

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

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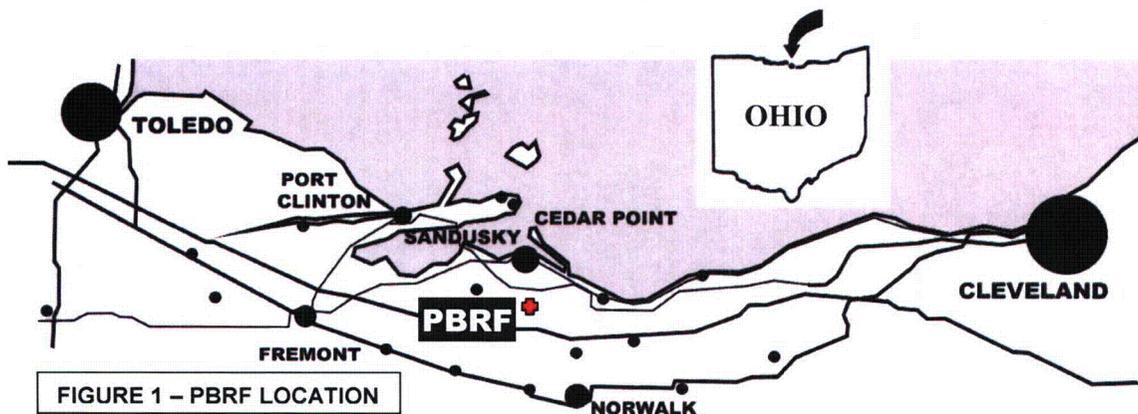
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CHARACTERIZATION REPORT FOR PLUM BROOK SEDIMENT IN STREAM MOUTH WETLANDS

INTRODUCTION

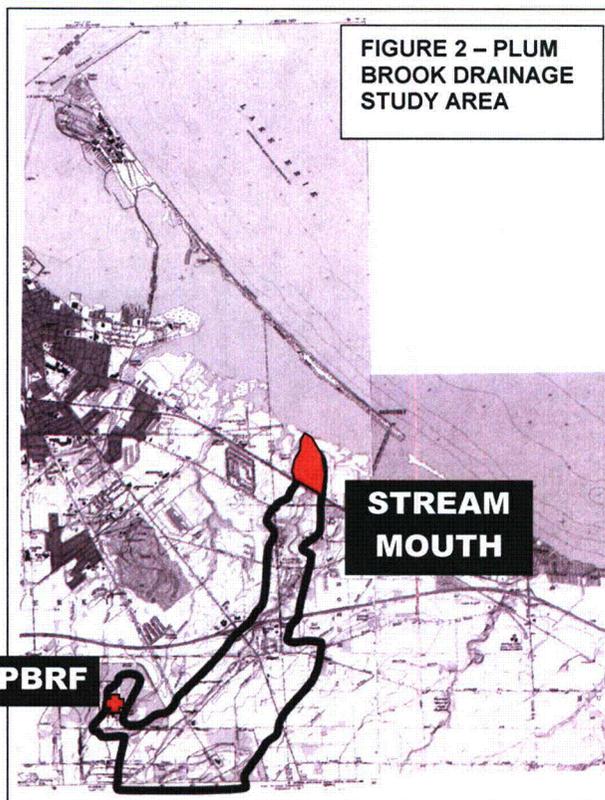
This report documents an investigation of the potential distribution of a radioactive isotope of the element cesium, known as ^{137}Cs , or Cs-137, in the stream mouth wetlands of Plum Brook near Sandusky, Ohio. This investigation was conducted to determine whether Cs-137 attributable to a decommissioned 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 (PBOW). The PBOW 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 (5×10^{-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:

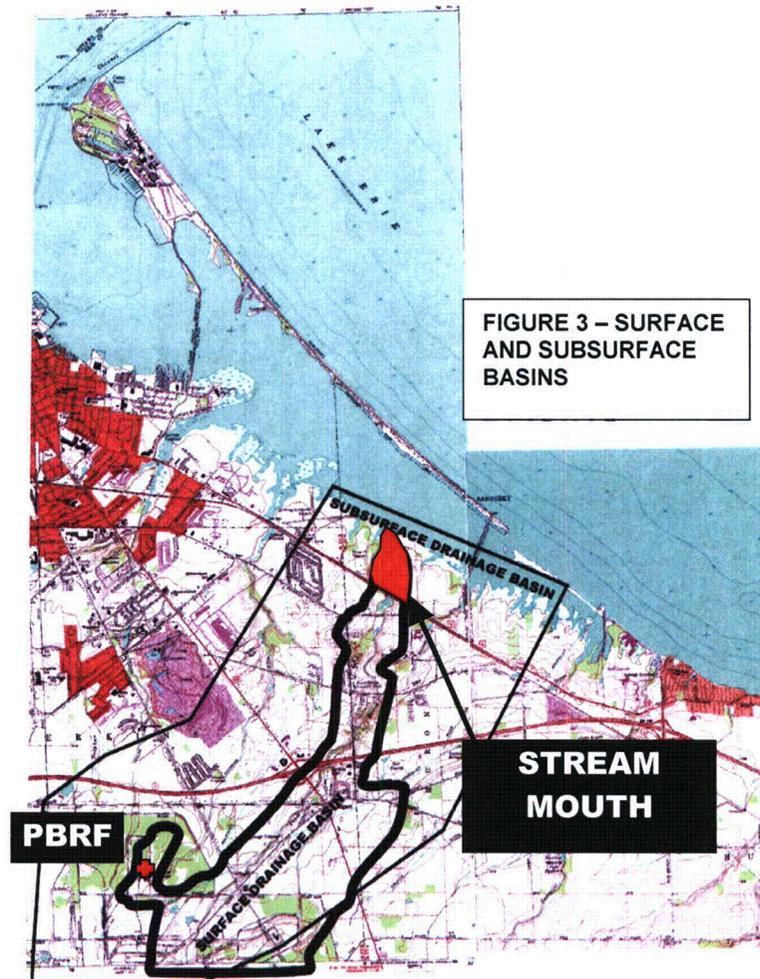
1. Ease of reaching the contaminated sediment with remediation equipment
2. Ease of removing only the contaminated sediment
3. Ease of separating contaminated clay from other materials

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.

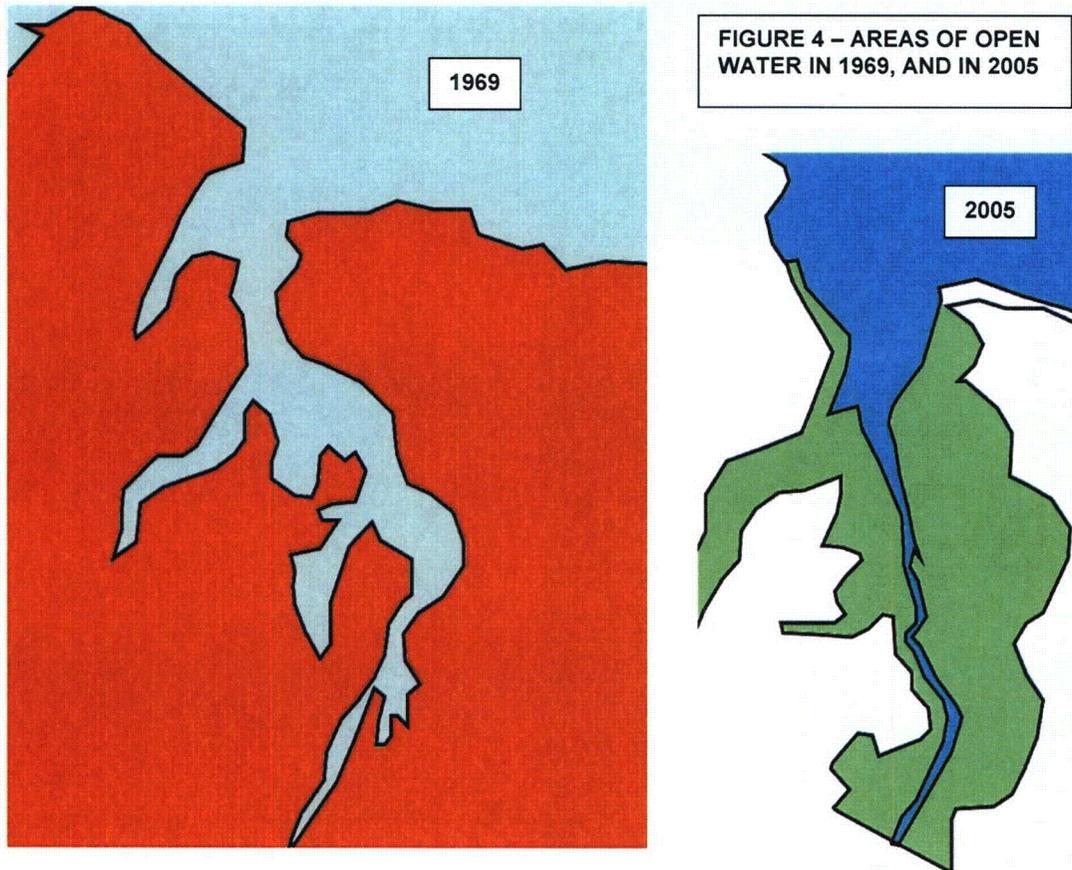
9. The computed minimum number was increased by applying a safety factor of 1.2 and rounding up, yielding a revised minimum number of 14 samples to characterize the variability in any sampled area.
10. In some of the depositional environments to be considered, 11 samples might not be enough to assure 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 Dzvonnar, 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

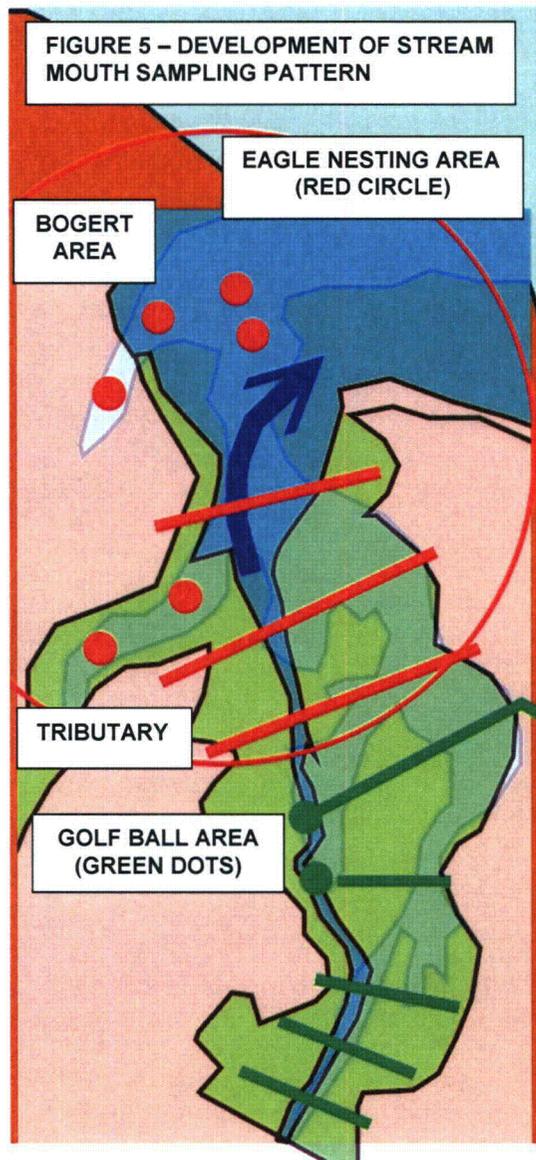
Through discussions with MetroParks personnel, sampling was planned to avoid times of bald eagle nesting, and to avoid permitted duck and deer hunting. During the stream mouth sampling effort, HaagEnviro maintained contact with the park system's Supervisor of Operational Services, James Lang. Sampling 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.

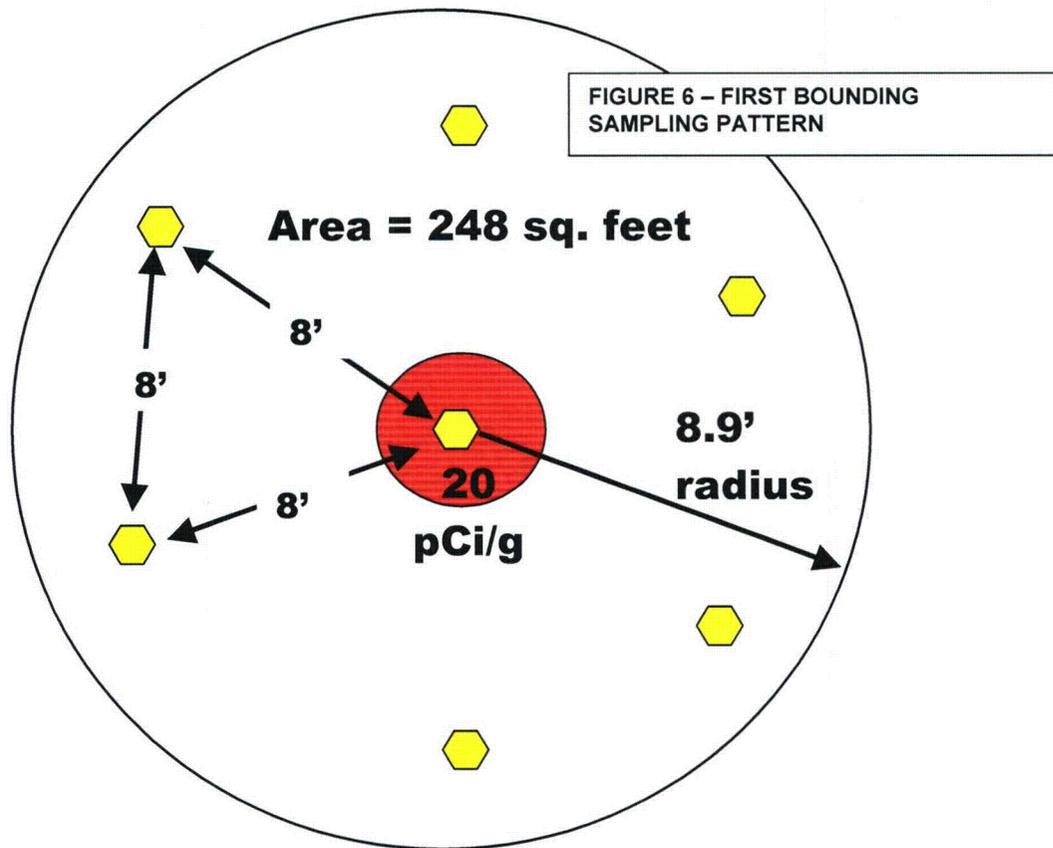
DEVELOPMENT OF INITIAL SAMPLING TRANSECTS

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.



DEVELOPMENT OF SECOND BOUNDING GRID

The key assumption underlying the second bounding investigation was that the two EMAs represented a continuum of lognormally distributed values within the stream channel, extending from US Route 6 at the South, through the delta at the North. Part of this Cs-137 distribution was expected to lie within the then-current stream channel. Part of this Cs-137 distribution was expected to lie within an abandoned stream channel that had been active in 1969.

Using this rationale, the sampling pattern shown in Figure 7 was developed. In this figure, the red dot represents one of the original EMAs, the blue dots depict the pattern of the first bounding trial, and the yellow dots depict the second bounding grid pattern.

The size of the survey area was based upon a stream width of 50 feet, and the maximum size for a Class 1 survey area, as defined in the FSSP. In order to survey the entire stream channel, beginning at US Route 6 and extending downstream into the delta, it was determined that 3 survey areas of this 50'x300' size would be needed. The first, labeled Area A, was centered on the highest EMA, which had produced a peak Cs-137 measurement of 20.6 pCi/g.

The second survey area, labeled B, was upstream of A, and was centered on the EMA that had produced a peak Cs-137 measurement of 11.7 pCi/g. The third survey area, labeled C, was downstream from A. Area C began in the then-current stream channel, but deviated downstream to the east of the channel, following the path that the stream had followed in 1969. The relationships between areas A, B and C are illustrated by Figure 8.

