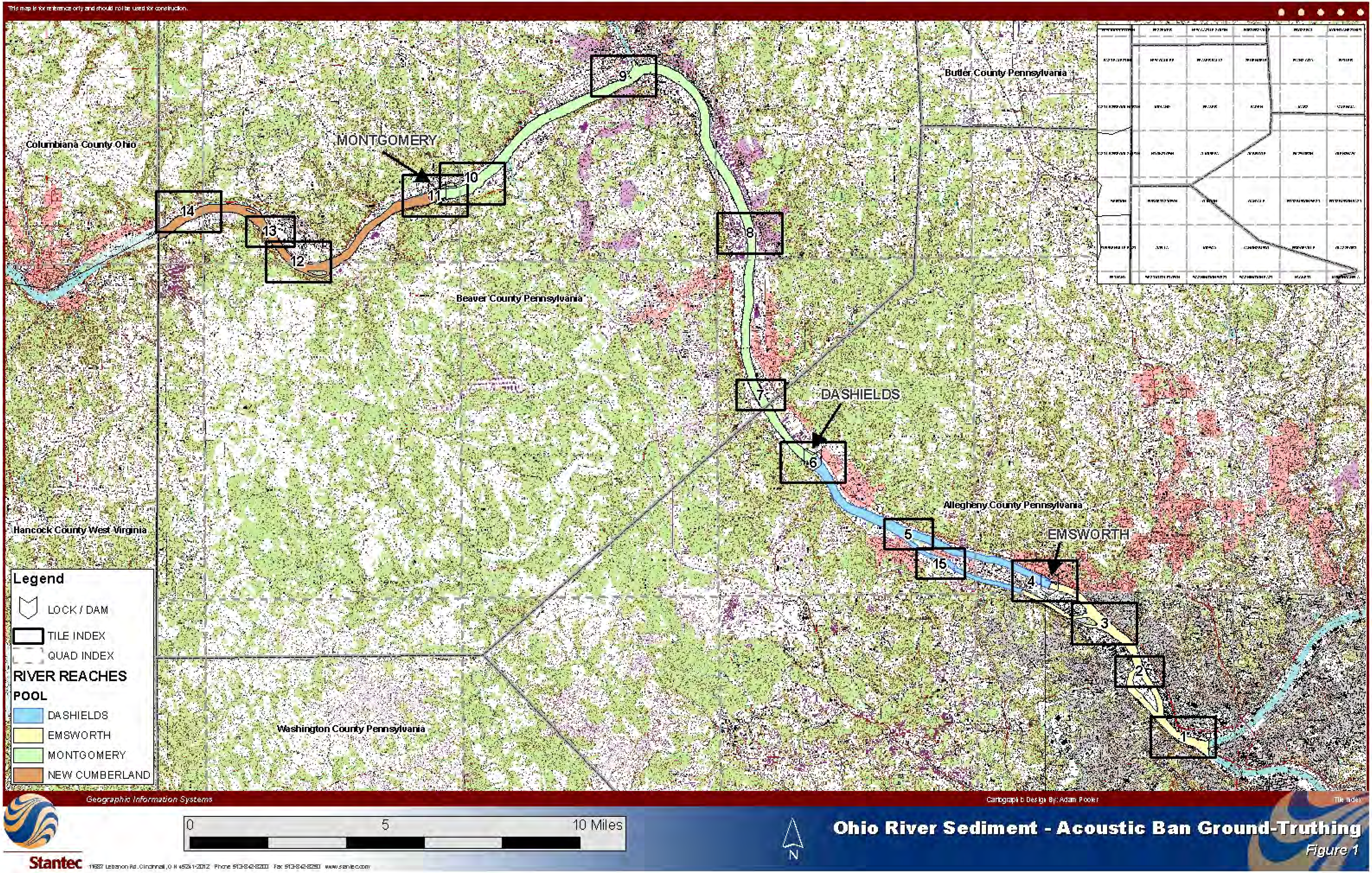
2.2 SITE SELECTION

Bathymetry and side scan sonar data were collected by a District contractor in the study area between July and mid-October of 2008. HYPACK/HYSWEEP 2008 and Quester Tangent Multiview software were used to delineate seven discrete acoustic classes, which are believed to be associated with discrete riverbed substrate types. The substrate classes were subsequently incorporated into ESRI shape files. **Table 1** illustrates the area of each acoustic class in the study area.

The District selected the number of stations (n = 248) and their geographic locations for field verification. Sampling effort was weighted by the area of each acoustic class with more effort occurring in those acoustic classes with the greatest areas. The substrate type represented by the acoustic classes was not disclosed to this study's investigators. Nineteen of the sample locations represent potential restoration sites. These locations were sampled in order to gain information about aquatic habitats in the area. Seven of the restoration sample locations were located outside of the area covered by the acoustic sonar survey. These locations are referred to as acoustic class 8 or "no class".

Table 1. Total area per acoustic class.

Acoustic Class	No. Sampling Locations	Area (acres)	Percent of Total
1	34	186	3.4
2	37	422	7.7
3	55	4611	83.8
4	37	121	2.2
5	17	11	0.2
6	31	94	1.7
7	30	59	1.1
Total	241	5506	100.0



Ohio River Sediment - Acoustic Ban Ground-Truthing

Figure 1

2.3 UNDERWATER DIGITAL IMAGERY

Underwater imagery was collected to: 1) document qualitative characteristics/variability in substrate that might not be readily apparent in the physical samples taken at each point, and 2) provide at least some form of substrate data if all six attempts to collect physical samples at a site proved unsuccessful. Images of the substrate at each sampling point were recorded using an Outland Technologies underwater video camera with a digital video recorder. Project personnel constructed an external housing (1.6 x 1.6 x 1.6 feet) around the waterproof camera (**Figure 2**) to standardize the height of the camera above the riverbed at each sample location. The camera height was adjustable but for this project was mounted 120 mm above the substrate. A light was mounted to the housing adjacent to the camera to illuminate substrates in the camera field of view when ambient light levels were low or absent. Images of a metric scale were recorded prior to deployment to provide a quantitative measure of the camera's field of view and to enable reviewers to discern the approximate particle sizes of coarser substrates within the image. Image 1-2 (Appendix D) should be used when attempting to determine particle sizes from the imagery. This approach provided a low-cost means to acquire data in areas that would otherwise be difficult or impossible to sample with a standard grab sampler (e.g., exposed bedrock, boulders, rubble).

Field personnel deployed the camera on the port (left) side of the boat while the grab sampler was lowered on the starboard (right) side at approximately the same time. The camera was deployed once at each of the 248 sample locations. The position of the boat, camera, and the grab sampler were monitored to ensure that neither device interfered with the operation of the other. The camera and housing were lowered slowly and carefully to avoid unnecessary suspension of fine sediments upon contact with the substrate. The camera was allowed to rest upon the river bed for a minimum of 60 seconds or until the analyst could see a clear image of the substrate in the on-board monitor. Field analysts were able to adjust both the focus of the camera and the intensity of the light in real time from the deck of the boat. Digital images were recorded in high-resolution TIFF format. The quality of the recorded images was dependent on several factors. Fine-grained sediments were more likely to be disturbed by the housing and suspended in the water column than coarse-grained sediments. Clay sized particles may stay in suspension far longer than the duration of the 60 second protocol (Bohn and Bebhardt 1989). In some cases near-bed hydraulic forces were sufficient to cause saltation (the movement of small particles along the bed in a series of skips and hops) thereby reducing the clarity of the recorded image. Other factors affecting image quality may have included the small size and resolution of viewing screen and the angle of the sun relative to the orientation of the cabin and the view screen. An image analyst watched each of the recorded segments for a sample location and exported the highest quality image.

Figure 2. External housing for the underwater camera (center of photo).

2.4 SEDIMENT SAMPLING

A 36 x 28 cm chain-rigged modified Van Veen sediment grab sampler with additional integral weights was used to collect material from the river bed. This instrument was chosen over the Shipek for the following reasons. Word (1975) found that a chain rigged Van Veen penetrated deeper into the sediments than the Shipek. Consequently this instrument may provide better representation of larger particle size classes. The mesh screen on the top of the Van Veen grab sampler allows water to pass through the instrument as it is dropped to the bottom thereby minimizing bow waves that may disturb the surface of sediments on the bed. Word (1975) concluded that surface disturbance was higher in the Shipek than the Van Veen. Both samplers have low washout rates in comparison to other samplers (e.g., orange-peel) (Word 1975). Finally, the Shipek is a spring-loaded sampler that must be “cocked” on the deck. There is some risk of unintended release and injury associated with this sampler due to the difficulty of placing it in the sampling position. In comparison the Van Veen is easy to prepare for sampling and the risk of premature release is negligible.

The Van Veen grab was deployed with a davit and motorized winch system mounted to a 24-foot Monarch™ with twin outboard motors (**Figure 3**). Field personnel attempted to collect at least two acceptable grab samples from each sampling point. An acceptable sample was defined as one in which riverbed material was collected and transported into the vessel without loss of silt or any other spillage.

Figure 3. Sediment sampling platform.

2.4.1 Grab Performance Assessment

Personnel visually inspected the grab as it was brought on board and recorded whether it was fully closed, partially closed, or wedged open due to the presence of some object. Partial closures were defined as instances where the grab retained some material (generally the coarser particle sizes) but was not fully closed. Open grabs (**Figure 4**) were defined as sample attempts where the object precluding closure of the grab (e.g., cobbles, gravel, bricks, sticks, etc.) was the only particle retained and all other material washed out.

Field personnel also photographed the sample (photos are provided in **Appendix A**) and inspected the sampler to determine if the sediment surface had been disturbed upon retrieval. Undisturbed samples often retained water and exhibited no evidence of washout. Indicators of washout included variable depths to the surface of the sediment, erosional features on the sediment surface (rilling), a change in particle sizes from one side of the grab to the other, and exposed laminate layers. Many of the “disturbed” samples exhibited an intermediate level of disturbance where some washout was evident in a portion of the grab (e.g., one corner) but the remainder of the sample appeared undisturbed. Field personnel collected sediment from the undisturbed portion of the grab and retained it for laboratory analysis for the purpose of verifying the acoustic signatures. These samples were classified in the field as “partially closed-disturbed”. Some partially closed-disturbed samples were discarded if field personnel detected clear or obvious surface disturbance over the entire sample or if insufficient “undisturbed” material was present for analysis. In some cases the sampler was retrieved in a fully closed position but was empty or contained only water. Closure and disturbance status were recorded on field data sheets for each grab attempt.

The grab performance assessment included measurement of the depth of grab penetration. Fine-soft sediments are inherently easier to sample than coarse sediments. In softer sediments the grab sampler typically penetrates deeper than in coarse sediments. For every grab sample that was retained for laboratory analysis, field personnel measured the distance from the top of the sediment sample to the top of sampler (**Figure 5**). This metric was defined as "grab fullness". Grab penetration was calculated by subtracting grab fullness from the full depth of the empty grab sampler.

Figure 4. Example of attempted sample with cobble wedged in grab.

Figure 5. Example of a grab fullness measurement.

2.4.2 Two-Stage Sampling Protocol

A two-stage sample protocol was implemented to address concerns that fine-scale variation might exist in the sediments at a given sampling location. As part of the inspection of the surface of the sediment sample, field personnel visually estimated the dominant particle size using the classes specified in **Table 2** and procedure below. If the dominant particle size in the first two grab samples differed by a particle size category (e.g., sand vs. gravel), field personnel re-deployed the grab sampler until four samples were collected or six attempts were made. If the dominant particle size of the first two acceptable samples fell within the same size category, field personnel proceeded to the next location.

Table 2. Particle size categories for two-stage sampling protocol.

Particle Size Category	Particle Size Range (mm)
Silt-clay-mud	≤ 0.0625
Sand	0.0625 - 1.0
Gravel	1.0 - 64
Cobble	64 - 256
Boulder	> 256

2.4.3 Grab Sample Sub-Sampling Protocol

Once the grab sampler was returned to the deck and secured, excess water retained in the sampler was siphoned off. The sample was photographed and visually examined for various physical characteristics through the top opening of the sampler. Once the visual examination was complete, the upper 3 cm of the grab sample was removed with a sampling spoon and placed into a sealed bag. As described previously field personnel retained grab samples with undisturbed surfaces or the “undisturbed” portion of a partially disturbed sample for analysis. This bag was placed into a second bag containing a tag with the sample identification number, date and time of sample and brief notes, as appropriate.

In circumstances where rocks or sticks prevented full closure of the grab sampler, field personnel measured and recorded the length of the intermediate axis (i.e., neither the longest or shortest) of the largest particles retained. This protocol was implemented as an adaptive measure after several days in the field and was intended to provide at least some data for locations where insufficient material was collected for laboratory analysis. No more than ten particles were measured in any failed sample.

2.4.4 Ancillary Observations

In addition to observations described above field personnel also recorded general notes on features of the remaining sediment with respect to potential biological relevance (e.g., strata changes, shell fragments, etc.). Field personnel visually estimated and recorded the dominant and sub-dominant particle size of this material. The samples were evaluated to determine if particle size stratification occurred parallel to the plane of the river bed (laminate), perpendicular to the plane of the river bed (interbedded) or in lenses below the surface. The lower stratum of the sediment was sieved through a ¼” mesh screen. Incidentally captured freshwater mussels, were returned to the water after having been photographed on a measuring board with a metric scale. Freshly dead or weathered valves, whether fragmentary or complete, were photographed (as appropriate) and returned to the water. Because enumeration of freshwater mussel populations in the study area was not the primary objective of the study, a trained biologist was a member of the crew for only a portion of the field effort. Sediment and other materials from the lower strata of the grab sample were returned to the water in a location that did not influence subsequent grab samples. Photocopies of the field notes are provided in **Appendix B**.

2.5 GLOBAL POSITIONING SYSTEM

Global positioning data were collected with a Trimble R8 receiver connected to a permanent base station via the Internet. The base station provided real time differentially corrected coordinates that are, according to the manufacturer's specifications, accurate to within 0.5 feet in the horizontal dimension on average. The GPS receiver was mounted on the davit directly above the location sampled by the grab. Coordinates for each grab sample were recorded while the sampler was in contact with the river bed. Field personnel confirmed that each grab sample fell within the desired acoustic signature polygon before to proceeding to the next sample site.

Some sample points located within large or broad areas were sampled without anchoring, as long as there was no chance that current would move the boat out of the mapped acoustic class polygon during the sampling effort. Most areas were sampled while the boat was anchored.

2.6 GRAIN SIZE ANALYSIS

Sediment samples were air dried and sieved by hand in the laboratory. The mesh sizes corresponded to a modified Wentworth classification system (**Table 3**). Each sieved fraction was weighed using a digital scale. Weights were handwritten on pre-configured data sheets and entered digitally into an electronic format compatible with a relational database. All laboratory procedures were consistent with the ASTM D422 and District laboratory accreditation procedures.

Table 3. Modified Wentworth classification system.

Wentworth Simple Dominance Size Class	Wentworth Strict Dominance Size Class	Diameter (mm)	Phi (Φ)	U.S. Standard Sieve Mesh #
Silt/fine sand (fines)	Fines	≤ 0.25	2.0	60
Medium sand	Medium Sand	≤ .50	1.0	35
Coarse sand	Coarse Sand	≤ 1.00	0.0	18
Fine gravel	Granule	≤ 4.00	-2.0	5
Medium gravel	Fine & Medium Gravel	≤ 16.00	-4.0	5/8" alternate
Coarse gravel	Coarse Gravel	≤ 64.00	-6.0	2 ½" alternate
Cobble	Cobble	< 256.00	-8.0	10" alternate
Boulder	Boulder	> 256.00	---	---

Samples were assigned to a single size class using a simple dominance criterion. That is, the portion of the sample that retained the greatest fraction of material on a given sieve was assigned to that particle size class. In the some cases the fraction retained by a single sieve was large (e.g., >90 percent) whereas in heterogeneous samples the fraction was small (e.g., <20 percent). This classification scheme will be referred to as "Simple Wentworth" for the remainder of the document.

Samples were also classified using a strict dominance algorithm (Strict Wentworth) where samples with a given fraction exceeding 50 percent of the total weight were assigned to a single category (e.g., cobble). Heterogeneous samples (i.e., samples with no single fraction >50 percent of the total) were categorized using the two greatest retained fractions (e.g., gravelly cobble). The strict dominance criterion was further characterized according to the degree of grain size gradation using a modification of ASTM 2000 D2487-00. It was necessary to modify the ASTM protocol because none of the sieves used in the analysis were small enough to distinguish between fine sand and silt and clay. This separate classification system was employed as a means to examine the relative degree of substrate heterogeneity in the sieved samples.

2.7 STATISTICAL ANALYSIS

The primary objective of this data report is to present the results of field ground-truthing studies conducted between August 28th and September 20th of 2009. A second objective was to provide the results of simple preliminary and exploratory analyses of the relationship between the acoustic classes and the field data. The field crew and analysts in this effort were blind concerning what substrate type was represented by each acoustic class. The data compilation and preliminary analyses of the ground-truthing data enabled characterization of the acoustic classes based on their mix of substrate types, grain size distributions, two proxies for bottom hardness (depth of grab penetration and frequency of empty grabs), water depth of sampling, frequency of vertical structure, and sampling location in the river channel. Characteristics were also summarized by pool. Lacking specific information on acoustic signal characteristics at the sampling site, sophisticated statistical analyses were not possible.

The general analytical approach for this effort was the following:

- Investigators compiled graphic and tabular summaries of the parameters measured in the field and in the laboratory including grain size distribution, grab sampler performance, and pool location with emphasis on relationship of the observations to acoustic class.

- Investigators performed simple statistical analyses to determine whether the acoustic classes differed significantly in substrate type, grain size, and other parameters

- Based on the outcomes and on plots of substrate type and grain sizes, these initial tests were followed by subsequent ones to distinguish and characterize groupings of the acoustic classes.

- The various lines of evidence were synthesized to draw preliminary conclusions regarding the relationship between the acoustic classes and the field ground truthing data.

For categorical data (e.g. frequency of substrate types), two non-parametric tests were performed: Chi-Square (χ^2) Goodness of Fit and Contingency Analysis. In the chi-square (χ^2) goodness of fit test, observed frequencies are compared to expected frequencies to determine if the set of frequencies are significantly different. Contingency analysis, which also returns a chi-square (χ^2) value, was used to assess when the frequency distributions differed among several categories. For numerical data (e.g., depth of grab penetration), a parametric Analysis of Variance (ANOVA) probability test was performed.

2.8 SURVEY CONDITIONS

Sample locations were surveyed during two field events from August 27, 2009 to September 4, 2009 and from September 10, 2009 to September 18, 2009 (**Figure 6**). The sediment sampling surveys occurred at the lowest practical flows and conditions were optimal for sampling the river bed in a stable state. Streamflows were relatively stable throughout the duration of the 2009 field work. Sediment sampling was conducted approximately one year after the acoustic sonar surveys and streamflows were generally similar to those that occurred during the 2008 acoustic sonar survey. It should be noted that streamflows were somewhat higher during the Emsworth acoustic sonar survey in July, 2008 and were considerably higher during annual peak flows (maximum Q = 136,000 cfs). It is likely that higher flows mobilized bed materials in at least some portion of the channel however the magnitude and extent of bed mobilization is presently unknown.

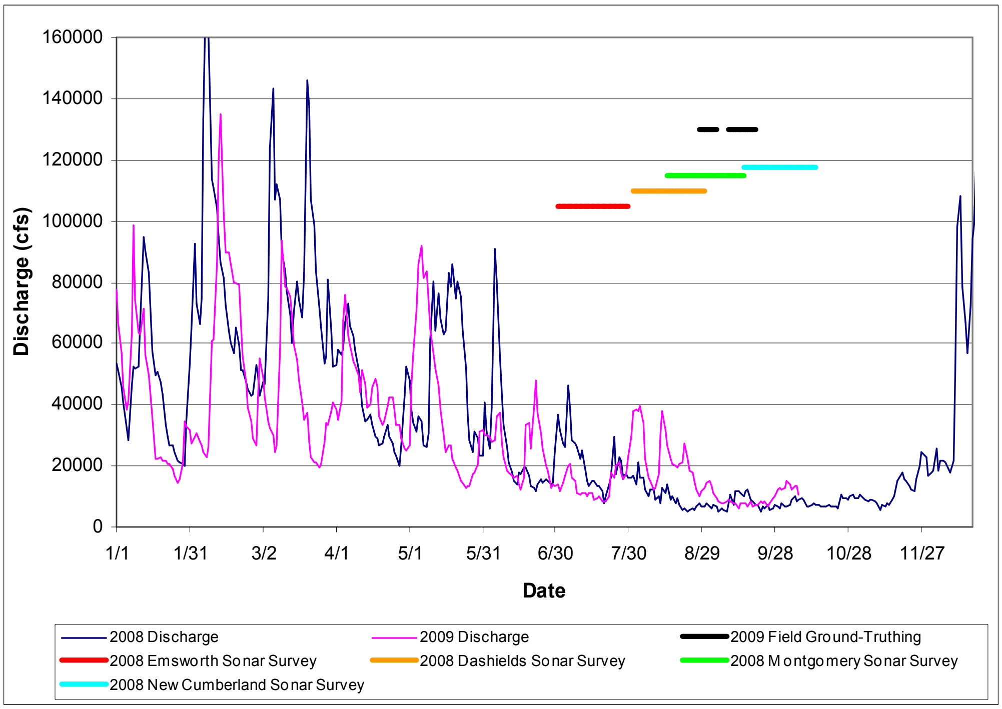


Figure 6. Average daily discharge (cfs) at USGS stream gauge 03086000 on the Ohio River at Sewickley, PA during the acoustic sonar surveys and the sediment sampling surveys.

