

**CHARACTERIZATION REPORT  
FOR PLUM BROOK SEDIMENT IN  
STREAM MOUTH WETLANDS**

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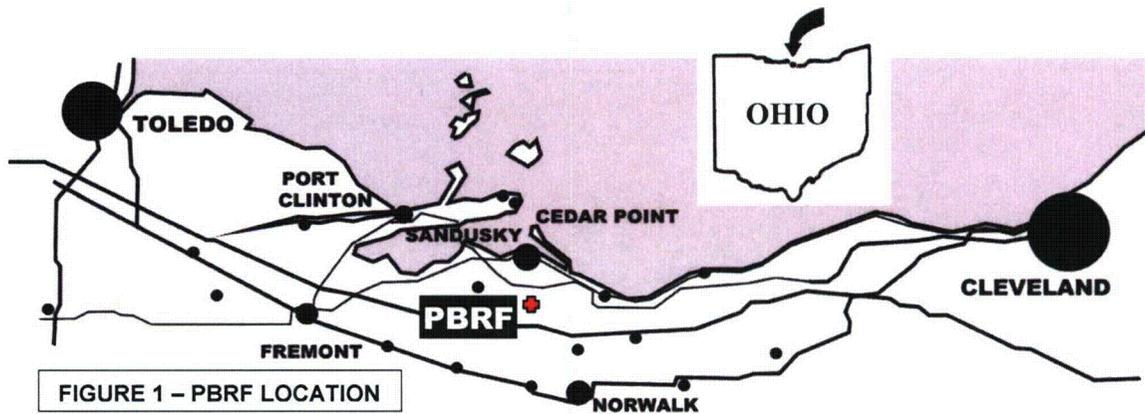
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# CHARACTERIZATION REPORT FOR PLUM BROOK SEDIMENT IN STREAM MOUTH WETLANDS

## INTRODUCTION

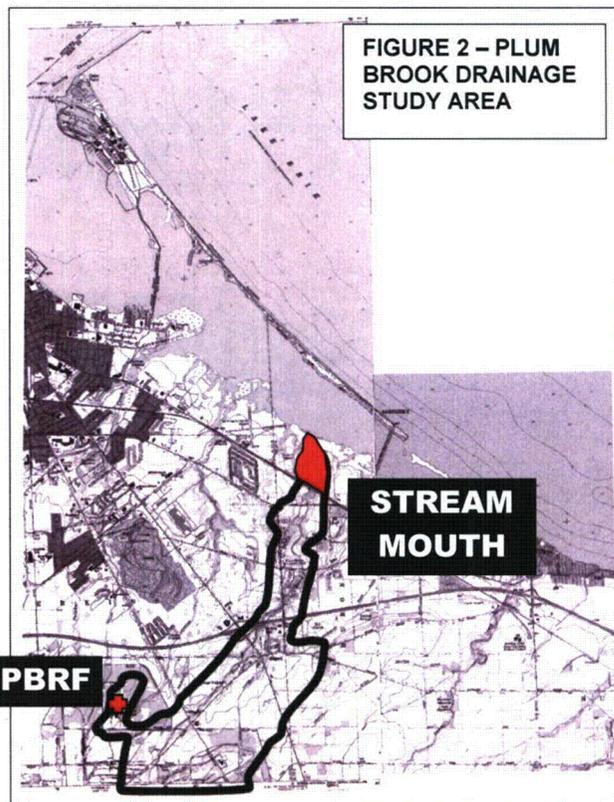
This report documents an investigation of the potential distribution of a radioactive isotope of the element cesium, known as  $^{137}\text{Cs}$ , or Cs-137, in the stream mouth wetlands of Plum Brook near Sandusky, Ohio. This investigation was conducted to determine whether Cs-137 attributable to a decommissioned reactor facility could be detected there, above the background levels attributable to atmospheric atomic bomb testing.



The Plum Brook Reactor Facility (PBRF) was built by the National Aeronautics and Space Administration (NASA), on property referred to as NASA's Plum Brook Station. The relative locations of the PBRF and the stream mouth wetlands are illustrated by Figures 1 and 2.

### PLUM BROOK FACILITY BACKGROUND

Prior to acquisition by NASA, the Plum Brook Station was known as the Plum Brook Ordnance Works (PBO). The PBO was a World War II-era facility that made explosives for the war effort, including TNT and Pentolite.



Operation of the PBOW ceased in 1945. Using a portion of the former site of the PBOW's Pentolite manufacturing facility, north of Pentolite Road, NASA began construction of a nuclear research facility in 1958. At this site, which NASA called the PBRF, NASA constructed two nuclear reactors, a 60 MW test reactor and a 100 KW research reactor. The reactors at the PBRF operated between 1961 and 1973.

Water was an essential element for nuclear reactor operations. Raw water from Lake Erie was pumped to the site at roughly 400-800 gallons per minute to support plant operations. Most raw water was softened through precipitation, sand filtering and chlorination to become process water. As needed, process water was de-ionized for the following uses: as the coolant for the nuclear reactors and experiment equipment; in the quadrants and canals for shielding when transferring radioactive materials; and in the analytical laboratories. The de-ionized water used for reactor and experiment cooling became radioactively contaminated due to exposure in the reactor, and that in the quadrants and canals due to mixing with radioactive sources (reactor water, experiment hardware, irradiated fuel, etc.).

Radioactively contaminated water was normally recycled for reuse on-site or stored for decay or batch release processing in areas such as the Hot and Cold Retention Areas (HRAs, CRAs) or the Emergency Retention Basin (ERB). Prior to release to the environment, stored waters were sampled and analyzed for chemical and radioisotope contaminants, and then, as appropriate, (1) treated by filtering, demineralization or evaporation to reduce the contamination levels or (2) diluted with uncontaminated water (raw or process water) for off-site release within existing Federal regulatory limits.

Water used in operation of the reactor was discharged off-site after analysis and/or continuous monitoring for radioactivity levels to ensure compliance with Federal regulatory requirements. PBRF utilized a water effluent monitoring system (WEMS) at the site boundary that continuously monitored radioactivity levels and volumes of surface and wastewater leaving the site. If radioactivity levels exceeded pre-set safety limits, the WEMS would shut associated gates that stopped any further releases from the site.

PBRF effluent water was released from the site directly into Pentolite Ditch, which runs along the south side of Pentolite Road. PBRF effluents mixed with drainage from the remains of the contaminated PBOW pond called the Pentolite Road Red Water Pond (PRRWP). This pond was south of Pentolite Ditch, just downstream from the reactor facility's WEMS. This former pond had once contained the acidic wash water from the TNT manufacturing process, known as red water. While the pond no longer exists, soil and groundwater in the area remain contaminated, and some leaching of red water into Pentolite Ditch has been known to occur.

#### **DISCOVERY OF OFF-SITE CESIUM-137**

Decommissioning of the PBRF was in progress at the time of this writing. During the decommissioning process, it was discovered that Cs-137 was detectable in the sediments

of Plum Brook, at the southern end of the part of the stream's drainage basin shown on the map in Figure 2.

### **DEVELOPMENT OF CHARACTERIZATION PLAN**

Based upon its initial testing results from the sediments of Plum Brook, NASA judged that it would be important to understand the stream and groundwater hydrology governing the distribution and deposition of Cs-137. NASA therefore commissioned a review of hydrogeologic data, and preparation of a characterization plan.

The characterization plan was based upon the results of the hydrogeologic review, as well as the results of scoping surveys that had been conducted previously for NASA. Those scoping surveys were conducted in meandering-stream sediments far upstream from the bay. The meandering-stream sediment testing results revealed scattered small areas of elevated Cs-137 activity, as opposed to a uniform distribution of Cs-137 activity over a broad area. Upon further evaluation, it was determined that the distribution of Cs-137 activity in the meandering-stream sediments was lognormal, which is typical for such settings.

The purpose of the study documented in this report was to assess the distribution of Cs-137 activity in the stream mouth wetlands, where Plum Brook entered East Sandusky Bay.

## CHARACTERIZATION PLAN OBJECTIVES

Sampling and analysis to determine the lateral and vertical character and extent of Cs-137 contamination had the following objectives:

1. Verify mechanisms of Cs-137 transport
2. Provide approximate accounting for all Cs-137 known to be released
3. Identify Cs-137 deposits still in transit
4. Locate final resting places of Cs-137 no longer in transit

Sampling and analysis to support possible future remediation, if warranted, added the following objective to the Characterization Plan:

5. Describe Cs-137 deposit characteristics that affect removal

The requirements to support objectives 1-4 are governed by standard principles of surface hydrology, geomorphology, and groundwater hydrology. Those concepts are embodied in USEPA's Sediment Sampling Quality Assurance User's Guide," (EPA 600/4-85-048, July 1985, NTIS #PB85-233542).

The requirements to support objective 5 can be guided by experience gained in the remediation of sediments. Those concepts are embodied in many of the projects conducted under USEPA's Superfund Innovative Technology (SITE) program, and in projects documented by USDOE's Technical Information Exchange (TIE) program.

## DATA QUALITY OBJECTIVES

Data quality objectives (DQOs) are developed to ensure that measurement data will be suitable for decision-making. The DQO development process requires one to identify a scientific “problem” to solve, to formulate a decision regarding that problem, and to specify a rule for making that decision.

The decision is normally framed as a hypothesis, which will be accepted or rejected. The decision rule often contains a statistical test, and is often stated as follows: “We will reject the hypothesis if the statistical test is greater than [a value].”

The problem statements, decisions, and decision rules for this plan are provided below. From these we can develop quantitative measures of the data quality needed to make the decisions.

## PROBLEM STATEMENTS

This sampling program was premised upon the assumption that Cs-137 was dissolved in water in the reactor’s primary cooling system. During each of 152 cycles of reactor operation, spanning a decade, water from this system was discharged into Pentolite Ditch, after careful monitoring to maintain contaminant levels below regulatory limits. It was estimated by former NASA employee Jack Crooks that Cs-137 producing a total of 5 millicuries ( $5 \times 10^{-3}$  curies), or 5,000,000,000 picoCuries ( $5,000,000,000 \times 10^{-12}$  curies) of radioactivity was discharged into Pentolite Ditch. Due to the natural radioactive decay of Cs-137, which has a half-life of 30 years, it was estimated that less than 2,500,000,000 picoCuries (pCi) of Cs-137 activity remained to be found in the years 2006 and 2007, when this study was conducted.

This sampling program was also premised upon the assumption that all of the Cs-137 dissolved in that cooling water was quickly and irreversibly adsorbed by clay minerals in fine sediment. Most of that fine sediment was expected to have been originally located in the bottom of Pentolite Ditch, and in Plum Brook sediments. Some of that fine sediment may have been originally located in the PBRF drainage systems. Some of that fine sediment may have been originally located in bedrock fractures.

Finally, this sampling program was premised upon the assumption that, wherever the contaminated fine sediment was transported since the reactor began operating in 1961, the Cs-137 was also transported.

**Problem Statement for Extent** – Clay minerals are created by the weathering of rock. Clays are carried by water, and are deposited in known patterns in different depositional environments. To define the extent of Cs-137 contamination, our goal was to identify clays over which PBRF cooling water passed, between 1961 and 1973. Once those clays were identified, our goal was to determine where they had traveled since 1961.

**Problem Statement for Remediation** – If remediation should be needed, the goal would be to remove as much Cs-137 as possible, with the smallest effect possible. It was considered that this would likely translate into a goal of removing contaminated clay, without removing other types of soil, which were expected to be relatively uncontaminated.

## **DECISIONS**

For each of seven identified depositional environments, including the stream mouth wetlands environment addressed by this report, the decisions to be made were as follows:

**Decision Regarding Extent** – Is Cs-137 absent, permanently present, or present and in transit? Does the sum of Cs-137 activity in the seven depositional environments account for the total Cs-137 activity discharged in PBRF cooling water?

**Decision Related to Remediation** – If present at levels of concern, can clay carrying Cs-137 be easily removed, without disturbing anything else?