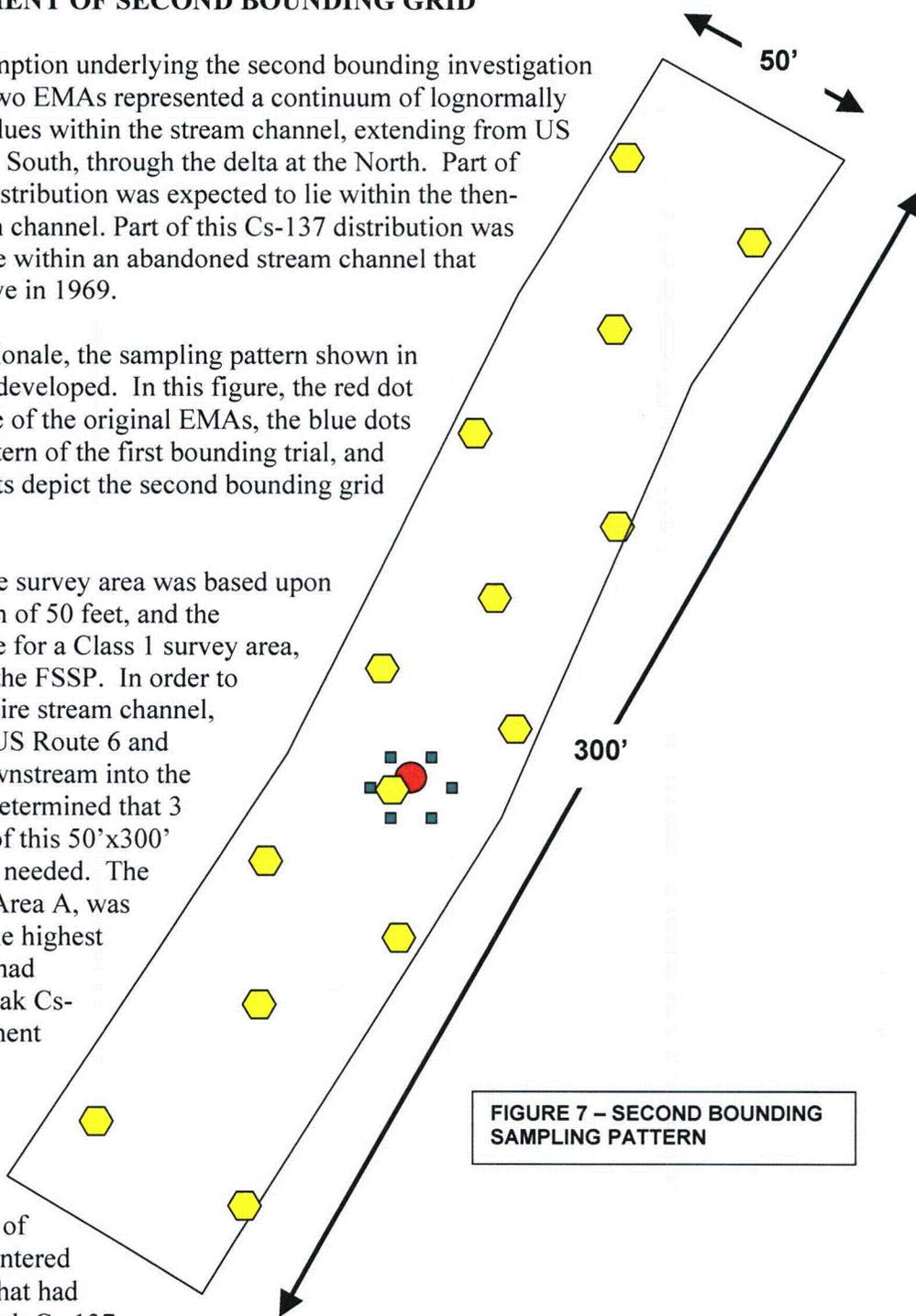


FIGURE 7 – SECOND BOUNDING SAMPLING PATTERN

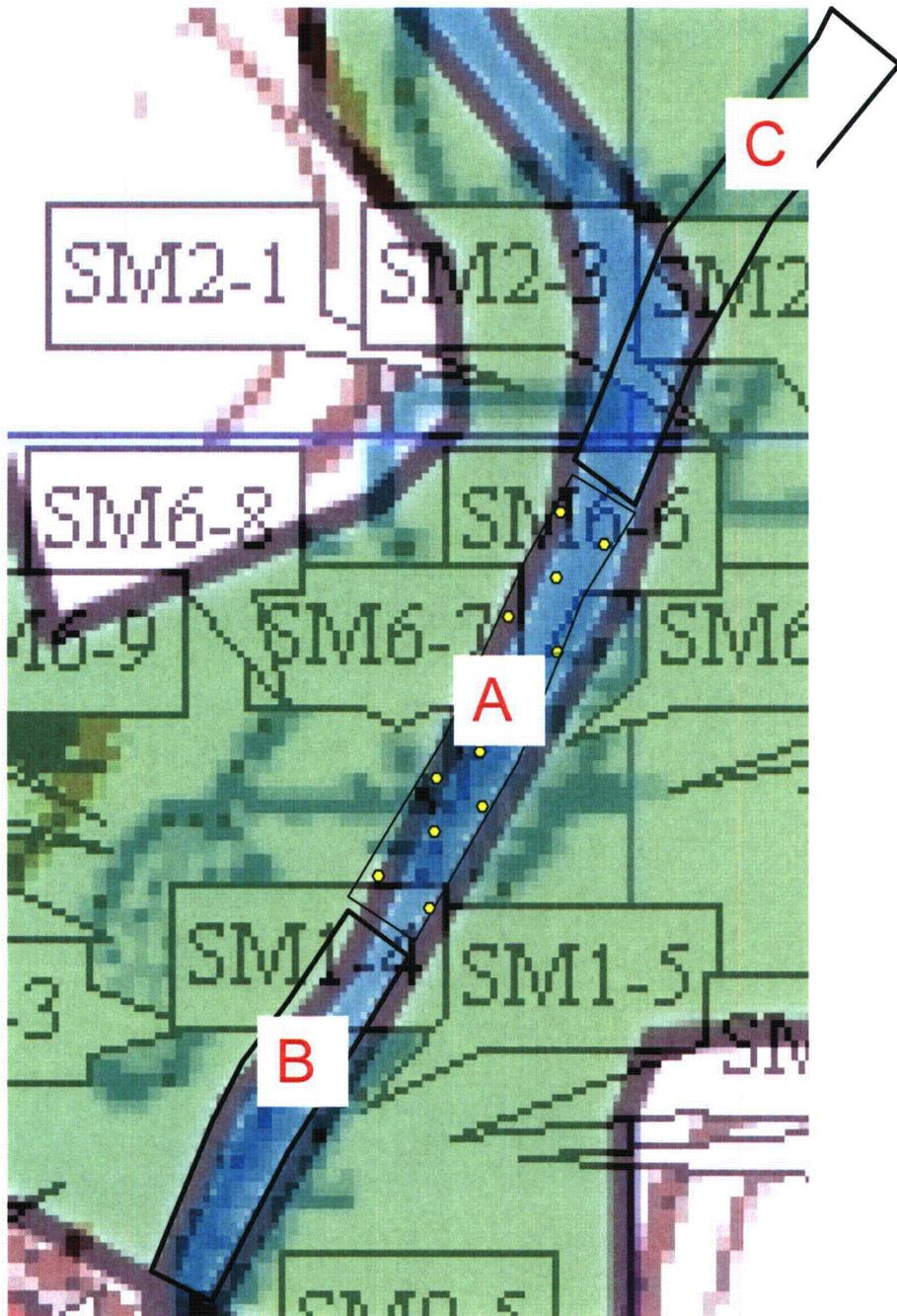


FIGURE 8 – RELATIVE LOCATIONS OF SECOND BOUNDING AREAS A, B AND C

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.



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 2350-1 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

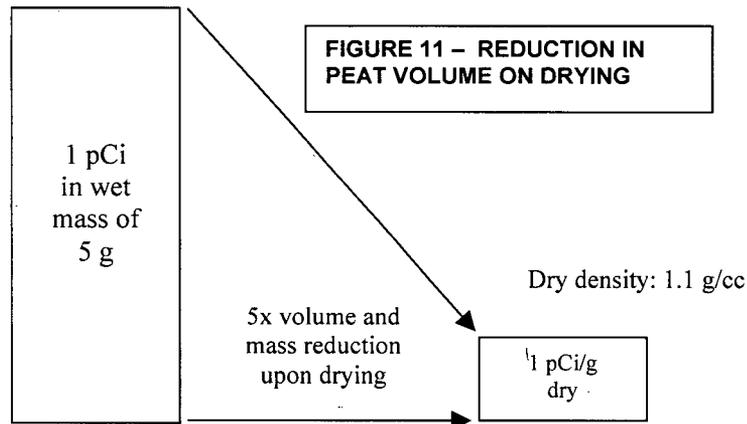
In the soil processing facility, the top 54 inches of the sample tubes were cut into appropriate lengths. Lines were marked 6" from the top, then every 12", down to a total length of 54". The tubes were cut along the marked lines, and the samples were pushed

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.

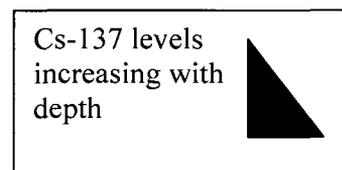
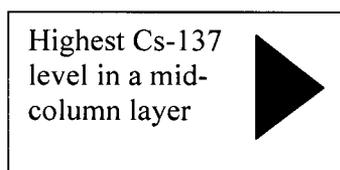
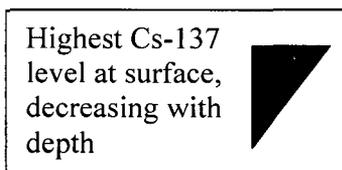
To evaluate the precision achieved by (sample processing + laboratory), QC duplicate analyses were compared to the results for the original field samples.

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, $\log(\text{Cs-137 results})$ 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 (H₂S) 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.

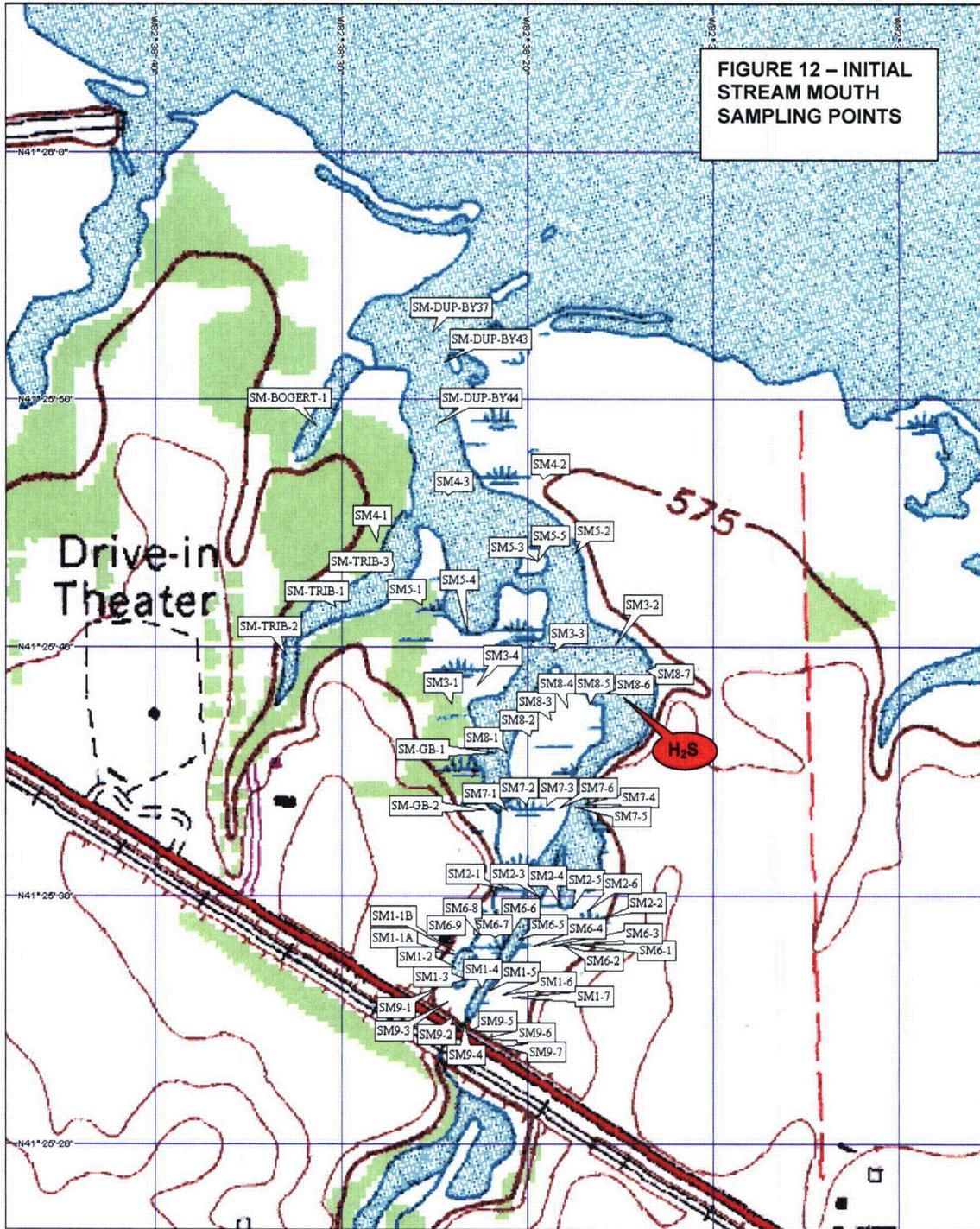
In response, the crew left the area of the odor, and returned with a 4-gas meter and a photoionization detector (PID). The 4-gas meter measured H₂S, carbon monoxide (CO), oxygen (O₂), and lower explosive limit (LEL). The PID measured volatile organic compounds (VOCs). The HaagEnviro scientists verified that the OSHA Permissible Exposure Limit (PEL) for H₂S 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 H₂S meter indicated peak readings over 30 ppm (exceeding the PEL of 20). CO, LEL, and O₂ 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.



**FIGURE 12 – INITIAL
STREAM MOUTH
SAMPLING POINTS**

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.

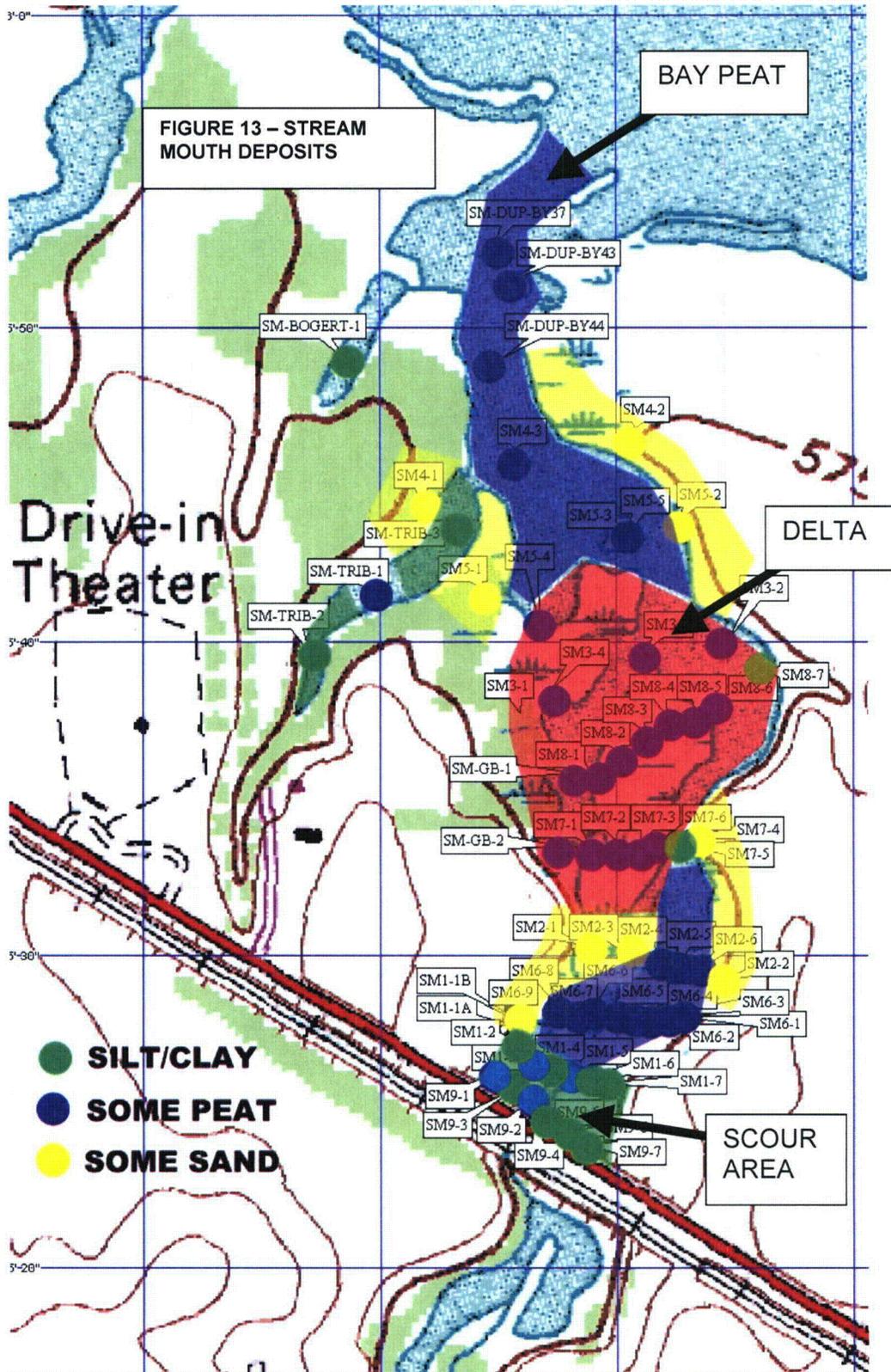
A map-view illustration of the highest Cs-137 results found in the initial transects is provided by Figure 16. Sample locations where Cs-137 was still being detected at the bottom of a core in the original transects are indicated on Figure 17. A detailed cross-sectional plot of the sediment deposits 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.



1/20/00 Copyright © 1999 DeLorme Yarmouth, ME 04096 Source Data: USGS 150 ft Scale: 1:6,400 Detail: 15:0 Datum: WGS84

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**

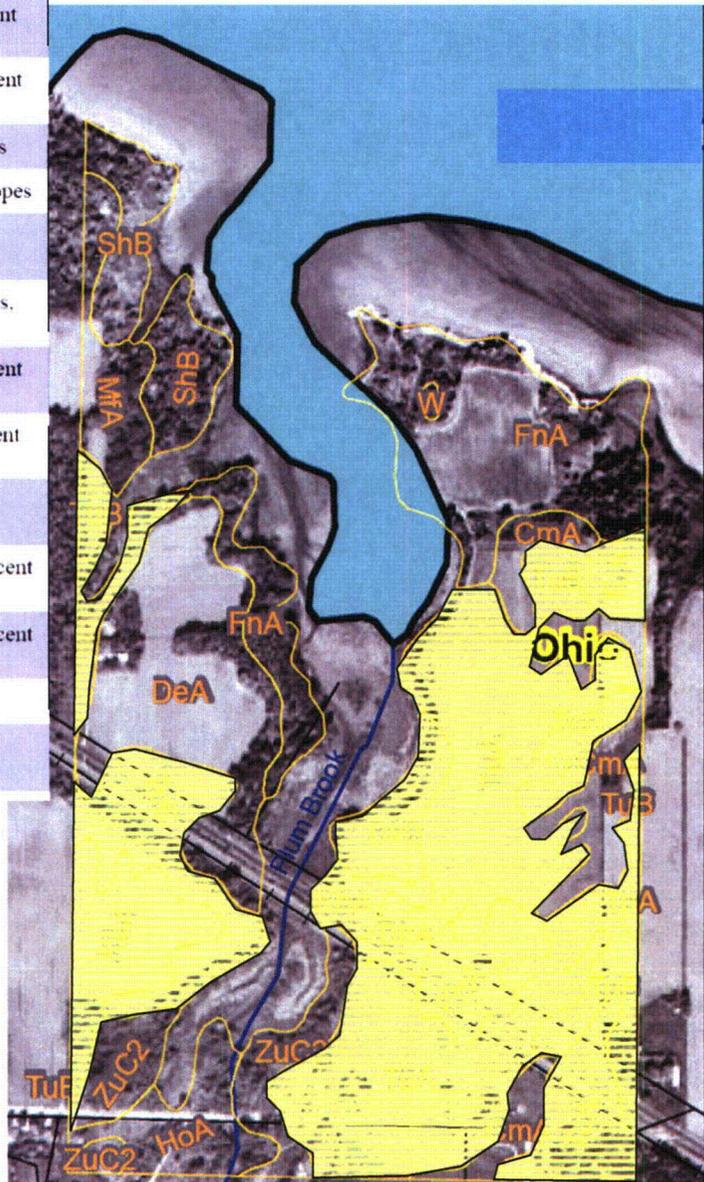


FIGURE 15 – STREAM MOUTH
SEDIMENTS

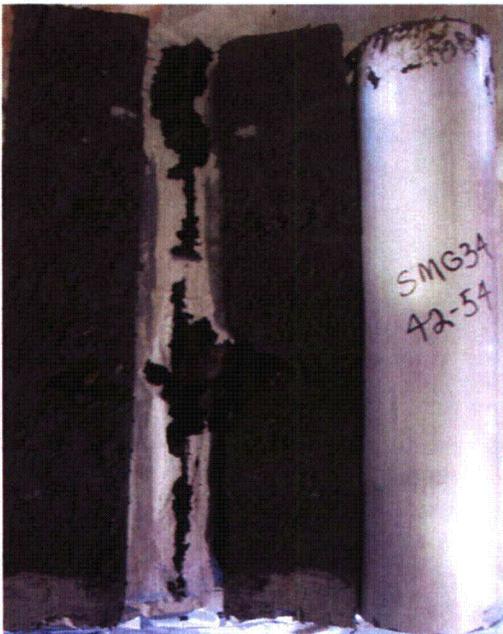


FINE SAND
AND SILT

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.