3.0 Results

3.1 FIELD OBSERVATIONS

3.1.1 Sampling Effort

Field personnel surveyed 248 sample locations and the grab sampler was deployed 968 times (**Table 4**). Grabs samples with undisturbed surfaces were retrieved at 61percent of the sample locations (n = 152). Empty grabs accounted for 53 percent of the total attempts and grabs with wholly or partially undisturbed surfaces accounted for the remainder. The bi-modal distribution in **Figure 7** indicates that two attempts were sufficient at approximately one-third of the sample locations. Six attempts were necessary at a similar number of sites. After six attempts without an acceptable sample, the field crew moved on to the next sampling location. Representative photos of substrates encountered during the survey appear in **Figure 8**.

Table 4. Grab sample inventory for 248 sample locations. Only samples with undisturbed (n = 258) or partially disturbed (n = 190) surfaces retained for purposes of verifying acoustic signatures (n = 448).

Acoustic Class	Sampling Locations Count	Grab Attempts	Disturbed or Empty Grabs	Grab Sample for Analysis	Samples with Undisturbed Surface	Samples with Partially Disturbed Surface
1	34	151	91	60	23	37
2	37	178	117	61	24	37
3	55	241	138	103	34	69
4	37	116	44	72	61	11
5	17	79	58	21	16	5
6	31	99	38	61	51	10
7	30	89	33	56	43	13
No Class	7	15	1	14	6	8
Total	248	968	520	448	258	190

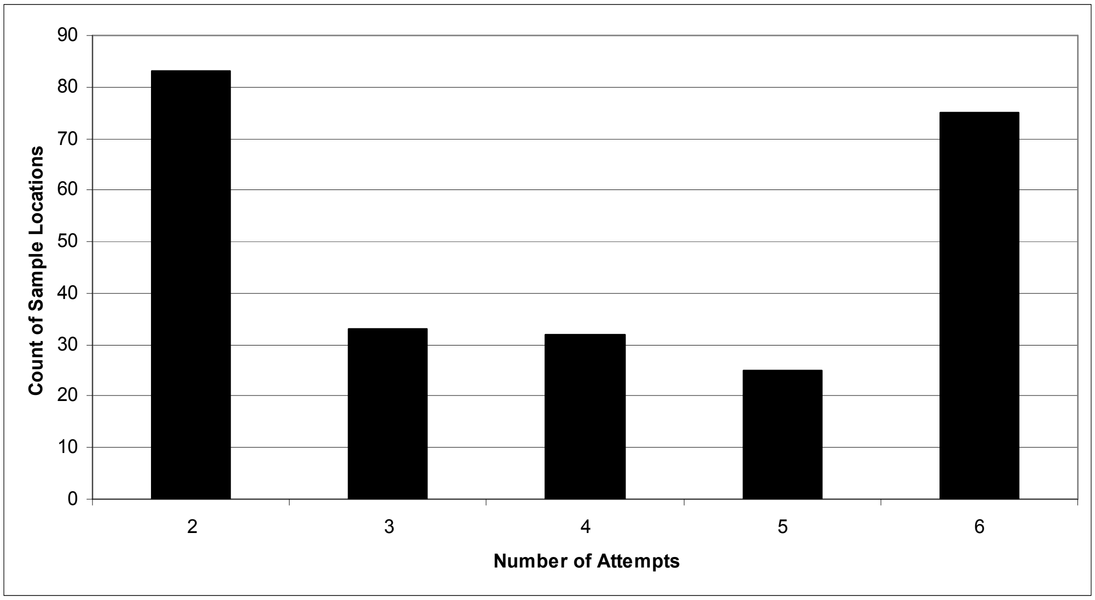


Figure 7. Count of sample locations (n = 248) by the total number of grab attempts (n = 968) at each locations. A minimum of two attempts were necessary at each sample location but no more than six samples were attempted.

Multiple grab samples (two or more) with undisturbed surfaces were retained for analysis at 97 sample locations (**Table 5**). As described Section 2.4.2 up to six grab attempts were necessary if field personnel perceived variation in the grain sizes observed in the grab sampler. Consequently, four sediment samples were analyzed in the laboratory at four sample locations and three samples were analyzed for one location. When considering both undisturbed and partially disturbed samples, field personnel retained three or more samples for analysis at 22 sample locations (**Table 6**).

Table 5. Total number of sample locations where multiple samples were retained for analysis, samples with undisturbed surfaces only. Grabs were attempted at 248 sample locations.

Number of Samples with Undisturbed Surfaces	Sample Location Count	Total Number of Undisturbed Samples
4	4	16
3	1	3
2	92	184
1	55	55
Total	152	258

Table 6. Total number of sample locations where multiple samples were retained for analysis. The tally includes samples with undisturbed and partially disturbed surfaces. Grabs were attempted at 248 sample locations.

Number of Samples with Undisturbed or Partially Disturbed Surfaces	Sample Location Count	Total Number of Samples
4	13	52
3	9	27
2	169	338
1	31	31
Total	222	448

a) b)

c) d)

Figure 8. Substrates retrieved by the Van Veen grab sampler a) fines, b) sand, c) gravel and d) cobble.

3.1.2 Grab Sampler Performance

3.1.2.1 Grab Attempts by Acoustic Class

Figure 9 illustrates the relative effort necessary to collect grab samples in each of the acoustic classes. The medians for the seven classes differed substantially. Classes 4, 6, and 7 required comparatively fewer attempts than acoustic classes 1, 2, and 3. More than 75 percent of the sample locations in acoustic classes 4, 6, and 7 were successfully sampled with less than four grab attempts. In comparison, more than 75 percent of the sample locations required at least four attempts for acoustic class 2. The median number of attempts was highest for acoustic classes 1, 2, and 5 and the range of necessary attempts was widest for acoustic class 5. Although the grab attempt counts were numerical data it was not possible to perform an ANOVA because the data were not normally distributed.

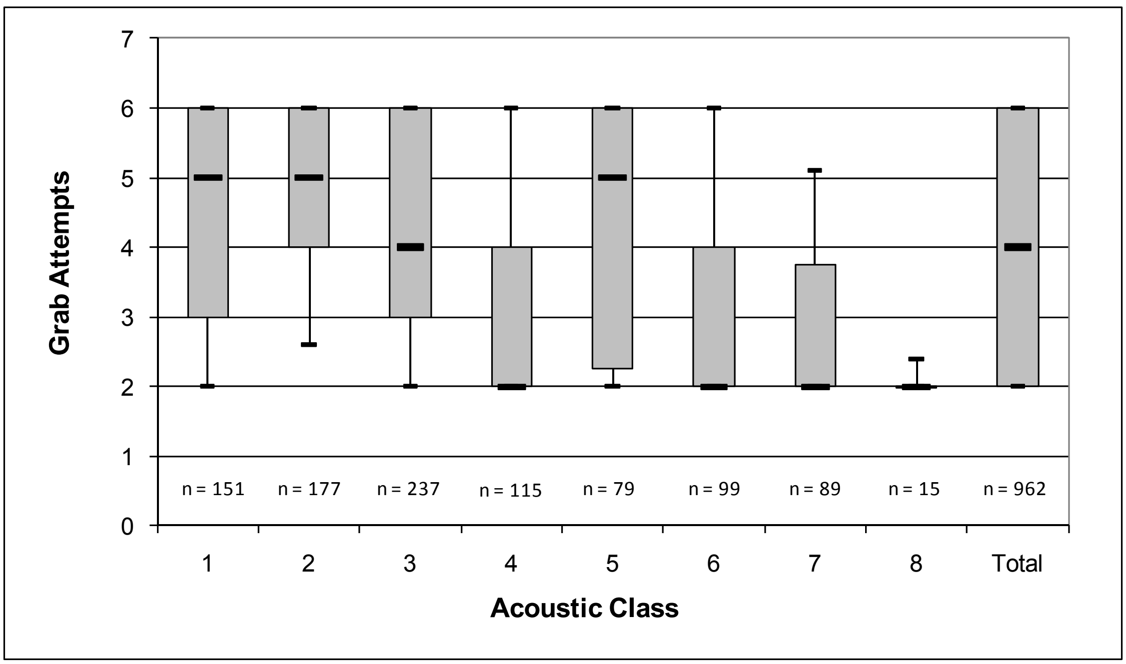


Figure 9. **Number of grab attempts by sample location (n = 248) for each acoustic class. Class 8 denotes samples collected from areas outside the limits of the acoustic sonar survey. Whiskers represent the 10th and 90th percentiles, boxes the 25th and 75th percentiles, and dashes median values. Totals do not include attempts where the boat drifted outside of the acoustic polygon.**

3.1.2.2 Empty and Disturbed Grabs by Acoustic Class

Grab samples with empty and disturbed surfaces comprised 73 percent of the total number of attempts in acoustic class 5 (**Table 4**). A substantial proportion of empty and disturbed grabs were also observed in grabs attempted in acoustic classes 1, 2, and 3 (59 percent, 65 percent, and 56 percent respectively) (**Figure 10**). There were significant differences in the number of empty and disturbed grab samples ($p < 0.001$) by acoustic class (**Table 7**). Frequencies for acoustic classes 4, 6, and 7 were statistically undistinguishable. The null hypothesis of equal distributions for acoustic classes 1, 2, and 3 was rejected. The inclusion of acoustic class 5 in the 4, 6, and 7 grouping resulted in rejection of the null hypothesis.

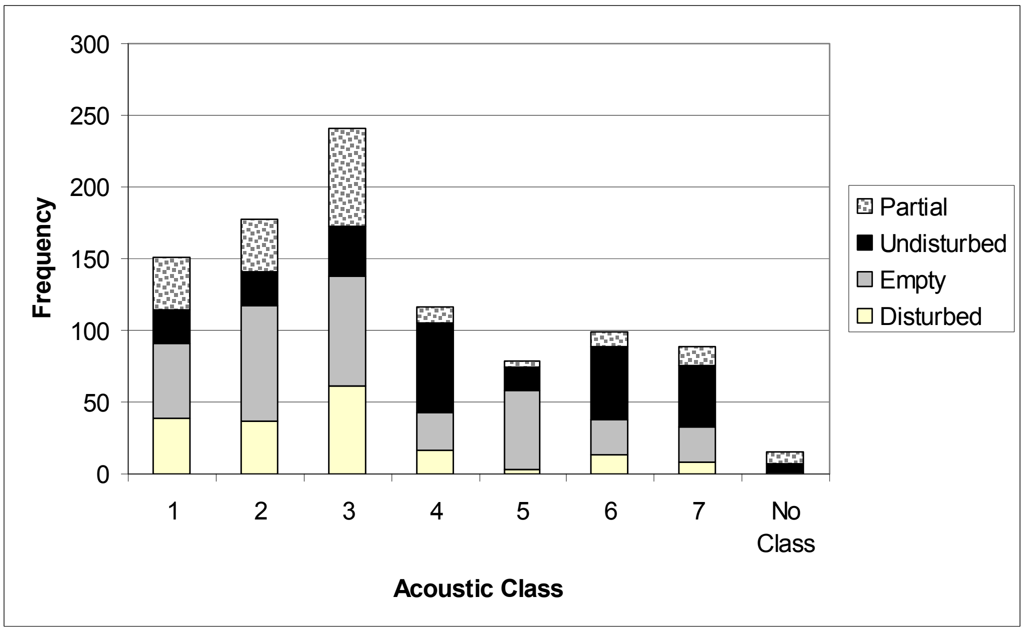


Figure 10. Distribution of grab sample attempts by acoustic class and surface disturbance category (n=968).

Table 7. Chi-square test results for the number of empty and disturbed grab samples (n = 520) by acoustic class.

Acoustic Classes	χ^2	*df*	*p*
1-7	134.1	6	< 0.001
1-3	8.6	2	0.013
1-3 and 5	32.9	3	< 0.001
4-7	8.1	3	0.043
4, 6 and 7	1.3	2	0.518

This analysis also examined grab attempts that, upon retrieval, were fully closed and empty. This class of grab is important because it is an indication of the sampler's ability (or inability) to penetrate the substrate. The null hypothesis for equal distributions between all seven acoustic classes was rejected. Acoustic class 5 was allocated the fewest number of sample locations (**Table 4**) but produced the highest number of fully closed empty grabs (**Figure 11**). When grouped with acoustic classes 1, 2, and 3 and 4, 6, and 7, the null hypothesis of equal distributions was rejected (**Table 8**). However, unlike other tests presented in this document, the null hypotheses for all groupings examined were rejected.

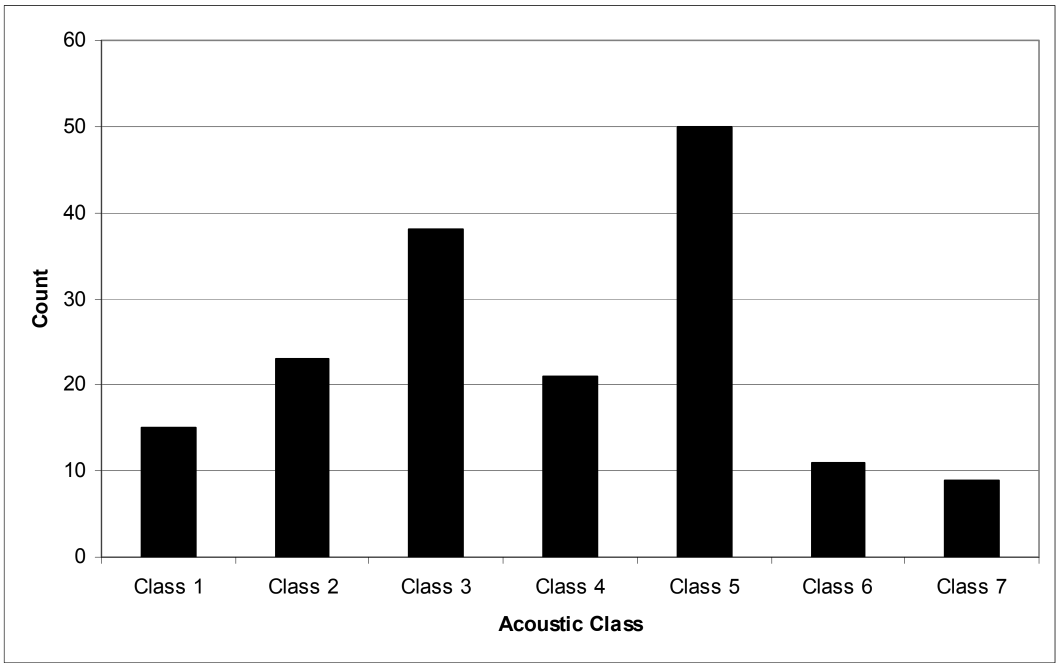


Figure 11. Count of grab attempts where sampler was fully closed and empty (n = 167).

Table 8. Chi-square test results for the number of empty grab samples (n = 167) by acoustic class.

Acoustic Classes	χ^2	*df*	*p*
1-7	56.9	6	< 0.001
1-3	10.8	2	0.005
1-3 and 5	23.1	3	< 0.001
4-7	47.2	3	< 0.001
4, 6 and 7	6.0	2	0.049

3.1.2.3 Grabs with Undisturbed Surfaces by Acoustic Class

Samples with undisturbed surfaces accounted for between 13 percent and 20 percent of the total number of attempted grabs in acoustic classes 1, 2, 3, and 5 (**Figure 10**). Undisturbed samples were comparatively more frequent in acoustic classes 4, 6, and 7 ranging between 48 percent and 50 percent of the total number of attempts for these classes. Chi-square test results for all classes combined suggest significant differences ($p< 0.001$) for the frequency of undisturbed samples between classes (**Table 9**). Moreover, the occurrence of undisturbed samples is determined by the acoustic class from which the sample originated. The null hypothesis that no difference existed in the number of undisturbed samples was accepted for acoustic classes 1, 2, and 3 and for classes 4, 6, and 7. The inclusion of acoustic class 5 in chi-square test with classes 4, 6, and 7 produced a p-value indicative of significant differences ($p < 0.001$) among the classes. Maps illustrating the location of grab samples with undisturbed surfaces can be found in **Appendix C**.

Table 9. Chi-square test results for grab samples with undisturbed surfaces.

Acoustic Classes	χ^2	*df*	*p*
1-7	44.9	6	< 0.001
1-3	2.7	2	0.254
1-3, and 5	8.4	3	0.079
4-7	26.1	3	< 0.001
4, 6, and 7	0.0	2	0.207

3.1.2.4 Grab Penetration

The Van Veen grab sampler penetrated deepest in acoustic class 6, indicating that soft sediments were generally present in this class (**Figure 12**). The median depth of penetration for acoustic class 4 (105 mm) was slightly less and the range of measurements was wider. The median value for class 7 (86 mm) was slightly lower still. There was considerable overlap in the central 50 percent of the grab penetration values for acoustic classes 4, 6 and 7. Nonetheless, the null hypothesis of equal means for these acoustic classes was rejected ($p = 0.022$) (**Table 10**). Grab penetration values were also clustered for acoustic classes 1, 2 and 3 suggesting similar grab penetration for substrates with these signatures. The null hypothesis of equal means was accepted for this class grouping ($p = 0.530$). Grab penetration was lowest for acoustic class 5 (median = 28 mm). Inclusion of this acoustic class in the various ANOVA groupings always resulted in rejection of the null hypothesis, indicating significant differences between this class and others. The inability of the grab sampler to penetrate sediments in acoustic class 5 and its apparent difference from the other acoustic classes will be a topic of discussion in nearly all of the analyses presented in subsequent sections of this document.

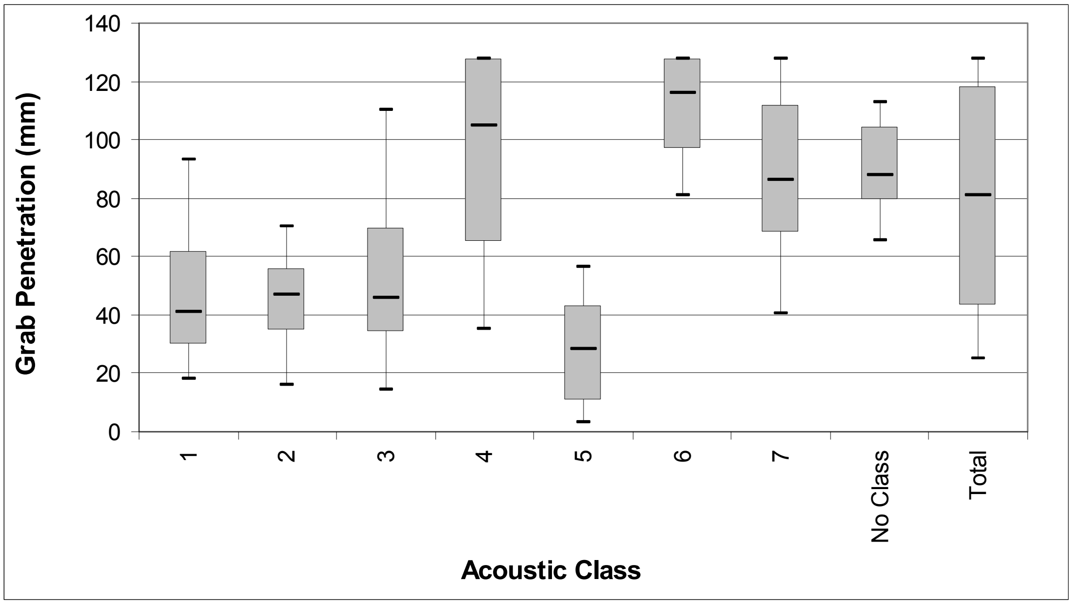


Figure 12. Grab penetration by acoustic class. The highest values on the y-axis represent grabs that penetrated furthest into the sediment. Whiskers represent the 10th and 90th percentiles, boxes the 25th and 75th percentiles, and dashes median values. Data comprised of only undisturbed grabs (n = 258).