## **INPUTS TO THE DECISIONS**

**Inputs to Decision Regarding Extent** – The extent decision was to be based upon the following factors, to be determined for each depositional environment:

1. Amount of Cs-137 activity per gram of sediment
2. Size of sediment areas contaminated by Cs-137
3. Mobility of the contaminated sediment

**Inputs to Decisions Regarding Remediation** – Remediation decisions, if any should be needed, were to be based upon the following factors, to be determined for each depositional environment:

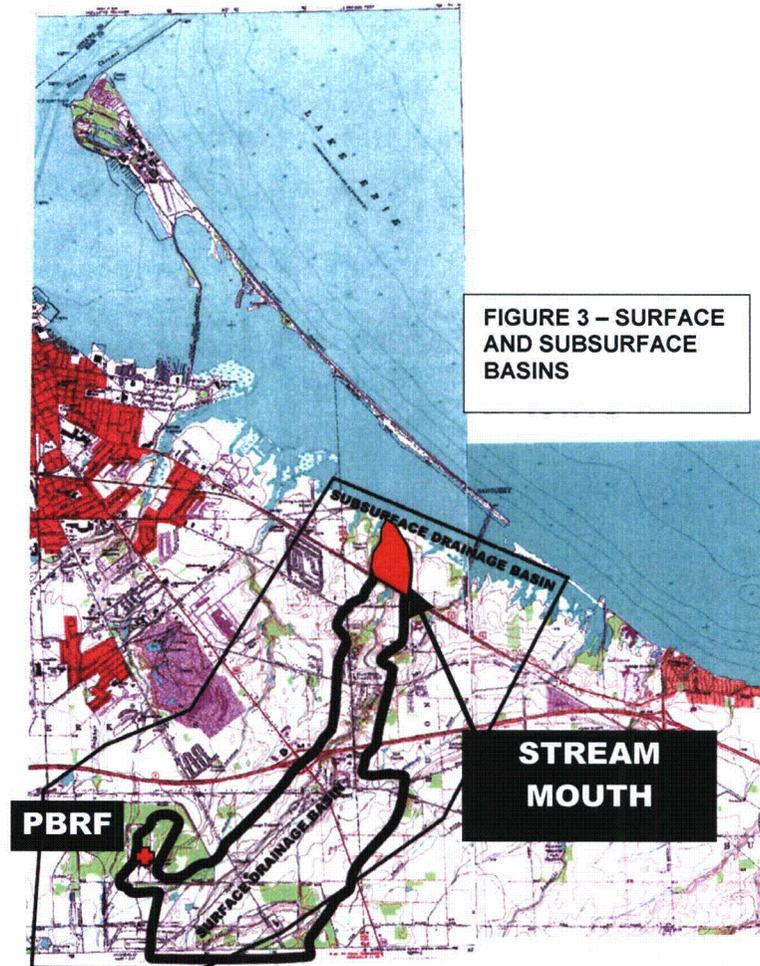
1. Ease of reaching the contaminated sediment with remediation equipment
2. Ease of removing only the contaminated sediment
3. Ease of separating contaminated clay from other materials

## **STUDY BOUNDARIES**

**Study Boundaries for Vertical and Lateral Extent** - To define the sediment depositional environments, the limits of the study area were determined to be (1) the surface drainage basin of Plum Brook, downstream of the PBRF, and (2) the groundwater basin in which the PBRF is located. These basins are illustrated in Figure 3.

For the determination of sediment movement within those basins, the hydrogeologic study identified the following 7 depositional environments to be evaluated for fine sediment carrying Cs-137:

1. Meandering streams
2. Stream backwaters
3. Ponds
4. Floodplain wetlands
5. Stream mouth wetlands
6. Bay behind barrier island
7. Rock fractures bearing groundwater



**Study Boundaries for Remediation** – Definition of remedial work areas, if any, was to be governed by residential character, distribution pattern of Cs-137, and equipment accessibility.

## DECISION RULES

**Decision Rules for Vertical and Lateral Extent** - were to be based upon amount of Cs-137 activity released versus amount found, and professional judgment that the limits of all reasonable depositional environments had been adequately explored. The latter is documented in a separate report, entitled “Development of Conceptual Model as basis for Characterization Plan,” also referred to during its development as the “Concept Report.”

**Decisions Rules for Remediation** – were to be determined, after the need for remediation, if any, was ascertained.

## **LIMITS ON DECISION ERRORS**

When Cs-137 from the PBRF reached the offsite environment, it was expected that it would be distributed lognormally. This was documented in the course of a “Minimum Number of Samples” task.

This means that variations of Cs-137 activity were considered significant when they varied by an order of magnitude. Thus, it was appropriate to consider masses “adequately balanced” when the amount of Cs-137 activity accounted for was within one order of magnitude of the amount estimated to have been released.

Many significant hydrogeologic patterns show variations that are best evaluated from an order-of-magnitude perspective. For example, soil grainsizes are typically graphed on a logarithmic scale. Differences in permeabilities are also considered significant only when they differ by orders of magnitude.

For the dimensions of depositional environments, a linear scale was appropriate. However, it was important to bear in mind that meaningful vertical geologic measurements span inches, while meaningful lateral geologic measurements span feet or miles. To identify a sediment layer that might represent a decade of Cs-137 deposition, it was judged that core samples should span an interval of no more than 3 inches. However, to adequately locate a sampling point in map view, a measurement needed to be reproducible only to within a few feet.

## **DATA QUALITY INDICATORS**

Data quality indicators (DQIs) are the mostly-quantitative parameters used to determine whether measurements are achieving the quality needed to support a particular decision. DQI values for this work are given below. DQIs related to lognormally distributed phenomena should be applied after the data are transformed. DQIs related to normally distributed phenomena should be applied to the original, untransformed, data. Variations attributable to sampling and testing are expected to be normally distributed. Variations attributable to the movement of Cs-137 by natural processes are expected to be lognormally distributed.

**Precision** – is also called repeatability. To assess repeatability in the onsite laboratory, the PBRF uses an approach described in NRC Inspection Manual 84750. That approach allows a greater margin for error when the statistical uncertainty underlying a result is large compared with the result itself. However, in this assessment, it was important to be able to compare the precisions achieved with other hydrogeologic investigations. For hydrogeologic/extent purposes, successive field measurements of the same area or sample are traditionally expected to yield results within 20% of one another, as measured by the relative percent difference (RPD).

RPD is defined here as follows:

$$\text{RPD} = (\text{duplicate 1} - \text{duplicate 2}) / \text{average}(\text{duplicate 1}, \text{duplicate 2})$$

However, when a phenomenon follows a lognormal distribution, RPD values less than 20% are not consistently achievable. Historical RPD values related to metals in soils often exceed 50% to 100%. For Cs-137 in co-located field samples, therefore, RPD should be measured after the test results have been transformed, as follows:

$$\text{RPD} = [\log(\text{dup1}) - \log(\text{dup2})] / \text{average}[\log(\text{dup1}), \log(\text{dup2})]$$

For this work, quantitative test results for all duplicate samples were expected to achieve RPDs less than 20%, after log-transformation.

In some cases, repeatability must be considered acceptable if presence or absence of the contaminant is the same in the original and duplicate samples. This was the rule applied here to assess the repeatability of testing results marked "Qualitative Analysis Only", and results that were below the minimum detectable activity (MDA). Results that were rejected were treated as if the contaminant was not detected.

**Accuracy** – is the degree to which measurements approach the "true" value. The accuracy of laboratory measurements is often evaluated by measurement of a known standard injected into a laboratory "blank". The resulting sample is called a Laboratory Control Sample (LCS), or a blank "spike." A LCS is typically analyzed along with each batch of samples. The ratio of the laboratory-measured value to the known value, for a standard that was added to a blank sample, is called the "spike recovery." For decision-making purposes without special evaluation, we expected contract laboratories to achieve spike recoveries between 80% and 120%.

In the PBRF onsite laboratory analysis of Cs-137 activity, samples were not grouped in batches, so there were no batch LCS spike results. According to PBRF procedure RP-021, a comparable measure of system accuracy was provided by means of daily quality control (QC) checks, in which Cs-137 sources traceable to the National Institute for Standards and Technology (NIST) were measured. The results obtained were plotted on control charts. Laboratory personnel undertook investigation if the results exceeded the warning limits, and corrective action was taken in the laboratory if the results exceeded the control limits. The warning limits were set at 2 standard deviations above or below the known activity, and the control limits were set at 3 standard deviations above or below the known activity. When the system was calibrated, it was expected that the test results would be within  $\pm 10\%$  of the known activity.

As another method of maintaining laboratory accuracy, the PBRF lab participated in the USDOE Mixed Analyte Performance Evaluation Program (MAPEP) cross-check program. Under this program, USDOE periodically sent blind spike samples to PBRF for analysis, and the results were sent back to DOE for agreement evaluation. The PBRF lab also performed analyses of inter-laboratory comparison samples. Sample Deviation Reports (SDRs) were prepared for comparison results that were not in agreement based

on the NRC Inspection Manual 84750 criteria. The PBRF Laboratory Manager provided HaagEnviro with a copy of the "PBRF Laboratory Quality Assurance Report", Third Edition, covering the period from January-June 2007. HaagEnviro reviewed the sections that were relevant to the work described in this Stream Mouth report.

A qualified data reviewer, Rod Case, also characterized accuracy of the PBRF onsite laboratory results. Based upon the reviewer's assessment, Cs-137 values reported above the minimum detectable activity (MDA) were marked either "Yes" or "No" on the PBRF onsite laboratory reports. If a result was marked "Yes," but the volume of the sample was less than the standard geometry for which the system was calibrated, then the PBRF onsite laboratory report was marked "Qualitative Analysis Only." For those cases, with undersized samples, it was expected that the reported activity was likely higher than the true activity.

For a particular deposit, HaagEnviro considered the mean of the log-transformed results to represent the "true" value, and used the standard deviation of the log-transformed results as an indicator of the accuracy achieved in measuring this "true" value. HaagEnviro then assessed the accuracy of the total measurement system, including sampling, soil processing, and laboratory analysis, by two means, as follows:

1. When trends in the data could be identified, HaagEnviro considered accuracy acceptable if the standard deviation of log-transformed, trend-removed results was less than 0.4. The basis of this criterion is further detailed under point 6 of "Completeness," below.
2. When no trends were noted in a deposit, HaagEnviro considered accuracy acceptable if the standard deviation of the log-transformed results was less than half the following: the log of the regulatory threshold of 12 pCi/g (1.08), minus the mean of the log-transformed results. This was based upon a simple formula for defining confidence intervals, taken from USEPA's SW-846, and the assumption that the mean plus two standard deviations represents at least a 95% confidence interval.

**Representativeness** – is often a non-quantitative DQI. A sample is considered representative of a condition if it is taken from the right place, at the right time. A representative sample must recover all of the parts of the medium being characterized. A representative sample must not contain contaminants from other samples.

To achieve representativeness in contaminant measurements, the contaminant's creation, fate, and transport must be understood and specified. That information is provided here in the section entitled "Expected Characteristics of the Stream Mouth Wetlands Depositional Environment."

To achieve representativeness, core samples must have good recovery. This type of recovery is defined as the length of the sample, divided by the distance that the sampling device was driven, expressed as a percentage. Sample recoveries in small-diameter,

thick-walled samplers such as GeoProbe samplers, one of the types used on this project, are typically less than 100%. For clay soils in this project, we employed the rule that sample recoveries of 80% are typical, and clay samples with recoveries less than 50% should be examined further. For organic soils (peat and muck), we employed the rule that sample recoveries of 50% are typical, and peat/muck samples with recoveries less than 30% should be examined further.

It was found in prior work in the Bay depositional environment that much better recoveries could be achieved using a larger-diameter, thin-walled tube sampler, driven by vibration. A device referred to as a vibracore sampler was therefore developed for use on this project, and much higher sample recoveries were obtained. The same DQIs were applied to vibracore samples as were used for GeoProbe samples.

To achieve representativeness, samples must have little or no cross-contamination. This is achieved by employing sampling procedures that minimize the movement of contaminated material from one part of the borehole to another, such as the GeoProbe dual-tube system or the vibracore system employed here. Both of these systems avoid the problem of repeatedly re-entering a borehole to sample successively deeper strata. Repeatedly re-entering a borehole tends to cause contaminants from higher strata to be carried down to cross-contaminate deeper strata.