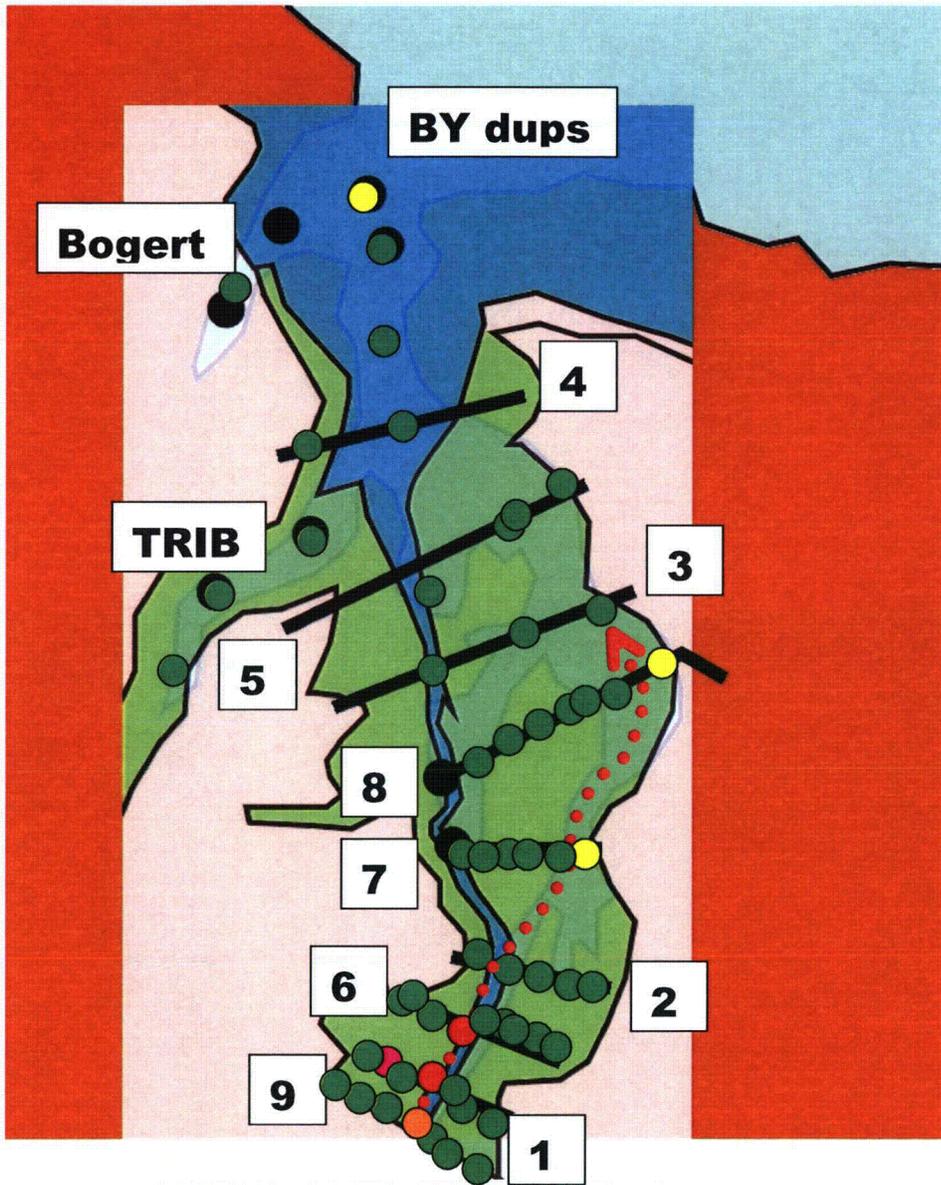


FIGURE 16 – HIGHEST RESULTS IN INITIAL TRANSECTS

- 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

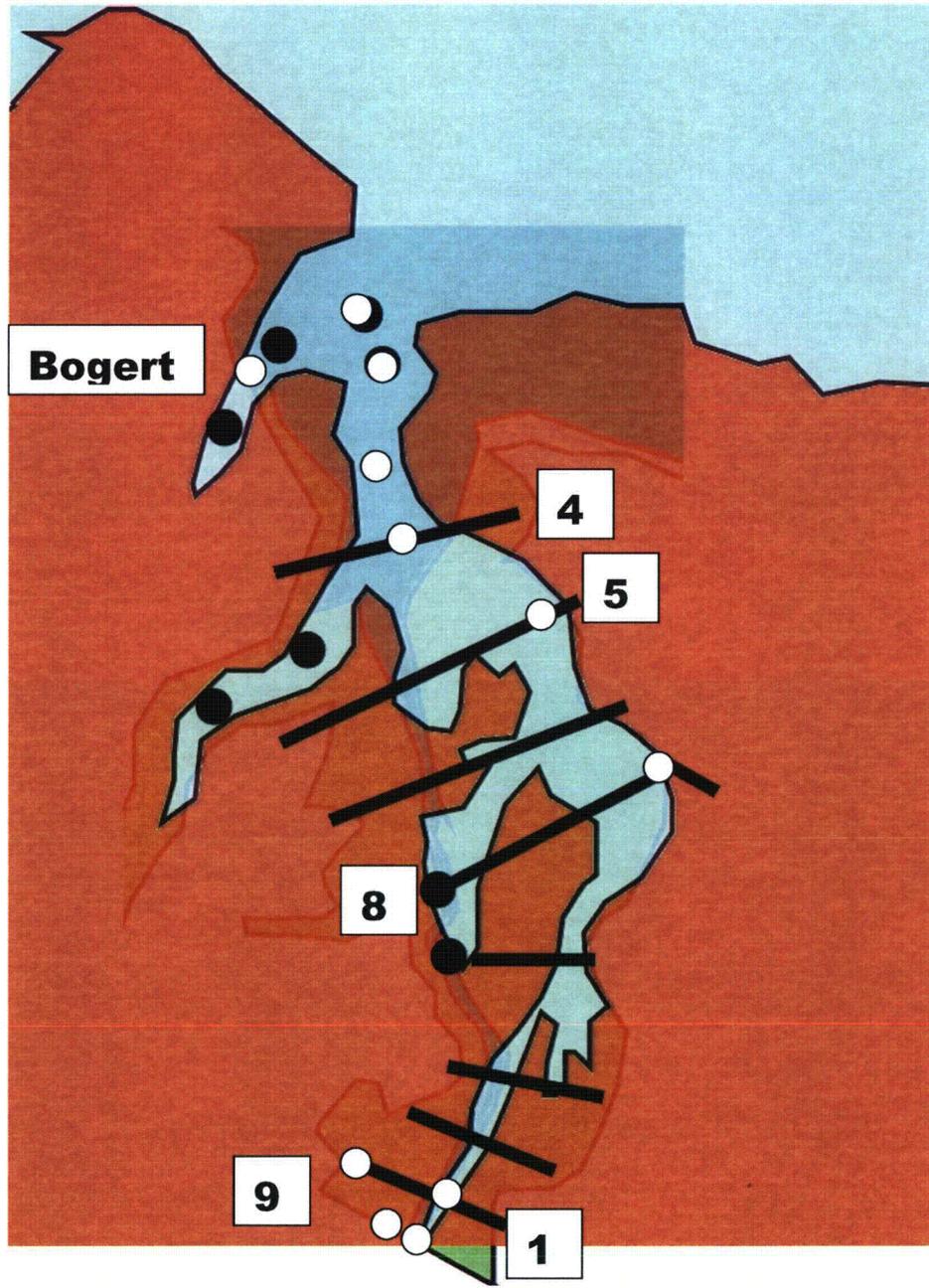
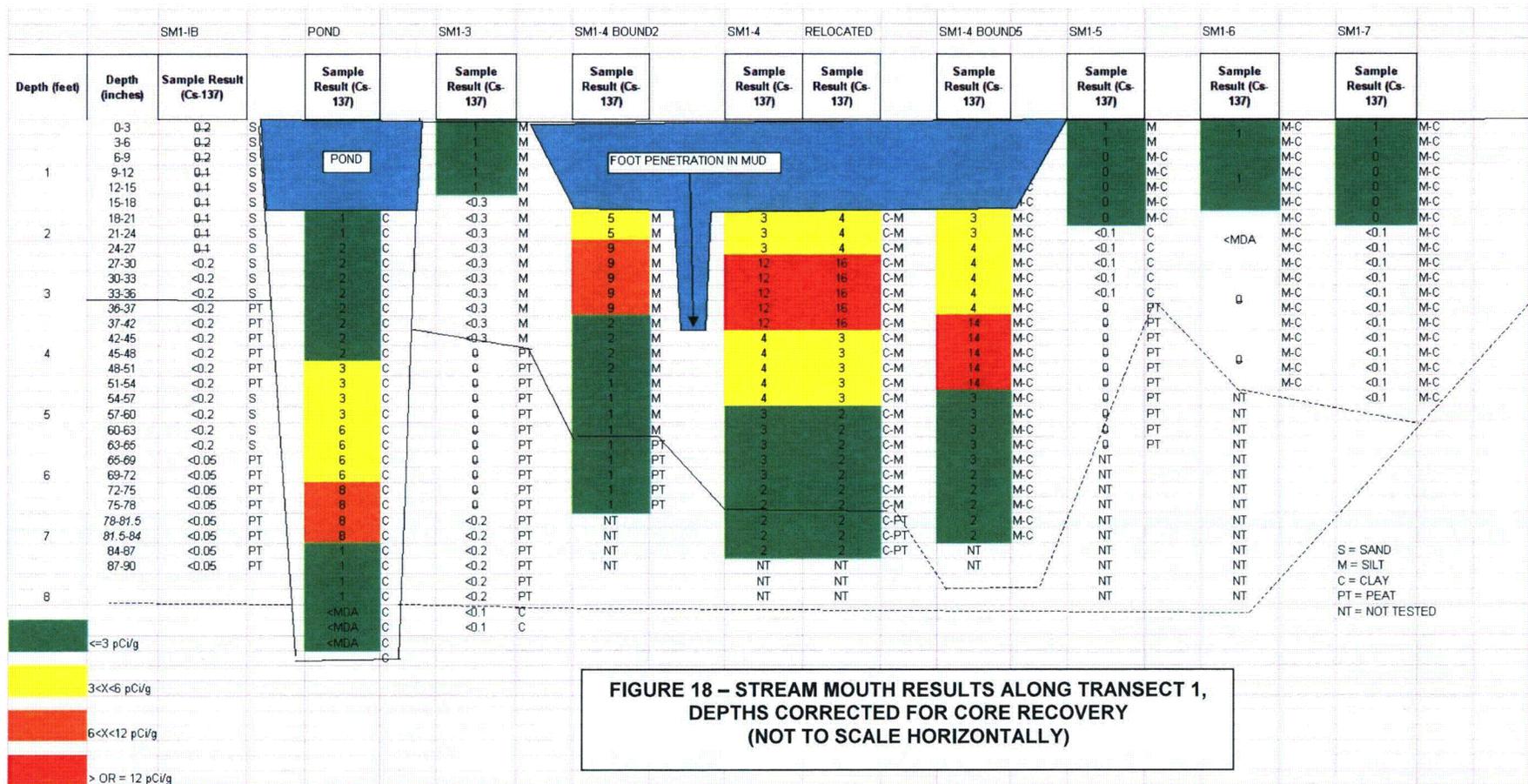


FIGURE 17 – LOCATIONS WHERE CS-137 WAS DETECTED AT BOTTOM OF CORE IN INITIAL TRANSECTS

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



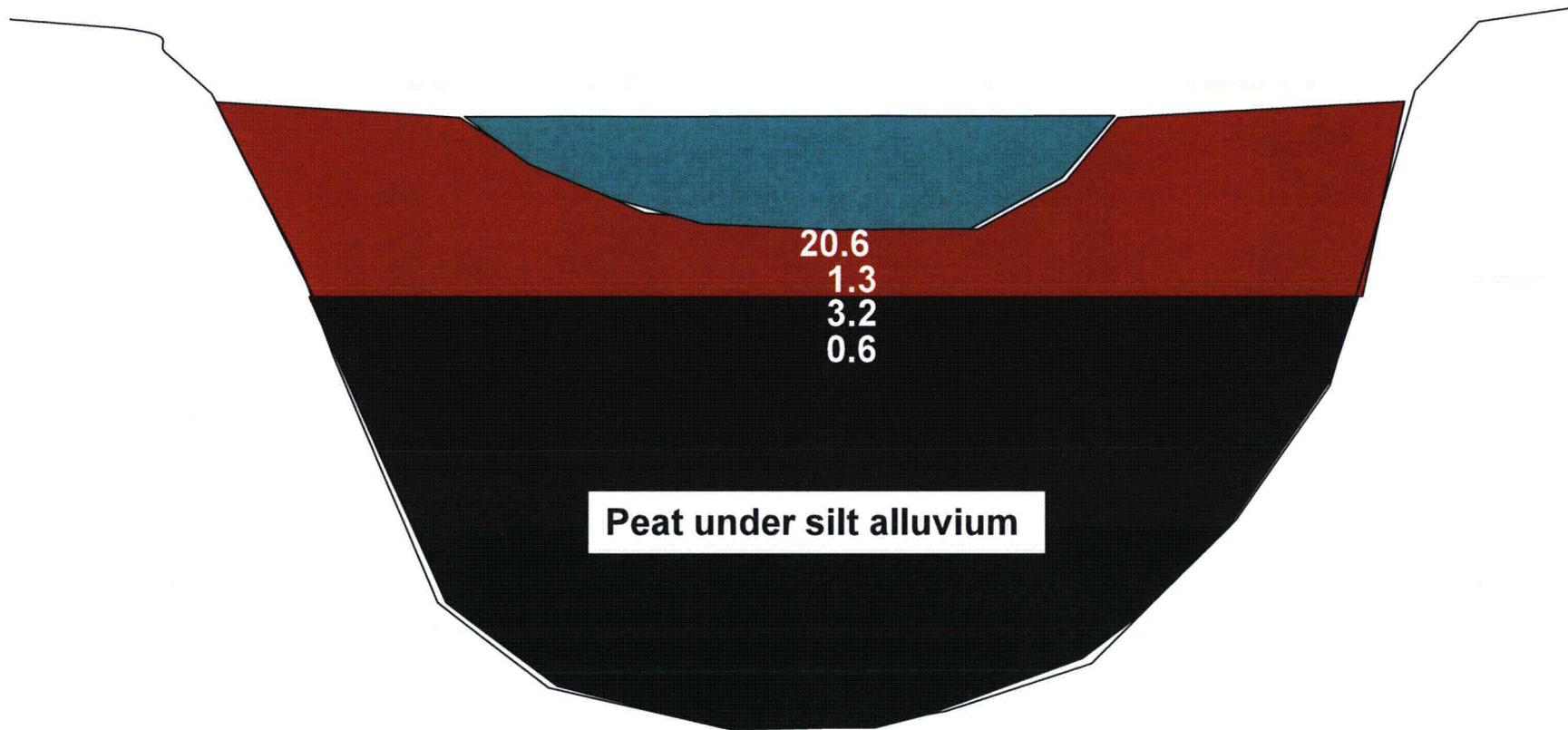


FIGURE 19 – HIGHEST STREAM MOUTH RESULTS IN ORIGINAL TRANSECTS, ON GENERALIZED CROSS-SECTION (NOT TO SCALE). RESULTS IN pCi/g.

FIRST BOUNDING SAMPLING AND TESTING OBSERVATIONS

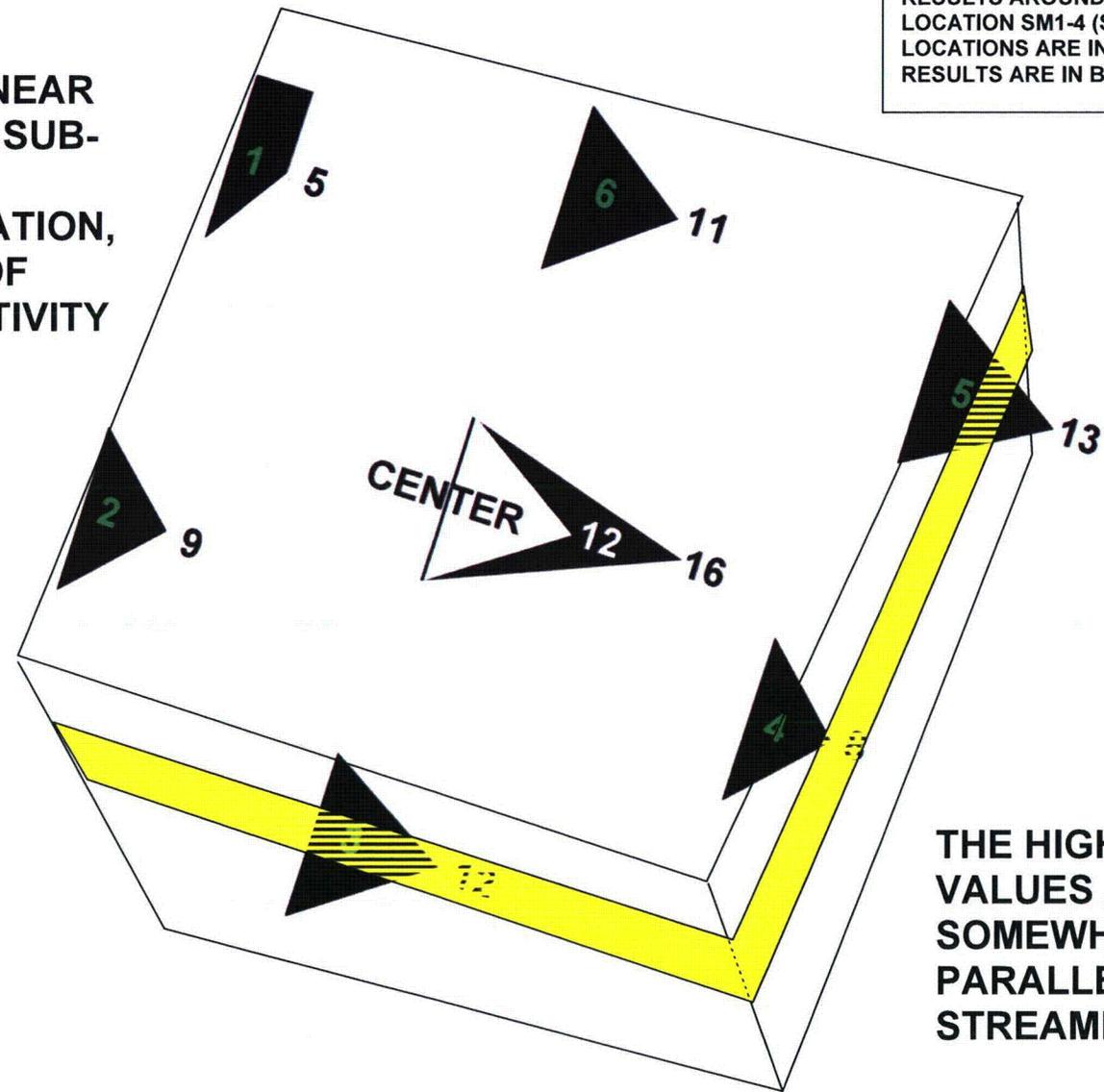
The results from the two EMAs, resampled in the first bounding efforts, are illustrated by Figures 20 and 21. As shown, the area near location SM1-4 has sub-surface contamination, beneath 6 inches of lower-activity stream-bottom sediment cover. This EMA originally produced a peak Cs-137 value of 11.7 pCi/g (rounded to 12 on the diagram); the re-located EMA produced a peak value of 16 pCi/g. The highest values detected in this sampling round were somewhat parallel to streamflow. The highest observed values, from upstream to downstream, were as follows: 12, (12 and 16), and 13 pCi/g.