Table 10. Analysis of Variance (ANOVA) of grab penetration by acoustic class.

Acoustic Classes	*F*	*P-value*
1-7	25.163	< 0.001
1-3	0.641	0.530
1-3, and 5	2.352	0.077
4-7	21.871	< 0.001
4,6, and 7	3.920	0.022

3.1.2.5 Sample Depth

Water depths measured at the time of sampling ranged between 1.5 and 46.7 feet (**Table 11**). The mean for all acoustic classes combined was 17.5 feet. The mean water depths for all acoustic classes were significantly different ($F = 50.094$; $p < 0.001$) (**Table 12**). Acoustic classes 3 and 4 were deepest on average and covered the greatest range of depths. Acoustic class 3 was primarily located in the center of the channel while the other acoustic classes, excluding class 5, occurred primarily on the lateral margins of the channel. Unlike analyses on variables presented in prior sections (e.g., grab attempts, empty grabs, surface disturbance), mean depths for acoustic classes 1, 2, and 3 were significantly different ($F = 93.252$; $p < 0.001$).

The large F-statistic for class grouping 1-3 indicates that these are distinct classes with the furthest class separation according to depth.

Table 11. Summary statistics for grab depth by acoustic class, all pools combined.

Acoustic Class	Mean Depth (Feet)	Standard Deviation	Maximum Depth (Feet)	Minimum Depth (Feet)	Count
1	14.1	0.9	17.0	12.5	34
2	11.1	1.7	15.0	7.0	37
3	24.3	7.2	42.9	12.0	57
4	25.3	9.0	46.7	11.7	36
5	21.8	4.0	27.0	16.0	15
6	12.6	5.0	25.0	5.0	31
7	11.8	1.5	15.2	7.0	31
No Class*	10.4	6.4	18.0	1.5	7
All Acoustic Classes	17.5	8.1	46.7	1.5	248

*Grab samples collected outside of area covered by the acoustic sonar survey.

Table 12. Analysis of Variance (ANOVA) for the depth of grab attempts per acoustic class.

Acoustic Classes	*F*	*P-value*
1-7	50.094	< 0.001
1-3	93.252	< 0.001
1-3, and 5	67.539	< 0.001
4-7	40.149	< 0.001
3, 4 and 5	0.941	0.393

Mean depths when stratified by pool and acoustic class (**Figure 13**) closely resemble the distribution observed for the project area in its entirety. However, grab sampling depths from the Dashields pool were shallower than those in other pools in acoustic classes 3 and 6.

Grab samples with undisturbed surfaces in acoustic class 4 were not obtained in Dashields pool. Nor were grab samples from acoustic class 5 obtained in Dashields or New Cumberland pools.

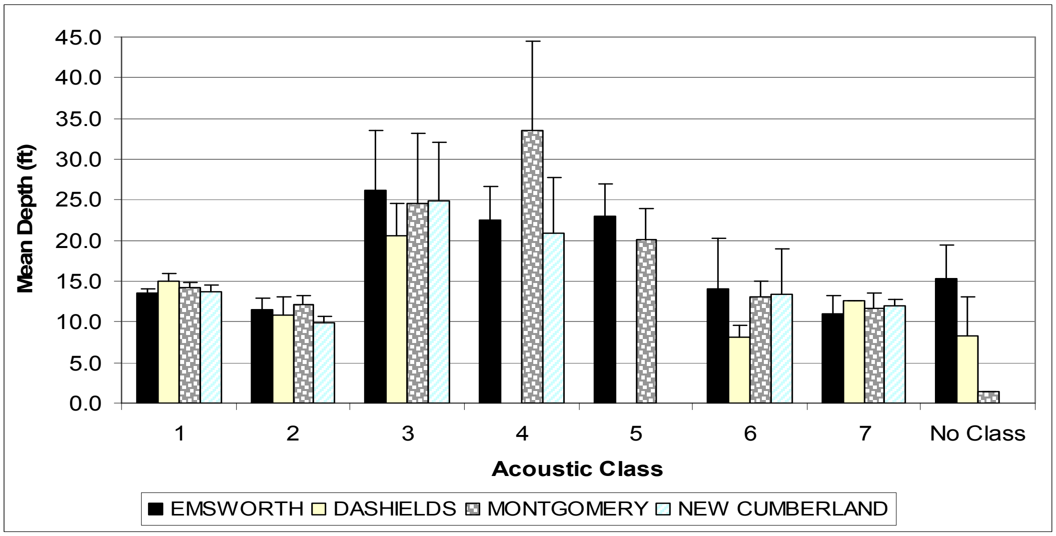


Figure 13. Mean depth of grabs (whiskers = standard deviation) with undisturbed surfaces by acoustic class and pool.

3.1.2.6 Sampling Location

Acoustic class 3 comprised 84 percent of the total area covered in the acoustic sonar survey (see **Table 1** for a summary and **Appendix C** for a visual presentation of the location of the various classes). Approximately 28 percent of acoustic class 3 (1310 acres) occurred within 200 feet of the channel margin while the remaining 3,300 acres were located in the main or mid channel (**Table 13**). With the exception of class 5, the majority of the remaining acoustic classes were primarily found along the channel margins. Exploratory analyses were undertaken to examine the influence of channel location on sampling success (i.e., undisturbed grab samples) and sampling failure (empty grab samples).

The location of the grab attempt, whether mid-channel or lateral margin, appears to influence whether or not the surface of the grab sample was disturbed upon retrieval. Undisturbed grabs occurred far more frequently in the margins than expected (χ^2 = 31.4; p <0.001) (**Table 14**). However, the frequency of empty grabs did not appear to depart from equal distribution (χ^2 = 0.2, p = 0.691).

Table 13. Area of acoustic classes (acres) by pool and location in the channel (margin versus main channel).

Acoustic Class	Channel Location*	Pool Name				Total
		DASHIELDS	EMSWORTH	MONTGOMERY	NEW CUMBERLAND	
1	MA	27	5	24	9	65
	MG	22	18	55	26	122
2	MA	25	4	38	12	79
	MG	88	61	155	39	343
3	MA	470	495	1,610	726	3,301
	MG	228	184	601	297	1311
4	MA	0	4	34	5	43
	MG	3	15	35	25	78
5	MA	0	1	3	0	5
	MG	1	3	2	1	6
6	MA	1	1	8	2	12
	MG	6	13	38	25	82
7	MA	0	0	0	4	4
	MG	7	6	24	18	55
	Total	878	811	2,627	1,189	5,506

* Note: MA = inside the main channel, MG = inside the margin (200 feet from shoreline)

Table 14. Chi-square test for main channel and channel margin grab samples.

Grab Variable	Main	Margin	χ^2	*df*	*p*
Undisturbed Grabs	84	174	31.4	1	< 0.001
Empty or Disturbed Grabs	252	261	0.2	1	0.691
Fully Closed Empty Grabs	81	86	0.1	1	0.699

3.1.3 Sample Stratification

Vertical layering in sampled sediments was most common in acoustic classes 4, 6, and 7 (**Figure 14**) and there was no departure from equal distribution ($\chi^2 = 0.0$; $p = 0.981$) among these three classes (**Table 15**). Inclusion of class 5 in the aforementioned grouping resulted in significant difference among classes for frequency of stratified samples ($p < 0.001$). The chi-square test indicated that distributions for acoustic classes 1, 2 and 3 were somewhat different but not significantly so at the alpha = 0.05 level. In stratified samples, the upper strata were typically comprised of silt and/or fine sand while the lower strata were comprised of gravelly substrates (**Figure 15**). Stratification was infrequent or rare in acoustic classes 1, 2, and 5, accounting for only 23, 9, and 13 percent of undisturbed grabs respectively. Other kinds of stratification such as lenses or interbedding (stratification perpendicular to the plane of the river bed) were not detected in any of the 968 grab samples.

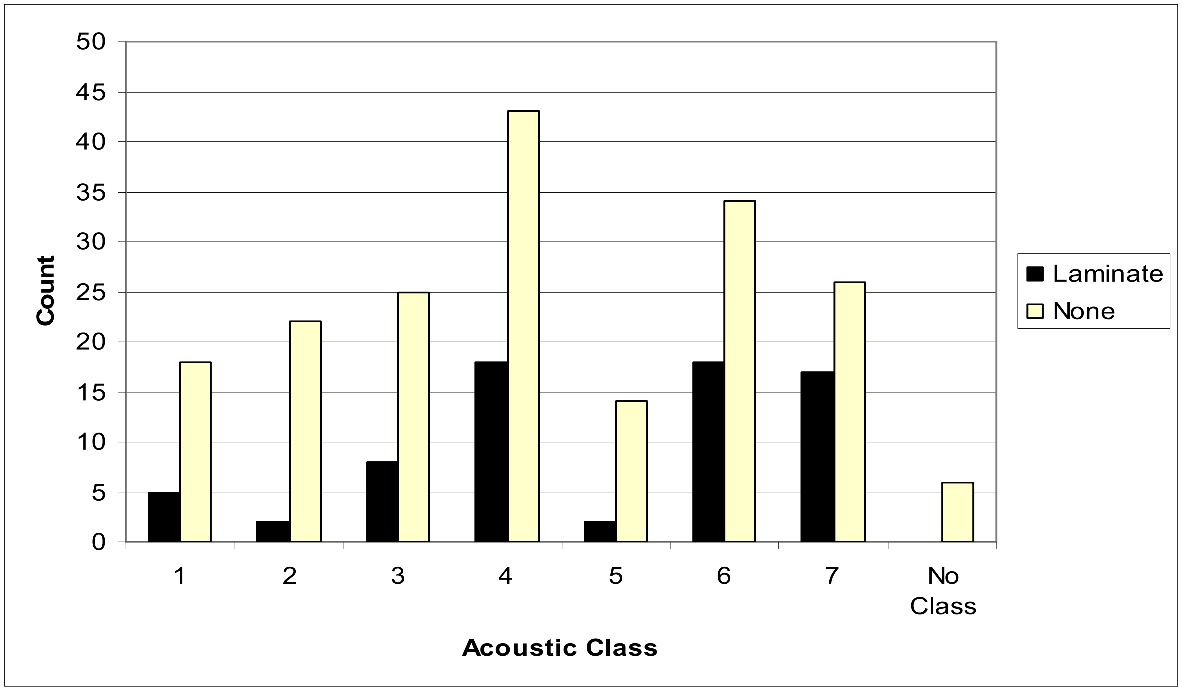


Figure 14. Frequency of grab samples where laminate stratification was observed, undisturbed grabs only (n = 258).

Table 15. Chi-square test results for samples with laminate vertical stratification by acoustic class.

Class Comparison	χ^2	*df*	*p*
1-7	31.6	6	< 0.001
1-3	4.6	2	0.099
1-3, and 5	7.3	3	0.062
4-7	13.1	3	0.004
4,6, and 7	0.0	2	0.981

a) b)

Figure 15. Example of grab sample with fines in the upper strata (a) and gravel substrates in the lower strata (b).

3.1.4 Underwater Imagery

Detailed examination of underwater imagery was beyond the scope of this analysis. Images representative of substrates encountered in the field are presented in **Figure 16** and the full set of images is provided on DVD with the report (**Appendix D**).

a)

b)

c)

d)

Figure 16. Underwater images of river bed substrates a) fines, b) sand, c) gravel, and d) cobble.

3.1.5 Odor

Sediment odor was infrequently observed in the study area and was classified in four groups: sediment anoxia; petroleum odor, decaying organic debris and trash. The odor of anoxic sediments was observed at one location (site 170.1) in map tile 14. The sediments at this location were fine-grained and collected from a depth of approximately 10.5 feet. Petroleum odor was observed at 28 sites described in **Table 16**. These sites ranged in depth between 6 and 23 feet and were primarily fine-grained. Petroleum like odor was restricted to the upper reaches of the river and was observed in tiles 2, 3, 4, 5, 6, and 7. Organic odor was observed at sites 117.1 and 117.4 in tile 7 and a trash odor was observed at site 207.2 in tile 2.

Table 16. Grab sample locations with petroleum odor.

Point ID	Latitude	Longitude	Depth	EDM Class	Simple Wentworth	Nearest Restoration Site	Distance to Restoration Site (FT)	Map Tile
3.1	14689205.7	1914805.73	12	7	Fines	1010	14339.95	1
3.2	14689222.2	1914822.47	12	7	Fines	1010	14338.95	1
4.1	14689281.2	1914756.97	20	4	Fines	1010	14251.26	1
4.2	14689272	1914743.32	20	4	Fines	1010	14248.94	1
5.1	14689119.4	1914828.78	13	7	CoGrv	1010	14419.68	1
5.2	14689123.3	1914830.18	13	7	Fines	1010	14417.71	1
12.2	14689202.7	1914918.76	7	6	Fines	1010	14417.96	1
16.1	14699584.4	1905493.7	14	6	Fines	1010	396.12	2
16.2	14699587.6	1905500.4	14	6	Fines	1010	398.38	2
17.1	14699756.4	1905458.69	19	4	Fines	1009	252.83	2
18.1	14699685.4	1905486.05	19	4	Fines	1010	322.72	2
18.2	14699661.7	1905480.88	19	4	Fines	1010	333.27	2
237.2	14699422.3	1905640.13	23	4	Fines	1010	614.63	2
1004.3	14707803.9	1899872.92	20	3	Fines	1004	0.00	3
59.1	14717665.8	1874669.93	10.3	6	Fines	1013	3186.59	5
59.2	14717695.1	1874649.02	10.3	6	Fines	1013	3222.23	5
60.1	14717541.8	1875139.82	6	6	Fines	1013	2787.31	5
60.2	14717552.6	1875155.76	6	6	Fines	1013	2786.18	5
61.1	14717652.9	1874803.31	12.6	7	Fines	1013	3087.36	5
61.2	14717649.1	1874804.22	12.6	7	Fines	1013	3083.91	5
62.1	14717532.8	1875309.03	12.4	7	Fines	1013	2679.78	5
62.2	14717526.2	1875327.55	12.4	7	Fines	1013	2663.73	5
63.4	14717915.3	1874133.37	13.3	2	Fines	1013	3741.72	5
52.2	14728333.3	1861169.4	18	5		1012	1619.72	6
52.3	14728356.8	1861170.49	18	5		1012	1629.55	6
53.2	14728326.2	1862421.84	8	6	Fines	1012	752.71	6
53.3	14728323.2	1862415.23	8	6	Fines	1012	751.57	6
54.1	14728239.1	1862438.02	8	6	Fines	1012	664.47	6

3.2 LABORATORY GRAIN SIZE ANALYSIS

3.2.1 Grain Size Cumulative Frequency Distribution

Figure 17 plots the mean value of the percentage of grab samples passing through a given sieve size. This analysis was stratified by acoustic class as a means to examine potential differences in the cumulative frequency distributions of the classes. This graphic illustrates that the acoustic classes represent two distinct clusters. Acoustic classes 1, 2, and 3 were much coarser than the remaining classes. The D_{50} (or median particle size) for these acoustic classes was within the gravel category (1.0 to 64.0 mm). For samples in acoustic classes 4, 5, 6 and 7, the mean values in **Figure 17** suggest that the majority of these samples were smaller than the 0.25 mm sieve. Within the two clusters some differences in grain size distributions were observed. For example, acoustic class 5 ranked second in terms of material passing through the 0.25 mm sieve. However, means from the remaining pans suggest that this class was coarser than the other acoustic classes in its cluster. Mean values for percent passing for acoustic classes 4 and 6 were similar for each of the sieves in the cumulative frequency distribution. The individual cumulative frequency distributions for the 448 samples analyzed are presented in **Appendix E**.

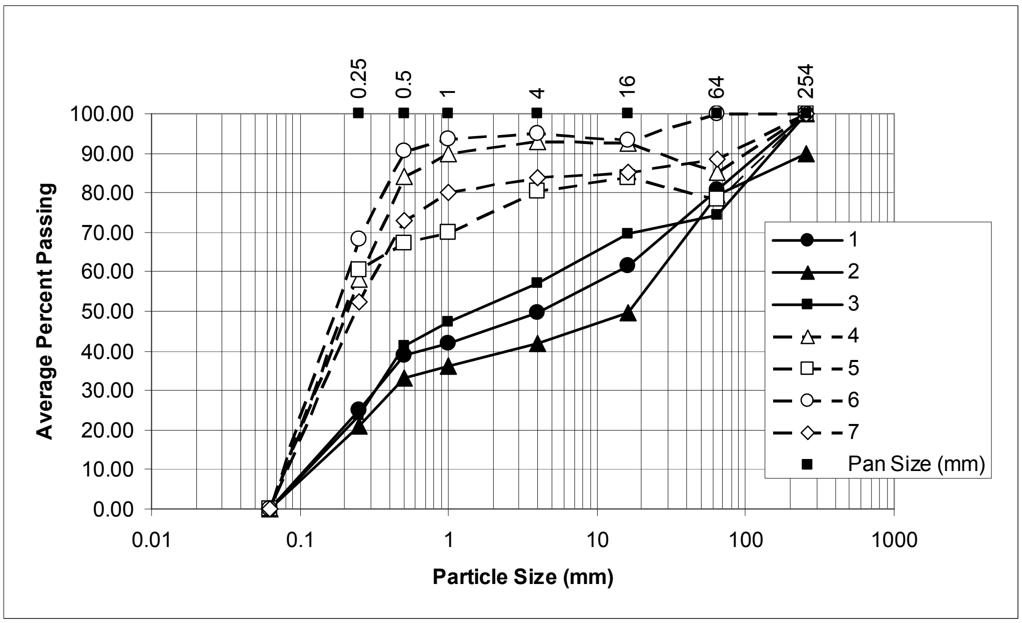


Figure 17. Mean percentage of sample passing through sieves by acoustic class for grabs with undisturbed surfaces.

3.2.2 Grain Size Gradation

Seventy-eight percent of the undisturbed grab samples were classified as fines or as having a substantial fraction comprised of fines (**Table 17**). Strict dominance (samples for which a single substrate fraction exceeded 50 percent of the sample) was observed in 213 of the 258 grab samples. Less than 18 percent (n = 45) of the 258 samples were comprised of substrates that fell below the strict dominance criterion and were “mixed”.

The degree of gradation is an aspect of particle size distribution. Well graded sediments have a wider range of particle sizes than poorly graded sediments. It should be noted that the discussion on grading that follows is limited to samples where fines comprise less than 5 percent of the sample. Using the strict dominance criterion and ASTM protocols (ASTM 2000 2487-00) for assessing gradation, it was determined that fewer than fifteen-percent of the grab samples with undisturbed surfaces were poorly graded and an additional six-percent were well graded. None of the sand dominant substrates were classified as well or poorly graded because of the high proportion of fines.

Table 17. Count of undisturbed sediment samples by acoustic class and degree of gradation.

ASTM Gradation	Strict Dominance Grain Size	Acoustic Class 1	2	3	4	5	6	7	8	Total	Strict	Mixed
Fines	Fines	5	4	6	41	11	40	28	5		140	
	Sandy Fines	1		2	3		2	1				9
	Granular Fines		1		2	1						4
	Gravelly Fines	1		1				2				4
	Subtotal	7	5	9	46	12	42	31	5	157		
Substrates with Fines	Sand with Fines$_{SM}$	1		1	1							3
	Med Sand$_{SM}$	2	2	4	10		7	3			28	
	Granular Sand$_{SM}$							1				1
	Medium & Coarse Sand$_{SM}$			1				1				2
	Coarse & Medium Sand$_{SM}$		1									1
	Granules$_{SM}$					1					1	
	Fine Granules$_{SM}$	1										1
	Gravelly Granules$_{SM}$					1						1
	Granular Gravel$_{F}$	1		1								2
	Fine to Coarse Gravel$_{F}$		1	1								2
	Coarse Gravel$_{F}$		1					1			2	
	Cobble$_{GM}$					1					1	
	Subtotal	5	5	8	11	3	7	6	0	45		
Well Graded	Granules$_{SW}$			1							1	
	Fine to Coarse Gravel$_{GW}$			1				1				2
	Coarse Gravel$_{GW}$	3	2	2			1				8	
	Cobbly Gravel$_{GW}$		1									1
	Cobble$_{GW}$			4							4	
	Subtotal	3	3	8	0	0	1	1	0	16		
Poorly Graded	Sandy Gravel$_{GP}$							1				1
	Granular Gravel$_{GP}$			2								2
	Fine to Coarse Gravel$_{GP}$		2	3	1							6
	Coarse Gravel$_{GP}$	4	6	1	2	1	1	3	1		19	
	Gravelly Cobble$_{GP}$	2		1								3
	Cobble$_{GP}$	2	2	2	1			1			8	
	Subtotal	8	10	9	4	1	1	5	1	39		
Other	Boulder		1								1	
	Grand Total	23	24	34	61	16	51	43	6	258	213	45

GW = well graded gravel; GP = poorly graded gravel; F = gravel with fines; SM = Sands with fines

3.2.3 Simple Wentworth Categories by Acoustic Class

3.2.3.1 Grab Samples with Undisturbed Surfaces

None of the acoustic classes uniformly corresponded to a single particle size class in the simple Wentworth classification system (**Figure 18**). Each acoustic class contains samples dominated by several different substrate types. Fines were classified as a dominant substrate in at least five grab samples in each acoustic class sampled. Fines and medium sand account for nearly as many grab samples in acoustic classes 1 and 3 as do the coarser substrates which these classes presumably represent. Gravels were comparatively infrequent in acoustic classes 4, 5, 6, and 7 but were still observed. Coarse sand and fine gravel as dominant substrates were virtually absent from the study area. Maps illustrating the spatial location and particles size category of grab samples in **Figure 18** are presented in **Appendix F**.