Adverse effects of cross-contamination may also be reduced by making efforts to sample areas expected to be least contaminated first, finishing a sampling run with areas expected to be most contaminated. That approach was not practical in this part of the work, as sampling area availability was dictated by the nesting times of protected bald eagles.

With driven tube-style samplers, the possibility exists that the walls of the tube will drag soft, cohesive material, such as clay, down from one part of the sample to the next. To evaluate this phenomenon, the HaagEnviro hydrogeologist reviewed photographs of the cores after they were cut open.

The degree of sample cross-contamination is sometimes measured by obtaining clean, or "blank" samples following sampler decontamination, or between tests in the laboratory. While field blanks can be quite useful for liquid samples, they are often quite ineffective in evaluating solids, and were not obtained. Laboratory blanks were prepared and tested according to the requirements of PBRF procedure RP-021. Testing results for blank samples are expected to show no detection of the contamination found in field samples.

**Completeness** – means having enough verified measurements to support a decision. "Verified" results are those that satisfy the other DQIs. Most hydrogeologic phenomena can be approximated by planar surfaces, or by logarithmic time-sequences. Since at least 3 points are required to define a plane or a curve, we employed the fundamental rule that 3 valid measurements distributed either in space or in time, are the minimum number to support a hydrogeologic/extent decision.

When the completeness decision rule is statistical, completeness can be specified as a number of verified samples, N, required to achieve a certain level of confidence. This was evaluated in a "Minimum Number of Samples" task, which reviewed the statistical distribution of test results obtained from Plum Brook stream meander areas near the PBRF. The key conclusions of that task were as follows:

1. For Cs-137 in the natural environment, the minimum practical quantitation limit (PQL) for the combined sampling/testing measurement system in use on the PBRF Decommissioning Project was 3 pCi/g. All results less than this have essentially the same meaning.
2. Cs-137 measurements in the natural environment surrounding the PBRF need to be transformed to log(measurement) before they are evaluated. After transformation, the results are expected to conform to the normal distribution.
3. Trends in Cs-137 measurements in the natural environments downstream of the PBRF can only be evaluated after log-transformation. The effects of trends need be removed before the statistical variance of the log-transformed results can be determined.
4. It is appropriate to employ evaluations based on the Student's t distribution in evaluating the log-transformed, trend-removed results of Cs-137 measurements in the environment surrounding the PBRF. In this situation, the Multi-Agency Radiation Survey and Site Assessment Manual (MARSSIM) supports use of parametric methods, over the non-parametric methods described in MARSSIM.
5. Estimation of the number of samples required to achieve Type I and Type II errors, as specified in the PBRF Final Status Survey Plan (FSSP), was controlled by 2 main factors: (1) the sample variance, and (2) the distance between the regulatory threshold and the representative value of Cs-137 in the environment, a distance called the "effect size."
6. The conservative maximum variance of log-transformed, trend-removed results identified in the "Minimum Number of Samples" task was 0.4; more samples would be required if the variance of a sample set should exceed 0.4.
7. The typical effect size was the difference between the proposed derived concentration guideline limit (DCGL) of 12 pCi/g, and the PQL of 3 pCi/g. More samples would be required if the representative level of Cs-137 activity were to exceed 3 pCi/g.
8. For the FSSP-specified Type I error rate of 5%, and the FSSP-specified Type II error rate of 10%, the factors above combined to yield a minimum number of 11 samples for each of the environments considered.

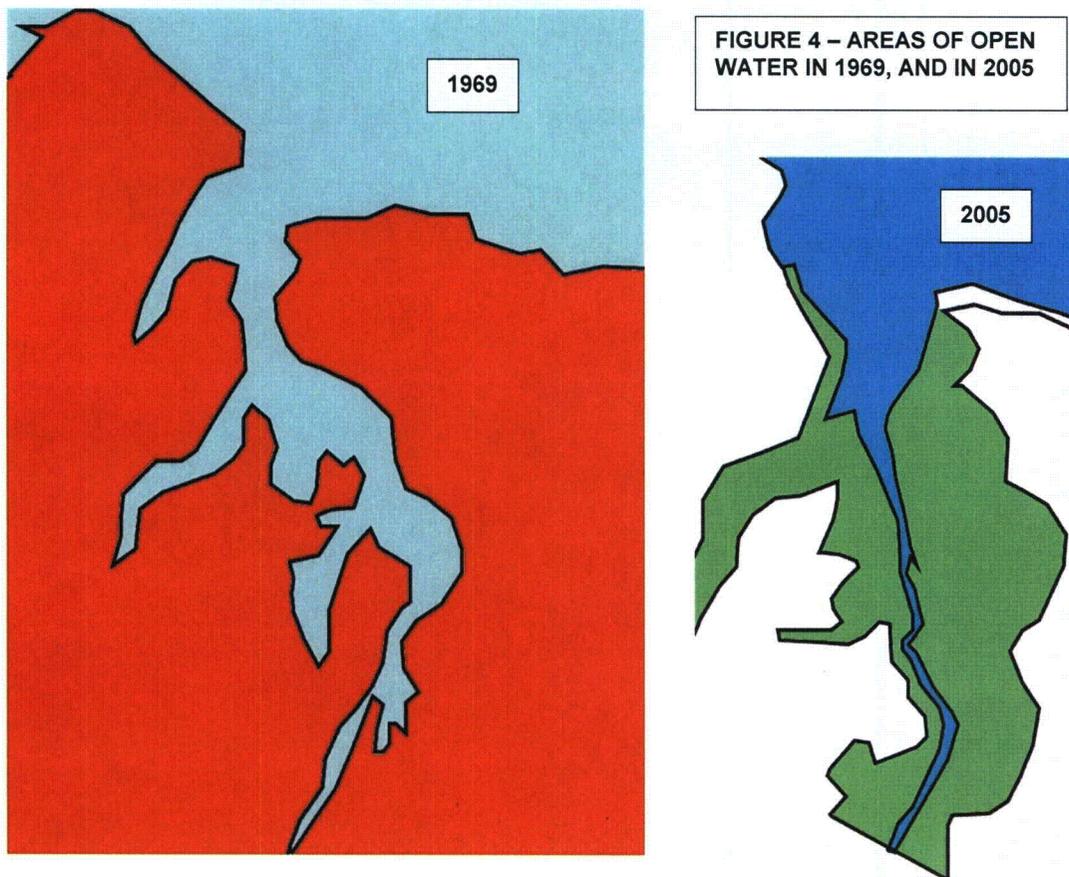
9. The computed minimum number was increased by applying a safety factor of 1.2 and rounding up, yielding a revised minimum number of 14 samples to characterize the variability in any sampled area.
10. In some of the depositional environments to be considered, 11 samples might not be enough to assure the investigator that areas of elevated concentration are identified. This will lead to reliance on scanning, and on geologic interpretation, to identify areas requiring more than 14 samples to accommodate expected variations in Cs-137 distribution.

**Comparability** – is achieved by using standard procedures for obtaining measurements. The field procedures employed are attached to this plan in Appendix A. The laboratory procedure that was employed was PBRF's RP-021.

## EXPECTED CHARACTERISTICS OF THE STREAM MOUTH WETLANDS DEPOSITIONAL ENVIRONMENT

The following section describes the expected characteristics of the stream mouth wetlands environment, one of 7 identified depositional environments. These characteristics were used to guide the field scientists in obtaining representative samples. It was desired to establish a pattern of layers corresponding to the years 1961 to present. Within this pattern, layers bearing fine sediment with Cs-137 were sought.

At the time of sampling, rising Lake Erie levels had flooded the fairly large flat area where the underfit Plum Brook entered the standing water behind the sand bar known as Cedar Point. Airphotos suggested that the now-flooded or “drowned” mouth of Plum Brook was formerly a floodplain wetland, but more recently became a fresh-water “estuary”, similar to the much-studied Old Woman Creek “estuary” nearby. Studies at Old Woman Creek indicated that sediment was deposited in that estuary when the Lake Erie level was high, and sediment was eroded and moved toward the lake when the lake level was low. Airphotos and maps suggested that the stream mouth area of Plum Brook was sometimes a braided distributary channel environment (mostly land), and at other times was a marsh environment (mostly water). Observed changes during and after the period of PBRF operation are illustrated in Figure 4.



Field observations, made during earlier sampling of the bay area, showed that the estuary area of the stream mouth was formerly a deeper channel, found to be nominally 10 feet deep at the center. The deeper channel was mostly filled in with organic peat/muck deposits. These peat/muck deposits differed from those found in the Bay, in that sample recoveries with the GeoProbe dual-tube sampler were extremely low in the stream mouth deposits. A bulk sample obtained to study the structure of the stream mouth peat/muck showed a mat with a significant fibrous root structure, much more than had been observed in the bay samples. It was interpreted that the fibrous structure moved out of the way of the dual-tube sampler, rather than being cut and entering the sample tube. After a literature search, consultation with Ohio EPA's Brent Kuenzli, and field trials at HaagEnviro's expense, a vibracore peat sampler was developed as the key sampling device for this part of the project.

Before sampling in the bay was conducted, it was expected that a delta deposit would be found, where the land-derived sediments from Plum Brook met the still waters of the bay. However, no such delta was found in the bay, so it was considered possible that the anticipated delta might be found in the stream mouth area.

Accordingly, the stream mouth was expected to be transitional between the peat deposits/ that dominated the bay, and land-derived sand, silt, and clay. As with the bay environment, it was expected that the peat, sand, silt, and clay would be relatively soft sediments, deposited over a 10-foot-deep channel that had been carved into much denser clay till. The dense clay till, representing the last glacial retreat, was at least thousands of years old. Thus, the interval affected by the PBRF would be found in the overlying soft sediments.

Considering these characteristics of the stream mouth area, it was expected that the deposits that might carry clay, bearing Cs-137, could be any of the following:

- Delta Deposits (clay below silt below sand)
- Flood Backwater Deposits (clay thinly spread over the top of the area)
- Marsh Channel Deposits (clay in channels, winding through deposits of peat)

The sampling effort was complicated by the fact that the stream mouth was part of the Steinen Wildlife Area, administered by Erie MetroParks. This nature preserve included a nesting area for bald eagles, which was protected from human approach during the nesting season.

## METHODS

HaagEnviro consulted with Erie MetroParks regarding protected areas, before and during the sampling effort. The MetroParks issued permits for the sampling effort.

Based upon the HaagEnviro Characterization Plan for the stream mouth wetlands depositional environment, another NASA contractor, MOTA, prepared Survey Request (SR) number 39 for the first part of this work. For sampling and testing work referred to as "bounding" efforts, personnel from MOTA and another contractor, SAIC, prepared SR 44 and SR 53. These project members were assigned to NASA's Final Status Survey (FSS) Group. SR 44 was based upon the MARSSIM concept of bounding an Elevated Measurement Area (EMA). It was assumed that the EMA contained a uniformly elevated activity level. SR 53 was based upon definition of the "representative" activity within an EMA in which activities were log-normally distributed. The NASA Radiation Safety Officer (RSO), Bill Stoner, approved each SR.

In the initial work, under SR 39, sampling transects were laid out by hydrogeologist Bob Haag, with the goal of spanning all of the soft sediments deposited within the channel above the glacial till. In the first bounding effort, under SR 44, Assistant RSO Rod Case developed the rationale. This led to a circular sampling pattern, which was defined by Rod Case and Bob Haag. The circular pattern was employed around each of two EMAs, one with a Cs-137 activity of 11.7 pCi/g discovered 6-18 inches below the stream bed, and the second with a Cs-137 activity of 20.6 pCi/g discovered 0-6 inches below the stream bed. In the second bounding effort, under SR 53, Bob Haag established triangular grid patterns, blanketing the streambed around each of the two EMAs. The grid was also extended somewhat downstream along an old, in-filled channel in Plum Brook's delta area.

In all cases, sample points were located with the aid of global positioning system (GPS) devices and related mapping software. Sampling methods included manual dual-tube GeoProbe, and a vibracore system using 3" aluminum sample tubes.