The area around the EMA at location SM6-6 had stream-bottom surface contamination that plunged under 6 inches of lower-activity cover to the west. This EMA originally produced a peak Cs-137 value of 20.6 pCi/g (rounded to 20 on the diagram); the re-located EMA produced a peak value of 6 pCi/g. The highest values were found parallel to streamflow. The highest observed values, from upstream to downstream, were as follows: 12, (20 and 6), and 12 pCi/g.

At the start of the first bounding effort for the EMA at SM6-6, some bounding samples were inadvertently obtained roughly 20 feet north of the actual location SM6-6. Two of the 7 samples obtained from that incorrect location were analyzed. Their results are reported in Appendix B as locations SM6-6 Bound 1 and SM6-6 Bound 2. Both locations produced Cs-137 values of about 7-8 pCi/g, spanning the top 18 inches of the stream bottom.

The observation that the first bounding approach failed to enclose an area in which all values were below 12 pCi/g led to execution of the second bounding approach.

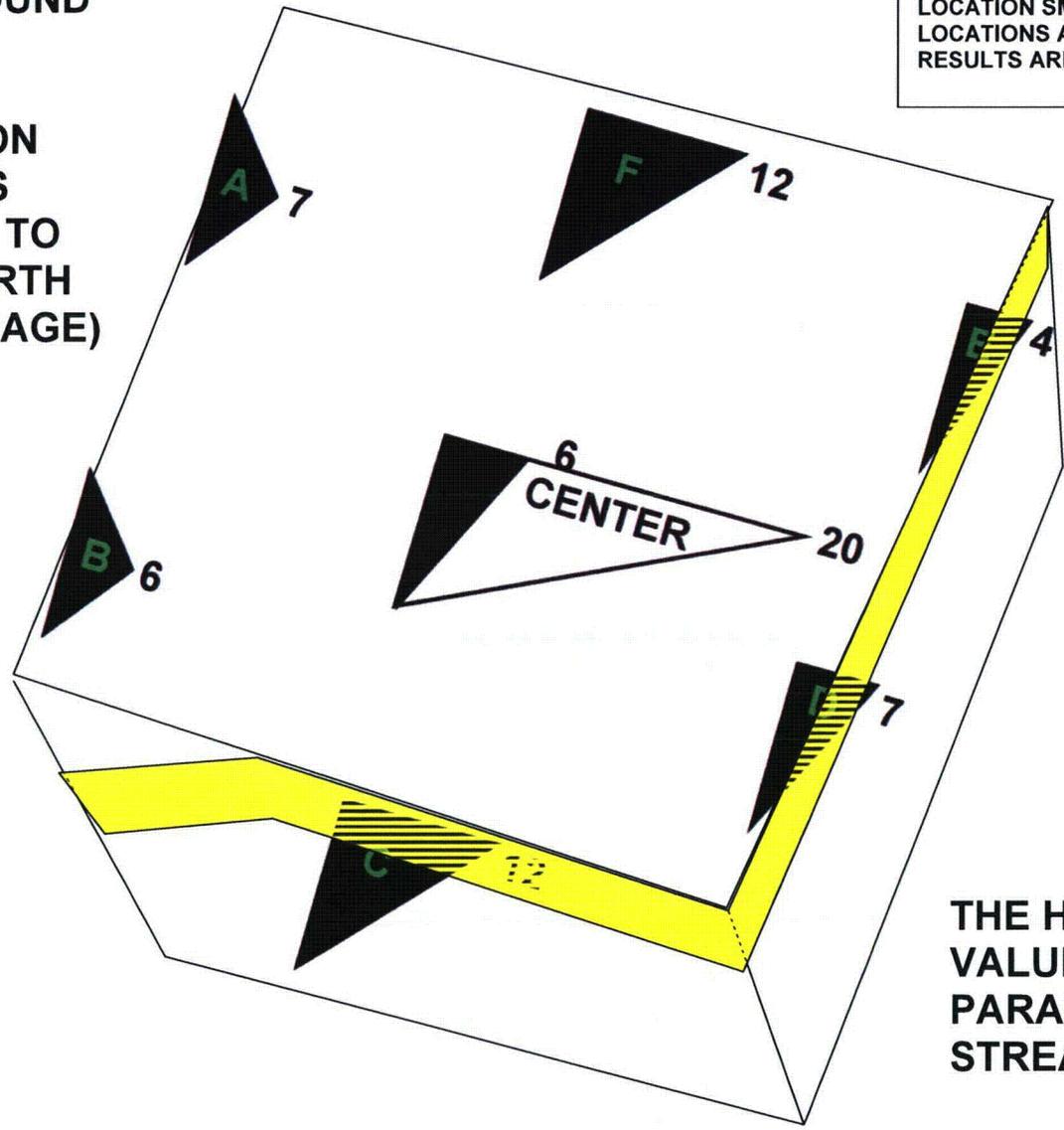
THE AREA NEAR
SM 1-4 HAS SUB-
SURFACE
CONTAMINATION,
UNDER 6" OF
LOWER-ACTIVITY
COVER



THE HIGHEST
VALUES ARE
SOMEWHAT
PARALLEL TO
STREAMFLOW

**THE AREA AROUND
SM 6-6 HAS
SURFACE
CONTAMINATION
THAT PLUNGES
UNDER COVER TO
THE WEST (NORTH
IS TO TOP OF PAGE)**

**FIGURE 21 – FIRST BOUNDING
RESULTS AROUND EMA AT
LOCATION SM6-6 (SAMPLE
LOCATIONS ARE IN GREEN,
RESULTS ARE IN BLACK)**



**THE HIGHEST
VALUES ARE
PARALLEL TO
STREAMFLOW**

SECOND BOUNDING SAMPLING AND TESTING OBSERVATIONS

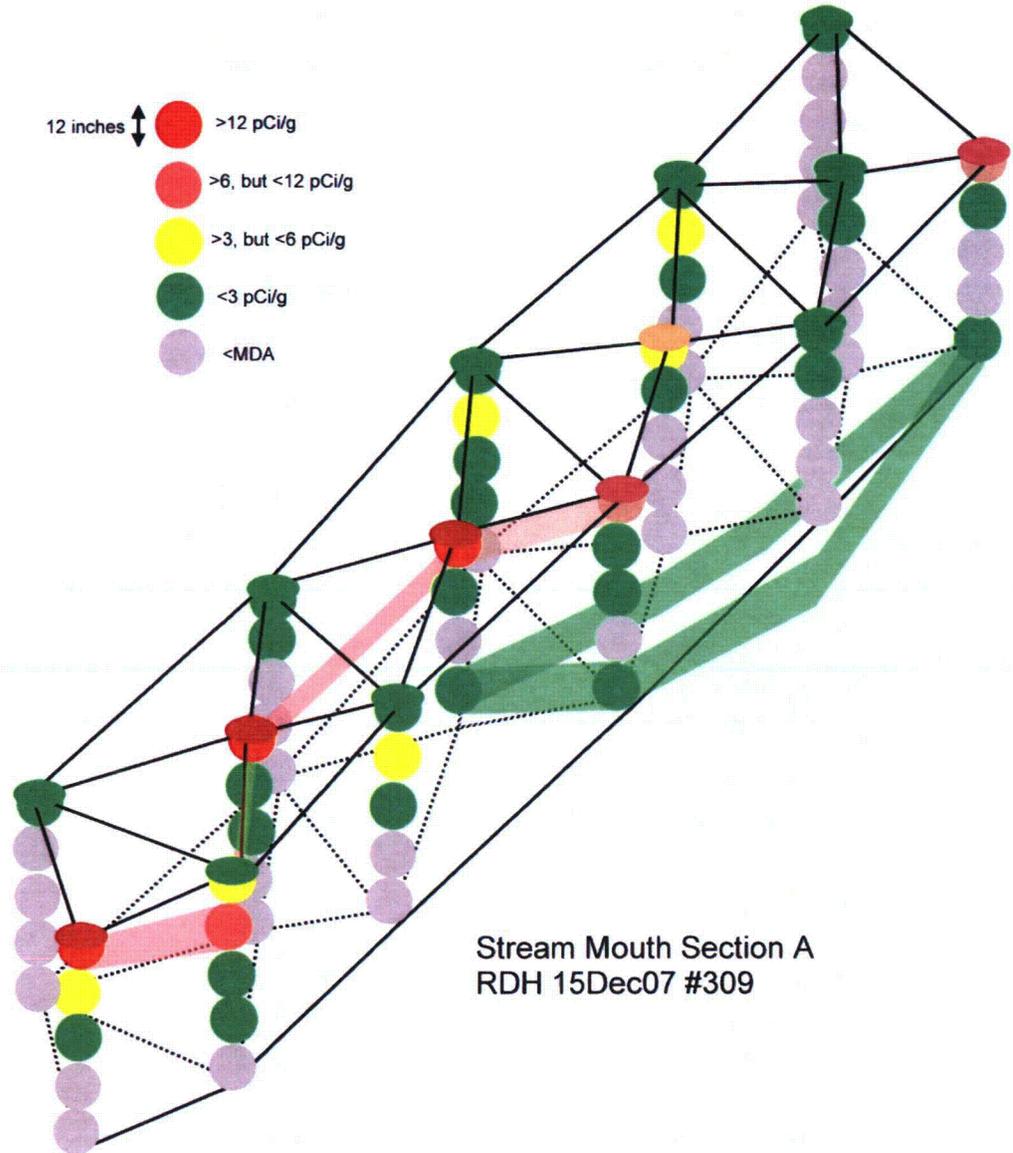
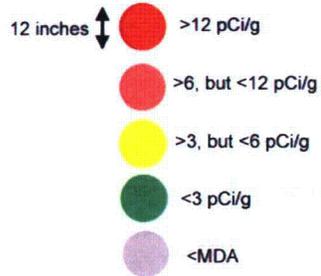
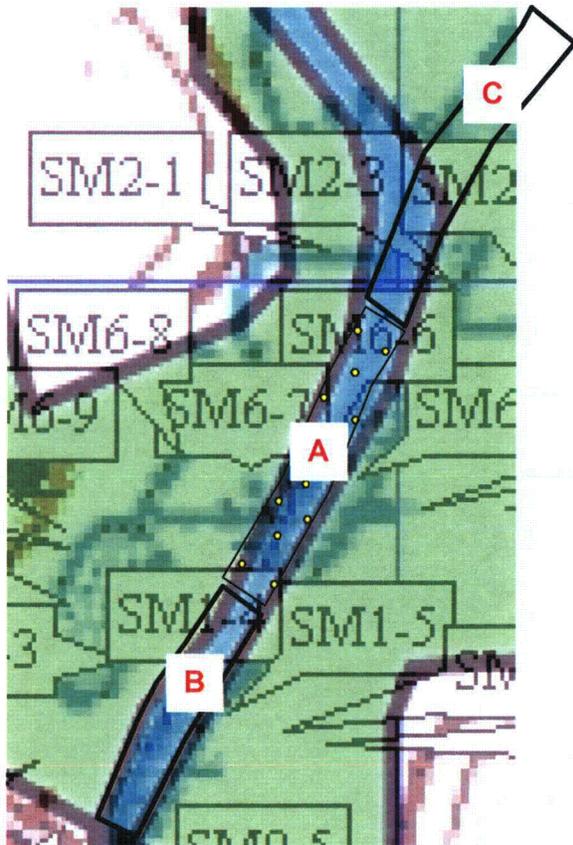
The results produced by the second bounding effort for the two EMAs are illustrated in Figures 22 through 36. Within this group of illustrations, Figures 22-24 represent the evaluation of section A, in which a lognormal distribution was observed around a declining trend line.

Figures 25-34 represent the evaluation of upstream section B, in which a lognormal distribution was observed about a trend. This trend increased, decreased, and increased again, versus distance down the stream. A simplified representation was selected as reasonable, in which the peak Cs-137 values were represented by a steady value of 10 pCi/g, with no trend up or down.

Figures 35 and 36 represent the evaluation of downstream section C, in which it was noted that two adjacent sample points indicated the presence of a discontinuous deposit with two peak Cs-137 values just over 6 pCi/g, and one adjacent peak value just over 3 pCi/g.

Using the approach described in the Methods section of this report, the representative peak value for Cs-137 in upstream section B was defined as 10 pCi/g, with no trend. The representative Cs-137 value in stream section A was defined as ranging from a high of 6.3 pCi/g at the upstream end, to a low of 2.5 pCi/g at the downstream end. The representative Cs-137 value in section C was defined as an isolated occurrence measuring 3-6 pCi/g.

FIGURE 22 – SECOND BOUNDING RESULTS AROUND EMA AT LOCATION SM6-6



STREAM MOUTH SECTION A RESULTS (pCi/g)

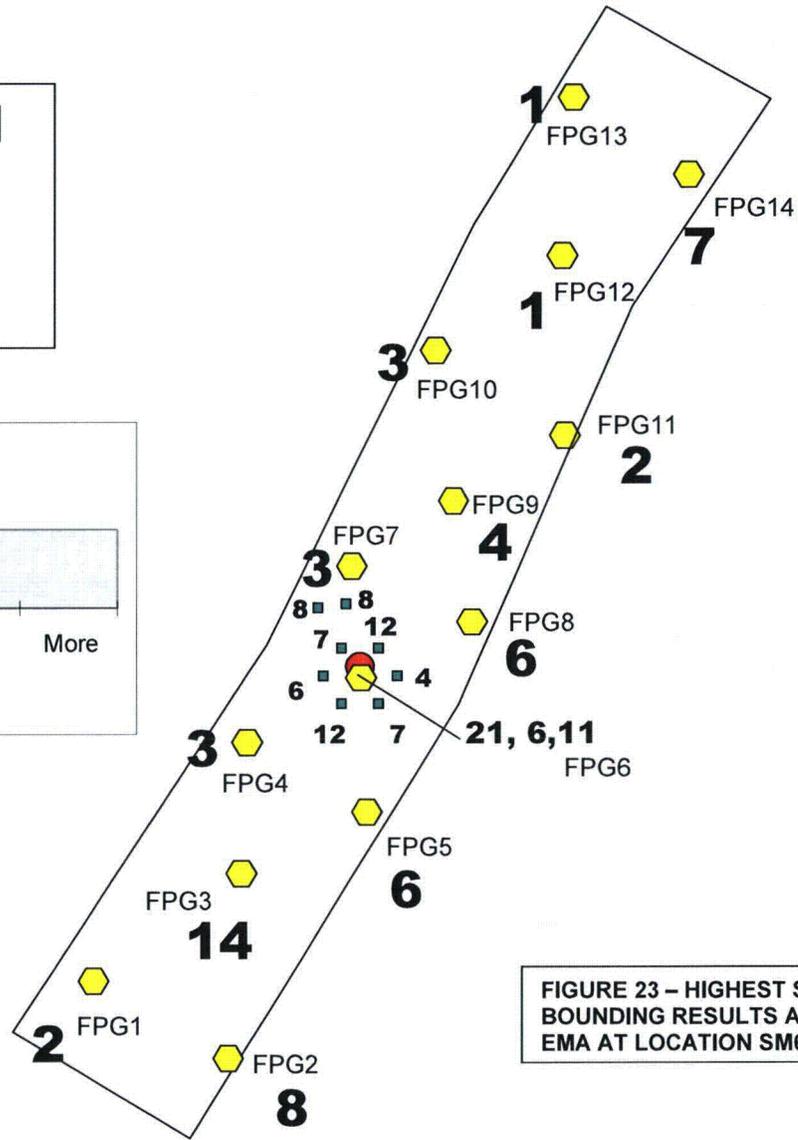
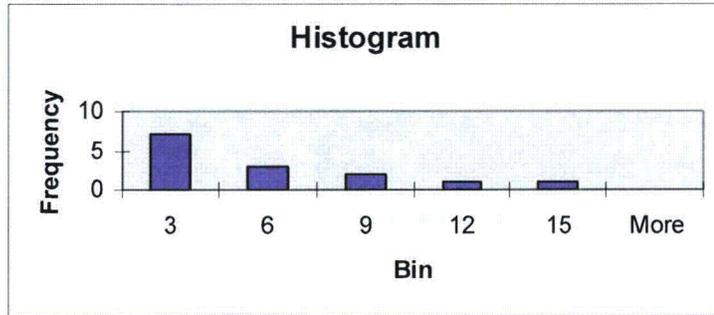


FIGURE 23 – HIGHEST SECOND BOUNDING RESULTS AROUND EMA AT LOCATION SM6-6

STREAM MOUTH SECTION A RESULTS (log pCi/g)