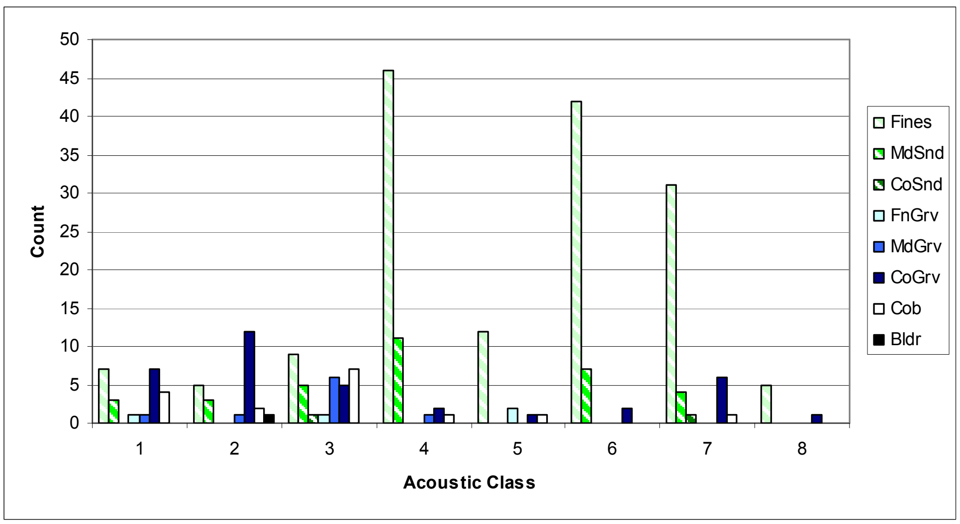


Figure 18. Dominant grain size by acoustic class for samples with undisturbed surfaces (n = 258).

Examination of the contingency table (**Table 18**) indicates that the acoustic classes differ significantly in the distribution of grain sizes. The test comparison 1-7 shows that the classes are significantly different in grain size distribution. However, the acoustic classes become inseparable when examining class groups 1-3 and 4, 6, and 7. The inclusion of class 5 in the remaining groupings suggests significant difference exists in the distribution of grain sizes for these classes. In this case acoustic class 5 appears unique with respect to the other classes.

Table 18. Chi-square contingency table results, simple Wentworth particle size classification versus acoustic class.

Acoustic Classes	χ^2	*df*	*p*
1-7	140.0	42	< 0.001
1-3	16.0	14	0.310
1-3, and 5	35.6	18	0.008
4-7	36.3	18	0.006
4,6,and 7	12.1	10	0.276

In **Table 19**, the grain size groups were further analyzed to determine if components depart from equal distributions when analyzed individually. Insufficient counts in cells of the table precluded analysis on many of the grain size groups. The null hypothesis that the distributions do not differ from equal must be accepted for both tests performed on grain sizes for the coarse-grained acoustic class 1-3 grouping. The fines component of the Class 4-7 does appear to depart from an equal distribution. This same component does not depart from an equal distribution in the test performed on Class 4, 6, and 7, indicating that acoustic class 5 is responsible for the departure.

Table 19. Individual chi-square tests for simple Wentworth particle size versus acoustic class.

Acoustic Classes	Grain Size Groups	χ^2	*df*	*p*
1-7	Fines	84.7	6	< 0.001
	MdSnd and CoSnd	N/A	N/A	N/A
	FnGrv, MdGrv, and CoGrv	N/A	N/A	N/A
	Cob and Bldr	N/A	N/A	N/A
1-3	Fines	1.1	2	0.565
	MdSnd and CoSnd	N/A	N/A	N/A
	FnGrv, MdGrv, and CoGrv	0.8	2	0.682
	Cob and Bldr	N/A	N/A	N/A
1-3, and 5	Fines	3.2	3	0.356
	MdSnd and CoSnd	N/A	N/A	N/A
	FnGrv, MdGrv, and CoGrv	N/A	N/A	N/A
	Cob and Bldr	N/A	N/A	N/A
4-7	Fines	21.2	3	< 0.001
	MdSnd and CoSnd	N/A	N/A	N/A
	FnGrv, MdGrv, and CoGrv	N/A	N/A	N/A
	Cob and Bldr	N/A	N/A	N/A
4, 6, and 7	Fines	3.0	2	0.218
	MdSnd and CoSnd	2.4	2	0.296
	FnGrv, MdGrv, and CoGrv	N/A	N/A	N/A
	Cob and Bldr	N/A	N/A	N/A

3.2.3.2 Grab Samples with Partially Disturbed Surfaces

Examination of a data set with both partially disturbed and undisturbed samples enables finer distinctions among both the coarse-grained samples and fine-grained groups but does not change the overall groupings based on grain size. The total number of coarse gravel dominant substrates increased substantially (**Figure 19**). Thus the greatest increases occurred in a substrate category that was among the most difficult to sample. For acoustic classes 1, 2 and 3, a three to four-fold increase in the number of dominant coarse gravel samples was observed. The remaining classes increased in frequency too, albeit to a lesser degree. The number of samples with fines as the dominant substrate also increased with the inclusion of partially disturbed samples, but the magnitude of increase was small in comparison to coarse gravel. The frequency of fine and medium gravel samples were essentially unchanged as was coarse sand.

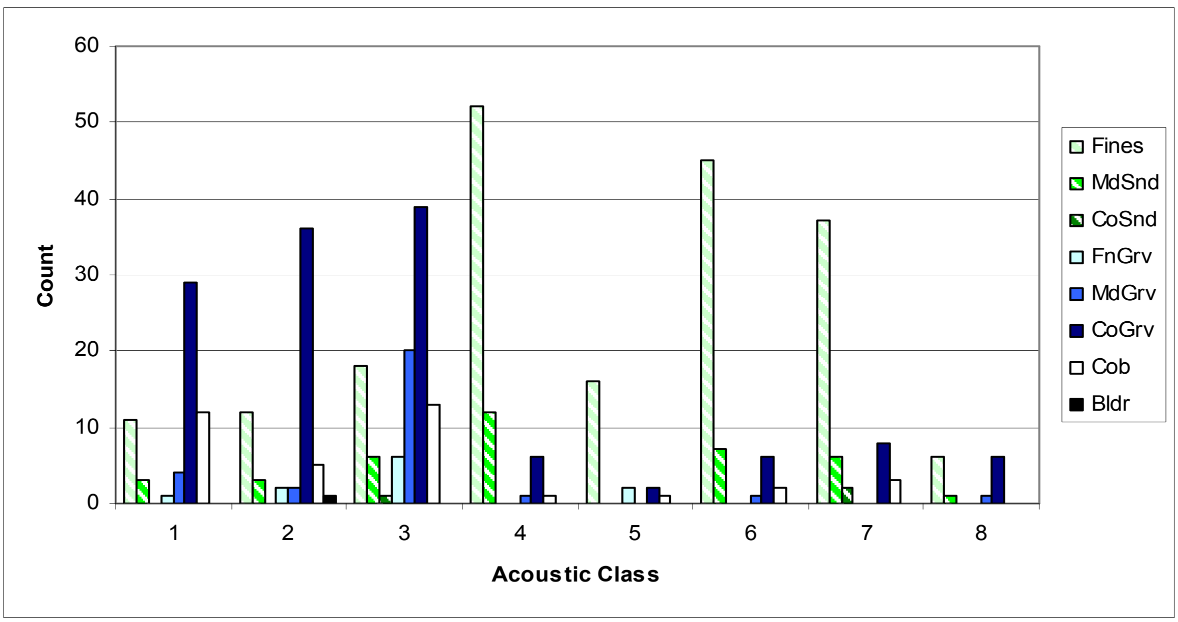


Figure 19. Dominant grain size by acoustic class for samples with undisturbed and partially disturbed surfaces (n = 448).

3.2.3.3 Fine-scale Sediment Variabililty

Fine-scale variability at sample locations was evaluated by comparing counts of particle sizes yielded from the first undisturbed grab sample to counts of particle sizes from subsequent samples. As presented in Table 20 at least two undisturbed samples were obtained from 97 sample locations. This resulted in 106 unique pairings between first and subsequent samples (i.e., 1st vs. 2nd = 92, 1st vs. 3rd = 2, 1st vs. 4th = 12). For samples characterized using the simple Wentworth classification system, nearly 80 percent of the initial samples matched subsequent samples (n = 84, **Table 20**). However, 59 percent of the samples with one to one correspondence (n = 62) were classified as fines with the remaining 21 percent spread across the other particle size categories. The number of subsequent samples with particle sizes larger than the initial sample equaled the number of samples with particle sizes smaller than the initial sample (n = 11, 10 percent of the total). Similar frequency distributions were observed using the ASTM classification system (**Table 21**). One to one correspondence was observed in 70 percent of the samples (n = 74) with 53 of those samples classified as fines (50 percent of the total). Particle sizes were classified as smaller than the initial sample in 18 instances (17 percent) and greater than the initial sample in 14 instances (13 percent). Both tables illustrate that when the first sample was fines there was a high likelihood that subsequent samples would be fines. When the first sample was cobble a high degree of departure was observed in subsequent samples.

Table 20. Count of particle sizes (simple Wentworth) in the first undisturbed sample collected at a sample location versus the particle size rank for the second, third, or fourth undisturbed sample collected at that location. Shading in the body of table indicates 1:1 correspondence between first sample and subsequent samples.

	Particle Size for Second, Third, or Fourth Undisturbed Sample								
Particle Size for First Undisturbed Sample	Fines	MdSnd	CoSnd	FnGrv	MdGrv	CoGrv	Cob	Bldr	Grand Total
Fines	62	3				1	1		67
MdSnd	4	12	1		1				18
CoSnd									0
FnGrv				1			1		2
MdGrv					1	1			2
CoGrv	1	1				6	1	1	10
Cob	1				2	2	2		7
Bldr									0
Grand Total	68	16	1	1	4	10	5	1	106

Simple Wentworth Classification System

Table 21. Count of particle sizes (ASTM) in the first undisturbed sample collected at a sample location versus the particle size rank for the second, third, or fourth undisturbed sample collected at that location. Shading in the body of table indicates 1:1 correspondence between first sample and subsequent samples.

	Particle Size Rank for Second, Third, or Fourth Undisturbed Sample.																		
Particle Size Rank First Undisturbed Sample	1	2	3	4	5	6	8	9	10	13	15	16	18	19	20	21	22	23	Grand Total
1	53	2	2		2	1								1			1		62
2	4																		4
3																			0
4	1																		1
5																			0
6	4					12	1												17
8																			0
9													1						1
10																1			1
13									1										1
15						1													1
16																			0
18												1	1						2
19	1													6				1	8
20																	1		1
21														1					1
22	1											1	1	1			2		6
23																			0
Grand Total	64	2	2	0	2	14	1	0	1	0	0	2	3	9	0	1	4	1	106

Particle size ranks correspond to the following size classes: 1 – Fines, 2 – Sandy Fines, 3 – Granular Fines, 4 – Gravelly Fines, 5 – Sand with Fines, 6 – Medium Sand, 8 – Medium & Coarse Sand, 9 – Coarse & Medium Sand, 10 – Granules, 13 – Gravelly Granules, 15 – Sandy Gravel, 16 – Granular Gravel, 18 – Fine to Coarse Gravel, 19 – Coarse Gravel, 20 – Cobbly Gravel, 21 – Gravelly Cobble, 22 – Cobble, 23 – Boulder. Categories simplified from ASTM categories presented in Table 16.

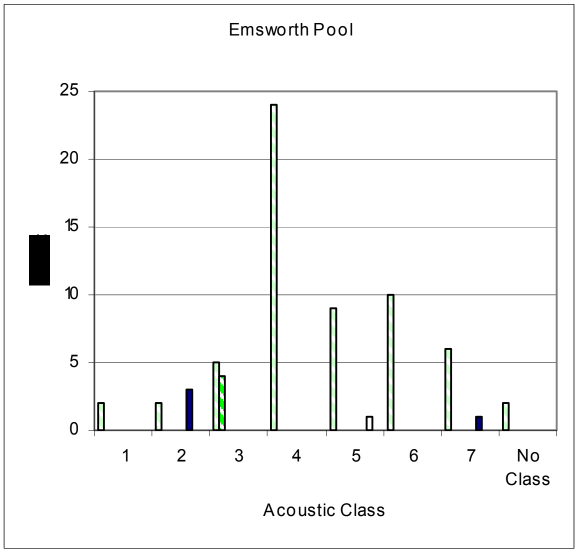
3.2.3.4 Simple Wentworth Classification by Pool

The distribution of dominant grain sizes varies substantially both among and within pools (**Figure 20**). Samples from Emsworth pool were almost wholly comprised of fines or medium sand. Acoustic classes 1, 2 and 3 which are dominated by coarse substrates in the study area as a whole, are dominated by fines and medium sand in Emsworth Pool.

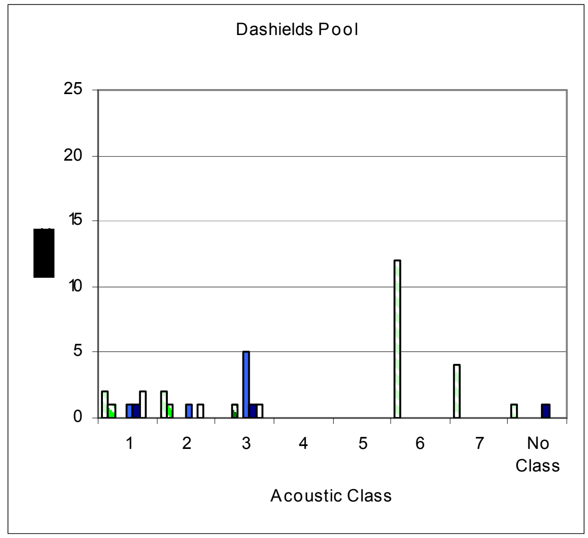
In New Cumberland pool, coarse-grained substrates were found in nearly every acoustic class. The only boulder-dominant substrate in the study was collected from acoustic class 2 in this pool. Cobbles occurred in four of seven acoustic classes including class 7 which is thought to be associated with fine-grained sediments. However, fewer fine-grained types of sediment were observed in acoustic classes 1, 2, and 3 than in the other pools.

Grab samples with undisturbed surfaces were not collected in acoustic classes 4 and 5 in Dashields pool. Fines were the only substrate representing acoustic classes 6 and 7. The remaining acoustic classes in Dashields pool are represented by no less than five dominant substrate types.

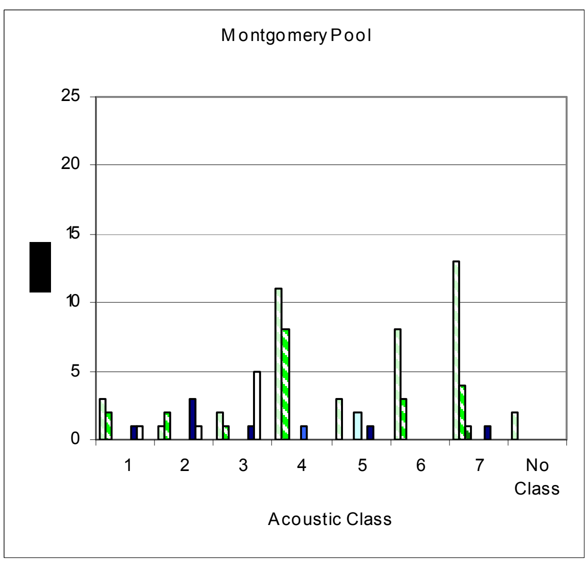
The particle size distributions in Montgomery pool appear superficially similar to the distribution observed for all pools combined, but with far fewer samples. However, the number of samples with cobbles observed in acoustic class 3 in Montgomery pool (n = 5) accounts for nearly all of the cobble samples observed in the entire study area for this class (n = 7).



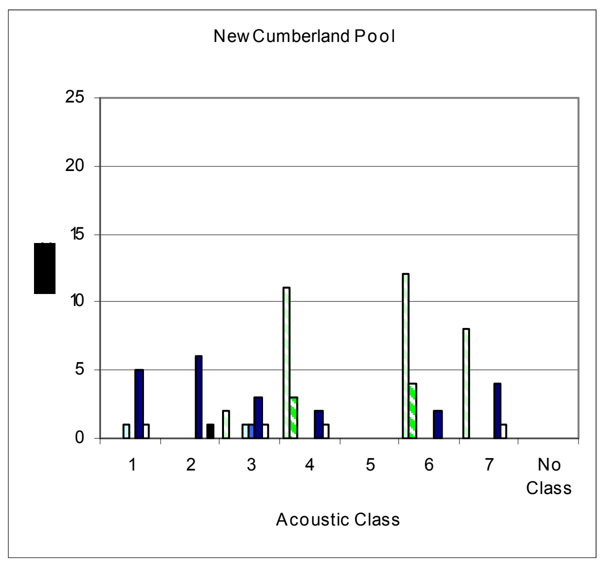
a)



b)



c)



d)

Figure 20. Dominant grain size by acoustic class for a) Emsworth pool, b) Dashields pool, c) Montgomery pool, and d) New Cumberland pool, undisturbed samples only. The legend for this figure is the same as Figure 19.

3.3 NATIVE FRESHWATER MUSSELS

Five live native freshwater mussels and valves from five deceased animals (3 fresh dead, 2 weathered) were observed in the study area. These observations were scattered throughout the study area and included Tiles 5, 9, 10, 11, 12 and 14 (**Figure 21**). At least four species were conclusively identified from these specimens. Representative photographs of some of the specimens are presented in **Figure 22** and descriptive statistics characterizing habitat conditions at the sample locations where mussels were found are presented in **Table 22**. The *Ligumia recta* valves from sample location 82 were wedged in the anchor and brought to the surface as it was retrieved. All other mussel observations were the result of grab capture. The identity of one live specimen captured in Tile 9 (Grab sample ID 1001-1) was not determined in the field because a biologist was not part of the crew. Photographs of the specimen were insufficiently detailed to allow for conclusive identification. This sample location is currently being investigated as a potential restoration area. The pair of valves observed at sample location 173 (Tile 14) were very small (18 mm) and in poor condition. However, the shape of the wing extending from the umbo suggests that the specimen was *Potamilus alatus* but may have been *Leptodea fragilis*. Both *Obliquaria reflexa* specimens were small (18 and 25 mm) suggesting that successful recruitment occurs for this species.

Live mussels were retrieved from acoustic classes 3, 4, 6 and 7. Visually assessed dominant and subdominant grain sizes for live animals were Coarse gravel-Coarse gravel, Medium sand-fine sand, and Silt/Clay-Fine Sand. Laboratory results for grab samples collected at these locations indicate that the sediments where mussels were found primarily comprised of fines with some coarse gravel substrates (**Figure 23**). The underlying sediment strata for these grab samples was judged to be the same as that observed in the upper 3cm. Depths occupied by live mussels ranged between 9.2 and 22 feet and averaged 13.6 feet.

Zebra mussels (*Dreissena polymorpha*) and Asiatic clams (*Corbicula fluminea*) were widely distributed and abundant throughout the study area. Asiatic clam shells (live and dead) were retrieved in at least 136 of 968 grab samples and zebra mussel shells were retrieved in 213 grab samples. The total number of live and dead Asiatic clams and zebra mussels was not recorded but likely exceeded 1,000 individuals for each species. Live zebra mussels were found attached to at least two live unionoids.