In the field, one or two HaagEnviro scientists directed locations, sampled, and made field judgments regarding the character of the depositional environments and the need for more or fewer samples. MOTA Operations Technician Greg Struck, and several others in rotation, assisted the scientists in sampling, sampler transport, preparation, and decontamination. A MOTA Radiation Protection (RP) Technician, Rich Dzvonar, maintained sample custody according to PBRF decommissioning procedures. Based upon results from a significant number of samples, the RP Technician was able to discontinue scanning the cores with a sodium iodide (NaI) detector. Such scanning had been a part of sample processing in earlier work.

Samples were transported to the PBRF site, where they were cut, screened, and processed for analysis in the soil processing facility at the PBRF site. During processing, a HaagEnviro technician or scientist screened the samples with a photoionization detector (PID).

The samples were analyzed quantitatively in the PBRF onsite laboratory. Data reduction and review involved comparison of results with DQIs, and a search for trends and patterns.

## NATURE PRESERVE CONSIDERATIONS

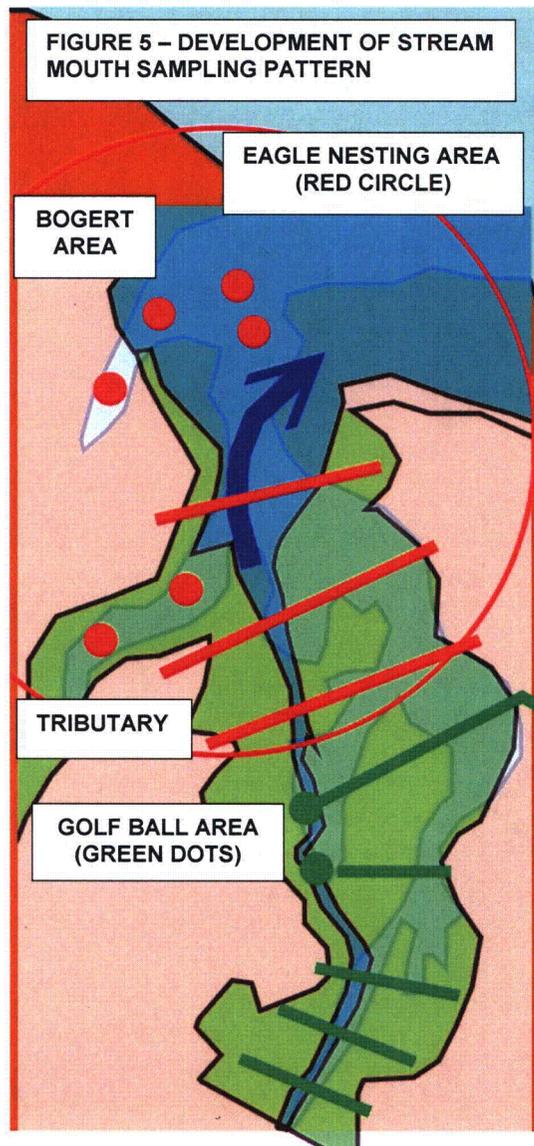
Through discussions with MetroParks personnel, sampling was planned to avoid times of bald eagle nesting, and to avoid permitted duck and deer hunting. During the stream mouth sampling effort, HaagEnviro maintained contact with the park system's Supervisor of Operational Services, James Lang. Sampling personnel were directed to stay out of certain hunting areas through December 31, 2006 and out of a ¼ mile radius from a bald eagle nesting area from January 1, 2007 through July 1, 2007.

The area was covered by standing water with a nominal depth of 1-36 inches in the stream, and 0-12 inches in areas of common reed (*Phragmites*) and cattails. Access to sampling points was by means of canoes provided by Erie MetroParks, and by foot.

## DEVELOPMENT OF INITIAL SAMPLING TRANSECTS

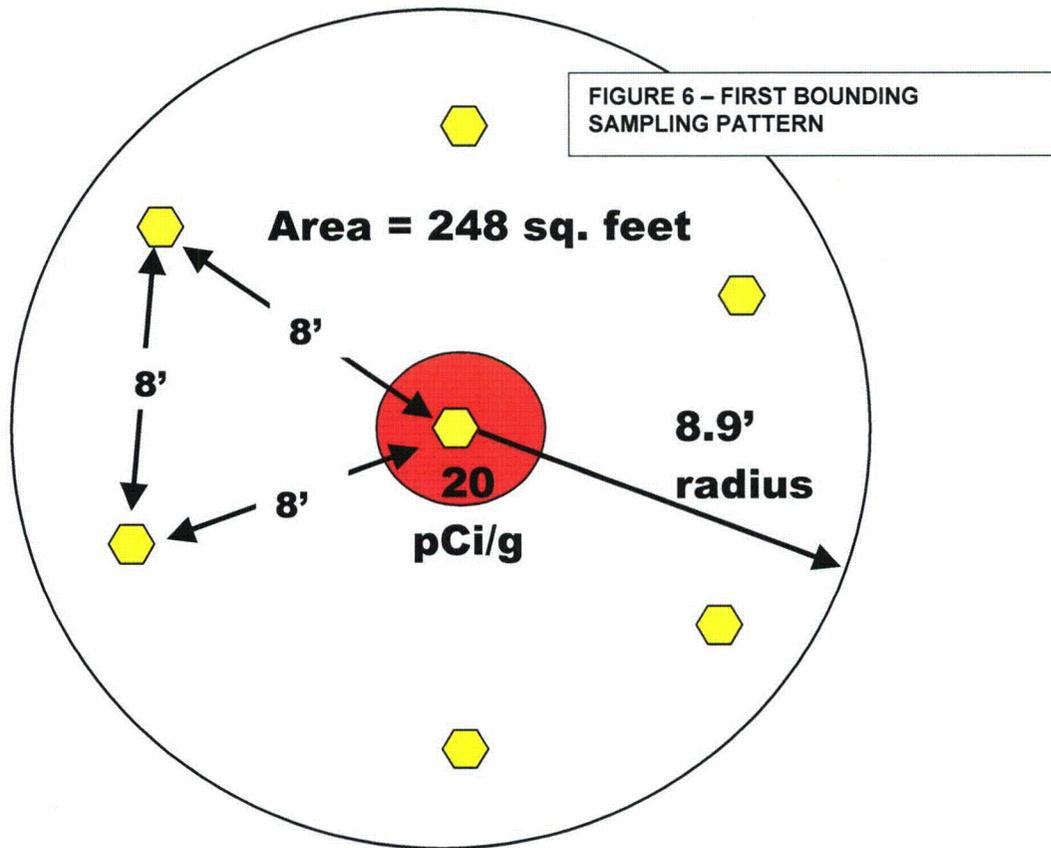
The East-West limit of each sampling transect was established by observing on topographic maps, and in the field, where the land rose from a low, flat surface characteristic of a wetland or a floodplain. As shown in Figure 5, transects thus spanned both current and past stream locations. Transects were arranged to yield cross-sections at right angles to the average direction of stream flow. Transect spacing, and the spacing of samples within each transect, were based upon the hydrogeologist's judgment of the sample density needed to identify continuous layers and areas of deposition.

The sequence in which transects were sampled was controlled by bald eagle nesting times. Sample points and transects shown in red in Figure 5 were performed first.





Using this rationale, the sampling pattern shown in Figure 6 was developed. For field practicality, it was determined that the central point would be re-located and sampled. Then 6 surrounding points, in an approximate 8-foot radius, would be sampled. Each location would be expected to yield 5 samples, from the following depth intervals, in inches: 0-6, 6-18, 18-30, 30-42, 42-54. This plan would yield a total of 35 samples.





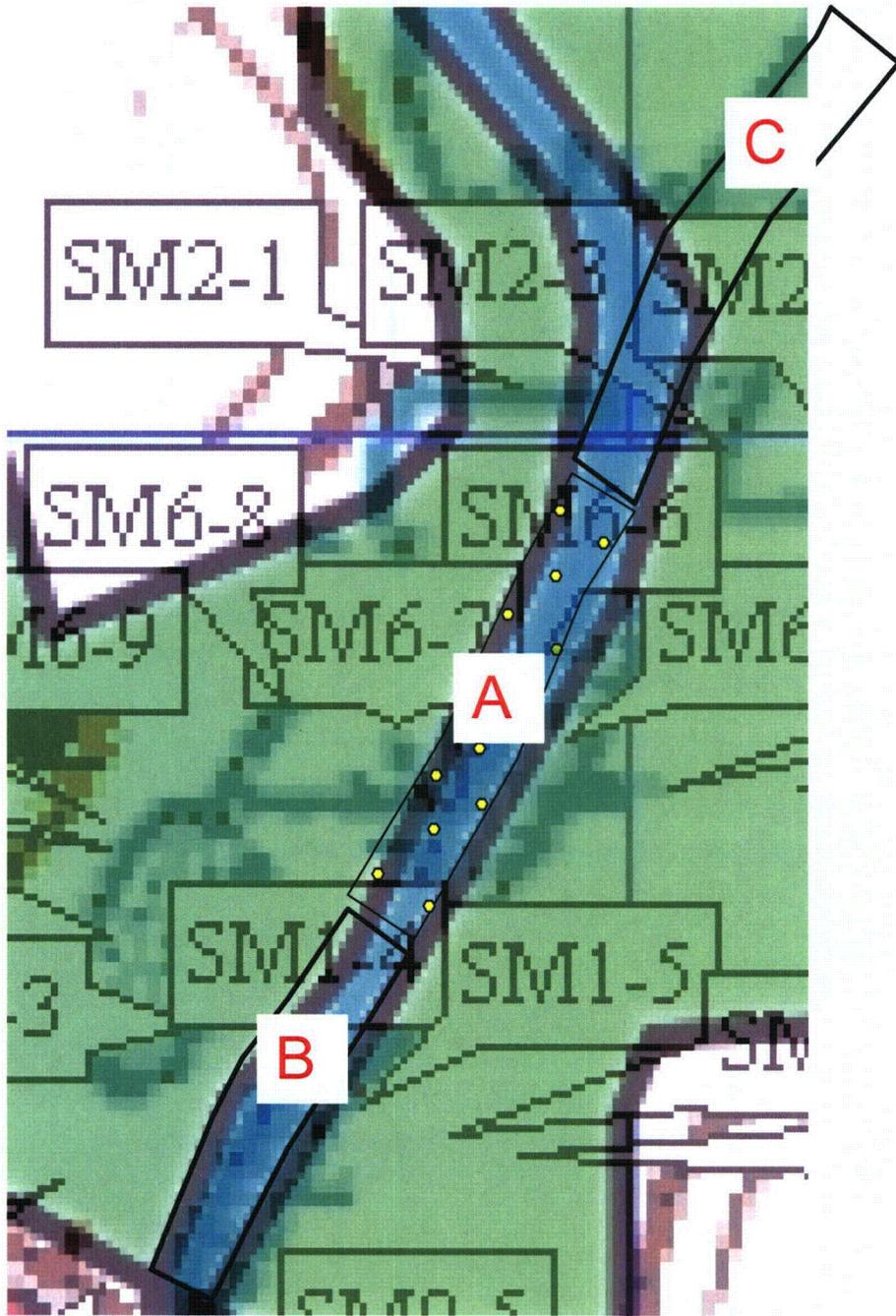


FIGURE 8 – RELATIVE LOCATIONS OF SECOND BOUNDING AREAS A, B AND C

## LOCATION OF SAMPLE POINTS

Sampling points were located in the field with GPS instrumentation for the initial transects, and using GPS plus a tape and compass for the bounding grid patterns. Hydrogeologist Bob Haag planned initial grid sample locations by plotting them on a USGS 7.5-minute topographic base map using DeLorme™ TopoQuad software. This yielded GPS coordinates that he transmitted to the scientists in the field. In the field, the scientists located initial transect sampling locations with HaagEnviro's GPS instrument, a Garmin eTrex Legend. For the bounding grid patterns, MOTA RP Technicians used GPS coordinates in a NASA-provided GPS device to identify key locations in the field, then measured from those key locations. After samples were obtained, the sample locations were recorded by the RP technician, using the NASA-provided GPS device, which was a Trimble model TSCe coupled with an integrated GPS/beacon antenna (part number 29653-00).