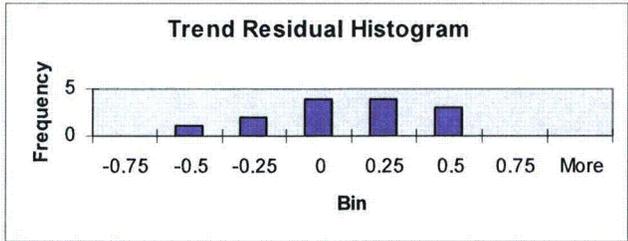
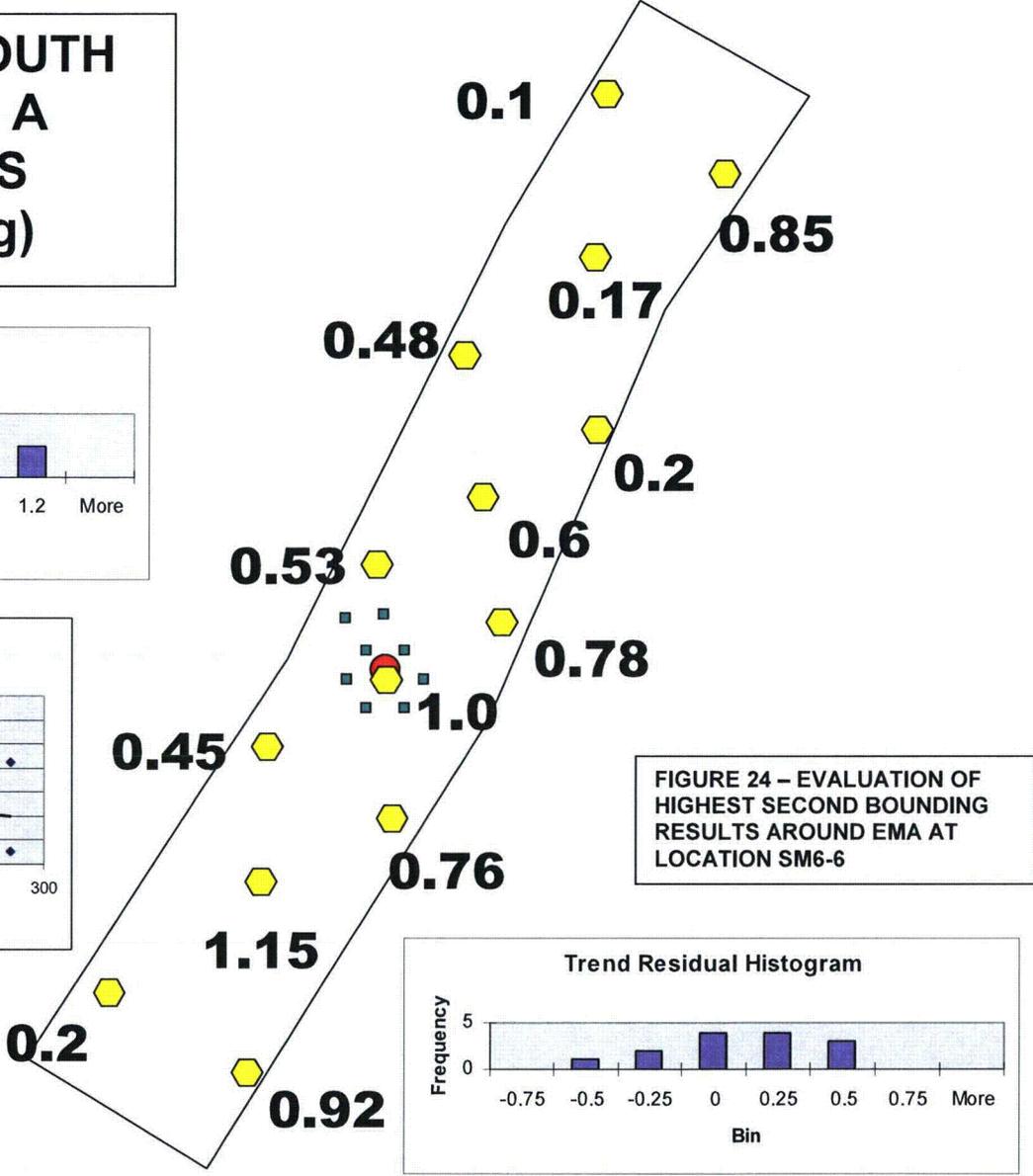
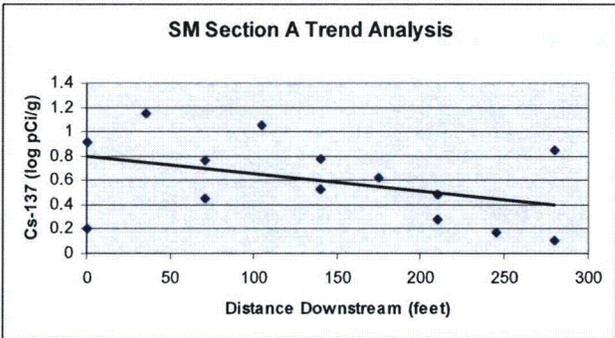
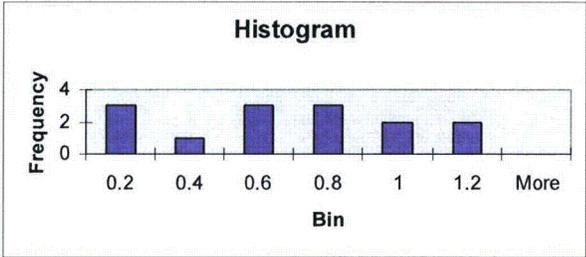


FIGURE 25 – SECOND BOUNDING RESULTS AROUND EMA AT LOCATION SM1-4

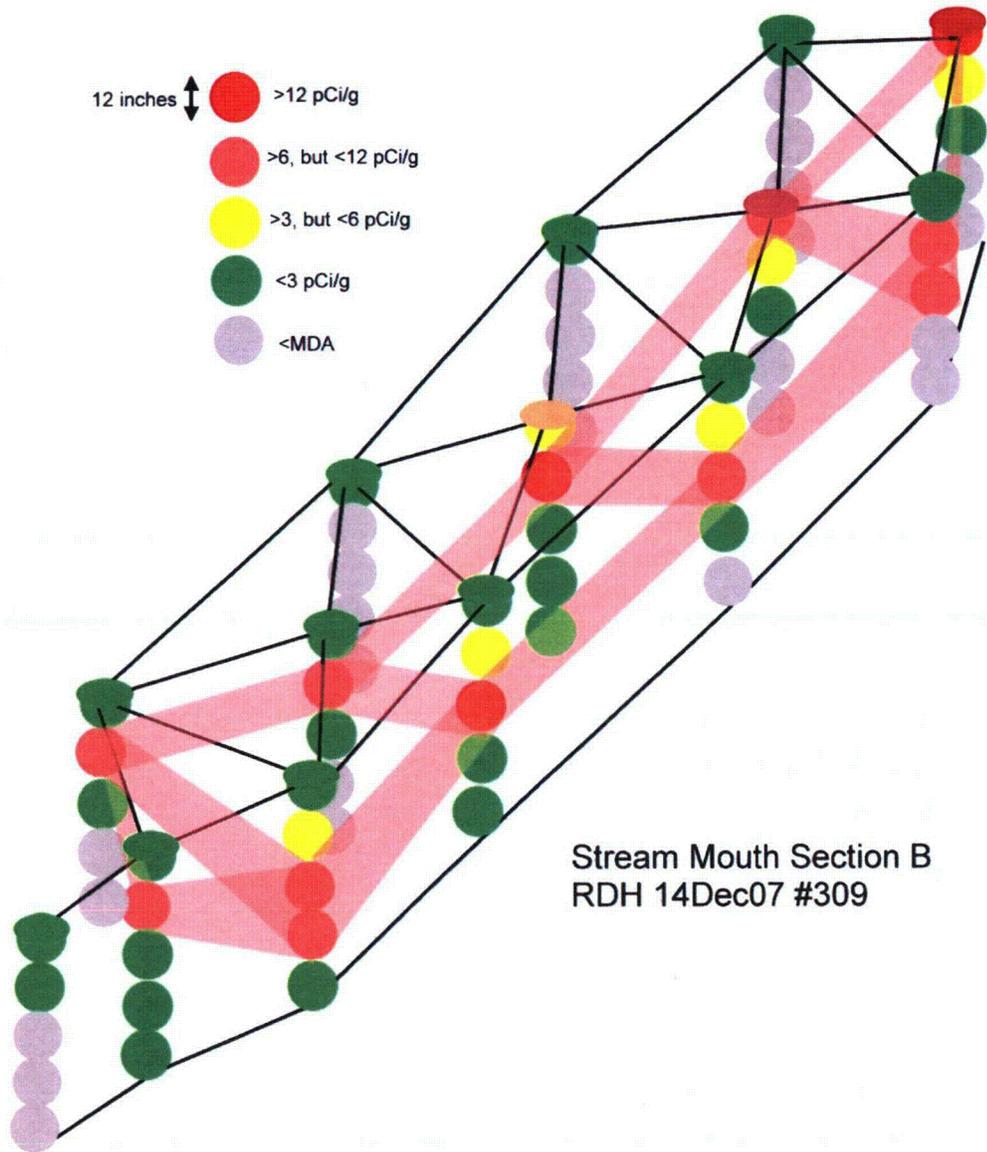
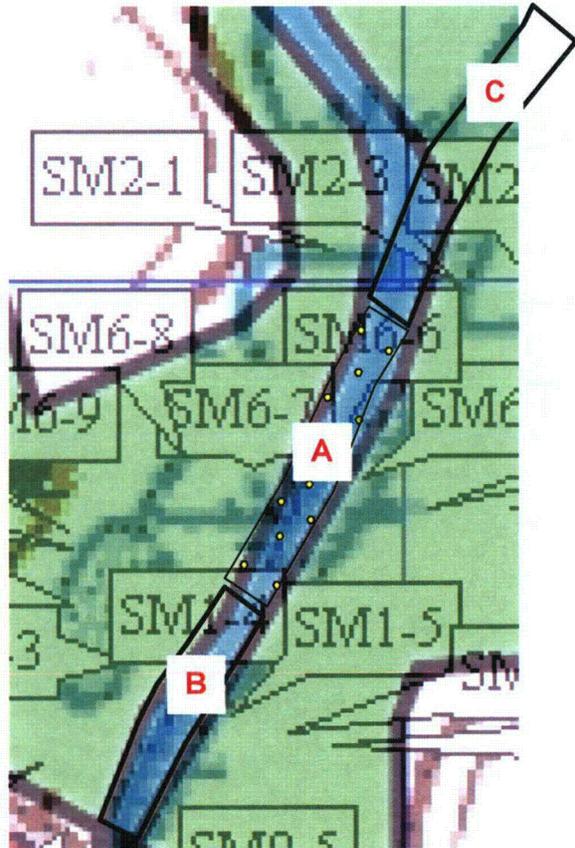
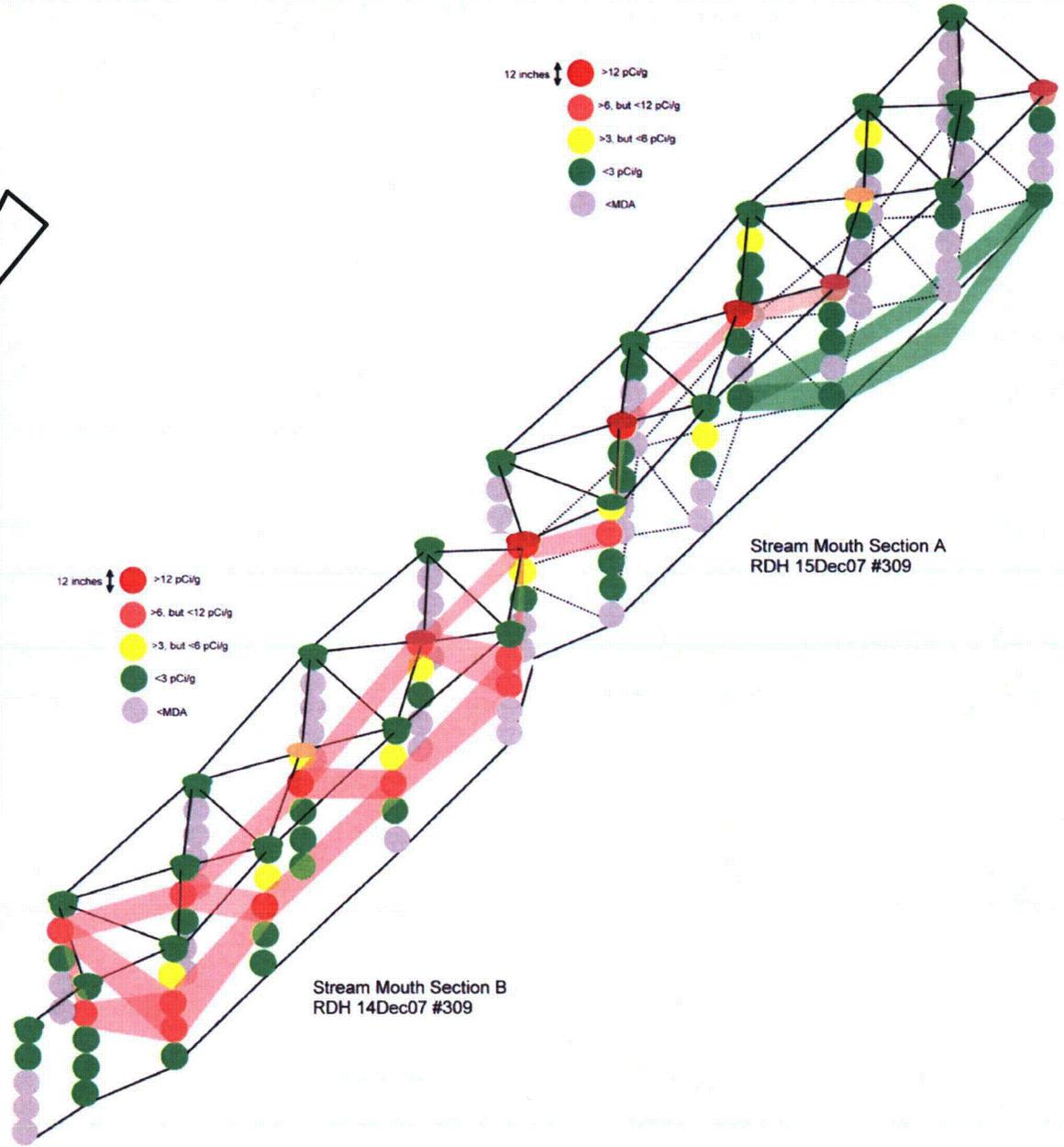
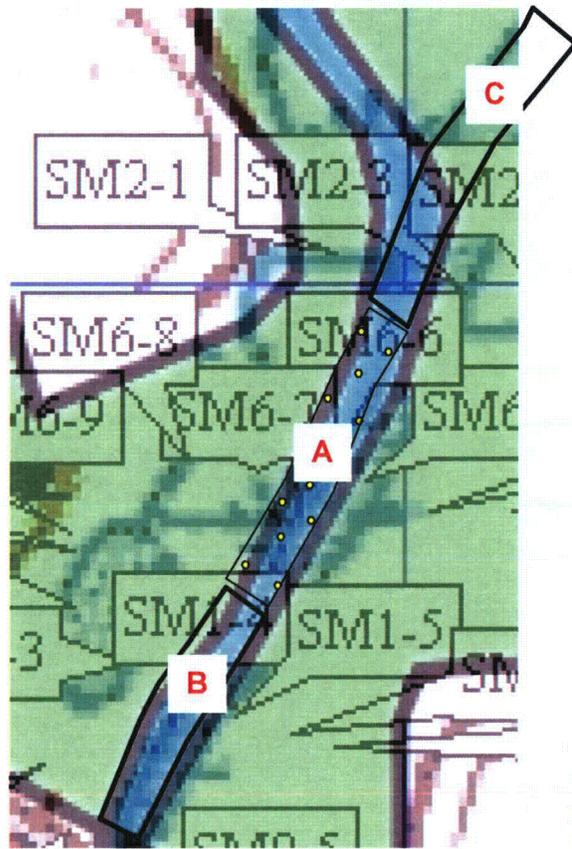


FIGURE 26 – SECOND BOUNDING RESULTS FOR SECTIONS A + B COMBINED



**STREAM MOUTH
SECTION B
RESULTS
(pCi/g)**

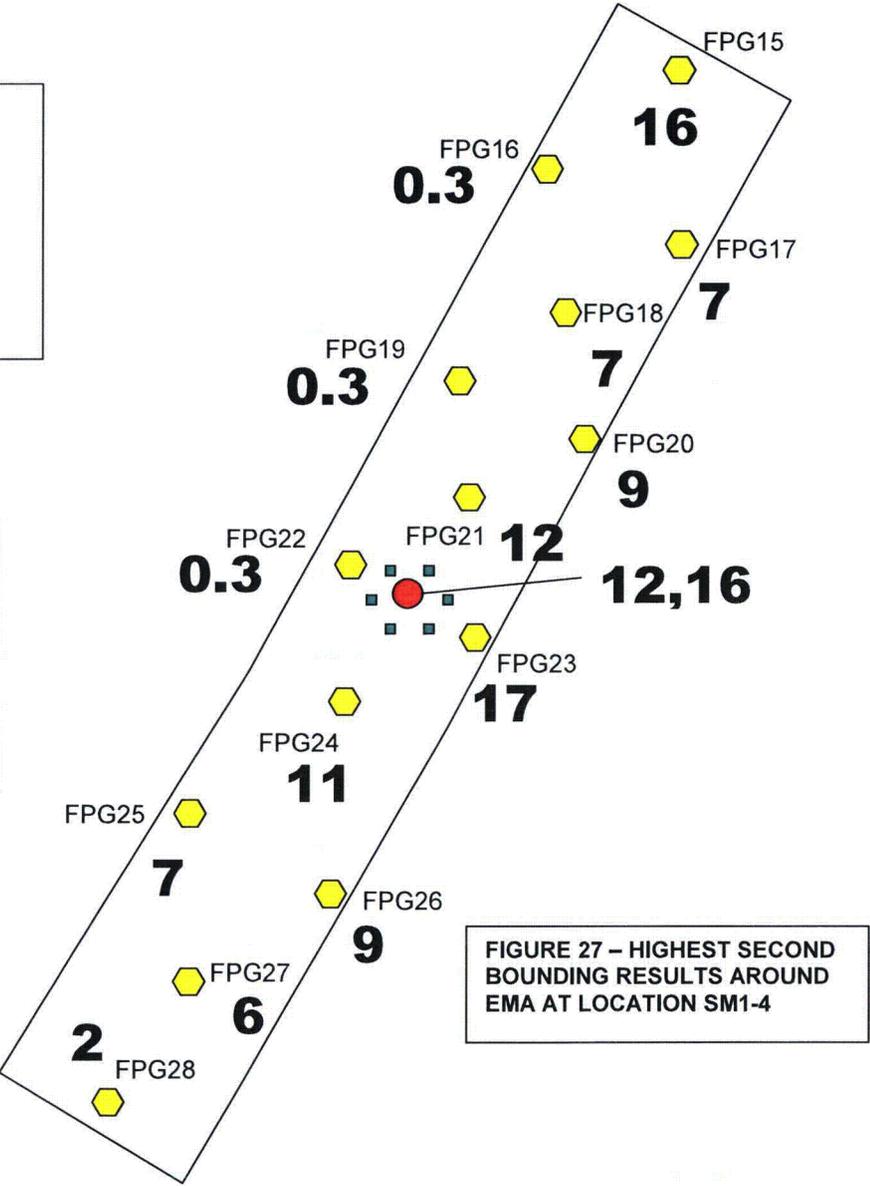
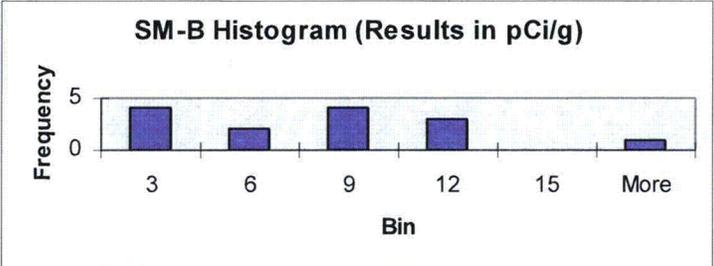
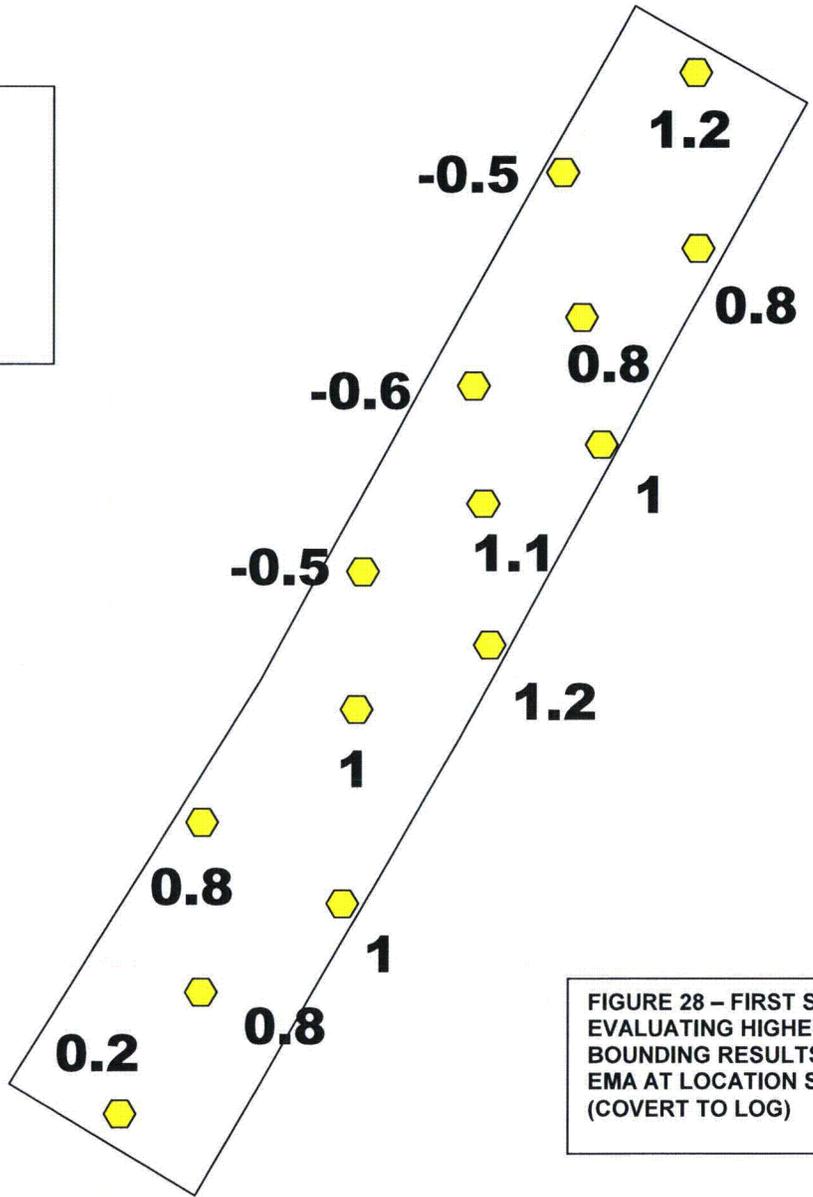