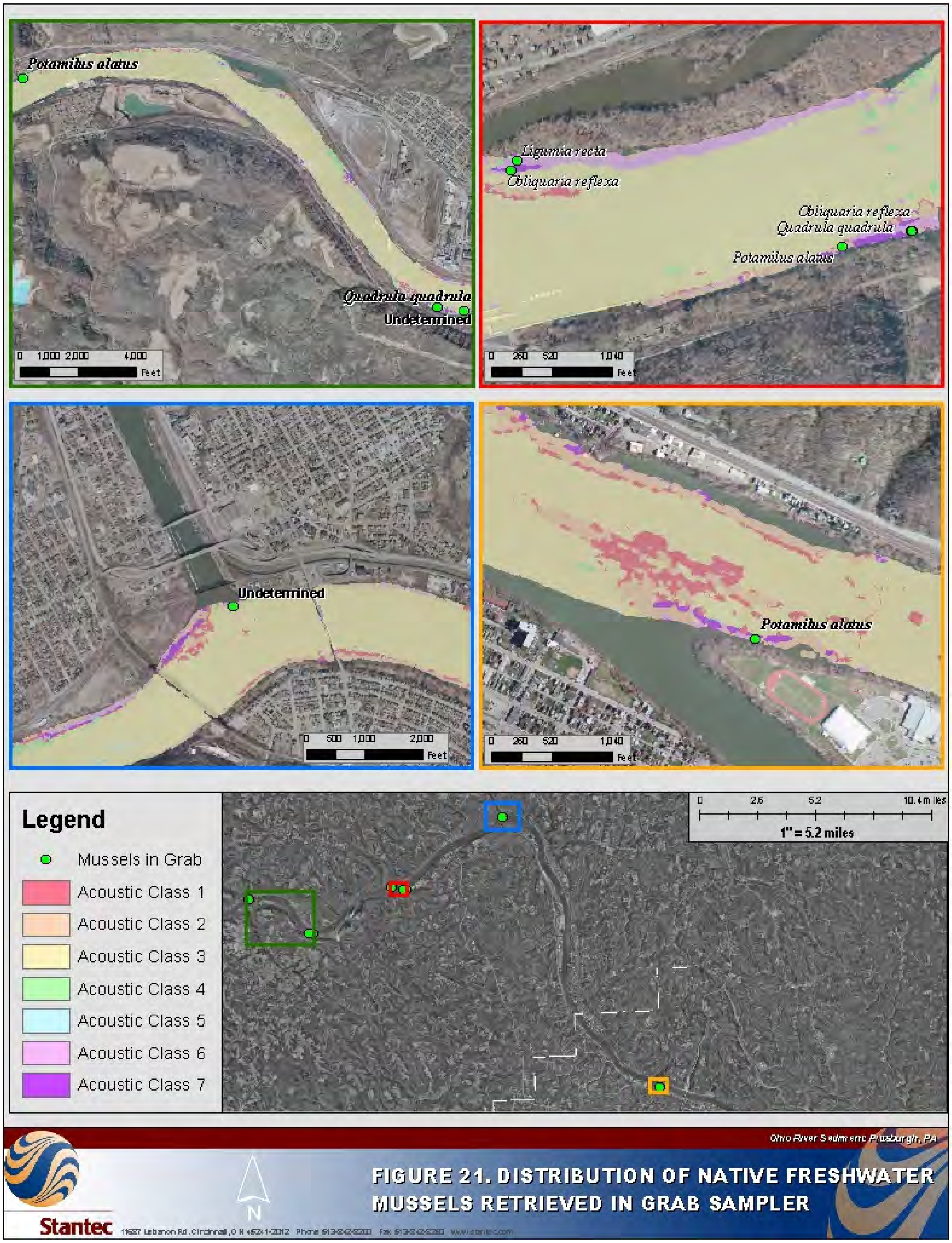


FIGURE 21. DISTRIBUTION OF NATIVE FRESHWATER MUSSELS RETRIEVED IN GRAB SAMPLER

a) *Ligumia recta* from sample location 82

b) Quadrula quadrula from grab 153-2

c) Obliquaria reflexa from grab 84-1

d) Potamilus alatus from grab 93-5

g) Asiatic clam shells in lower strata of sample

h) Cobbles in grab with live zebra mussels

Figure 22. Representative photos of mollusc taxa.

Table 22. Native freshwater mussel species captured by the sediment grab sampler and sample location characteristics.

Species	Valve Status	Point_ID	Date	Acoustic Class	Map Tile	Depth (feet)	Grab Closure	Sample Surface	Grab Fullness	Sample Stratification	Dominant Surface Grain Size	Subdominant Surface Grain Size	Subsurface Dominant Grain Size	Subsurface Subdominant Grain Size	Underwater Image Index	Undisturbed Grab
Undetermined	Live	1001-1	9/17/2009	3	9	22	Partial	Disturbed	Empty	None	CoGrv	N/A	N/A	N/A	8-17	NO
		1001-2	9/17/2009	3	9	22	Partial	Disturbed	Empty	None	CoGrv	N/A	N/A	N/A	8-17	NO
		1001-3	9/17/2009	3	9	22	Partial	Disturbed	88	None	CoGrv	MdGr	N/A	N/A	8-17	NO
		1001-4	9/17/2009	3	9	22	Partial	Disturbed	90	None	CoGrv	MdGr	N/A	N/A	8-17	NO
		153-1	9/1/2009	4	12	15.8	Full	Disturbed	68	None	MdSnd	FiSnd	N/A	N/A	2-39	NO
Quadrula quadrula	Live	153-2	9/1/2009	4	12	15.8	Full	Undisturbed	74	None	Si/Cl	FiSnd	N/A	N/A	2-39	YES
		153-3	9/1/2009	4	12	15.8	Partial	Disturbed	Empty	None	CoGrv	N/A	N/A	N/A	2-39	NO
		153-4	9/1/2009	4	12	15.8	Partial	Disturbed	45	None	Si/Cl	CoGrv	N/A	N/A	2-39	NO
		153-5	9/1/2009	4	12	15.8	Partial	Undisturbed	53	None	MdSnd	FiSnd	N/A	N/A	2-39	YES
		158-1	9/1/2009	7	12	12.2	Open	N/A	Empty	None	Cob	N/A	N/A	N/A	2-35	NO
Undetermined	Weathered	158-2	9/1/2009	7	12	12.2	Full	Undisturbed	57	Laminate	Si/Cl	CoGrv	MdGr	CoGrv	2-35	YES
		158-3	9/1/2009	7	12	12.2	Full	Undisturbed	85	Laminate	Si/Cl	Si/Cl	Si/CL	CoGrv	2-35	YES
		173-1	9/2/2009	6	14	25	Open	N/A	Empty	None	N/A	N/A	N/A	N/A	3-13	NO
		173-2	9/2/2009	6	14	9	Full	Undisturbed	5	None	Si/Cl	FiSnd	N/A	N/A	3-13	YES
Potamilus alatus	Weathered	173-3	9/2/2009	6	14	9	Full	Undisturbed	0	None	Si/Cl	FiSnd	N/A	N/A	3-13	YES
Potamilus alatus	Fresh dead	60-1	9/3/2009	6	5	6	Full	Undisturbed	25	None	Si/Cl	FiSnd	N/A	N/A	4-12	YES
		60-2	9/3/2009	6	5	6	Full	Undisturbed	47	Laminate	Si/Cl	Si/Cl	N/A	N/A	4-12	YES
		82-1	8/30/2009	6	11	14.3	Full	Undisturbed	45	None	Si/Cl	FiSnd	N/A	N/A	2-2	YES
Ligumia recta	Fresh dead	82-2	8/30/2009	6	11	14.3	Full	Undisturbed	59	Laminate	Si/Cl	MdSnd	Si/Cl	FnGr	2-2	YES
Obliquaria reflexa	Live	84-1	8/30/2009	7	11	11.9	Full	Undisturbed	62	None	Si/Cl	FiSnd	N/A	N/A	2-4	YES
		84-2	8/30/2009	7	11	11.9	Full	Undisturbed	92	None	Si/Cl	Si/Cl	N/A	N/A	2-4	YES
Quadrula quadrula	Live	91-1	8/31/2009	6	10	9.2	Full	Undisturbed	0	None	Si/Cl	FiSnd	N/A	N/A	2-23	YES
Obliquaria reflexa	Live	91-2	8/31/2009	6	10	9.2	Full	Undisturbed	0	None	Si/Cl	FiSnd	N/A	N/A	2-23	YES
		93-1	8/31/2009	2	10	12.9	Partial	Disturbed	Empty	None	N/A	N/A	N/A	N/A	2-19	NO
		93-2	8/31/2009	2	10	12.9	Open	N/A	Empty	None	Cob	N/A	N/A	N/A	2-19	NO
		93-3	8/31/2009	2	10	12.9	Full	Undisturbed	79	None	CoGrv	Si/Cl	N/A	N/A	2-19	YES
		93-4	8/31/2009	2	10	12.9	Partial	Disturbed	Empty	None	Cob	N/A	N/A	N/A	2-19	NO
Potamilus alatus	Fresh dead	93-5	8/31/2009	2	10	12.9	Partial	Undisturbed	93	None	Cob	CoGrv	N/A	N/A	2-19	YES

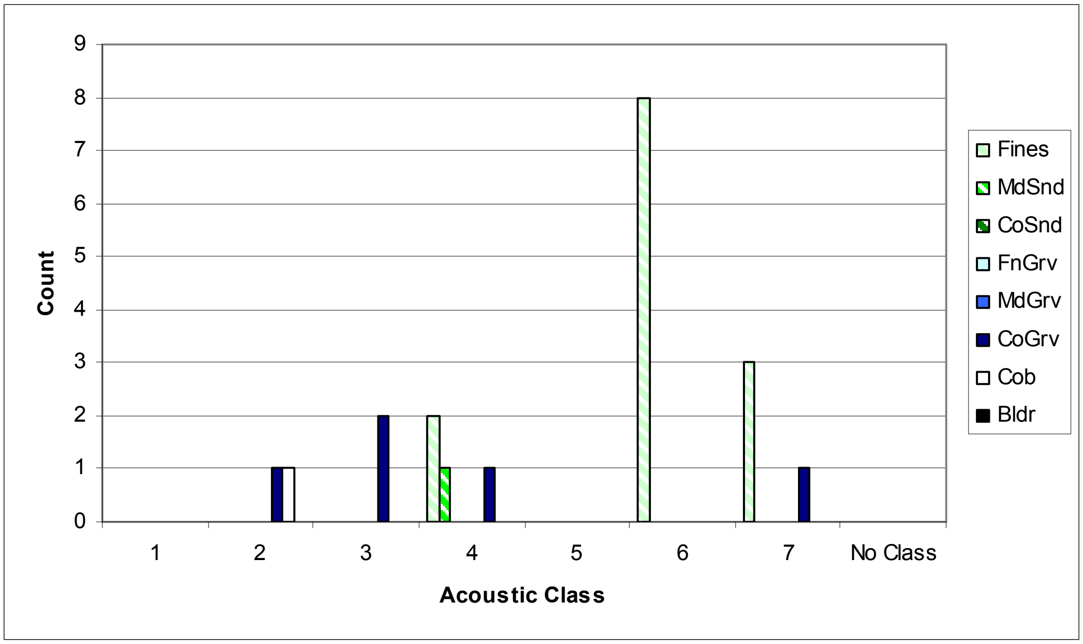


Figure 23. Dominant grain size by acoustic class for grab samples in locations where native freshwater mussels were found.

3.4 POTENTIAL RESTORATION SITES

River substrates were sampled at nineteen locations identified by the District as potential restoration sites. Eleven locations were affiliated with acoustic class 3, one location with acoustic class 2, and seven locations with no assigned acoustic class. A total of 66 grabs were attempted and returned 10 undisturbed, 26 partially disturbed, 13 open and 17 empty grab samples. Grabs with undisturbed surfaces were collected at six sample locations for a total of ten samples. Seven of the 10 samples were classified as fines, two as medium sand and one as coarse gravel (**Figure 24**). The coarse gravel sample was poorly graded and the two sand samples had substantial fractions comprised of fines. Depths for the 19 locations averaged 21.4 feet (standard deviation = 11.1). A brief summary of field measurements is presented in **Table 23**. The full record of measurements for these points is presented in **Appendix G** (Field Observations) and **Appendix H** (Grain Size). Restoration sites have point identification numbers in the 1,000 series.

At sample location 1004, field personnel detected strong petroleum like odors in the grab sample. No chemical analyses were performed as part of this study. However, contaminated sediments may affect the restoration potential of this location and should be considered as planning for this location proceeds. The odor observed at sample location 1004 was not an isolated incident. **Table 16** contains a list of grab samples with similar odors, their geographic coordinates and proximity to locations identified by the District as having potential for restoration.

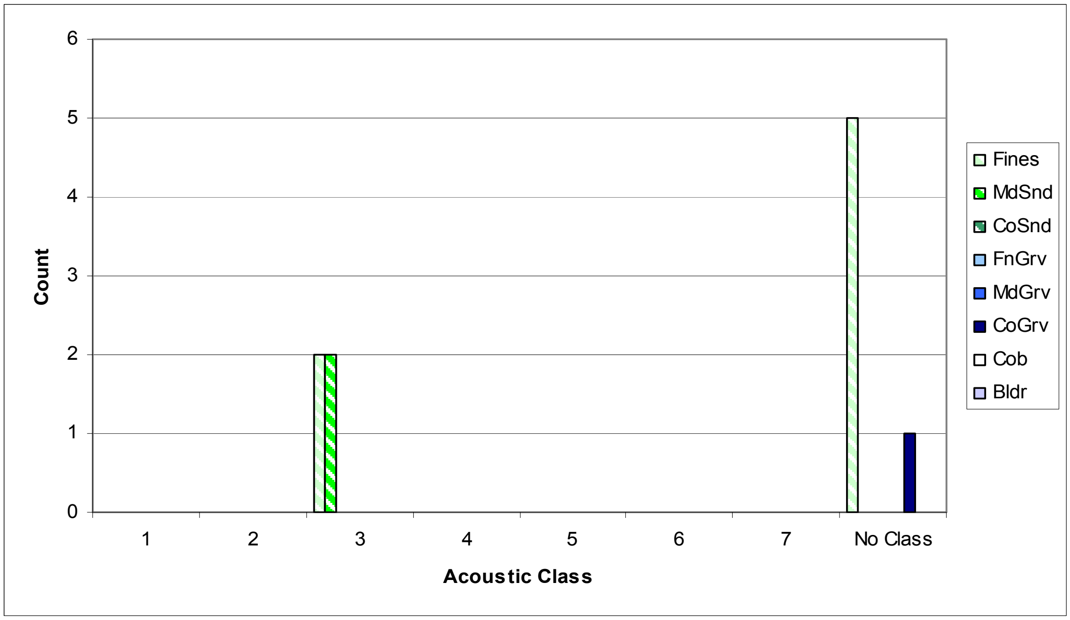


Figure 24. Dominant grain size by acoustic class at potential restoration sites, undisturbed samples only.

Table 23. Summary grain size data for potential restoration sites.

Point ID	Site ID	Grab	Map Tile	Undisturbed Grab	Acoustic Class	Depth	Stratification	Grab Penetration	Image Index	Lab ID	D10	D30	D60	ASTM Grain Size	Simple Wentworth
1000.1	1000	1	9	NO	3	29	None	30	8-16	227	14.08	21.83	34.56	Coarse Gravel.GP	CoGrv
1000.4	1000	4	9	NO	3	29	None	68	8-16	228	3.54	6.08	11.69	Fine & Med Gravel.GP	MdGrv
1001.3	1001	3	9	NO	3	22	None	40	8-17	229	16.69	24.43	36.01	Coarse Gravel.GP	CoGrv
1001.4	1001	4	9	NO	3	22	None	38	8-17	230	15.99	23.69	36.35	Coarse Gravel.GP	CoGrv
1002.1	1002	1	9	NO	3	23	None	8	8-18	231	1.00	4.35	8.18	Fine & Med Gravel.GW	MdGrv
1002.2	1002	2	9	NO	3	23	None	43	8-18	232	0.57	4.09	9.21	Fine & Med Gravel.GP	MdGrv
1003.1	1003	1	9	YES	8	1.5	None	83	8-19	233	0.00	0.01	0.05	Fines	Fines
1003.2	1003	2	9	YES	8	1.5	None	78	8-19	234	0.00	0.00	0.00	Fines	Fines
1004.2	1004	2	3	NO	3	20	None	93	8-34	235	0.10	0.92	6.40	Fine & Med Gravel.F	MdGrv
1004.3	1004	3	3	NO	3	20	Laminate	108	8-34	236	0.08	0.20	1.87	Gravelly Fines	Fines
1005.4	1005	4	3	NO	3	25	None	33	8-33	237	4.82	15.13	28.51	Coarse Gravel.GW	CoGrv
1005.5	1005	5	3	NO	3	25	None	33	8-33	238	10.74	21.19	34.97	Coarse Gravel.GP	CoGrv
1006.1	1006	1	3	NO	3	31	None	48	8-32	239	1.92	8.83	24.38	Coarse Gravel.GW	CoGrv
1006.6	1006	6	3	NO	3	31	None	38	8-32	240	14.55	22.37	35.70	Coarse Gravel.GP	CoGrv
1007.6	1007	6	3	NO	3	32	None	16	8-31	241	10.33	20.18	34.02	Coarse Gravel.GP	CoGrv
1008.1	1008	1	3	NO	3	31	None	0	8-30	242	0.18	0.42	2.58	Gravelly Granules.SM	FnGrv
1009.3	1009	3	2	YES	3	40	None	40	8-28	243	0.07	0.10	0.24	Fines	Fines
1009.4	1009	4	2	YES	3	40	Laminate	128	8-28	244	0.04	0.07	0.17	Fines	Fines
1010.1	1010	1	2	NO	3	33	None	-9999	8-29	245	0.1846	0.23	0.332	Med Sand.SM	MdSnd

Table 23. Summary grain size data for potential restoration sites *(continued).*

oint ID	Site ID	Grab	Map Tile	Undisturbed Grab	Acoustic Class	Depth	Stratification	Grab Penetration	Image Index	Lab ID	D10	D30	D60	ASTM Grain Size	Simple Wentworth
1010.2	1010	2	2	YES	3	33	None	10	8-29	246	0.1603	0.21	0.319	Med Sand.SM	MdSnd
1010.3	1010	3	2	YES	3	33	None	118	8-29	247	0.1976	0.24	0.331	Med Sand.SM	MdSnd
1011.1	1011	1	2	NO	3	35	None	33	8-27	248	0.2292	4.35	13.13	Fine to Coarse Gravel.GP	MdGrv
1012.1	1012	1	6	NO	2	13	None	43	8-23	249	20.749	56.4	116.6	Cobble.GW	Cob
1012.2	1012	2	6	NO	2	13	None	33	8-23	250	15.248	23.2	34.93	Coarse Gravel.GP	CoGrv
1013.1	1013	1	15	NO	8	1.5	None	-9999	N/A	251	2.477	6.77	18.32	Fine to Coarse Gravel.GW	CoGrv
1013.2	1013	2	15	NO	8	3.5	None	58	8-24	252	18.07	31.3	72.69	Coarse Gravel.GP	CoGrv
1014.1	1014	1	15	YES	8	13	None	53	8-25	253	17	24	36.83	Coarse Gravel.GP	CoGrv
1014.2	1014	2	15	NO	8	12	None	68	8-25	254	16.269	24	36.61	Coarse Gravel.GP	CoGrv
1015.1	1015	1	15	NO	8	8.5	None	58	8-26	255	0.0122	0.05	0.392	Fines	Fines
1015.2	1015	2	15	YES	8	8.5	None	93	8-26	256	1E-05	0	0.007	Fines	Fines
1016.1	1016	1	3	NO	8	17.5	None	33	8-37	257	16.809	24.5	37.11	Coarse Gravel.GP	CoGrv
1016.2	1016	2	3	NO	8	17.5	None	23	8-37	258	18.417	24.2	37.67	Coarse Gravel.GP	CoGrv
1017.1	1017	1	3	YES	8	18	None	118	8-36	259	0.0243	0.05	0.151	Fines	Fines
1017.2	1017	2	3	YES	8	18	None	108	8-36	260	0.0194	0.04	0.128	Fines	Fines
1018.2	1018	2	3	NO	8	10.5	None	78	8-35	261	0.1872	0.48	2.963	Granular Gravel.F	MdGrv
1018.3	1018	3	3	NO	8	10.5	None	38	8-35	262	0.1654	0.33	1.779	Sand with Fines.SM	MdSnd

4.0 Discussion

4.1 EVALUATION OF SAMPLING METHODOLOGY

The methods and equipment used in this field effort worked well under a variety of conditions from high to low velocities, in coarse and fine-grained substrates, in the shallows and in deeper pools. The use of a single sampling instrument ensured that sampling effort was comparable between and among sample locations. The methods were appropriate given the short sampling window, available funds to complete the work, and the desired sampling intensity. Nevertheless, in this field effort, as in all field studies, opportunities exist to refine or improve elements of the effort. This section will evaluate the field methods with respect to their ability to successfully collect samples of different types of river substrate. It will also make recommendations for additional or different data to resolve differences in the side scan sonar and particle size results.