HaagEnviro and MOTA also used these GPS devices to record the locations of certain field observations, such as the limits of golf balls that had washed down stream and were deposited in a stretch of the stream mouth, and a location in which hydrogen sulfide gas was bubbling up in the wetland.

## SAMPLING METHODS

Core samples in the initial transects were obtained from 64 locations. Core samples were taken by one of two methods: manual dual-tube GeoProbe or vibracore.

In the GeoProbe approach, illustrated in Figure 9, a 5-foot-long dual-tube sampler was driven down to the desired depth, or to hard-clay resistance.



The metal parts of the GeoProbe sampling equipment were decontaminated before each borehole was started. Each 5-foot-long sample was captured in a new plastic tube, which was inserted inside the metal drive tube. When the sample was extracted in its plastic

tube, the metal drive tube remained in place to keep the hole open. For a second 5-foot sampling run in the same hole, a new plastic tube was attached to drive rods and was lowered to the bottom of the hole. Additional drive rods and outer tube sections were then added to the top of the sampling string, and the sampler was driven to greater depth. After the last sample was obtained, the steel sampling tubes were extracted with the help of a tripod and winch, or a truck jack and chain.

In the vibracore approach, shown in Figure 10, HaagEnviro's backpack mounted, gas powered vibrator was attached to the top of a 3-inch-diameter, 10-foot-long, aluminum tube. Each tube was then vibrated down into the ground until refusal or the desired sample depth was reached. Sample compression, if any, was measured by lowering a tape measure into the top of the sample tube. A rubber worm-clamped cap was then placed on the top of the tube to create suction, and the tube was extracted from the ground. In dry areas, this was achieved initially with a tripod and winch, and later with a truck jack and chain. In water-covered areas, extraction was achieved by 2-3 people pulling up with pipe wrenches. After the tube was extracted from the ground, the bottom was capped, and the depth from the top of the tube to the top of the sample was again measured, to determine if any part of the sample had been lost from the bottom, or if any further sample compression had occurred. Any empty tubing at the top of the sample was cut off. The top of the tube was re-capped, and the tube was marked with an indelible pen. Initially, the top and bottom caps were duct-taped to avoid leakage; this later proved unnecessary and was discontinued.

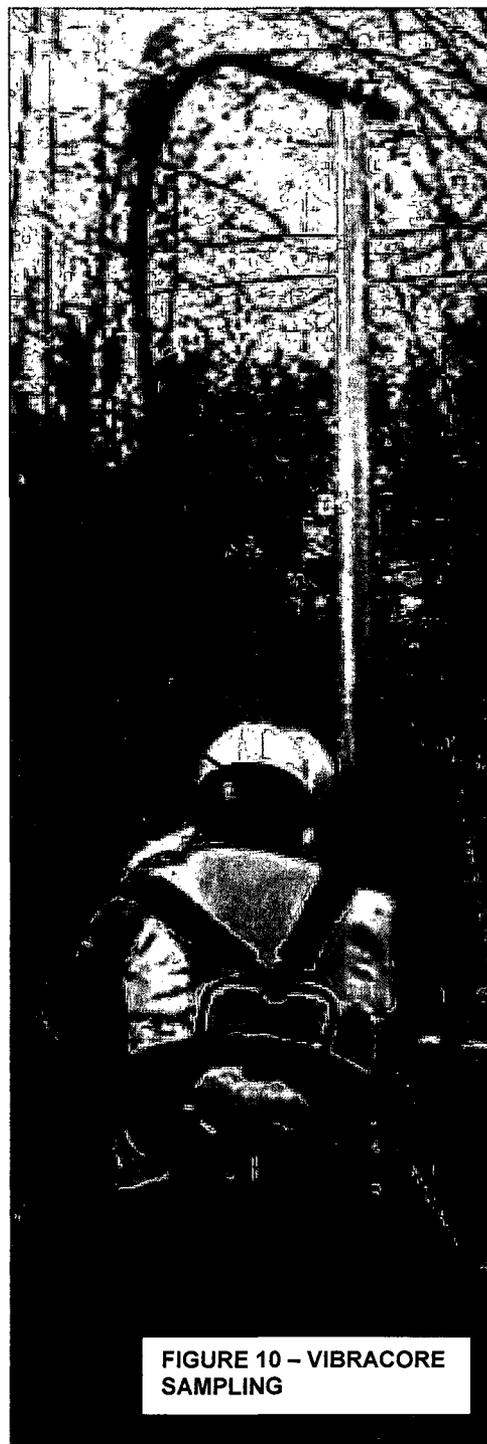


FIGURE 10 – VIBRACORE SAMPLING

By either sampling method in the initial transects, it was considered that pre-1961 sediments had been reached, and sampling could be terminated, when hard clay was encountered. In the later bounding work, it was considered that either refusal at hard clay, or 6 feet of sample depth would be sufficient to achieve the objectives of the FSSP.

In the initial transects, one field duplicate borehole was sampled to repeat a stream mouth sampling location, and 3 duplicate boreholes were obtained in locations previously sampled during the bay investigation. In the first round of bounding samples, one of the seven samples in each EMA was re-located over the spot with the highest prior testing result.

### **SAMPLE FIELD-SCREENING AND CHAIN-OF-CUSTODY DOCUMENTATION**

In the earliest sampling work, the RP Technician field-screened the sampling devices and samples for radioactivity, using a NASA-provided NaI meter. This was a Ludlum model 2350 meter with a model 4410 probe, and a gamma-spectrum window set to focus on Cs-137 activity. This window was established at 50 KeV above and below the Cs-137 peak of 662 KeV. The meter was source checked by MOTA personnel at the PBRF site at the beginning and end of each field day. As the work progressed, the RP Technician was able to dispense with this field screening, because only background readings were obtained, and a large volume of data indicated that higher readings would not be obtained. The samples were transported under chain-of-custody (COC) control by the RP Technician, to the sample-processing trailer at the PBRF site.

Screening for organic chemicals during the processing of some of the second bounding samples produced some elevated readings on a HaagEnviro 11.7 eV PID, which was an HnU model PI-101. This led to comparison readings with a NASA-provided PID, which was a Mini RAE 2000 model PGM-7600. This was initially fitted with a 10.6 eV lamp, which was later changed to an 11.7 eV lamp. The HaagEnviro PID was calibrated each day by a HaagEnviro employee. The NASA PID was calibrated each day by a MOTA employee. In each case, calibration was performed using isobutylene gas with a concentration of 100 parts per million (ppm).

Elevated readings on the HaagEnviro PID were first noted during the processing of Flood Plain samples, and further investigations by chemical testing are detailed in the Flood Plain report. In short, two Flood Plain soil samples were tested for volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), pesticides, and nitrate fertilizers. The testing for VOCs and SVOCs included a search for tentatively identified compounds (TICs). Further investigations during Stream Mouth sample processing included an air sample obtained by NASA Safety Officer Hank Bayes. This air sample was obtained from a sample cut that had produced an elevated reading with the HaagEnviro PID. To investigate further, Bob Haag took the HaagEnviro PID into the Stream Mouth area, and monitored ambient air in the breathing zone, and at ground level.

### **PREPARATION OF SAMPLES FOR QUANTITATIVE ANALYSIS**

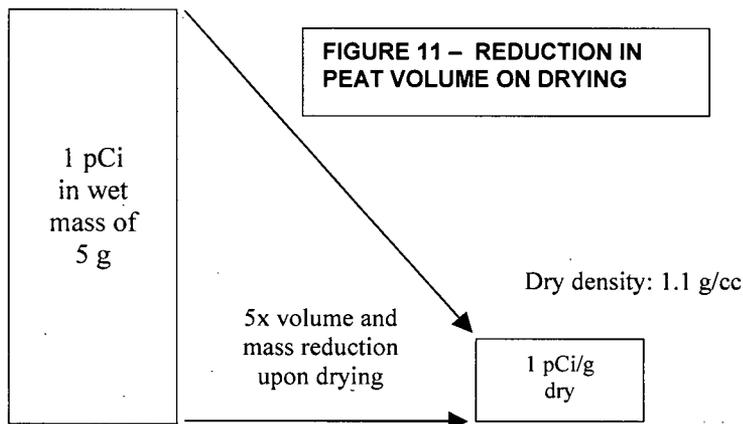
In the soil processing facility, the top 54 inches of the sample tubes were cut into appropriate lengths. Lines were marked 6" from the top, then every 12", down to a total length of 54". The tubes were cut along the marked lines, and the samples were pushed

out into disposable aluminum pans. The samples were cut in half vertically, laid open and photographed. The samples were then dried, recombined if they were dried in separate halves, pulverized, sieved, and homogenized following PBRF procedure CS-04. Appropriate aliquots were made for analysis in the PBRF onsite laboratory. The balance of each sample tube, below 54", was retained for potential future analysis.

In the prior Bay investigation, it had been noted that samples of organic peat/muck lost a great deal of their volume and weight when they were dried, ground, and sieved for analysis. A typical weight reduction, for composite sample BY-7-83, was approximated in the bay study, and the final weight appeared to be only 17% of the starting weight. Such a reduction in weight could cause a significant increase in apparent Cs-137 activity, because that activity, in pCi, is reported per gram of dry soil. HaagEnviro's original assumption, before carefully documented volume and density reduction tests were performed in the stream mouth study, was that the typical weight reduction between the wet pre-testing samples and the dried samples ready for testing would be 5-to-1.

In that case, the resultant activity could be magnified 5 times between sampling and analysis, by comparison with mineral soils that would lose less volume and mass upon drying. This is illustrated by Figure 11. To check the preliminary assessment, three sets of measurements were made in the course of stream mouth sample preparation, to assess the reductions in volume and weight that were caused by sample processing. Three samples were measured and weighed before and after the processing described above.

Water density: 1.0 g/cc  
 Peat solids density: 1.1 g/cc  
 Total wet density: ~ 1 g/cc



## QUANTITATIVE LABORATORY ANALYSIS

The processed samples were analyzed by gamma spectroscopy in the PBRF onsite laboratory following PBRF procedure RP-021.

## DATA REDUCTION, INTERPRETATION, AND REPORTING

Copies of laboratory reports were provided to HaagEnviro for data reduction and interpretation. HaagEnviro summarized the results in a spreadsheet format, provided as Appendix B.

HaagEnviro identified Cs-137 detections in laboratory results by highlighting them in three colors within the spreadsheets, as follows:

**Violet:** Cs-137 detection in surface 6 inches (maximum exposure potential)

**Yellow:** Cs-137 detection in mid-column

**Orange:** Cs-137 detection at base of sample interval (possible deeper contamination)

These colored columns were evaluated for compatibility with the expected depositional model(s). In a recent-deposit setting, it was anticipated that Cs-137 would be detected only at the surface and in mid-column. In a pond or delta setting, it was anticipated that Cs-137 would be detected at some depth, with little or no Cs-137 in the overlying sediments. Detections highlighted in orange were flagged for special scrutiny.

To evaluate the precision achieved in the laboratory, recounts were compared to the results for the original field samples.

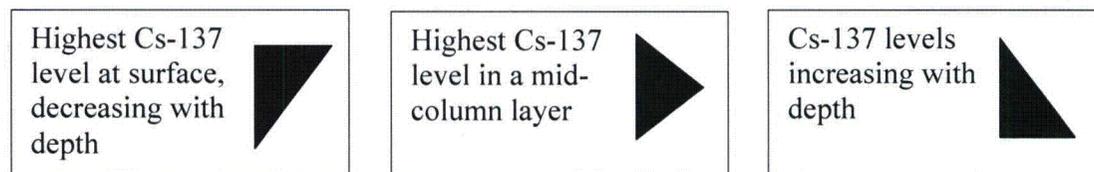
To evaluate the precision achieved by (sample processing + laboratory), QC duplicate analyses were compared to the results for the original field samples.

To assess the precision achieved by the total measurement system (sampling + sample processing + laboratory), co-located field samples were compared to one another. Six co-located samples were obtained, but only 3 of those spanned the same depth intervals.

Results and interpretations were posted on graphics that were presented to NASA personnel in weekly briefings.

The highest initial transect results were posted in map view, and reviewed for patterns of elevated Cs-137 levels.