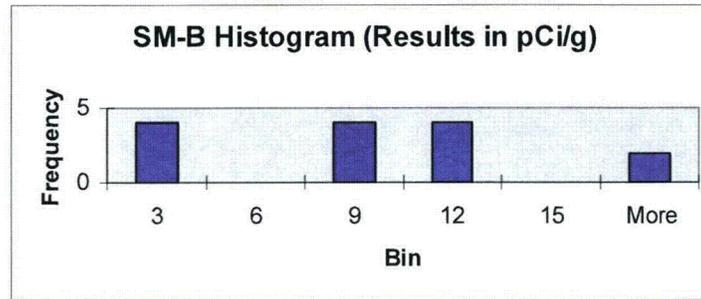
FIGURE 27 - HIGHEST SECOND BOUNDING RESULTS AROUND EMA AT LOCATION SM1-4

**STREAM MOUTH
SECTION B
RESULTS
(log pCi/g)**



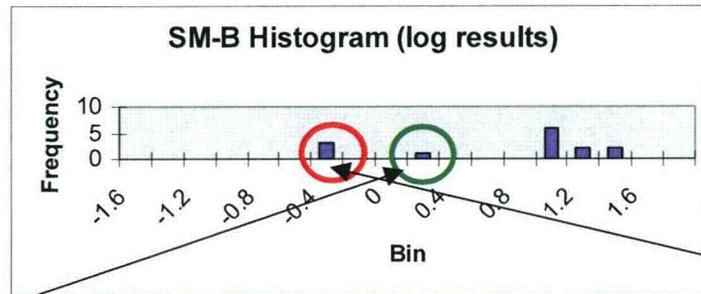
**FIGURE 28 – FIRST STEP IN
EVALUATING HIGHEST SECOND
BOUNDING RESULTS AROUND
EMA AT LOCATION SM1-4
(COVERT TO LOG)**

FIGURE 29 – EVALUATION OF HIGHEST SECOND BOUNDING RESULTS AROUND EMA AT LOCATION SM1-4



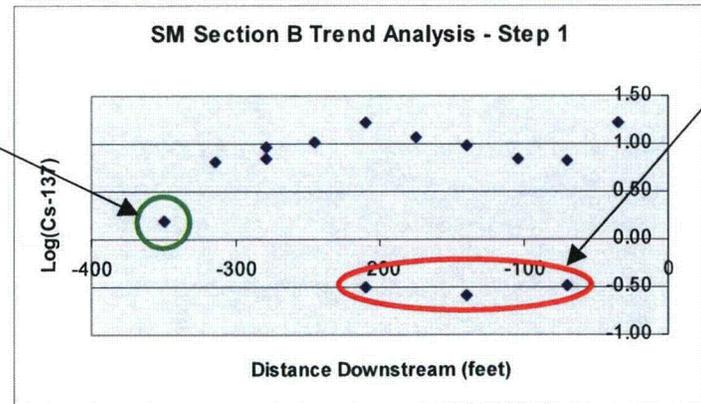
(Not a bell curve)

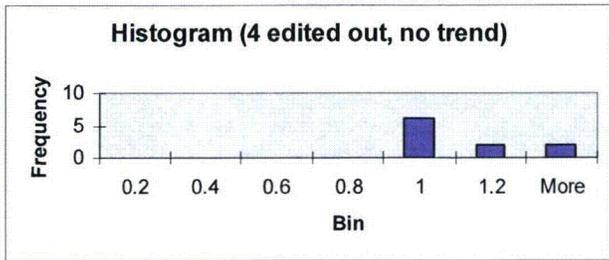
(Not a bell curve)



Clearly not part of the pattern

Maybe part of the pattern

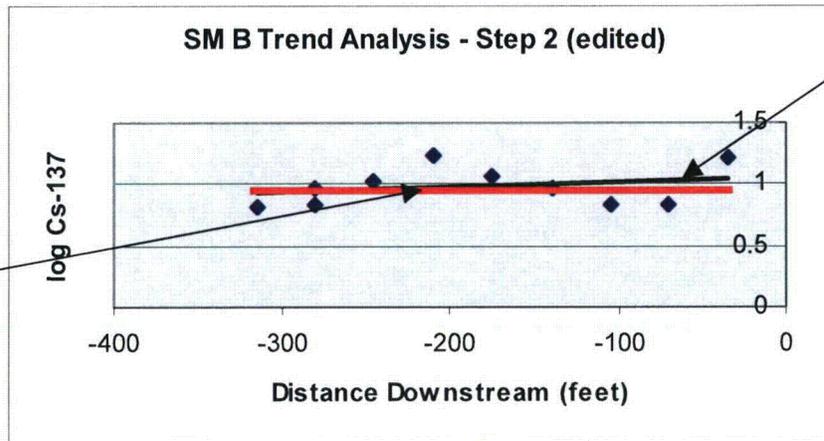




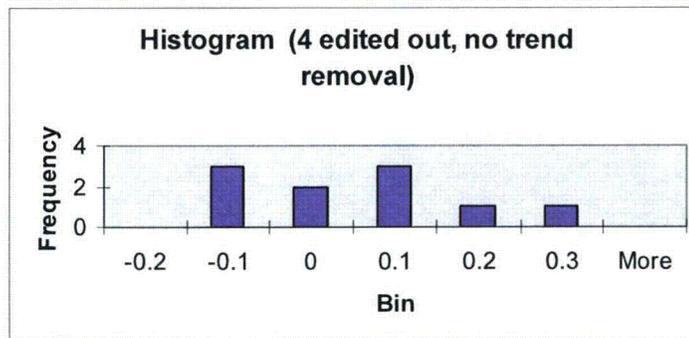
(Not a bell curve)

FIGURE 30 – CONTINUED EVALUATION OF HIGHEST SECOND BOUNDING RESULTS AROUND EMA AT LOCATION SM1-4 (EDIT OUT 4 POINTS)

No-trend straight line (red)



Trend line (black)



(Not a bell curve)

No Trend

Trend

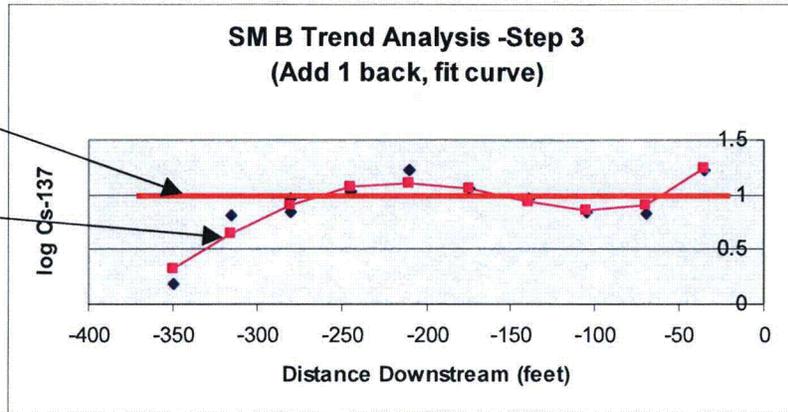
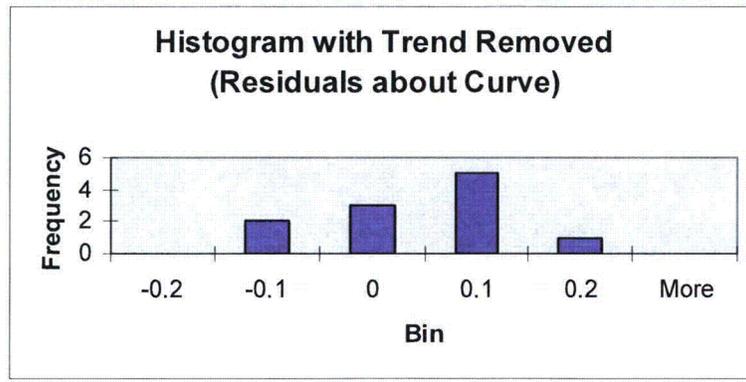


FIGURE 31 – CONTINUED EVALUATION OF HIGHEST SECOND BOUNDING RESULTS AROUND EMA AT LOCATION SM1-4 (ADD 1 POINT BACK)



(More like a bell curve)

STREAM MOUTH SECTION B INTERPRETATIONS

- 3 low points are not part of the Cs-137 deposit
- Reasonable: With 4th point edited out, the Cs-137 deposit has a uniform log = 1.0, representative value = 10 pCi/g
- Most accurate: The Cs-137 deposit log values follow a curve

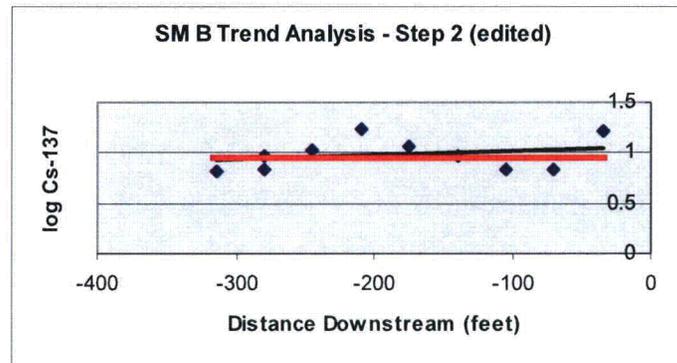


FIGURE 32 – FINAL EVALUATION OF HIGHEST SECOND BOUNDING RESULTS AROUND EMA AT LOCATION SM1-4

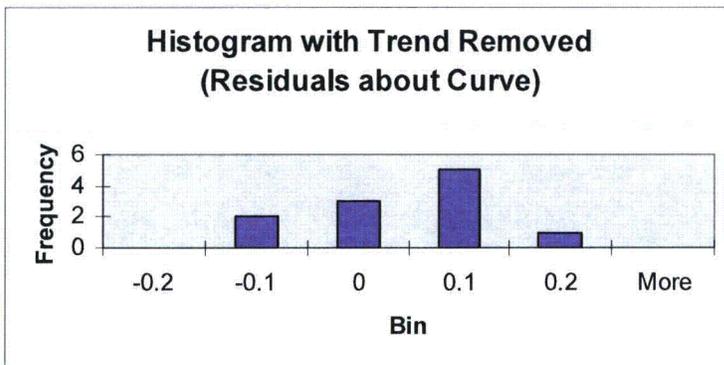
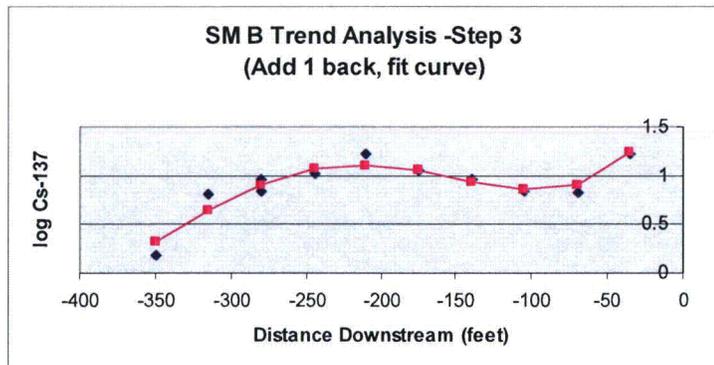


FIGURE 33 – ERROR BOUNDS FOR STREAM SECTION B

STREAM MOUTH SECTION B RESULTS (log pCi/g)

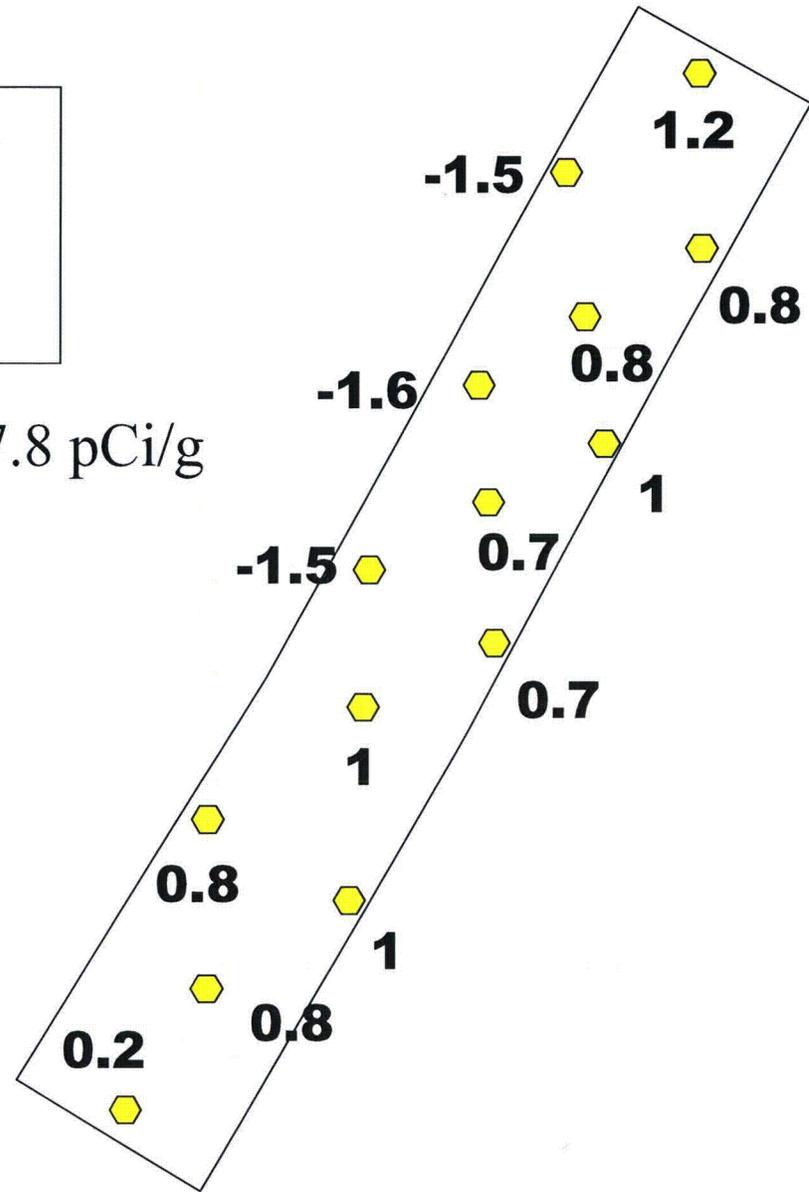
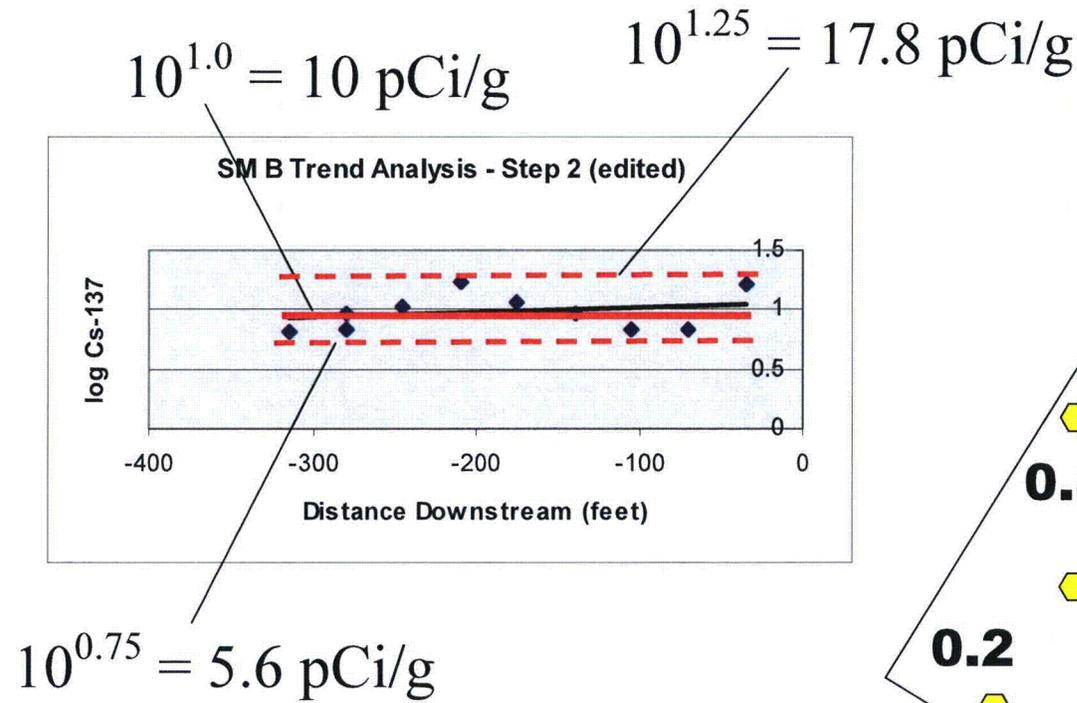