4.1.1 High Velocity Areas

Project personnel were unable to sample the high velocity areas immediately downstream of Montgomery Dam. It was possible to maintain boat position over the sample point but it was not possible to engage the grab sampler. The force of flow maintained tension on the steel cable attached to the grab sampler even after grab was resting on the substrate. This tension prevented the chain from releasing and consequently the jaws of the grab did not close as the sampler was retrieved. Repeated attempts to release a sufficient amount of cable to take the tension off of the grab sampler were unsuccessful.

If samples from this area are needed, it may be necessary to use a larger Van Veen sampler with a heavier cable to successfully sample substrates. Under this scenario it would also be necessary to use a larger boat and davit for sampling. The tradeoffs associated with a shift to larger gear must be considered carefully. First, the cost of deploying this equipment will be higher because of increased cycling times, decreased mobility, and higher operational costs (fuel, winches, etc.). Second, results from the larger instrument may not be readily comparable to samples collected with the smaller grab (e.g., ANOVA for penetration depth). Third, some shallow areas may be inaccessible to a larger vessel.

The likelihood of successfully sampling high velocity areas may also be increased by adjusting the configuration of the gates releasing water during the sampling event to optimize water velocities in the areas to be sampled. Because sediments in the high velocity areas will likely be coarse, we suggest investigating the possibility of adding additional weight to the sampler. In a review of grab samplers, Murdoch and Azcue (1995) indicate that the heavier weight of the Van Veen sampler is more suitable for deeper depths and stronger currents than the Birge-Ekman, Ponar, and Shipek samplers.

4.1.2 Sampler Performance in Coarse Sediments

Empty and disturbed grabs were more frequent in the coarse-grained acoustic classes than in fine-grained acoustic classes. However, more than 50 of the 258 sediment samples with undisturbed surfaces were comprised of coarse-grained substrates (i.e., coarse gravel or coarser) (**Table 17**). The undisturbed samples included cobble (n = 21) and boulder (n = 1). Fine-grained substrates were commonly observed in the coarse-grained acoustic classes, and fine-scale variability was observed between first and subsequent grab samples. In combination, these findings suggest that while the Van Veen sampler may be limited in its ability to pick up coarse-grained substrates, it is fine-scale variability, not sampler limitation that is responsible for the inability to discriminate between coarse-grained acoustic classes.

Use of a larger Van Veen sampler might produce fewer disturbed or empty grabs. However, the use of a larger Van Veen would entail the same cost vs. performance considerations discussed above. Increasing the weight on the sampler used in this study may also decrease the sample failure rate.

4.1.3 Surface Disturbance

Samples exhibiting an intermediate level of disturbance where some washout was evident in a portion of the grab (e.g., one corner) but the remainder of the sample appeared undisturbed were retained and analyzed for the purpose of verifying the acoustic signatures. The total number of coarse gravel substrates increased substantially in the partially disturbed samples in comparison to the undisturbed samples. The frequency of fines in partially disturbed samples was also much lower than observed in undisturbed samples. The null hypothesis of equal distributions for partial disturbed versus undisturbed samples was rejected (χ^2 = 115, df = 5, p <0.0001). Thus the disturbed grabs may over represent coarse-grained sediments and underestimate the amount of fines present. It was not possible to exhaustively analyze data from the partially disturbed grabs within the scope of this analysis. Further investigation to determine their utility in verifying the acoustic signatures is warranted.

4.1.4 Silt and Fine Sand

The District elected to forgo the use of use of a U.S. Standard Sieve Mesh # 230 (0.0625 mm) as a cost savings measure. Consequently it was necessary to combine silt/detritus and fine sand into a single category defined as “fines.” More than 60% of the undisturbed samples were classified as fines (**Table 17**) and the cumulative frequency distributions for the acoustic classes (**Figure 17**) indicate that majority of the material in acoustic classes 4, 5, 6, and 7 was smaller than the smallest pan size. The inability to discriminate between silt and fine sand may contribute to the inability to distinguish between the acoustic classes associated with fine-grained substrates.

4.1.5 Underwater Imagery

The underwater camera was deployed once at each sample location whereas the grab sampler was deployed up to six times. As **Tables 20** and **21** illustrate fine-scale variation in substrate types was observed in 20 to 30 percent of the samples. Therefore an image from a single location on the river bed may not be sufficient to determine particle sizes at sample locations where sediment samples could not be obtained. The images should, however, give a good representation of substrates for the first grab attempt. In future sampling efforts it may be advisable to deploy the camera 1) when the initial samples were empty or disturbed or 2) with every grab attempt.

4.1.6 Upper Strata Sub-Sampling Protocol

This study confirmed that different substrate types have different acoustic signatures and successfully identified three broad groupings: acoustic classes 1, 2, and 3; acoustic class 5; and acoustic classes 4, 6, and 7. However, much of the variation in the substrates could not be explained by the seven acoustic classes. As described in Section 2.4.3, after completing the visual inspection of the grab sampler, field personnel removed the upper 3 cm of undisturbed material with a sampling spoon. This protocol was selected in consultation with the District was applied uniformly to all samples prepared for laboratory analysis. The degree to which this protocol matches the penetration depth of the acoustic sonar is currently unknown and investigation on this matter was not within the scope of the present analysis. Review of existing studies may be warranted to determine if the uniformly applied 3 cm sub-sampling depth was justified or if more elaborate protocols might be warranted (e.g., 3 cm for fines, 6 cm fines with laminate structure).

4.1.7 Native Freshwater Mussel Abundance

One of the stated goals of the larger project is to model suitable habitats for native freshwater mussels. Given the small number of native freshwater mussel observations, it is difficult to draw quantitative conclusions about the relationship between mussels and the substrate. Some potential patterns did emerge: native mussels seem to occur on the margins of the channel; they occur in a narrow range of depths; and they were found in a wide range of substrates. The sediment data from this study represent a very good snapshot of “available” habitat. Targeted sediment sampling in known mussel locations may provide a better picture of “suitable” habitat.

4.2 POTENTIAL INFLUENCE OF EXTERNAL FACTORS

In addition to matters regarding the nature of the acoustic data, there are other issues that may affect relationships between the acoustic signatures and the sediment sampling data.

4.2.1 Bed mobilization

Streamflows during the months of the 2008 acoustic sonar survey (mean = 12,100 cfs) and the 2009 ground-truthing survey (mean = 9,600 cfs) were similar, with the exception of a brief period at the beginning of the Emsworth acoustic sonar survey where the peak discharge was approximately 46,000 cfs. In the intervening period between the acoustic survey and the ground-truthing survey there were six occasions where peak discharge exceeded 80,000 cfs, one of which exceeded 135,000 cfs. It is likely that higher flows mobilized bed materials in at least some portion of the channel; however, the magnitude and extent of bed mobilization is presently unknown. If the bed was mobilized between the two surveys, localized deposition and/or scour may have redistributed sediments in patterns that differ from those present during the earlier acoustic survey.

Other factors also point to the need to understand sediment transport dynamics in the system. For example, the lack of Hydrogen Sulfide odor in almost all sediments suggests that the fine-grained sediment is recently settled with little opportunity to become anoxic. Also, undisturbed samples were obtained with greater frequency on the channel margin than in the center of the channel. This result may be related to sediment transport dynamics or to other factors as described below.

4.2.2 Propwash

During the course of field studies there were several occasions where tugs produced noticeable turbidity plumes in the wake of their passage. Such plumes most likely occur when river stages are low and when the tugs pass through relatively shallow areas. The extent to which tug passage may influence scour patterns on the river bed or redistribute fines is currently unknown. In at least one instance, at Emsworth pool, prop wash generated plumes were observed upstream of the lock in areas where the grab repeatedly failed to penetrate the sediments.

4.2.3 Gravel Mining

Large scale in-channel commercial gravel mining was observed during the course of the sediment sampling field surveys. The extent to which these operations alter substrate composition in the project area is a matter that warrants further investigation.

4.2.4 Hydrologic Variability

The areas immediately downstream of the dams are those most likely to be armored and to experience wide swings in hydraulic conditions. Fine sediment deposits downstream of the influence of a dam spill may expand and contract spatially with the rise and fall of the hydrograph. This is just one example of spatial and temporal variability that may be encountered in the system.

4.3 RECOMMENDATIONS FOR IMPROVED SAMPLING

Based on the Evaluation Sampling Methodology it is possible to offer to the following recommendations for future sampling efforts designed to verify acoustic sonar signatures:

- Adjust the gate release schedules at the dams to reduce velocity in sampling areas and, possibly, add weight to the Van Veen grab sampler.

- Examine data from the “partially disturbed” samples in greater detail to determine if adjustments to protocols for identifying acceptable samples are necessary.

- Revisit the potential use of the U.S. Standard Sieve Mesh #230 in light of project objectives and financial resources.
- Analyze the underwater imagery to examine the performance of the protocols used in this study.
- Deploy underwater camera more frequently in coarse-grained substrates or when fine-scale variation is suspected.
- Conduct literature review to evaluate the protocol for sub-sampling in the upper 3 cm of each sample.
- Sample sediments in known mussel beds to better characterize "suitable" mussel habitat in the project area.

4.4 CHARACTERISTICS OF ACOUSTIC CLASSES

Based on examination of grain size distributions in undisturbed samples, most samples were primarily fines (157/258 = 61percent). Samples dominated by other grain sizes frequently had fines (45/258 = 17 percent). Sand dominated samples comprised a small proportion of the total (35/258 = 14 percent). Just 15 percent of total number of samples (39/258 = 15 percent) were comprised of coarse-grained sediments as the dominant fraction *and* had fines comprising less than 10 percent of the total sample. Cobbles were dominant in 5 percent of the samples and only one boulder dominant sample was found.

Based on grain size (**Table 24**), there are three groups of acoustic classes that are significantly different:

- Classes 1, 2, and 3 are distinct from the others and have coarse-grained sediments;
- Classes 4, 5, 6, and 7 are distinct from classes 1, 2, and 3 and have fine-grained sediments; and
- Class 5 is distinct from classes 4, 6, and 7 and lacks the medium sand found in classes 4, 6, and 7.

Examination of a data set with both partially disturbed and undisturbed samples enables finer distinctions among both the coarse-grained samples and fine-grained groups but does not change the overall groupings based on grain size. Overall less than about 25 percent of the grab samples (n = 448) have one grain size component that constitutes more than 80 percent of the sample weight. The highest proportion of samples approaching uniformity occurs in acoustic classes 5 (47 percent) and 6 (44 percent). Acoustic classes 3 and 1 have the lowest proportion of samples approaching uniformity (16 percent and 19 percent respectively).

Other characteristics of the grab samples and the field effort (**Table 24**) provide consistent significant differences for these same three groups: acoustic classes 1, 2, and 3; acoustic classes 4, 6, and 7, and acoustic class 5. Acoustic classes 1, 2, and 3 have about the same percentage of empty and disturbed grabs (56 percent to 65 percent) and mean depth of penetration (40 to 48 mm). Acoustic classes 4, 6, 7 have lower percentages of empty and disturbed grabs (37 percent to 38 percent) and higher depth of penetration (88 to 115 mm). Acoustic Class 5 is distinct in having the highest percentage of empty and disturbed grabs (73 percent) and the lowest depth of penetration (28 mm). Laminate structure was observed with highest frequency in acoustic classes 6 (35 percent) and 7 (40 percent) and lowest frequency in acoustic classes 2 (8 percent) and 5 (12.5 percent).

With regard to depth, the acoustic classes do not follow the same pattern. They appear to be stratified in two groups, those with mean depths greater than 20 feet and those with mean depths less than 20 feet. The greatest sampling depths occur in acoustic classes 3, 4, and 5 and the smallest depths occur in acoustic classes 7 and 2. The deepest acoustic classes also produced the highest proportion of grab attempts that were fully closed and empty with this occurring in acoustic class 5 far more frequently than any of the other classes.

When examined individually, each acoustic class has the following distinguishing characteristics:

- Acoustic class 1 is coarse-grained with samples that are cobble and some samples that are fines. This class may have the “hardest” bottom of the coarse-grained substrates;
- Acoustic class 2 is coarse-grained with some samples that are fines;
- Acoustic class 3 is coarse-grained with some samples that are medium sand and fines. It has the deepest sampling depths, highest frequency of laminate structure and the widest range of substrate types;
- Acoustic class 4 is fine-grained with the most samples comprised of fines and some samples comprised of medium sand. It is the deepest of the fine-grained acoustic classes;
- Acoustic class 5 is fine-grained with most samples comprised of fines. Medium sand was absent from this class. Acoustic class 5 is distinct from the other classes and is hypothesized to be a “skin” of fine-grained sediment over hard pan or bedrock;
- Acoustic class 6 is fine-grained with most samples comprised of fines and other samples that are medium sand or coarse gravel. This acoustic class is primarily restricted to shallower depths; and
- Acoustic class 7 is fine-grained with most samples comprised of fines and other samples that are coarse gravel or medium sand. The shallower depth of penetration and the higher proportion of samples with laminate stratification suggests AC7 is a “harder” bottom substrate than acoustic class 6.

The distribution of dominant grain sizes varies substantially both among and within pools. Samples from Emsworth pool were almost entirely fine-grained substrates while New Cumberland pool was skewed toward coarse-grained substrates. The range of particle sizes observed in samples from Dashields and Montgomery were wider than observed at the other pools.

Table 24. Grand Summary.

Aspect	Acoustic Class 1	2	3	4	5	6	7	Total, Median, or Mean
Grain Size Distribution	Coarse	Coarse	Coarse	Fine	Fine	Fine	Fine	
Dominant Samples (Undisturbed and Partially Disturbed)	Coarse Gravel	Coarse Gravel	Coarse Gravel	Fines	Fines	Fines	Fines	N/A
Sub-Dominant Samples (Undisturbed and Partially Disturbed)	Cobble, Fines	Fines	Medium Gravel, Fines	Medium Sand	Fine Gravel	Medium Sand, Coarse Gravel	Coarse Gravel, Medium Sand	N/A
% of samples (undisturbed) with one component greater than 80%	21.7%	12.5%	8.8%	24.6%	56.3%	49.0%	20.9%	28.3%
% of total grabs that are empty or disturbed	60%	65%	56%	37%	73%	38%	37%	53%
% of grab attempts that are empty	10%	13%	16%	18%	63%	11%	10%	18%
Median Depth of Grab Penetration	41	47	46	105	28	116	86	81
% of samples with laminate structure	21.7%	8.7%	24.2%	29.5%	12.5%	35.3%	39.5%	27.3%
Mean Depth (ft) of Grab Samples	14	11	24	25	22	13	10	17.5
Maximum Depth (ft) of Grab Samples	17	15	43	47	27	25	15	27
% of Samples within margin	65%	79%	0%	71%	13%	92%	98%	68%

5.0 Conclusion

The acoustic sonar survey produced broad maps of substrate classes in the study area. Ground-truthing was conducted to test associations between sediment collected in the field and the acoustic classes. Using the field data, significant differences were detected among the seven classes. The acoustic classes show association with sediments in the following grain size categories: 1) coarse-grained; 2) fine-grained; and 3) fine-grained over hard bottom. Other sampling metrics such as grab penetration, empty grab attempts, laminate structure (**Table 24**) are consistent with those associations.

Even though samples with coarse-grained sediment was dominant in acoustic classes 1, 2, and 3, samples with fines or sand were observed at low frequency. Conversely, samples with coarse-grained substrates were found in low frequencies in fine-grained acoustic classes 4, 5, 6, and 7. At the level of present analyses, the ground-truthing data distinguished significant difference in substrate types among three groups of acoustic classes but did not distinguish significant differences among the classes within each group. A more sophisticated approach using multivariate analysis on grain size distributions and other variables may be able to further distinguish the acoustic classes. The true test of correlation for the acoustic data will require regression analysis with a sophisticated model and using location-specific acoustic signal characteristics as the dependent variable rather than acoustic class. The seven acoustic classes, as currently structured, will not support a robust regression model. This regression analysis must occur at a finer scale of resolution than the acoustic class.

6.0 Acknowledgements

Carmen Agouridis of the University of Kentucky provided comments and constructive feedback on an early draft of this document. Tom Maier and Conrad Weiser of the District reviewed the draft document and provided comments. Their comments and our responses are included as Appendix I. Cody Fleece, Joe Templeton, Adam Pooler, Joey Seamands, Richard Andrews, and Christopher Krumm participated in the field effort.

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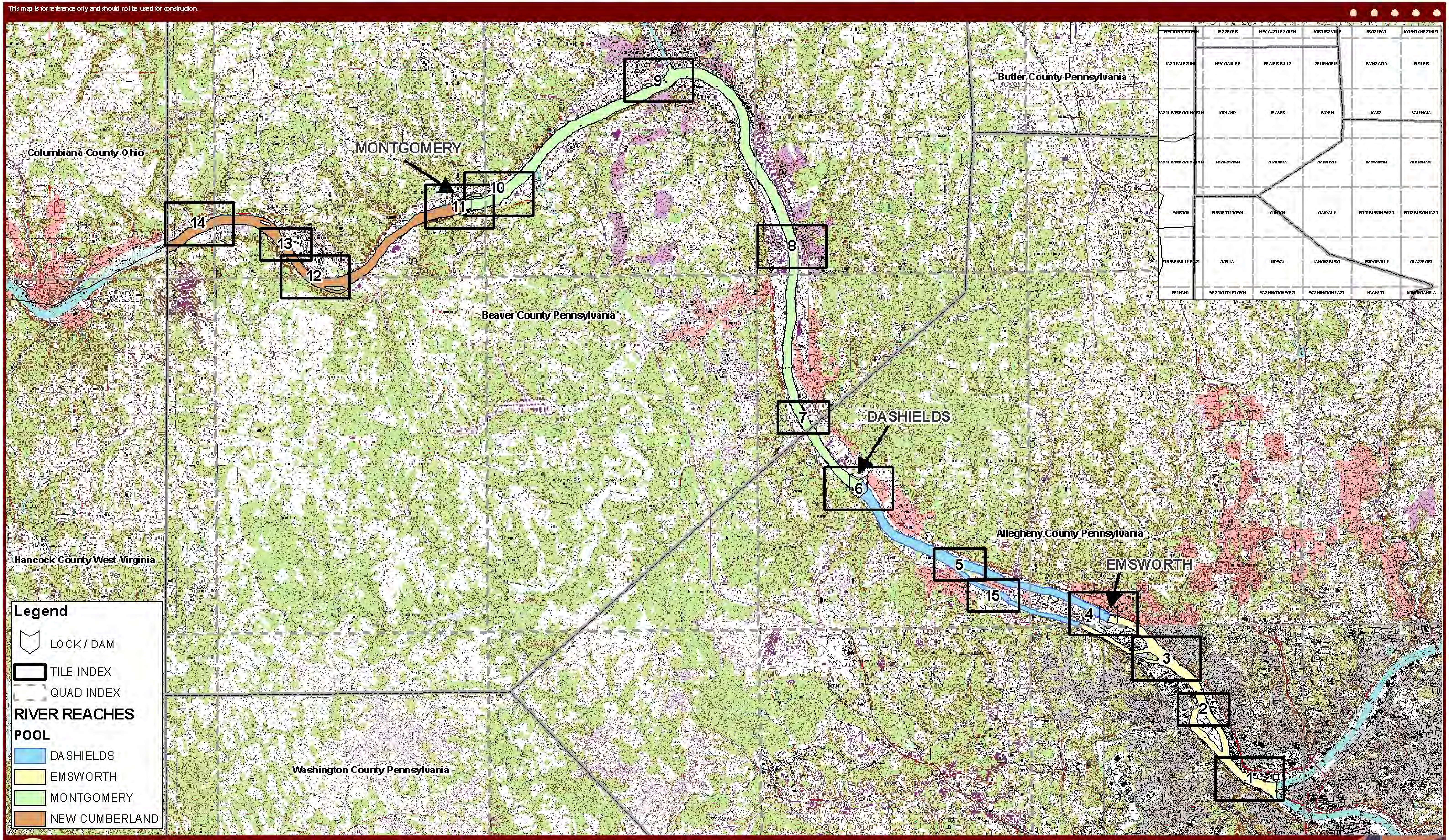

Geographic Information Systems

Cartographic Design By: Adam Pooler

0 5 10 Miles

N

Ohio River Sediment - Acoustic Ban Ground-Truthing

Figure 1

Stantec

Only sites with undisturbed grabs labeled. The " -# " represents the number of undisturbed grabs per site.

TILE 1

Appendix C-1. Surface Disturbance and Closure Status

Ohio River Sediment: Pittsburgh, PA

Stantec
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Only sites with undisturbed grabs labeled. The " -# " represents the number of undisturbed grabs per site.