The first bounding results were plotted in map view using three graphic indicators, illustrated below:



Using these icons, a block diagram was then prepared for each EMA, and the character of the elevated deposits was described.

The second bounding results were assessed in a multi-step process, as follows:

1. The most elevated Cs-137 results were posted for each location in map view, and the map was reviewed for patterns.
2. For the most elevated results, log(Cs-137 results) values were posted in map view, and reviewed for patterns
3. Log values were plotted versus distance downstream, and a trend line was fitted to this plot of results
4. Points judged to be outliers to the trend were removed, and the trend line was re-fitted to the remaining results
5. The log values of the upstream and downstream ends of the trend line were converted back to Cs-137 values, by raising  $10^{\log(\text{upstream})}$  and  $10^{\log(\text{downstream})}$
6. The “representative” value of Cs-137 for the stream section was reported as ranging from  $10^{\log(\text{upstream})}$  to  $10^{\log(\text{downstream})}$

## OBSERVATIONS

Observations made while executing each of the described methods are provided below.

### NATURE PRESERVE OBSERVATIONS

While approaching a planned sampling point in the middle of the Stream Mouth wetland, the sampling crew noted a rotten-egg scent, which generally indicates the presence of hydrogen sulfide (H<sub>2</sub>S) gas. HaagEnviro had encountered similar, natural emanations of this gas when sampling bedrock-monitoring wells on the PBRF site, in water-supply wells in Hancock County, and in stagnant water that had been standing in a basement over a period of years.

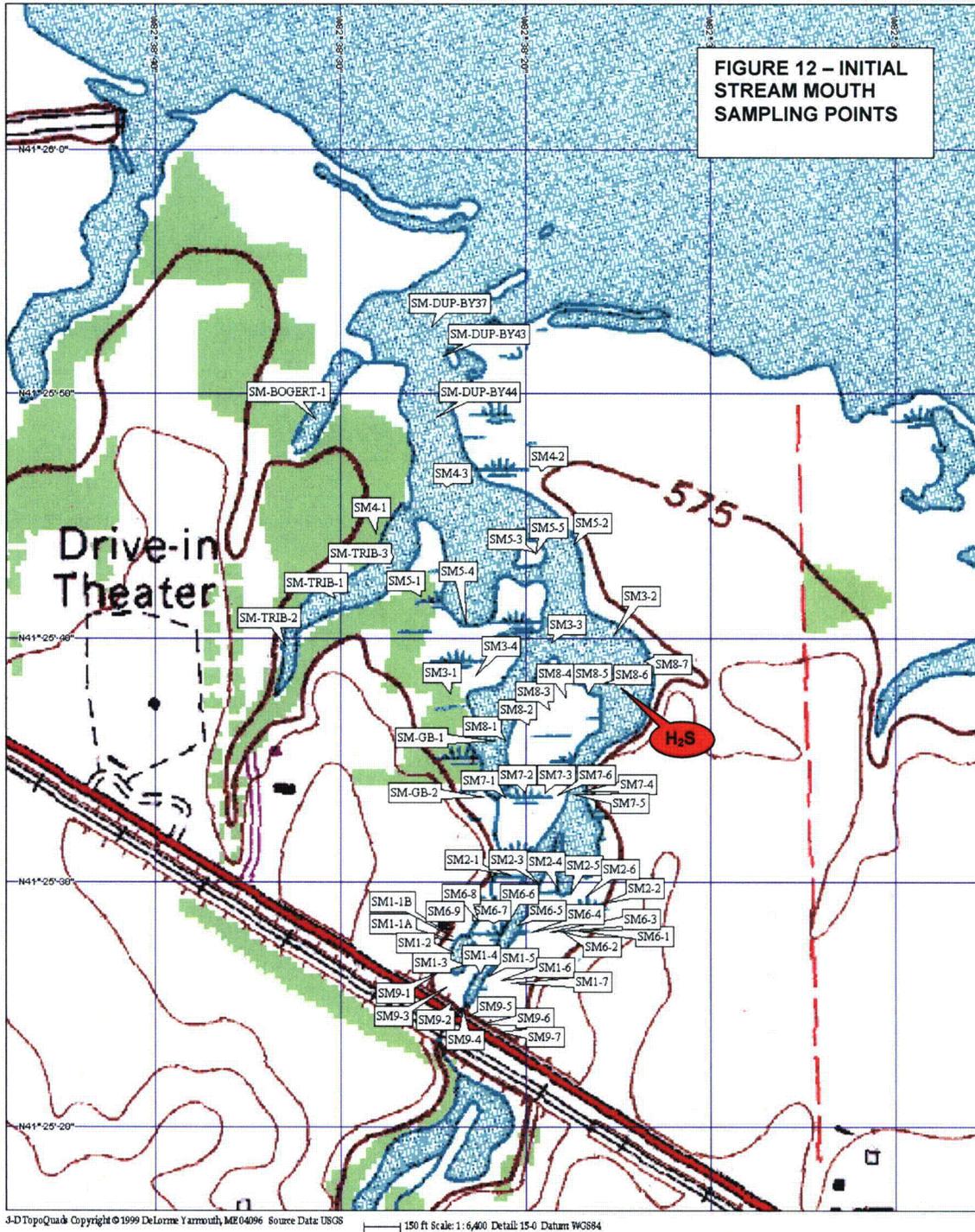
In response, the crew left the area of the odor, and returned with a 4-gas meter and a photoionization detector (PID). The 4-gas meter measured H<sub>2</sub>S, carbon monoxide (CO), oxygen (O<sub>2</sub>), and lower explosive limit (LEL). The PID measured volatile organic compounds (VOCs). The HaagEnviro scientists verified that the OSHA Permissible Exposure Limit (PEL) for H<sub>2</sub>S was 20 ppm, with a 10-minute maximum of 50 ppm. HaagEnviro used a PID-reading guideline of 10 ppm to exit a work area pending further investigation.

As the staff returned with the meters to investigate, they observed bubbles coming up through the water. At ground level, the H<sub>2</sub>S meter indicated peak readings over 30 ppm (exceeding the PEL of 20). CO, LEL, and O<sub>2</sub> readings were below levels of concern. PID readings at ground level peaked at about 100 ppm (exceeding the exit guideline of 10). Readings obtained in the breathing zone were all below levels of concern.

A MOTA RP Technician recorded the coordinates of the observed bubbles, as follows: North 41°, 25' 38.290", West 82°, 38' 15.226". This location is plotted in red on Figure 12.

HaagEnviro elected not to sample this location, and moved on to other sample points, where they did not encounter any odors.

Based on some nearby plantings, HaagEnviro speculated that the location with the odors might have been the discharge point for a former septic system, perhaps originally associated with a house or cabin that was no longer present. The Erie MetroParks staff did not know of any such structures in that area.



## INITIAL TRANSECT SAMPLING AND TESTING OBSERVATIONS

**General Sediment Patterns** – Based on the photographs obtained after the samples were extruded from the core tubing, the sediment types were seen to include sand, silt, peat, soft clay and dense clay. The dense clay, when found near the bottom of the core, was judged to be glacial till. The other sediments were considered to be post-glacial. Figure 13 illustrates the distribution of post-glacial sediment deposits in the stream mouth in map view. A corresponding soil survey map, with sand deposits highlighted, is provided in Figure 14. Figure 15 illustrates the character of the deposits that were found in the stream mouth environment.

A map-view illustration of the highest Cs-137 results found in the initial transects is provided by Figure 16. Sample locations where Cs-137 was still being detected at the bottom of a core in the original transects are indicated on Figure 17. A detailed cross-sectional plot of the sediment deposits along transect 1 is provided in Figure 18, and a generalized cross-section of sediments along nearby transect 6 is given by Figure 19. Both of the cross-sectional plots also provide Cs-137 results, including the two initial EMAs (locations 1-4 and 6-6).

**Sand Deposits** - Much of the sand observed exhibited an appearance associated with dune deposits, being light-colored and very fine-grained. Sand of this type was observed in samples obtained at the eastern or western extremes of transects, where the land surface was rising up out of the wetland. Sand was also noted in the center of transect 2.

**Silt and Soft Clay Deposits** - Silt and clay were seen to be dominant in the area just downstream of US Route 6. This was the area traversed by transects 9 and 1, and by grid-sampling area B. It is marked "Scour Area" on Figure 13.

**Peat Deposits** - Peat deposits dominated transects 6 and 5. Peat also dominated in 4 northerly points nearest the bay.

**Delta Deposits** – The delta is represented by transects 3, 7 and 8. In a central area, represented by transects 7 and 8, an alternation of layers of silt and peat could be observed, suggesting alternating dominance by stream deposits (silt) and bay deposits (peat). In the more upstream transect 7, the alternation between silt and peat was frequent and rhythmic. In transect 8, closer to the bay, the sequence was more typically silt overlying peat, suggesting that bay deposits had dominated in earlier years, and land-derived sediments had been more dominant in later years. Finding a delta area, where land-derived deposits encroached over still-water deposits, had been an early objective of the bay investigation. In the bay investigation, it had been expected that a delta would be found, where sand would advance over silt, and silt would advance over clay. Clay, at the bottom of that sequence of deposits, was expected to be the characteristic still-water deposit in the bay. However, in the bay study, it was instead found that the characteristic still-water deposit was peat, and no delta was identified in the bay. In the Stream Mouth, the central-area deposit of silt over peat appeared to be the actual form of the delta that the Characterization Plan had anticipated in the bay.

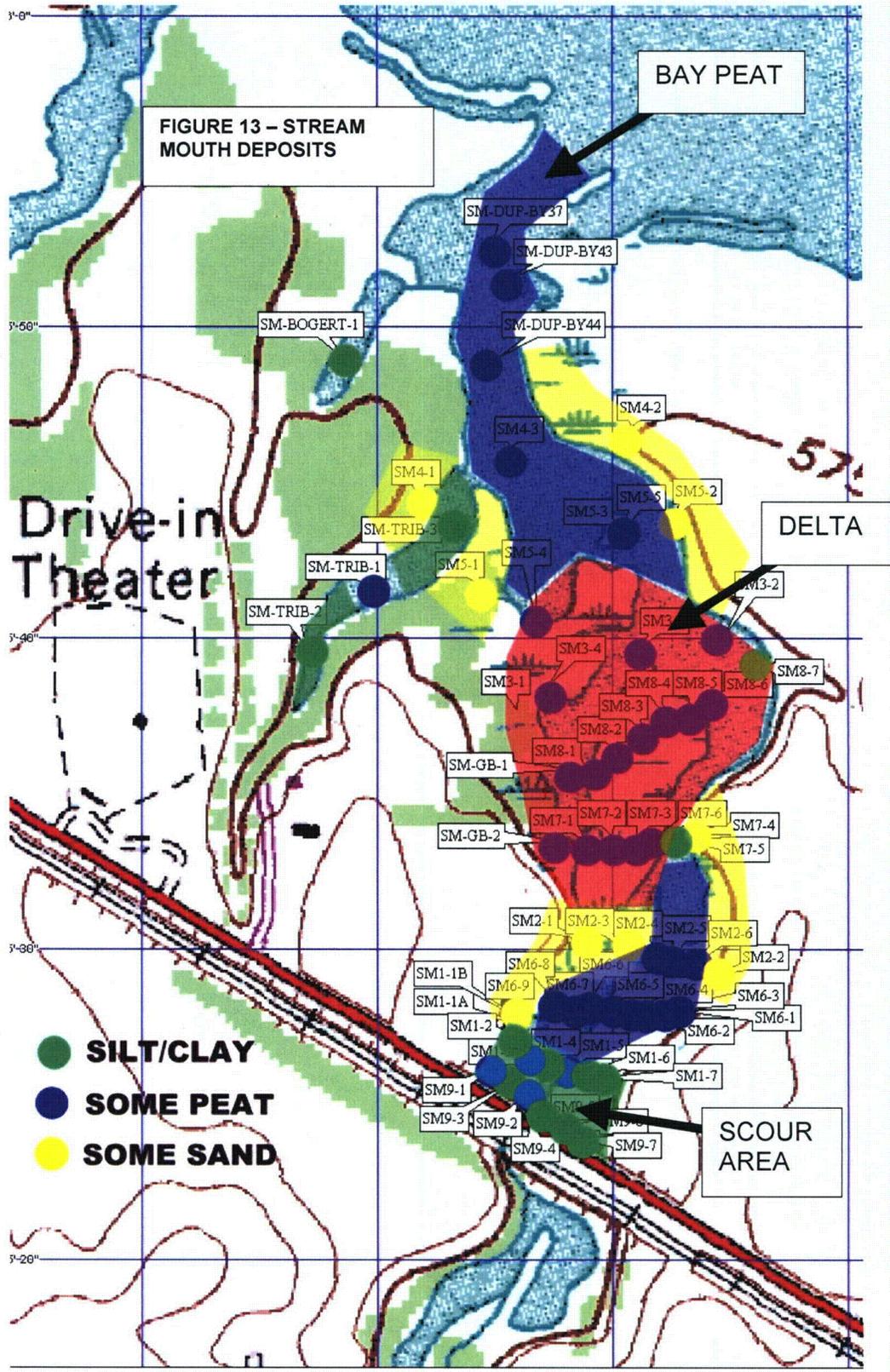


FIGURE 14 – STREAM MOUTH  
SOIL SURVEY

Web Soil Survey 1.1  
National Cooperative Soil Survey

Source of Map: Natural Resources Conservation Service  
Web Soil Survey URL: <http://websoilsurvey.nrcs.usda.gov>