FIGURE 34 – ERROR BOUNDS FOR STREAM SECTIONS B + A

STREAM MOUTH SECTION A+B TRENDS COMBINED

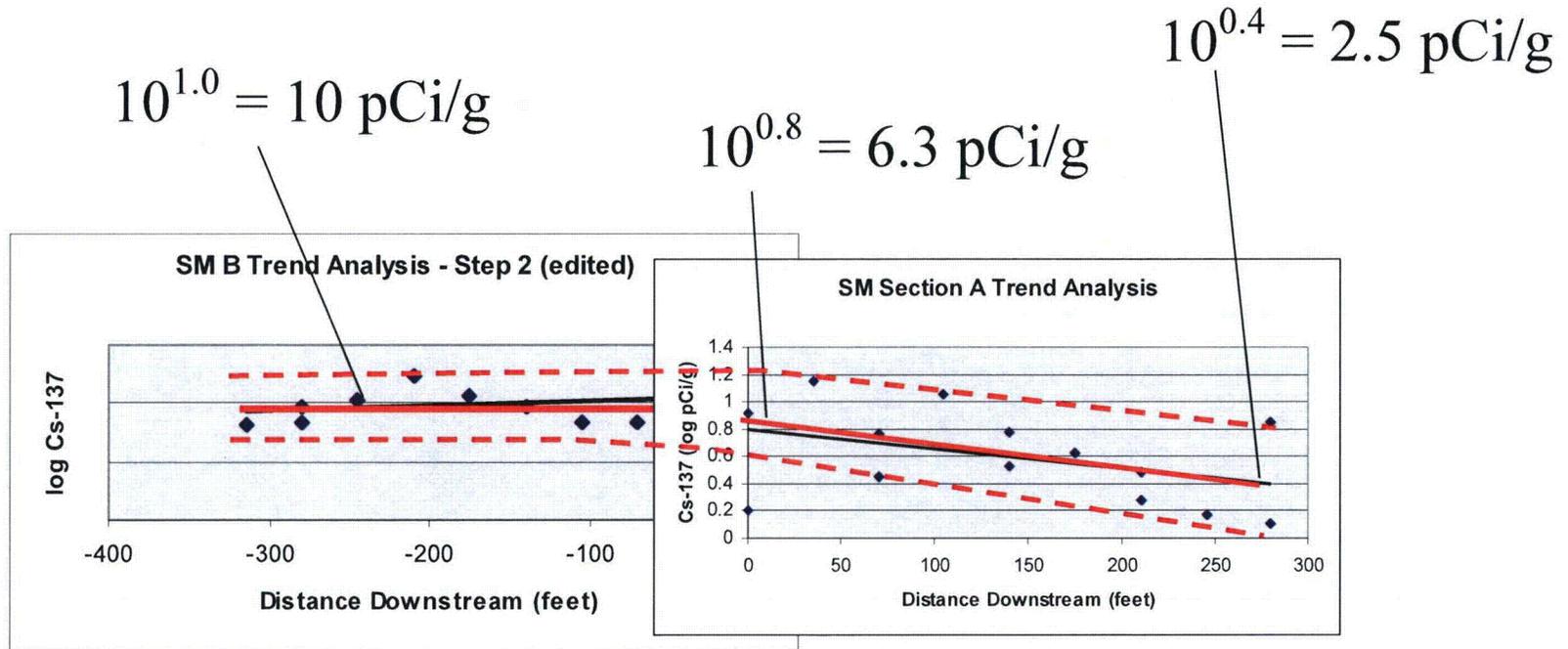


FIGURE 35 – RESULTS FOR STREAM SECTION C

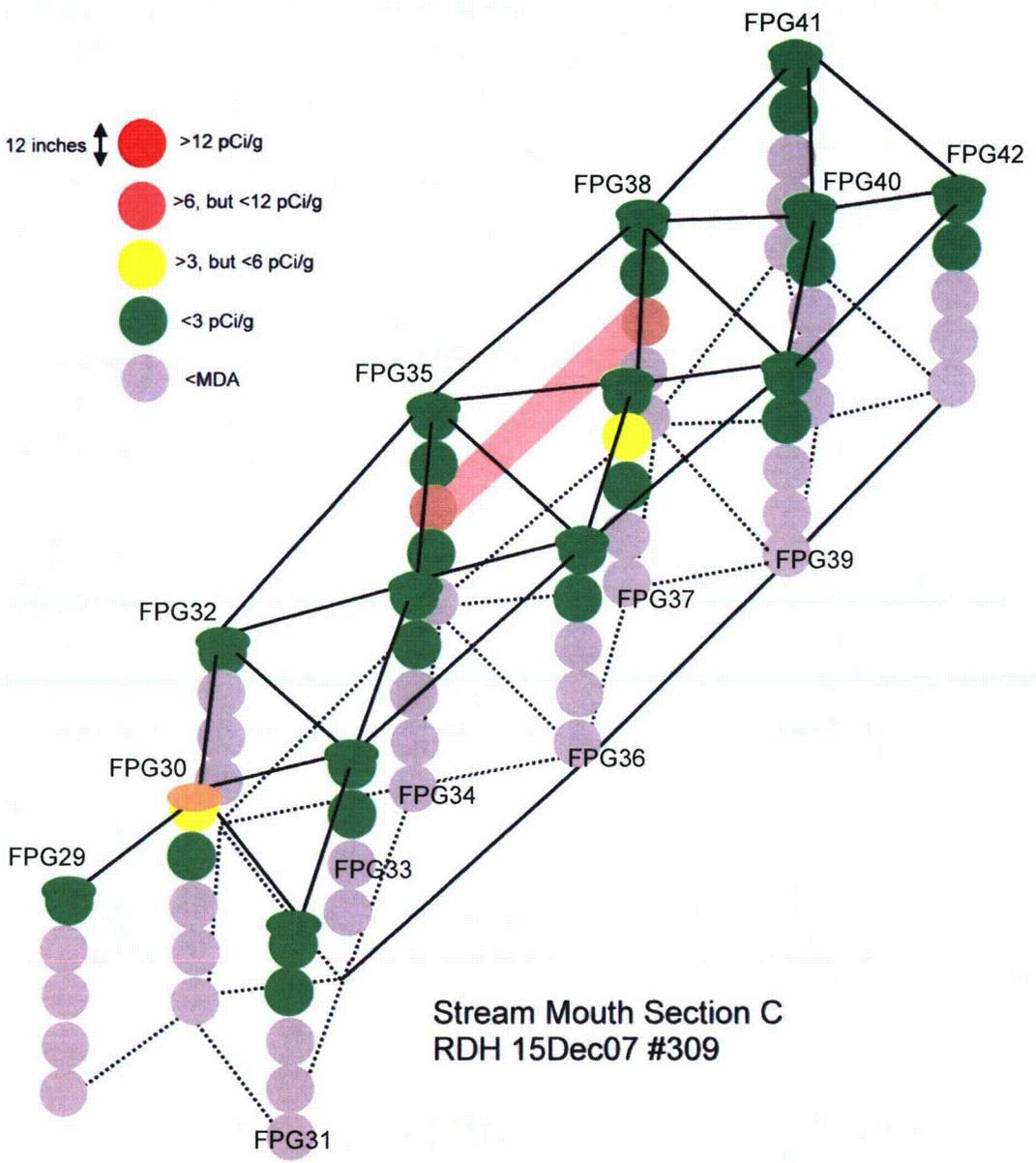
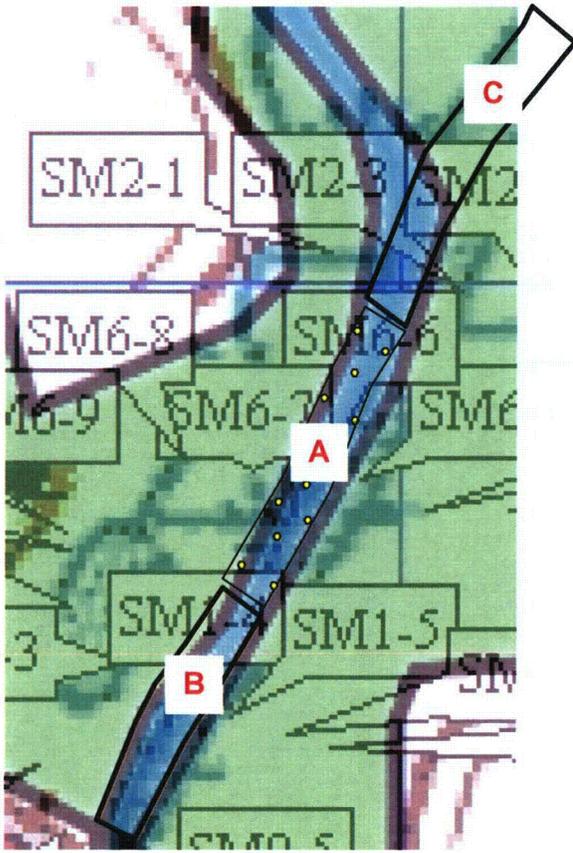
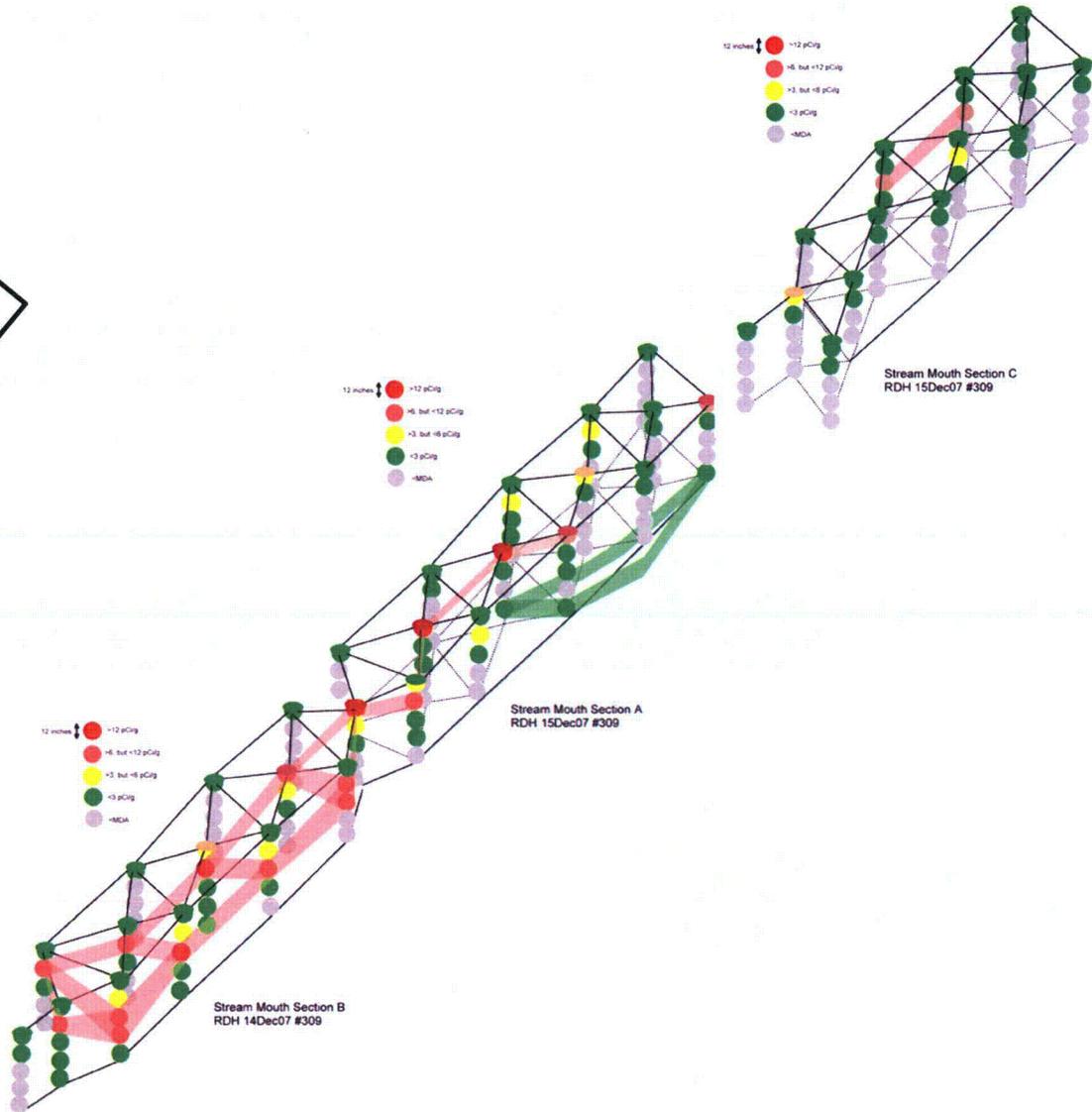
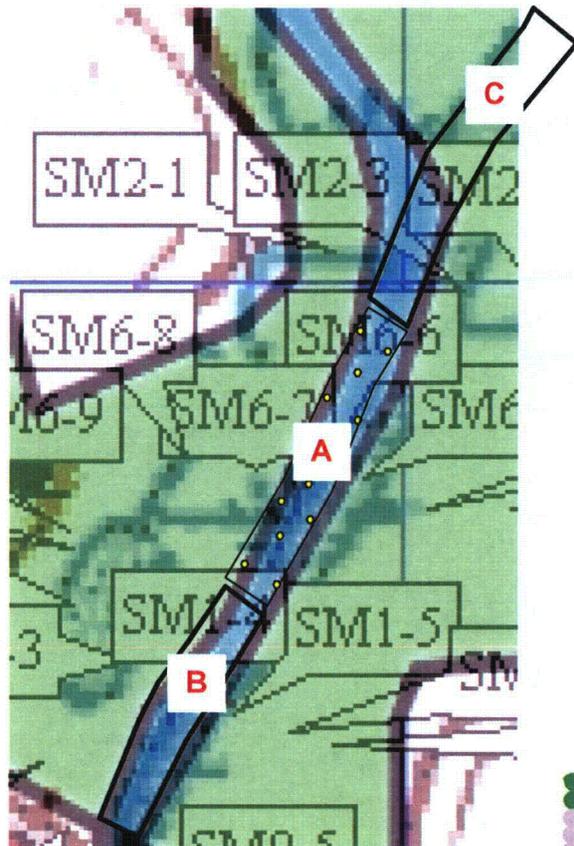


FIGURE 36 – COMBINED RESULTS FOR STREAM SECTION B, A, AND C



OBSERVATIONS RELATED TO DATA QUALITY INDICATORS (DQIs)

The performance of the measurement system, as expressed by the various DQIs, was evaluated for the laboratory alone, for the laboratory + soil processing, and for the laboratory + soil processing + sampling. Observations related strictly to the laboratory were included in the third edition of the PBRF Laboratory Quality Assurance Report. The laboratory report identified no issues that would adversely affect the results employed in this Stream Mouth report.

DQI observations more specifically related to the Stream Mouth work are discussed below. In the Stream Mouth work, a total of 569 original field samples were tested. Recounts were performed on 24 of those samples, or 1 in 24. QC duplicates were prepared, after processing, for 50 samples, or 1 in 11.

Precision – Laboratory recounts were performed on 24 samples. Four of the RPDs calculated for these 24 samples (one in 6) exceeded the criterion that the original and the duplicate should be within 20% of one another. In all of the cases where the RPD exceeded 20%, the original and the duplicate results were less than about 1 pCi/g. RPD comparison after log transformation yielded more values over the 20% limit, so this criterion was set aside as not useful.

QC duplicates, or “splits” were prepared, during sample processing, for 50 samples. Six of the RPDs calculated for these 50 samples (about one in 8) exceeded the criterion that the original and the duplicate should be within 20% of one another. In all of the cases where the RPD exceeded 20%, the original and the duplicate results were less than about 1 pCi/g. RPD comparison after log transformation yielded more values over the 20% limit, so this criterion was set aside as not useful.

Four field duplicates, or “co-located” samples, were obtained at locations chosen by HaagEnviro. The selections included 3 locations sampled earlier during the bay investigation, and 1 location from the Stream Mouth investigation that had produced low core recoveries. The 3 samples that duplicated bay locations were labeled: SM-DUP-BY37, SM-DUP-BY43, and SM-DUP-BY44. Geoprobe sample location SM5-3 had low recovery and was re-sampled with the vibracore device. The vibracore duplicate was labeled SM5-5. Depths analyzed from the 3 co-located samples in the bay did not match the depths from those locations analyzed during the bay investigation. The depth intervals covered by the co-located vibracore sample on transect 5 were slightly different from the original Geoprobe sample intervals. However, when the corresponding layers from the two locations were compared, the RPD results were nearly within the 20% limit (20.5%).

All recounts, splits and co-located sample results are included in the spreadsheet file attached as Appendix B.

Accuracy – The scatter of measurements about the “true” or “representative” result was estimated after the results had been transformed to log(results). The following two examples illustrate what this means in terms of the scatter of results.

On Figure 34, the best-fit line was placed at about 1.0. Transformed back to pCi/g, that gave a “representative” value of 10 pCi/g. One can observe that the upper error band above the best-fit line is at about 1.25. Transformed back to pCi/g, this would be 17.8 pCi/g. The lower error band below the best-fit line is at about 0.75. Transformed back to pCi/g, this would be 5.6 pCi/g. Thus, one might estimate that the error about a best-fit value of about 10 pCi/g is 7.8 pCi/g above 10, and 4.4 pCi/g below 10. Another way to express this is that one may expect some values to be as high as 178% of the representative value, and some values to be as low as 56% of the representative value.

On the right side of Figure 34, the best-fit line for section A was placed at about 0.4. Transformed back to pCi/g, that gave a representative value of 2.5 pCi/g. One can observe that the upper error band above a best-fit value of 0.4 is at about 0.8. Transformed back to pCi/g, this would be 6.3 pCi/g. The lower error band below the best-fit line is at about 0.1. Transformed back to pCi/g, this would be 1.25 pCi/g. Thus, one might estimate that the error about a best-fit value of about 2.5 pCi/g is about 4 pCi/g above 2.5, and about 1 pCi/g below 2.5. Another way to express this is that one may expect some values to be as much as 250% of the representative value, and some values to be as low as 50% of the representative value.

From these two examples one may observe that, in this lognormal distribution, one can expect some elevated measurements to be twice as high as the “representative” value. One can also expect that some of the lowest measurements will be as little as half of the “representative” value.