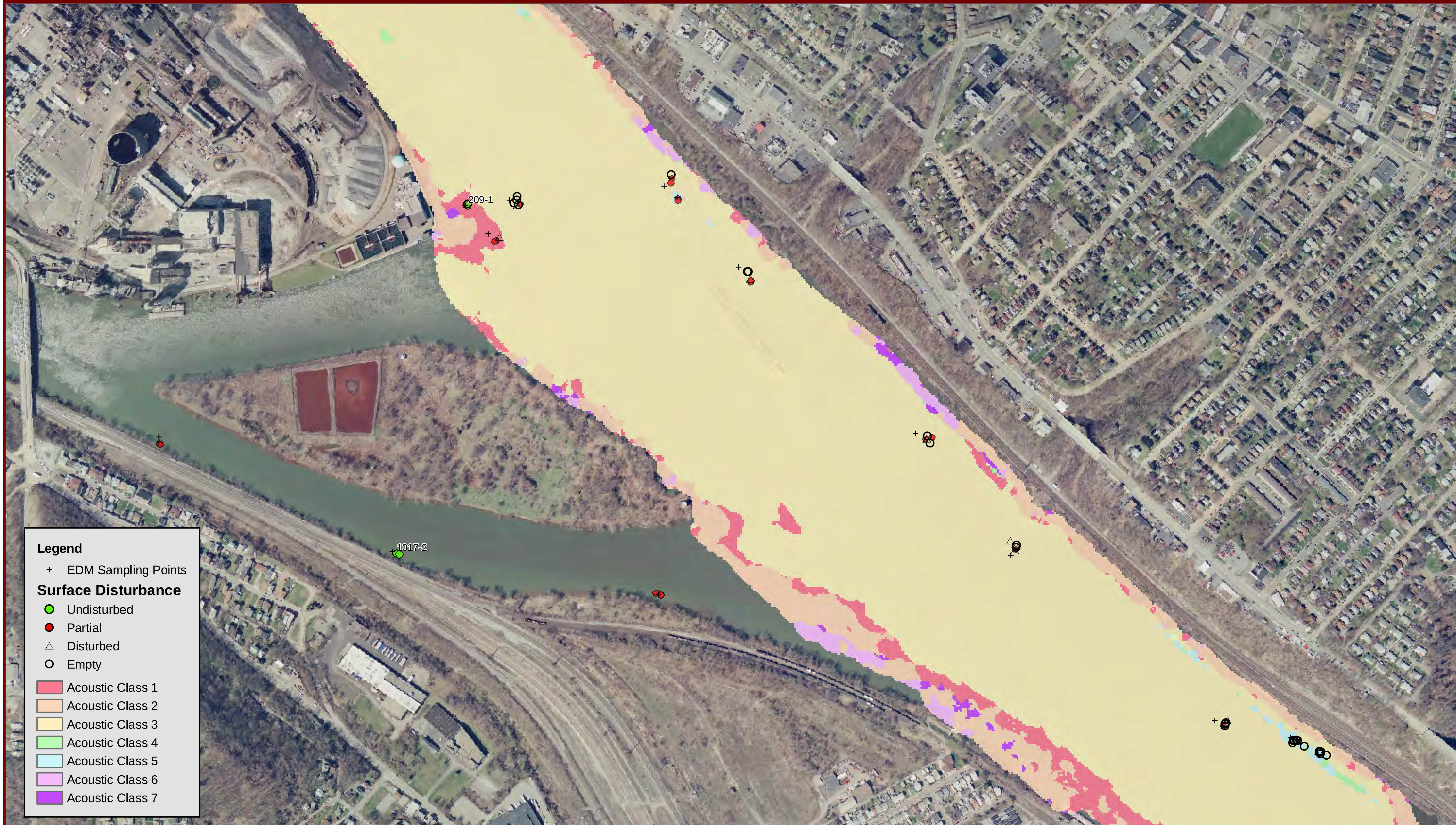
TILE 2

Appendix C-2. Surface Disturbance and Closure Status

Ohio River Sediment: Pittsburgh, PA

Stantec 11687 Lebanon Rd. Cincinnati, OH 45241-2012 Phone 513-842-8200 Fax 513-842-8250 www.stantec.com

Only sites with undisturbed grabs labeled. The " -# " represents the number of undisturbed grabs per site.



TILE 3

0 250 500 1,000 Feet

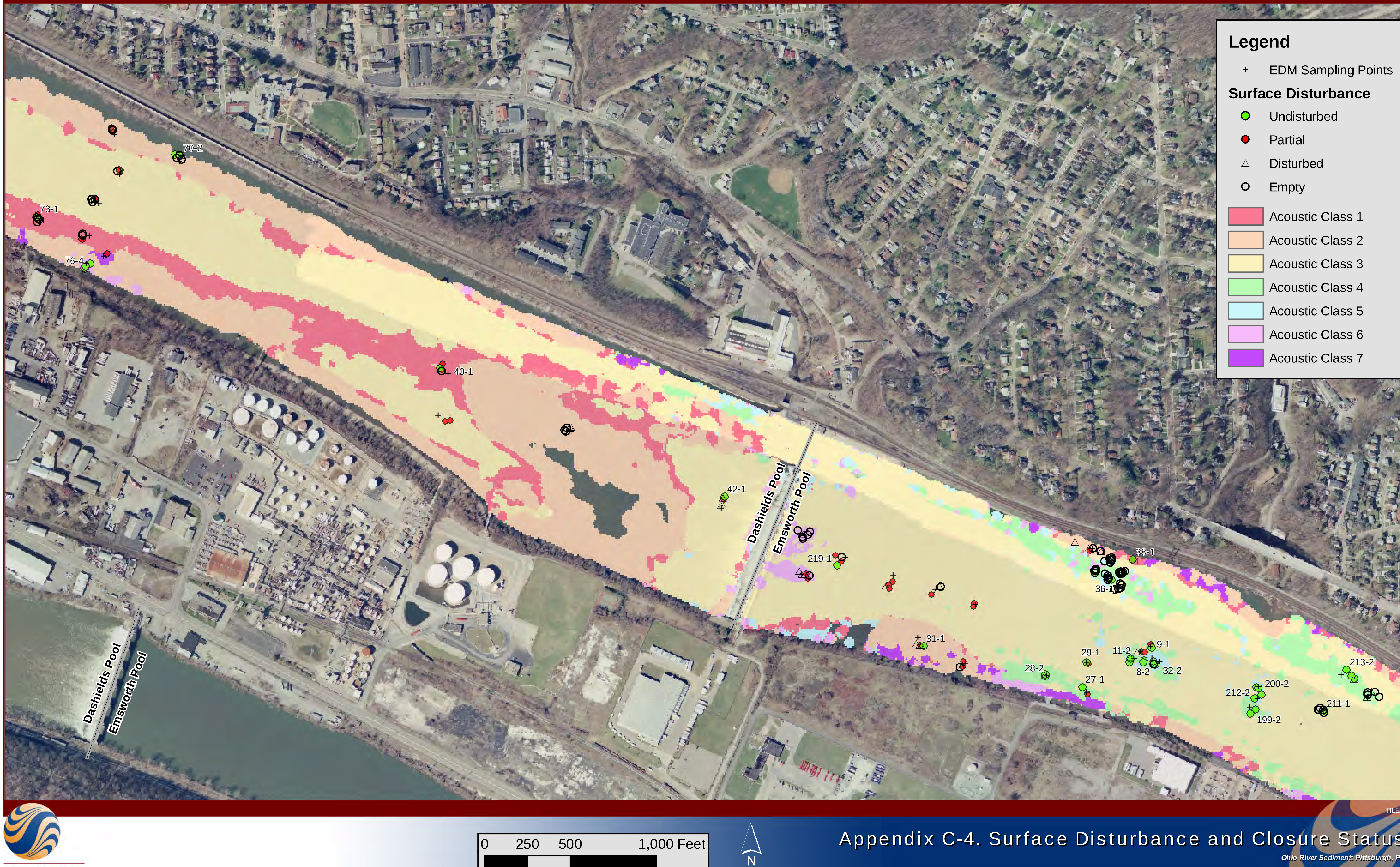
N

Appendix C-3. Surface Disturbance and Closure Status

Ohio River Sediment: Pittsburgh, PA

Stantec
11687 Lebanon Rd. Cincinnati, OH 45241-2012 Phone 513-842-8200 Fax 513-842-8250 www.stantec.com

Only sites with undisturbed grabs labeled. The " -# " represents the number of undisturbed grabs per site.



Appendix C-4. Surface Disturbance and Closure Status

Ohio River Sediment: Pittsburgh, PA

Stantec
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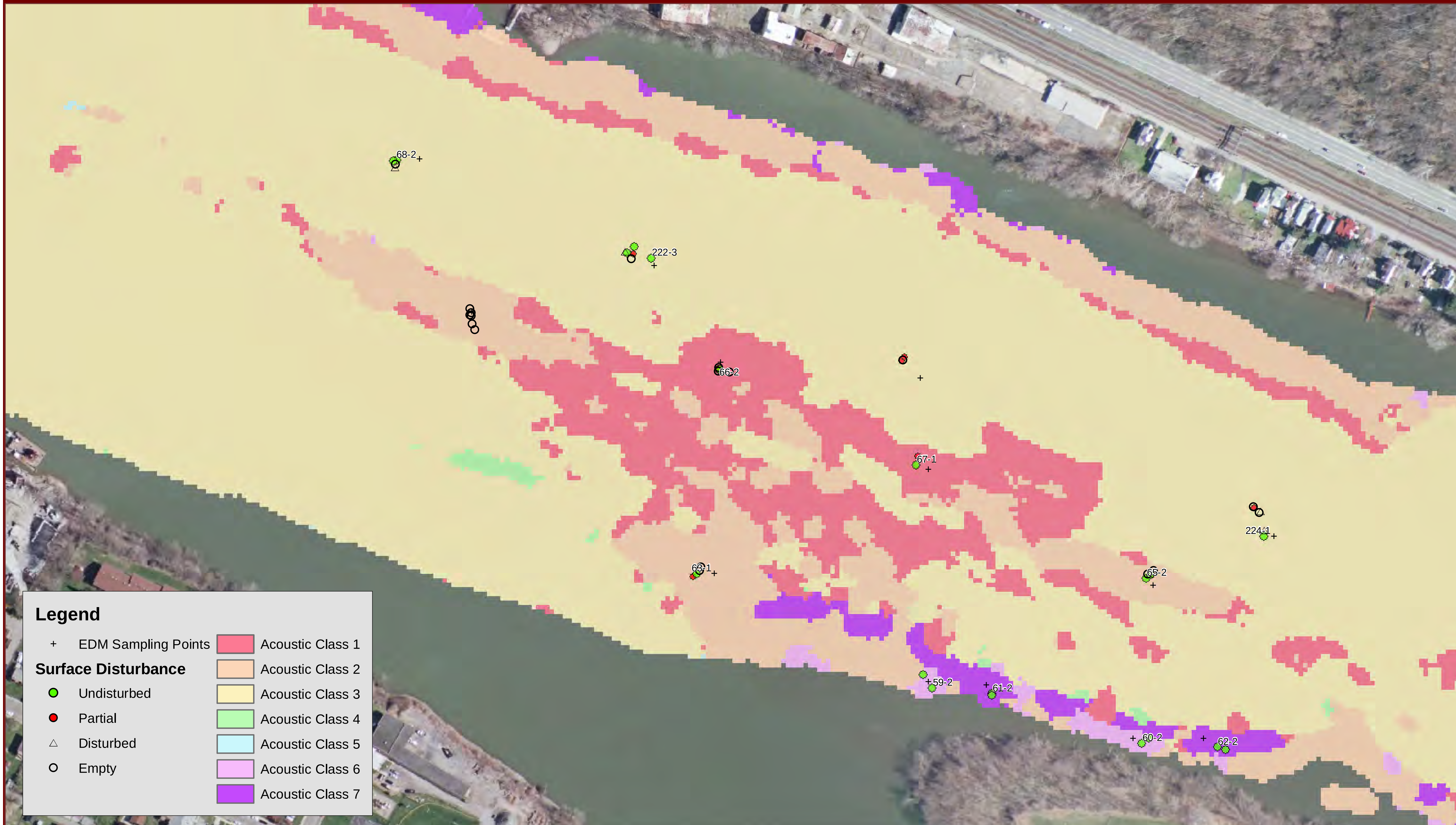
Only sites with undisturbed grabs labeled. The " -# " represents the number of undisturbed grabs per site.



TILE 5

0 100 200 400 Feet

N

Appendix C-5. Surface Disturbance and Closure Status

Ohio River Sediment: Pittsburgh, PA

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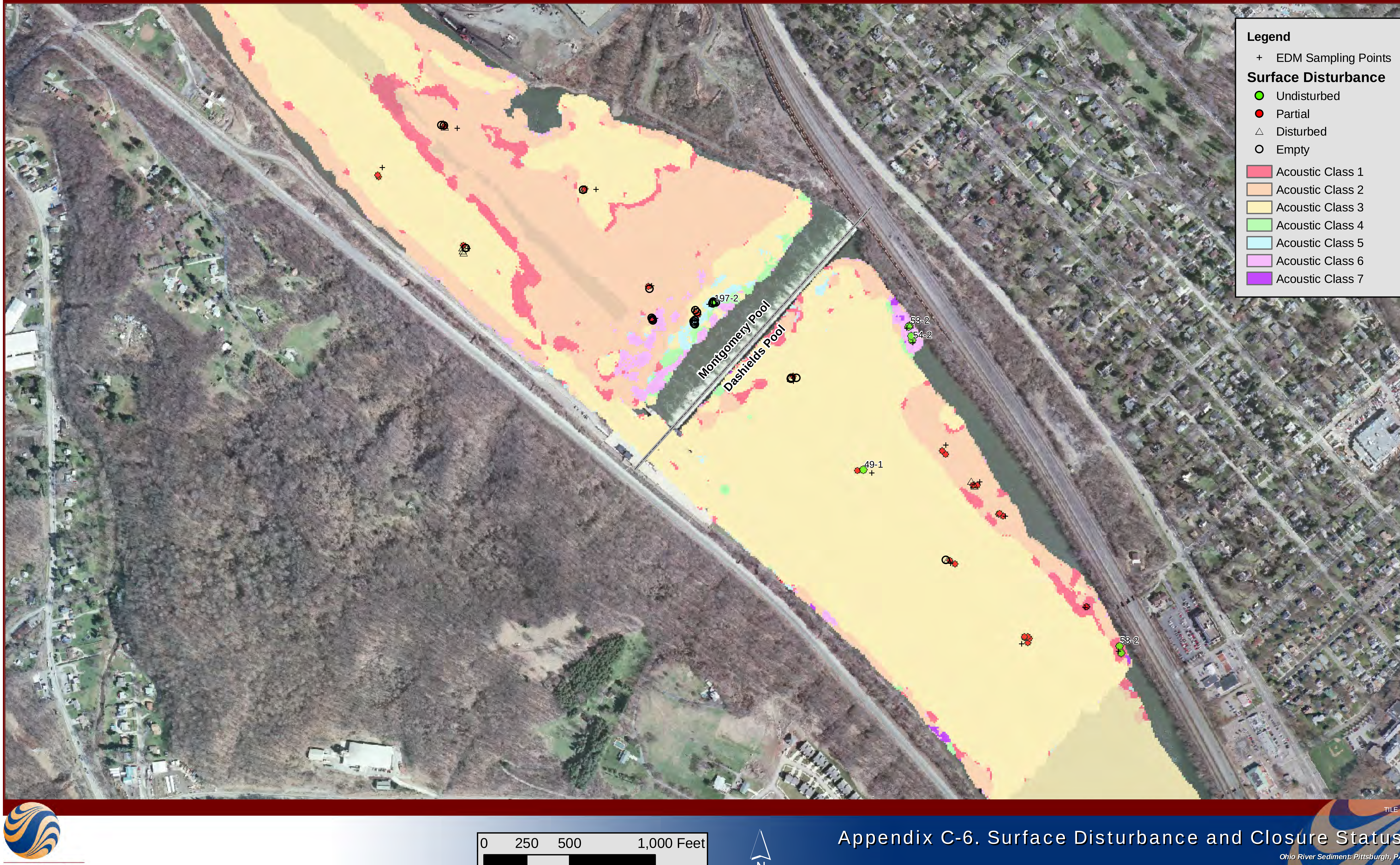
Only sites with undisturbed grabs labeled. The " -# " represents the number of undisturbed grabs per site.



TILE 6

Appendix C-6. Surface Disturbance and Closure Status

Ohio River Sediment: Pittsburgh, PA

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Only sites with undisturbed grabs labeled. The " -# " represents the number of undisturbed grabs per site.

TILE 7

Appendix C-7. Surface Disturbance and Closure Status

Ohio River Sediment: Pittsburgh, PA

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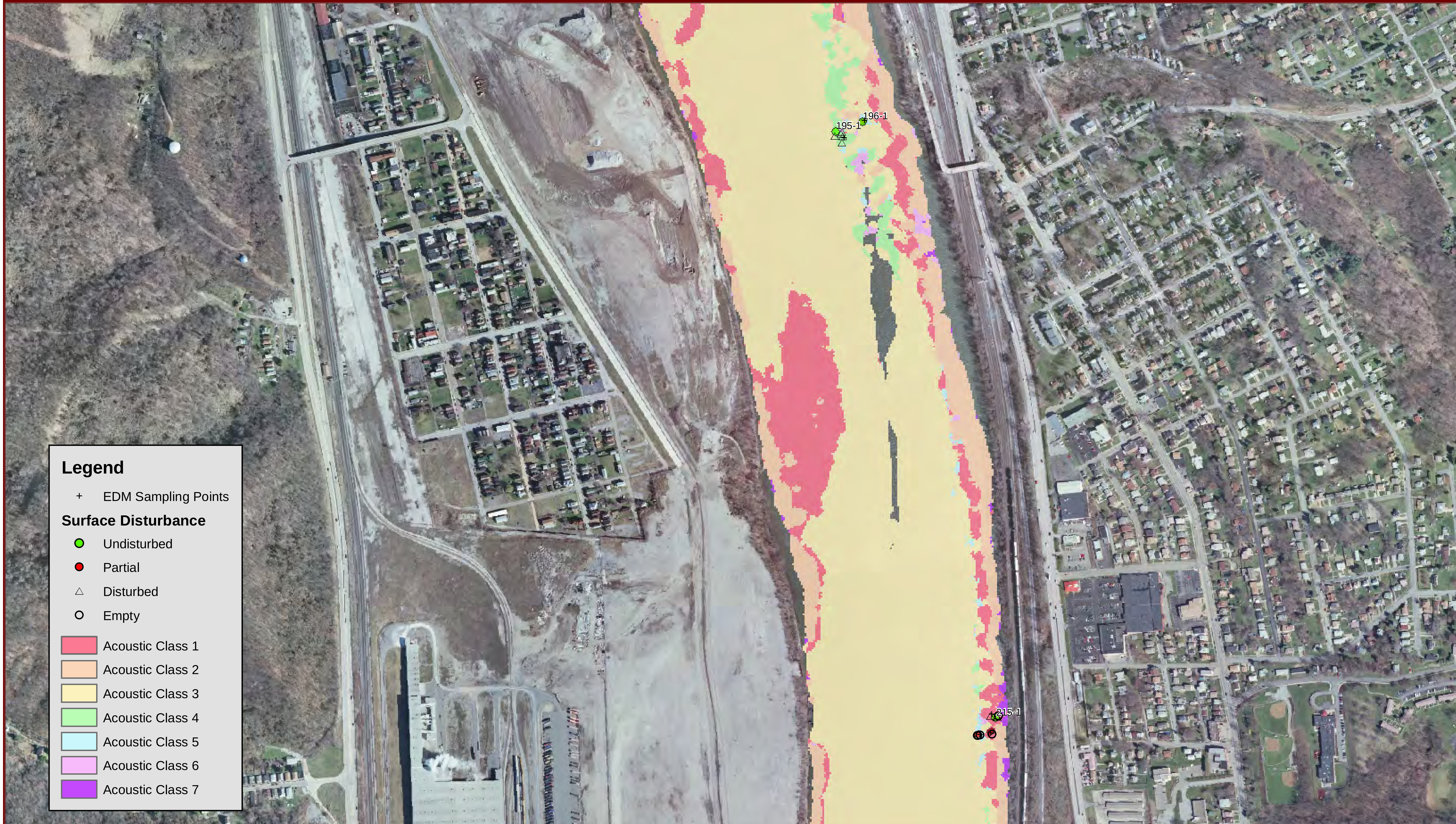
Only sites with undisturbed grabs labeled. The " -# " represents the number of undisturbed grabs per site.