Map Unit Symbol	Map Unit Name
BkA	Bixler loamy fine sand, 0 to 2 percent slopes
BkB	Bixler loamy fine sand, 2 to 6 percent slopes
CmA	Colwood loam, 0 to 1 percent slopes
DeA	Del Rey silt loam, 0 to 2 percent slopes
FnA	Fluvaquents, silty, 0 to 1 percent slopes, frequently flooded
HoA	Holly silt loam, 0 to 1 percent slopes, occasionally flooded
KbA	Kibbie fine sandy loam, 0 to 2 percent slopes
MfA	Milford silty clay loam, 0 to 1 percent slopes
ShB	Shinrock silt loam, 2 to 6 percent slopes
TuA	Tuscola fine sandy loam, 0 to 2 percent slopes
TuB	Tuscola fine sandy loam, 2 to 6 percent slopes
W	Water
ZuC2	Zurich silt loam, 6 to 12 percent slopes, eroded

**Soils with  
"Sand" in  
Name**

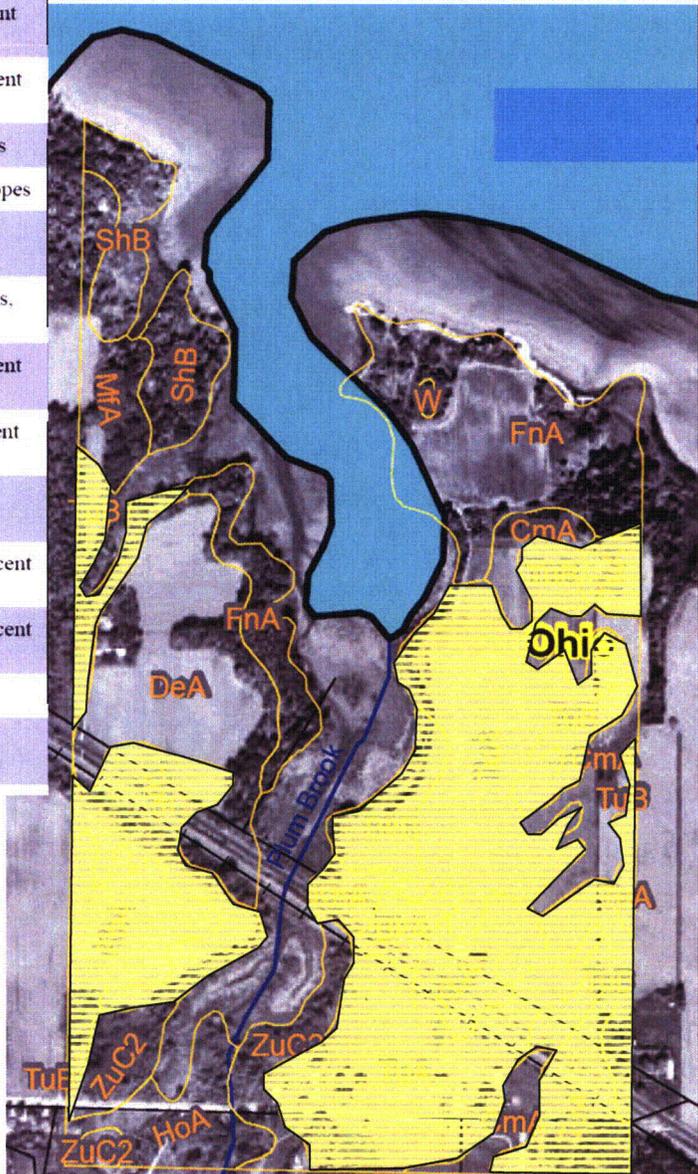


FIGURE 15 – STREAM MOUTH  
SEDIMENTS

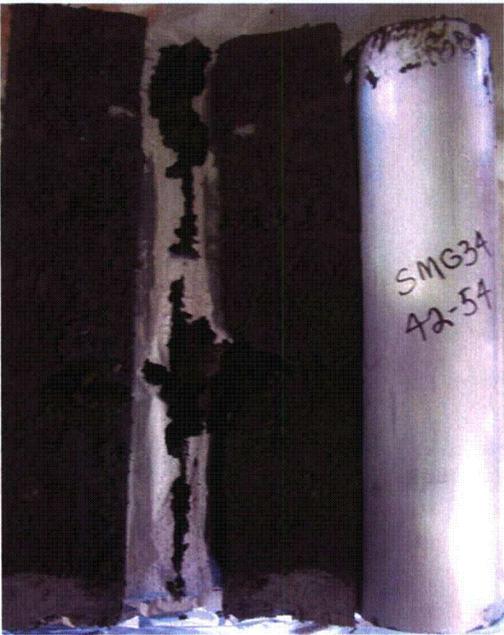


FINE SAND  
AND SILT



INTERBEDDED PEAT AND CLAY

PEAT OVER CLAY TILL



DENSE  
GLACIAL  
TILL



**Cs-137 Results in Initial Transects** – As shown by Figure 16, peak Cs-137 results approached or exceeded 12 pCi/g in two locations in the initial transect sampling effort. One of these was found at Stream Mouth (SM) location 1-4, also called SM1-4, where a peak value of 11.7 pCi/g was detected. The second was found at SM location 6-6, where a peak value of 20.6 pCi/g was reported. Both of these EMAs were found in the existing stream channel. Downstream, the next highest Cs-137 values found were in an abandoned channel, which had carried the stream in 1969. These values were 3.9 pCi/g at SM location 7-5, and 3.4 pCi/g at SM location 8-7. A value of 2.54 pCi/g at SM location 5-5 may also be related to this channel, as may be a value of 2.32 pCi/g at SM location 4-3. The value of 11.7 pCi/g was found in the depth interval of 6-18” below the active stream bottom, the 20.6 pCi/g was found at 0-6” below the active stream bottom, the 3.9 pCi/g was reported at 6-18” below the in-filled land surface above the old channel, the 3.4 pCi/g was reported at 18-30” below the in-filled land surface above the old channel, and the 2.54 and 2.32 pCi/g values were reported 6-18” below the surface. The balance of the downstream detections of Cs-137 observed were scattered above and below 1 pCi/g (ranging from 0.3-1.3), and were generally found in the upper 18” of the sample column, with most of the highest values in the upper 6” sampled. Upstream from the EMA at location SM1-4, some Cs-137 detections extended to greater depths. In particular, a value of 1.2 pCi/g was found in the 42-54” interval at location 9-2, and a value of 2.6 pCi/g was found in the 42-54” interval at location 9-4.

In most sampling locations, Cs-137 values less than the Minimum Detectable Activity (MDA) were found at some depth below the surface. Figure 17 shows the locations where this was not achieved. In all such cases where the full vertical extent of the Cs-137 distribution was not defined, it was noted that all values at the bottom of the sample column were less than 12 pCi/g. However, it was not possible to assert that all of the patterns of detection versus depth were showing a declining concentration.

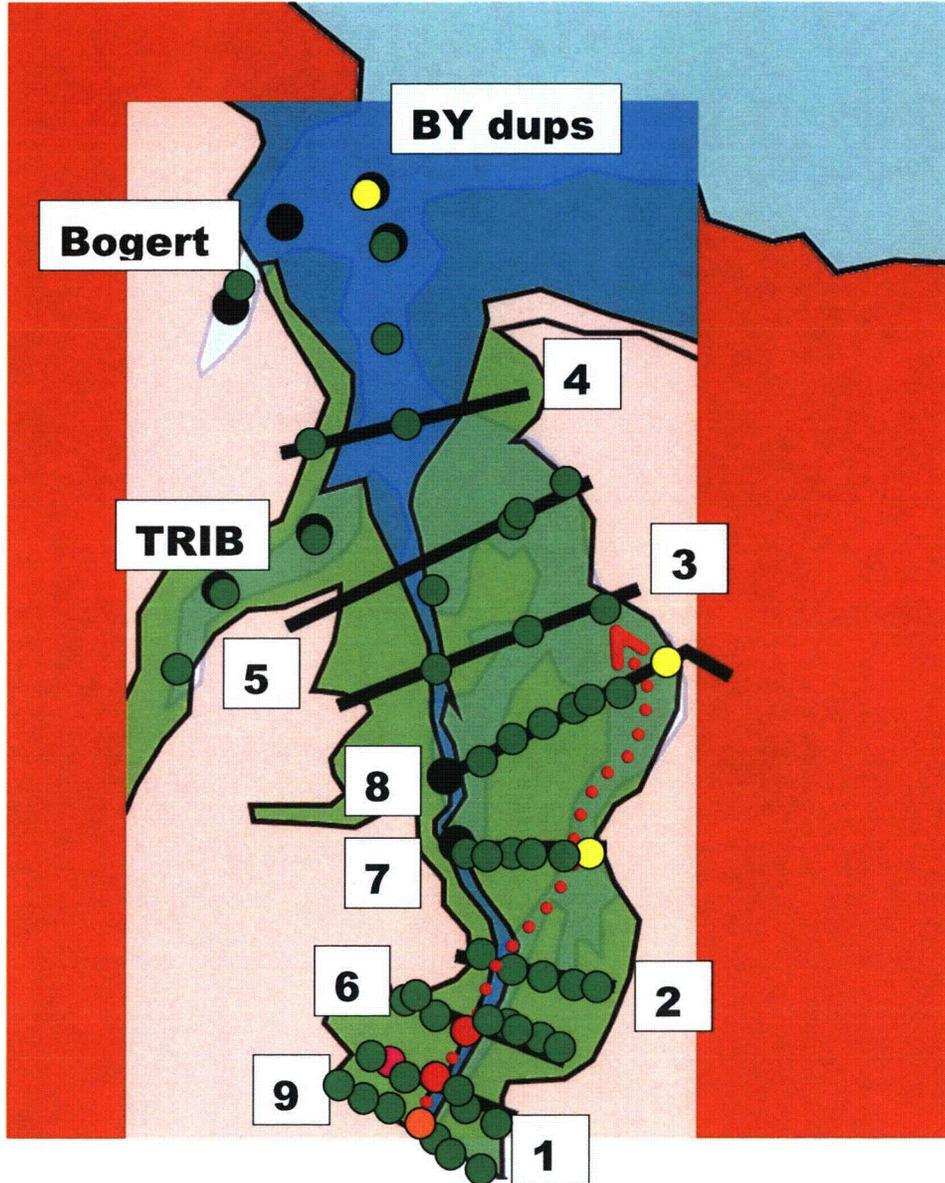


FIGURE 16 – HIGHEST RESULTS IN INITIAL TRANSECTS

- Cs-137 > 11.5 pCi/g
- Cs-137 = 7.7 pCi/g (at 5' in pond)
- Cs-137 = 6-11.5 pCi/g
- Cs-137 = 3-6 pCi/g
- Cs-137 detected, but < 3 pCi/g

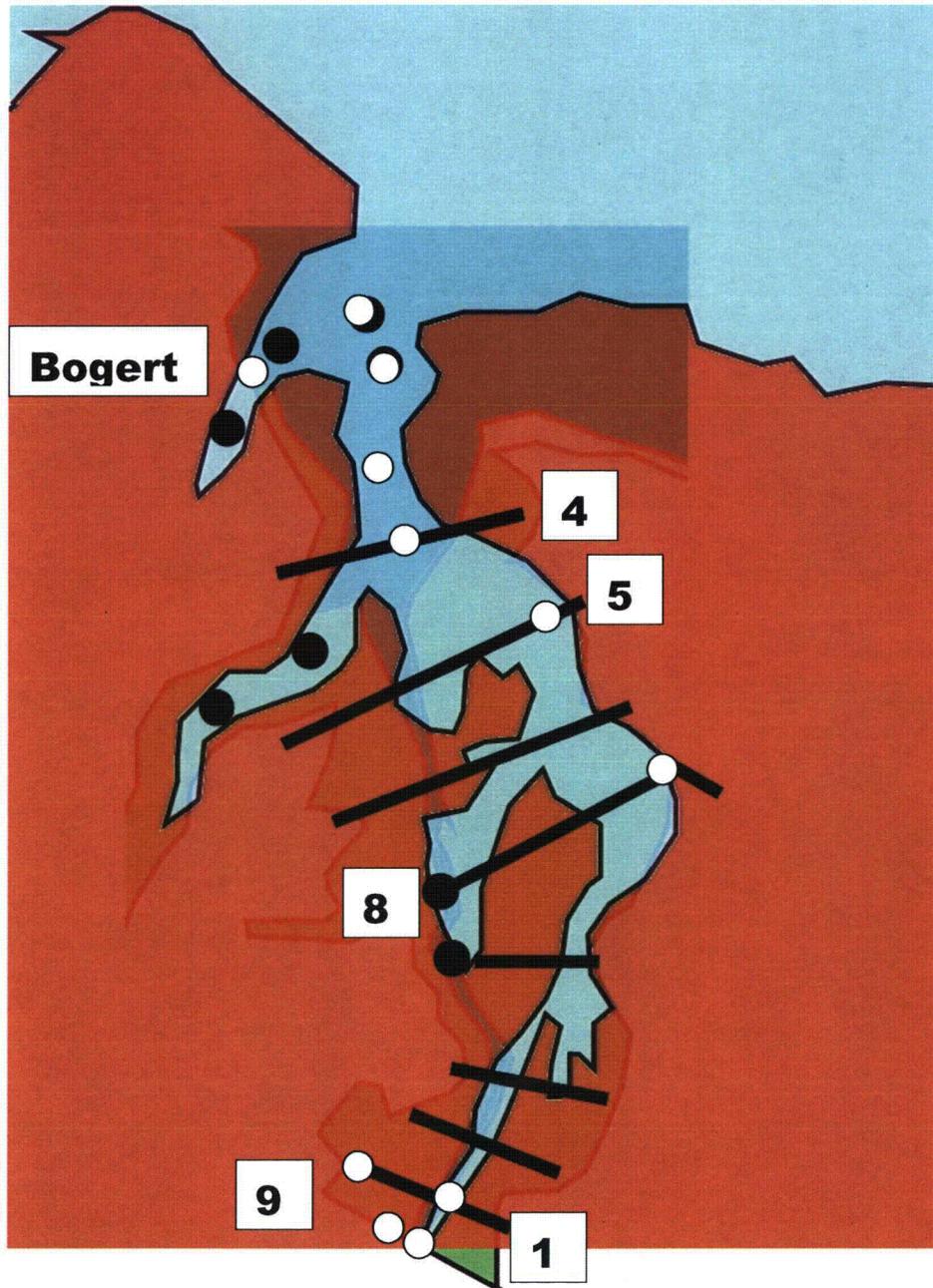
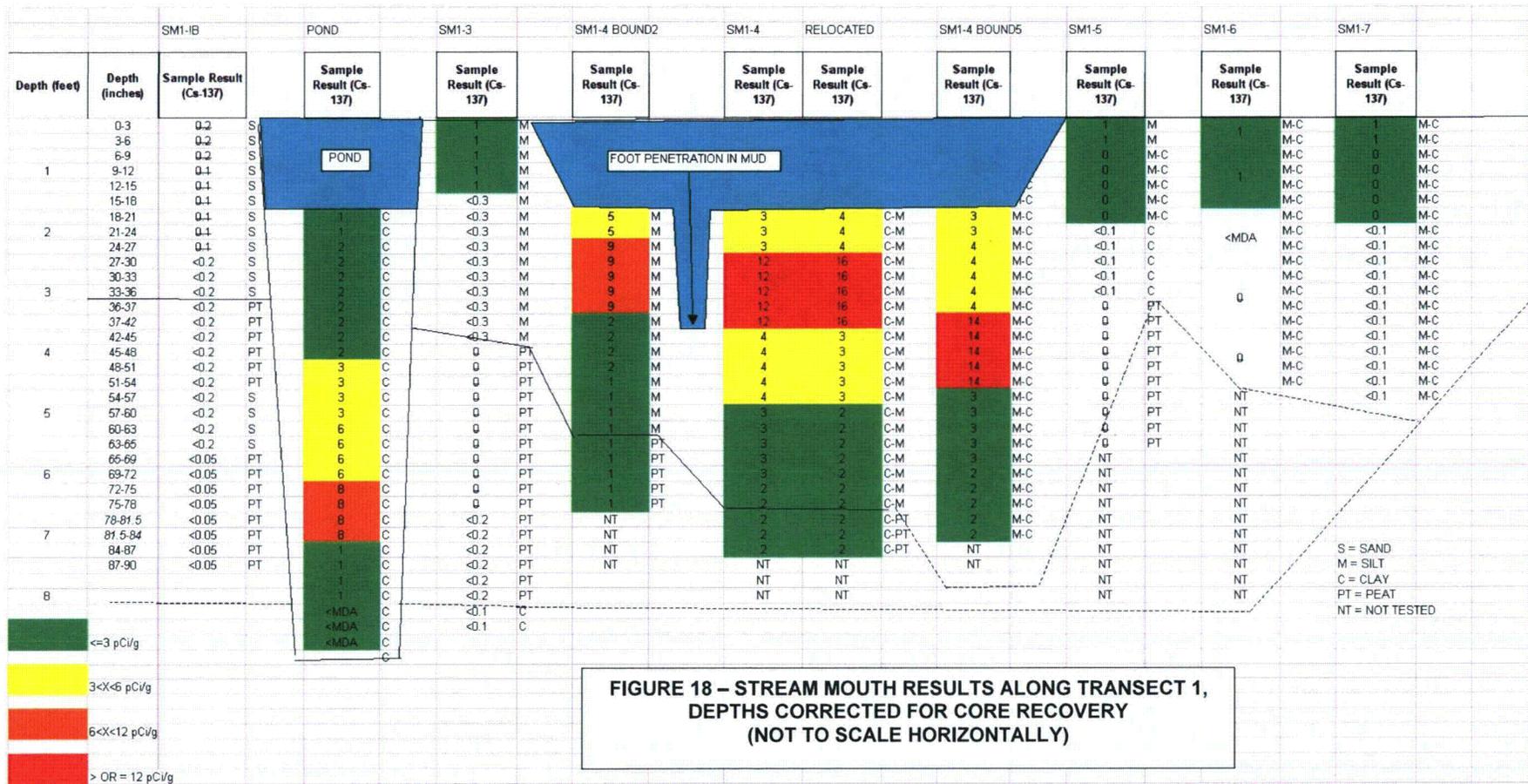


FIGURE 17 – LOCATIONS WHERE CS-137 WAS DETECTED AT BOTTOM OF CORE IN INITIAL TRANSECTS

- Originally Planned Sample Locations and Transects
- Actual Locations Where Vertical Extent Was Not Fully Defined



**FIGURE 18 – STREAM MOUTH RESULTS ALONG TRANSECT 1, DEPTHS CORRECTED FOR CORE RECOVERY (NOT TO SCALE HORIZONTALLY)**

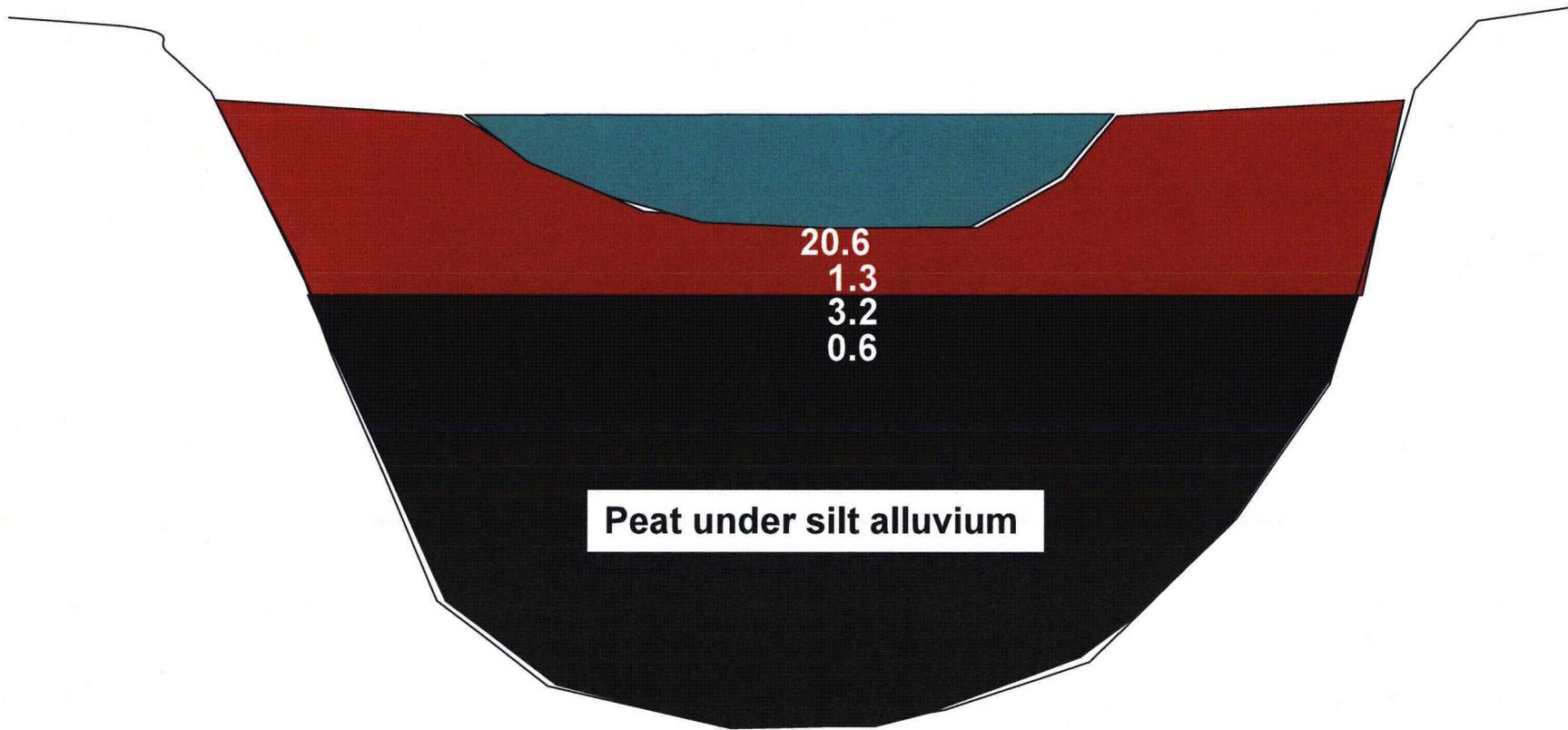


FIGURE 19 – HIGHEST STREAM MOUTH RESULTS IN ORIGINAL TRANSECTS, ON GENERALIZED CROSS-SECTION (NOT TO SCALE). RESULTS IN pCi/g.