TILE 8

0 250 500 1,000 Feet

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Appendix C-8. Surface Disturbance and Closure Status

Ohio River Sediment: Pittsburgh, PA

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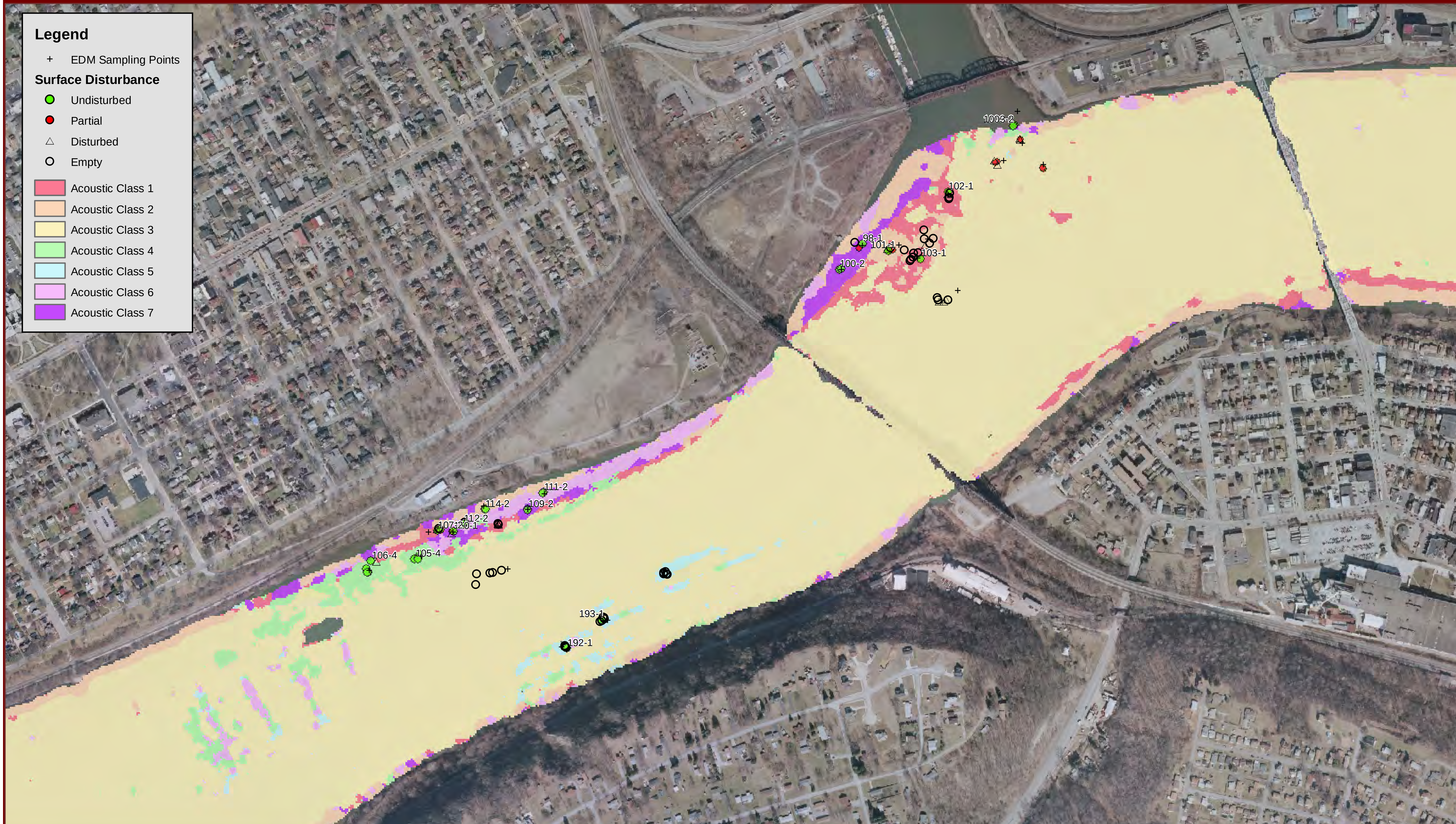
Only sites with undisturbed grabs labeled. The " -# " represents the number of undisturbed grabs per site.



TILE 9

0 250 500 1,000 Feet

N

Appendix C-9. Surface Disturbance and Closure Status

Ohio River Sediment: Pittsburgh, PA

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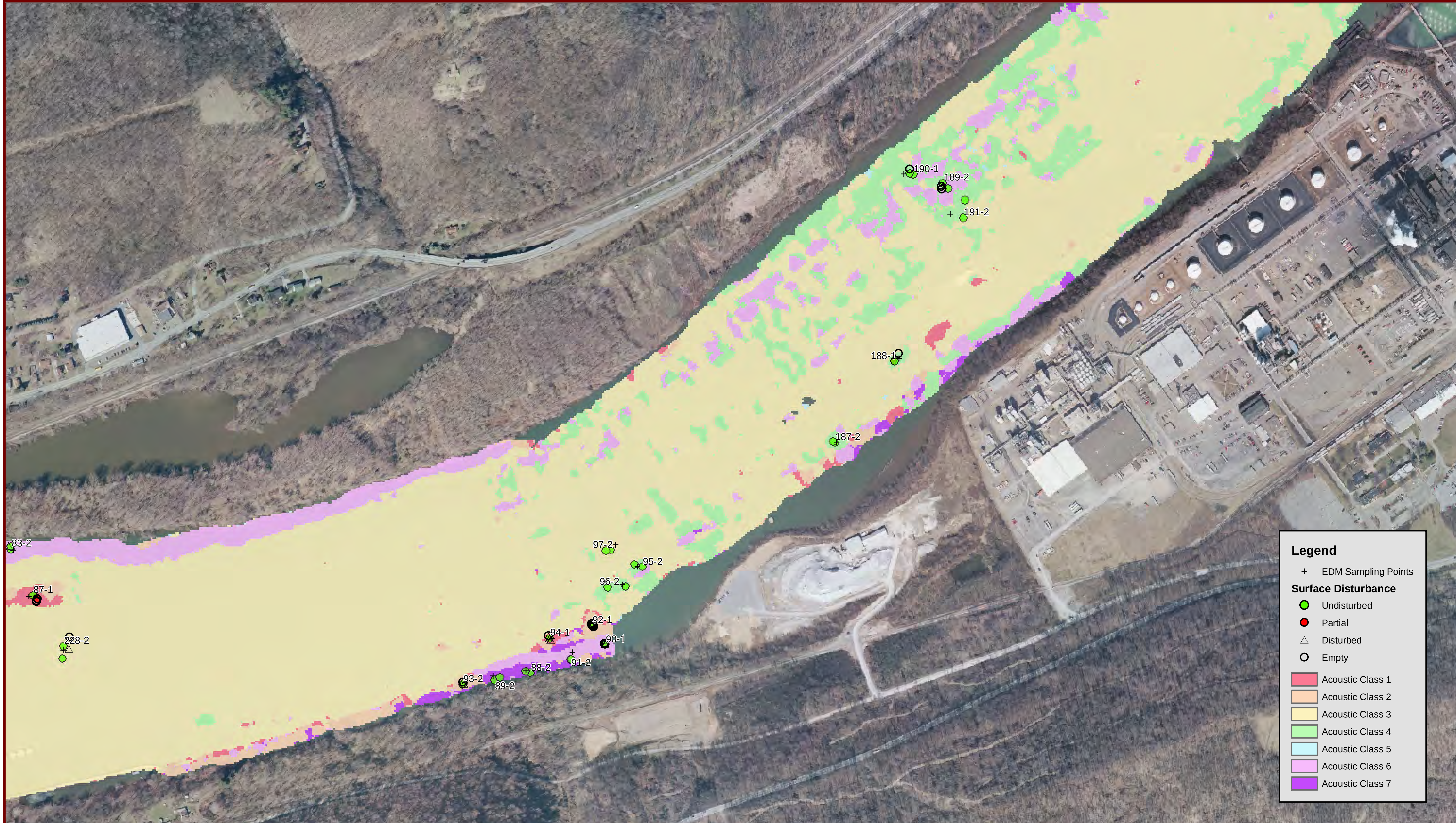
Only sites with undisturbed grabs labeled. The " -# " represents the number of undisturbed grabs per site.



TILE 10

0 250 500 1,000 Feet

N

Appendix C-10. Surface Disturbance and Closure Status

Ohio River Sediment: Pittsburgh, PA

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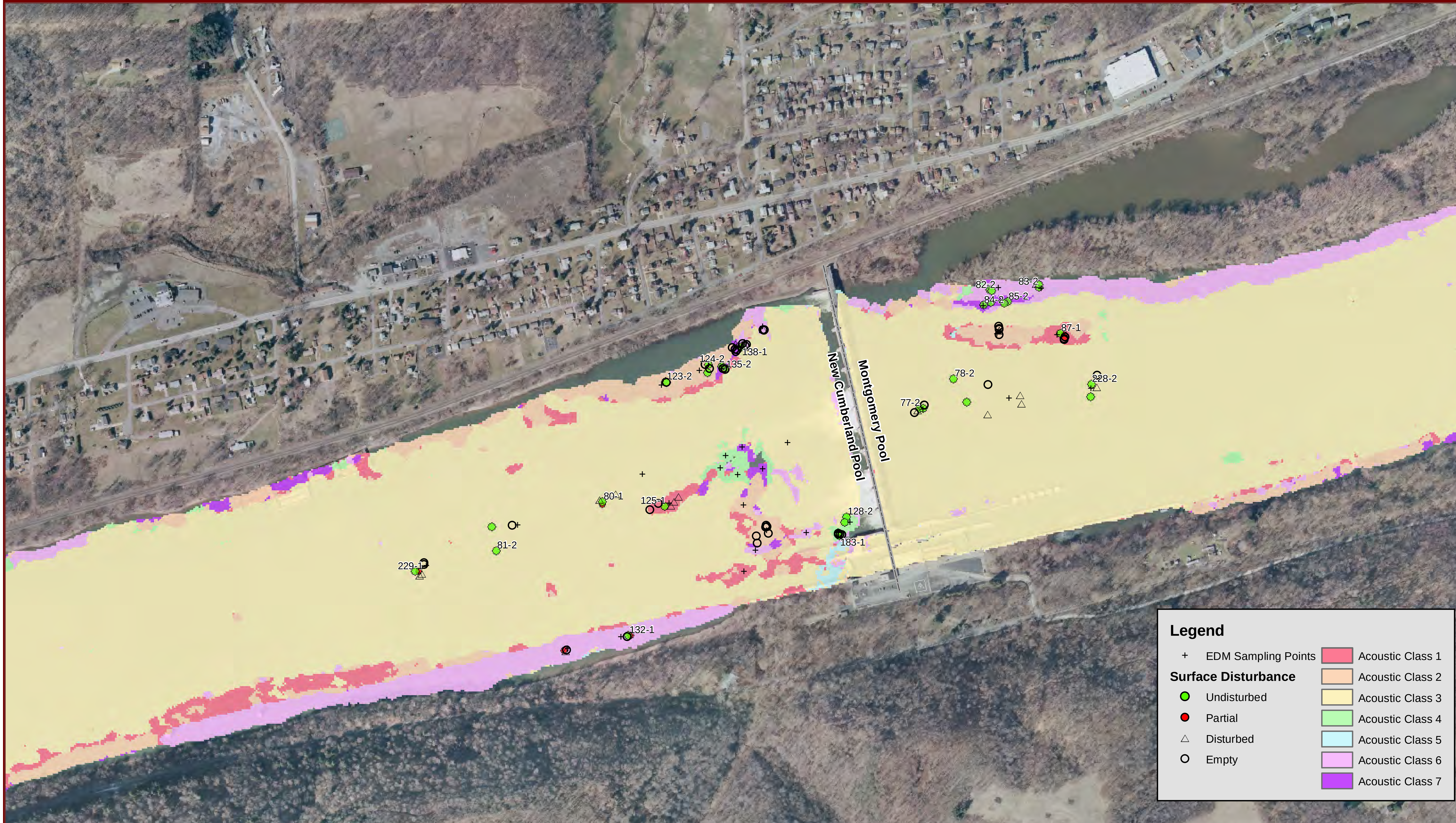

TILE 11

Appendix C-11. Surface Disturbance and Closure Status

Ohio River Sediment: Pittsburgh, PA

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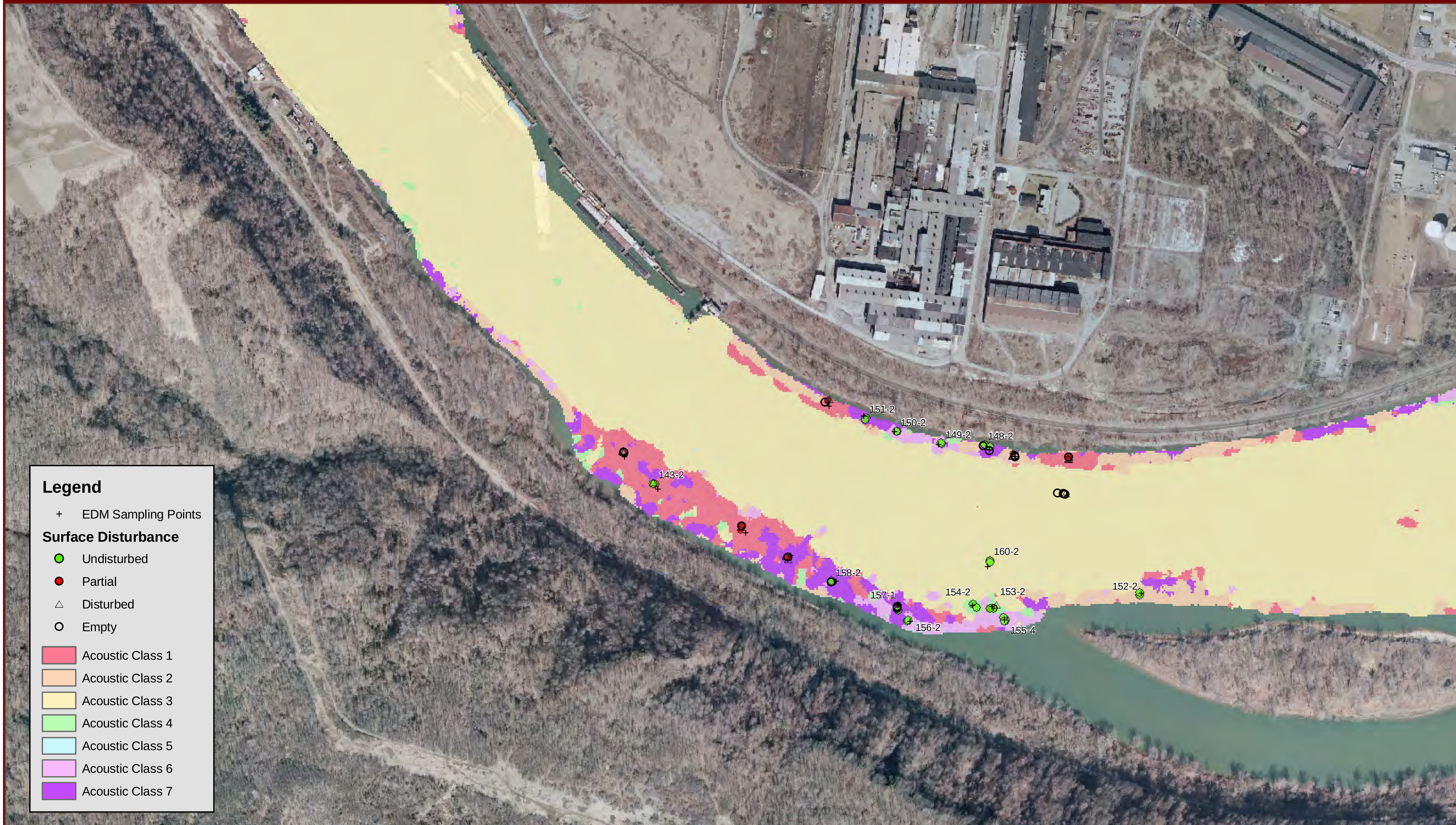

TILE 12

0 250 500 1,000 Feet

N

Appendix C-12. Surface Disturbance and Closure Status

Ohio River Sediment: Pittsburgh, PA

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Only sites with undisturbed grabs labeled. The " -# " represents the number of undisturbed grabs per site.

TILE 13

Appendix C-13. Surface Disturbance and Closure Status

Ohio River Sediment: Pittsburgh, PA

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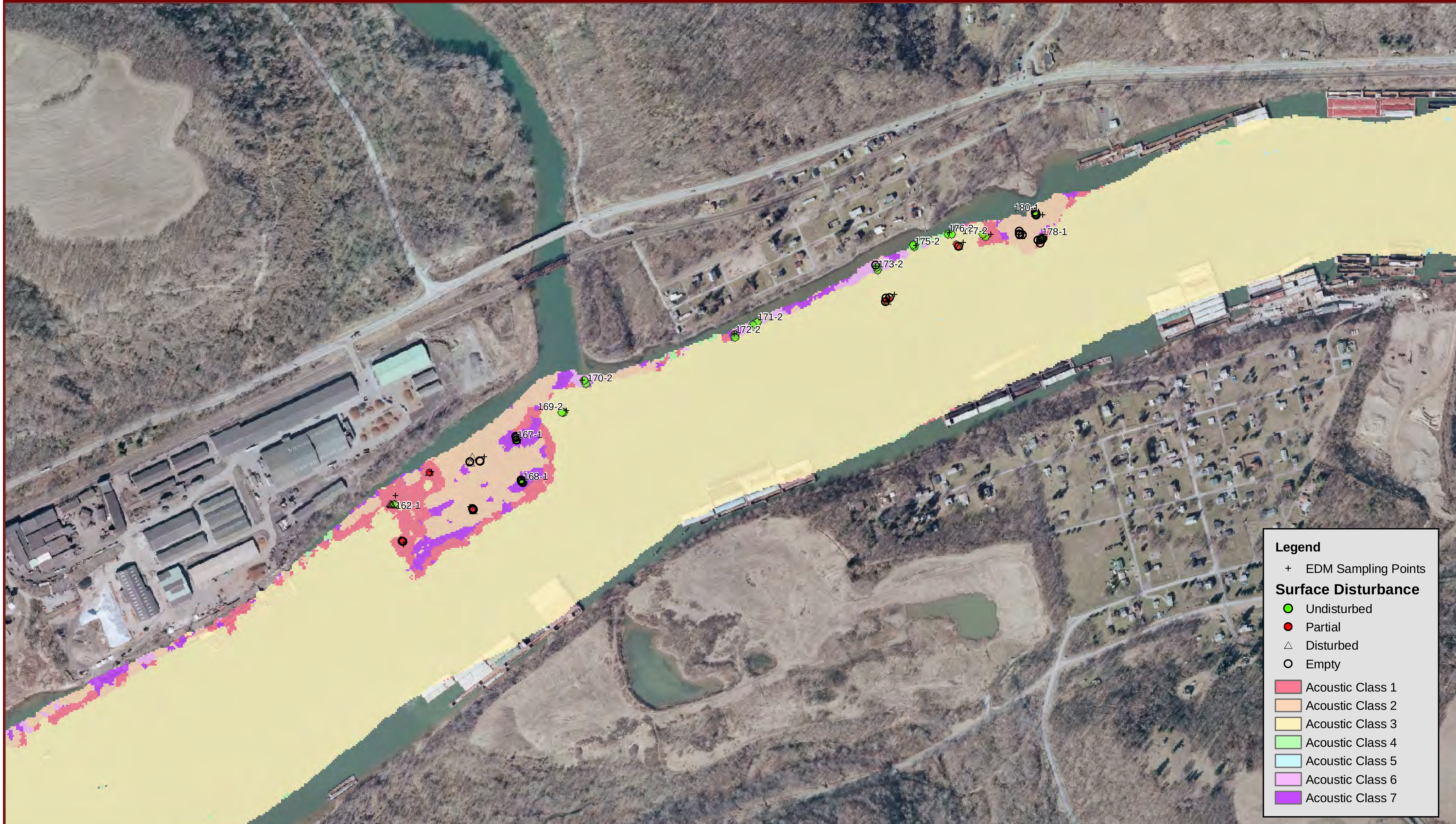
Only sites with undisturbed grabs labeled. The " -# " represents the number of undisturbed grabs per site.



TILE 14

Appendix C-14. Surface Disturbance and Closure Status

Ohio River Sediment: Pittsburgh, PA

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Only sites with undisturbed grabs labeled. The " -# " represents the number of undisturbed grabs per site.

TILE 15 Restoration

0 200 400 Feet

N

Appendix C-15. Surface Disturbance and Closure Status

Ohio River Sediment: Pittsburgh, PA

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