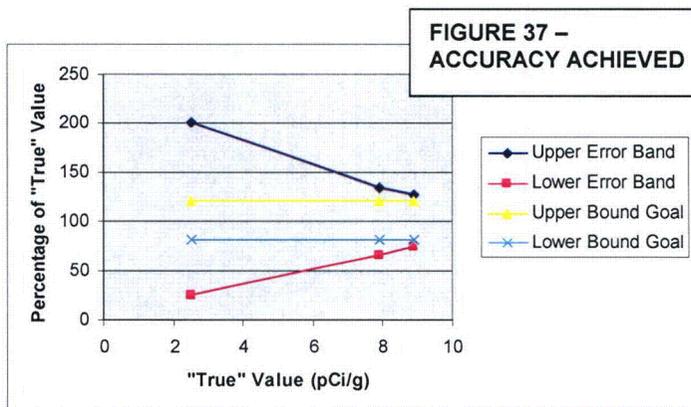
Our DQI for accuracy is that values should lie within 80% to 120% of the “true” value, after log transformation. In the first example above, the “true” value was 1.0, the upper error limit was at 1.25, and the lower error limit was at 0.75. The upper value of 1.25 is only slightly more than 120% ($1.25/1.0 = 1.25$, or 125%). The lower value of 0.75 is slightly less than 80% ($0.75/1.0 = 0.75$, or 75%).

In the second example above, the “true” value was 0.4, the upper error limit was at 0.8, and the lower error limit was at 0.1. The upper value of 0.8 is substantially more than 120% ($0.8/0.4 = 2.00$, or 200%). The lower value of 0.1 is also substantially less than 80% ($0.1/0.4 = 0.25$, or 25%).

A third example can be drawn from the center of Figure 34. By inspection of the combined plots for sections A+B, it is reasonable to use 0.9 as the “true” value. The upper error limit appears to be at about 1.2, and the lower error limit appears to be at about 0.6. The upper value of 1.2 is slightly more than 120% ($1.2/0.9 = 1.33$, or 133%). The lower value of 0.6 is also slightly less than 80% ($0.6/0.9 = 0.66$, or 66%).

These examples are summarized in Figure 37. From this graph, it appears that the DQIs are likely to be achieved only when the representative value exceeds 9 pCi/g. From earlier observations, this means that we can achieve our accuracy target when the range of values is roughly 18 pCi/g (200% of representative) to 4.5 pCi/g (50% of representative).

The sample variance for the log-transformed results in section B was 0.02, which was acceptably less than the target of 0.4. The sample variance for the log-transformed trend residuals in section A was 0.09, which was acceptably less than the target of 0.4.



As noted in the Methods section, 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.

For the results in Stream Mouth section B, it was considered reasonable to evaluate the results as if no trend was present. In that data set, the "representative" log-transformed value was 1.0, the standard deviation of the log-transformed results was 0.156, and the mean of the log-transformed results was 0.978. To apply the test above to determine whether accuracy was sufficient, the following question was to be answered using the mean:

Is $s(\log \text{ transformed results}) < (\log(12\text{pCi/g}) - \text{mean}(\log \text{ transformed results}))$
 Is $0.156 < (1.08 - 0.978)/2$?
 Is $0.156 < 0.051$?

Using the "representative" best-fit value of 1.0, instead of the mean of 0.978, the question would be as follows:

Is $0.156 < (1.08 - 1.0)/2$?
 Is $0.156 < 0.04$?

In both trials, the answer was no, so this test of accuracy suggests that the scatter about the "representative" log value of 1.0 may be too large to support a conclusion that the "representative" log value of 1.0 is less than the regulatory threshold log value of 1.08, at a 95% confidence level. The result might be more favorable if more than only the most elevated activities were included in the assessment.

Completeness – Defining completeness is an assessment of whether we have a sufficient number of samples to support a determination that the “representative” value is less than the regulatory threshold. The preceding assessment of accuracy suggests that the number of samples obtained in section B (14 samples) is not sufficient to make that determination. The preceding discussion of sample variances supports the assumption underlying the sample-number calculation, that variance is less than 0.40. The other assumption underlying the sample-number calculation was that the “effect size” between the “representative” value and the regulatory threshold was a least $|\log(3 \text{ pCi/g}) - \log(12 \text{ pCi/g})| = |0.48 - 1.08| = 0.6$. As the log of the “representative” value was taken to be 1.0 (not 0.48), this criterion was clearly not met. It is generally true that, the smaller the “effect size” is, the greater is the number of samples needed to achieve the desired confidence in a decision. In the minimum samples task, it was noted that as many as 50 samples would be needed to support the decision that an 8 pCi/g “representative” value was less than a 12 pCi/g regulatory threshold, with a confidence of 95%, and a power of 0.9. For section B, a required number of at least 25 samples was obtained by re-running the minimum samples statistical analysis with the following values: standard deviation = 0.15, effect size = <0.6, power = 0.9, alpha = 0.05, two-tailed.

Representativeness – The posting of field-screening results, in Appendix B, allowed HaagEnviro to observe the sample recoveries achieved. In the initial round of transect sampling, 11 Geoprobe samples (from 8 locations), out of 27 samples taken, produced a recovery of less than 50%. One low-recovery Geoprobe-sampled location (SM5-3) was re-sampled with the vibracore device (SM5-5). One vibracore sample, out of 47 taken, produced a recovery of less than 50% (SM8-7: 49%, a water filled gap of 16.5" was noted in the sample tube). Core photographs were examined for all of these samples, and no problems in using them were evident. In general, the low recoveries were related to peat, which is recovered much better by the vibracore sampler than by the GeoProbe sampler. Recoveries from the remaining Stream Mouth samples were acceptable.

Laboratory blanks tested during the stream mouth wetlands investigation all produced results that were either less than the MDA, or were rejected upon data review. Blank results are included in the spreadsheet provided in Appendix B. Review of cores and corresponding testing results suggested that carry-down generally did not occur to a significant extent. Two examples in which drag-down did occur are shown in Figure 38.



Comparability – The procedures discussed in this report were consistently followed, by a fairly consistent set of sampling team members. Hydrogeologist Bob Haag and Principal Scientist Ruth Haag were personally involved in some of the later sampling efforts, replacing Scientists Ben Patterson and Phil Weimer, as well as Environmental Technician Ryan Bloom. RP Technician Rich Dzvonar and D&D Technician Greg Struck were involved in all of the sampling efforts, and most of the sample processing work. The PBRF onsite laboratory analyst changed during the course of this work, but the procedures remained constant. Analytical oversight and data review continued to be provided by Assistant RSO Rod Case. Some minor adjustments were made along the way, such as eliminating the duct-taping of tube caps. When Hydrogeologist Bob Haag became personally involved in the last few rounds of sample processing, some of the PID testing of sample cuts was adjusted at his discretion.

OBSERVATIONS FROM PREPARING SAMPLES FOR ANALYSIS

Screening for Radioactivity – Initial scanning for radioactivity produced no readings sufficiently above background to warrant concern or further inquiry. RP personnel therefore suspended scanning.

Screening for Organic Chemicals – During soil processing, some samples produced elevated readings on a HaagEnviro 11.7 eV PID. Often, readings taken in the opening of a freshly cut sample interval produced a response on the HaagEnviro PID that exceeded the meter's upper limit, which was 2000 ppm. Comparison readings with the NASA-provided PID were not similarly elevated. Both meters calibrated properly, using the same 100-ppm isobutylene gas. Both meters responded similarly to periodic checks in which the tip of a Sharpie™ pen was placed in front of each meter's probe. In such checks, both meters responded with readings ranging up to nearly 100 ppm.

With the NASA-provided 10.2 eV PID, the highest reading obtained was 40 ppm at the 42" depth in sample location SM6-4. The highest reading with the NASA 10.2 eV PID at any other sample location was 8 ppm, at the bottom of sample location SM6-3. With the HaagEnviro 11.7 eV PID, many readings caused the meter to "peg," exceeding the maximum reading of 2000 ppm. When the NASA-provided PID was outfitted with an 11.7 eV lamp, no similarly elevated readings were obtained with the NASA meter, which routinely read either 0.0 ppm, or a few ppm, up to a maximum of about 5 ppm in ambient air.

When Bob Haag periodically took the HaagEnviro PID outside the soil-processing trailer, outdoor ambient-air readings of approximately 200 ppm were obtained on occasion.

In the field, when Bob Haag took the HaagEnviro 11.7 eV PID through tall reeds to the stream's edge, the HaagEnviro PID produced readings up to 200 ppm, with background readings outside the reeds of approximately 40-50 ppm. As breezes passed, the meter readings spiked up to 100-200 ppm.

With the probe held at face level as Bob Haag walked next to the stream, the HaagEnviro PID readings dropped to 0.0 ppm. With the probe held a few inches off the ground at the stream's edge, the HaagEnviro PID "pegged" over 2000 ppm, just as it often did in the sample-processing trailer.

An air sample obtained by NASA Safety Officer Hank Bayes, from a sample cut that had produced an elevated reading with the HaagEnviro PID, produced a detection only for acetone, which was reportedly found at a level of 0.6 ppm.

The elevated-reading phenomenon first appeared during the processing of samples from the Flood Plain area, which is discussed in a separate report. Laboratory testing of Flood Plain samples for organic chemicals resulted in the following positive detections:

- Phenol, at a level of 2.9 ppm in soil (2,900 parts per billion, or ppb)
- Acetone, at an estimated level of 0.0052 ppm in soil (5.2 ppb)
- A few unidentified SVOC compounds
- An "Unknown Aldol condensate," which the laboratory interpreted was created when the laboratory added acetone in the testing process, and this added acetone reacted with natural soil materials

In response to the periodically elevated PID readings, ventilation in the soil-processing trailer was increased.

Peat Volume and Density Upon Drying for Testing - HaagEnviro's original estimate, before detailed volume and density reduction measurements were made, was that the

typical weight reduction due to sample processing would be 5 to 1. Reductions documented in this study were as follows:

1. Peat – length reduced from 12” to 5”; weight reduced from 1515g to 369g
2. Peat – length reduced from 12” to 4.5”; weight reduced from 1502g to 331g
3. Peat/Sand mixture – length reduced from 12” to 10.75”; weight reduced from 1120g to 1009g

These results showed that processing reduced the peat weight by a factor of approximately 3 to 1. This suggested that the activity per unit weight of peat could be overstated by a factor of 3, compared with mineral soil types, such as sand, silt, or clay.

OBSERVATIONS ON OTHER RADIONUCLIDES

Besides Cs-137, other radionuclides of interest are defined in FSSP Table A-7, and include the following:

- ⁶⁰Cobalt (Co-60)
- ¹⁵⁴Europium (Eu-154)
- ³H (Tritium)
- ¹²⁹Iodine (I-129)
- ⁹⁰Strontium (Sr-90)
- ²³³Uranium and ²³⁴Uranium (U-233/234)
- ²³⁵Uranium and ²³⁶Uranium (U-235/236)

Of these radionuclides of interest, only the following were included in the PBRF laboratory reports:

- ¹³⁷Cesium (Cs-137)
- ⁶⁰Cobalt (Co-60)
- ¹⁵⁴Europium (Eu-154)
- ²³⁵Uranium (U-235)

In the original transect and first bounding results, the following occurrences of Co-60 were reported:

SM1-2 54-66: 0.26 pCi/g (Cs-137 was 7.7 pCi/g, the most elevated in this pond)
SM1-4 6-18: 0.25 pCi/g (Cs-137 was 11.7 pCi/g)
SM1-4Bound3 6-18: 0.085 pCi/g (Cs-137 was 11.9 pCi/g)
SM1-4Bound3 18-30: 0.138 pCi/g (Cs-137 was 3.5 pCi/g)
SM1-4Bound5 18-30: 0.23 pCi/g (Cs-137 was 13.5 pCi/g)
SM1-4Bound4 6-18: 0.26 pCi/g (Cs-137 was 11.4 pCi/g)
SM6-6 30-42QC: 0.27 pCi/g (Cs-137 was 0.73 pCi/g, Co-60 was not in the duplicate)

In the grid-sampling results for Areas A, B, and C, only 1 detection of a non-Cs-137 radionuclide of interest was reported. That was a Co-60 value of 0.68 pCi/g, in the QC duplicate for sample SMG2 0-6. The corresponding value of Cs-137 was 2.81 pCi/g. Co-60 was not detected in the original sample of this duplicate pair.

INTERPRETATIONS

The interpretations provided in this section are intended to respond to the topics listed under the heading “Characterization Plan Objectives”.

MECHANISM OF CS-137 TRANSPORT

The proposed mechanism of Cs-137 transport appeared to be confirmed by this work. It continued to appear that clays bearing Cs-137 from the PBRF were deposited in the Stream Mouth depositional environment. It continued to appear that higher-than-typical amounts of Cs-137 discharged in 1968 were transported downstream by the area’s largest recorded flood, in 1969. Details of these interpretations follow.

Background Cs-137 – It was assumed that atmospheric testing of nuclear weapons during the time that the PBRF operated contributed a Cs-137 background, which was assumed to average 0.3 pCi/g over the top 6 inches of soil. This was based on soil testing by others on Star Island in nearby Old Woman Creek, where the upper 4 inches of soil showed a peak value of about 0.6 pCi/g, and an average of roughly 0.3 pCi/g or less; and the soil below a 6-inch depth contributed almost no activity. These estimates were based upon Figure 3 on page 58 of Volume 31 of the Journal of Environmental Quality (Jan.-Feb. 2002). The NASA RSO for the PBRF decommissioning project indicated that values up to 1 pCi/g had appeared to represent background conditions in other parts of the PBRF work. In this investigation, it was interpreted that any Cs-137 values that exceeded 1 pCi/g were attributable to the PBRF. Below 1 pCi/g, this study lacked solid data for making the split between background and PBRF. For estimating purposes, a background value of 0.5 pCi/g was assumed in the section entitled, “ACCOUNTING FOR CS-137 KNOWN TO BE RELEASED.”

It is important to recall that the practical quantitation limit (PQL) for this project’s total measurement system (sampling + processing + laboratory) was estimated to be 3 pCi/g, meaning that all measurements in this study below 3 pCi/g are essentially the same. Values less than 3 pCi/g may be considered as qualitative estimates at some risk, since values below this level were not consistently reproducible.

Another way to distinguish Cs-137 attributable to PBRF from background Cs-137 is to look for other radionuclides characteristic of PBRF. Among the other radionuclides listed in FSSP Table A-7, only Co-60 was detected offsite. When Co-60 did appear, it was always in association with elevated levels of Cs-137. This is not consistent with the expected behavior of Co-60, which is expected to behave like calcium. There is no reason to expect Co-60 to adsorb to clay minerals, as is expected for Cs-137. Based on this assumption, a strong correlation between Cs-137 and Co-60 results would not be expected. However, in the results reported here, and in other results nearer the PBRF, it did appear that Co-60 and Cs-137 were positively correlated, and Co-60 activities were typically about 1.5% of Cs-137 activities (this ratio was based upon Pentolite Ditch results, evaluated elsewhere). Co-60 did not always appear when Cs-137 levels were elevated, but Co-60 only appeared when Cs-137 levels were elevated. Thus, it is

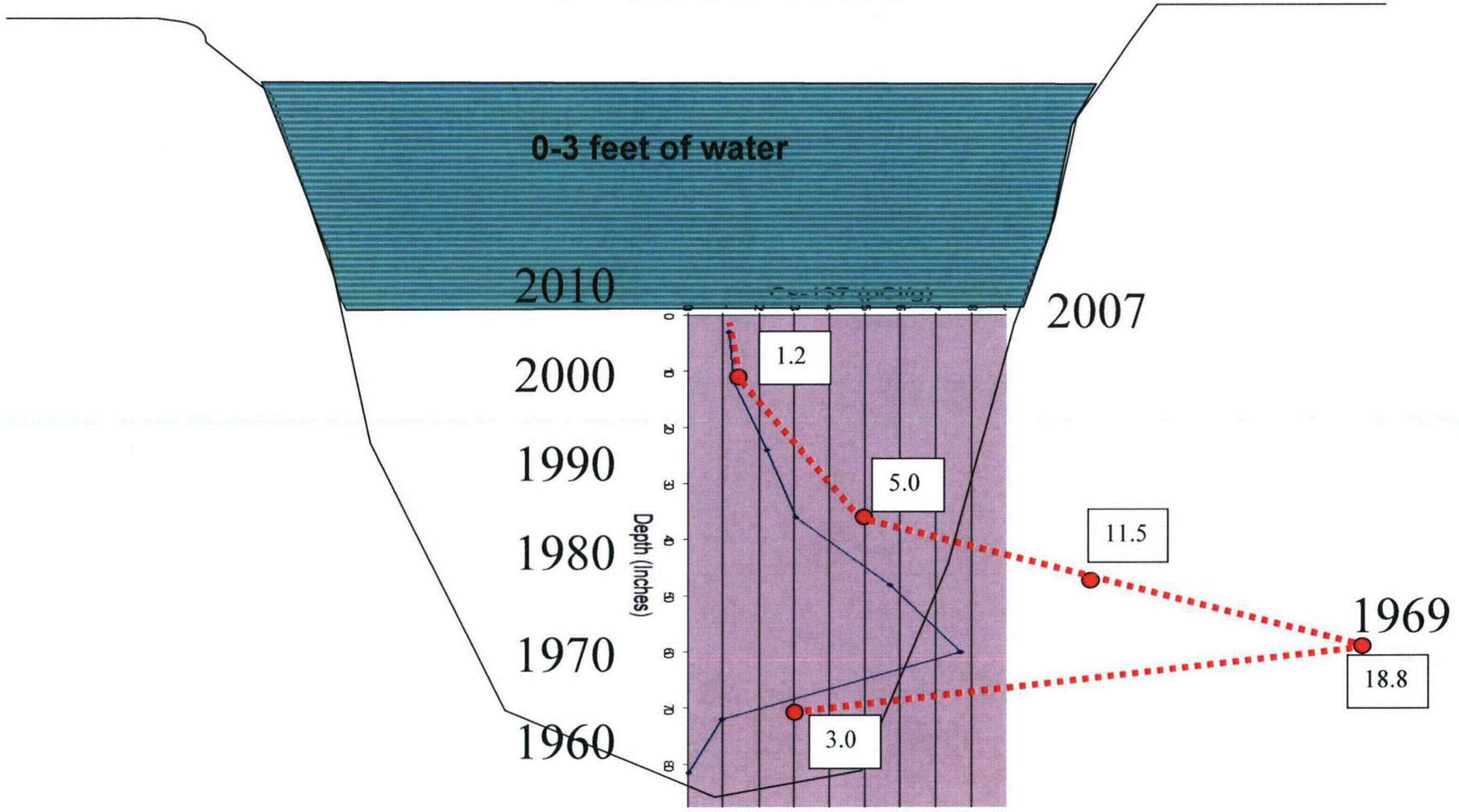
interpreted that the mechanism of Co-60 migration is similar to that for Cs-137. If Cs-137 is adsorbing on clay minerals, this means that Co-60 is also adsorbing on clay minerals.

The presence of Co-60 is not a useful way to distinguish PBRF Cs-137 from background Cs-137. This is due to the observation that Co-60 only becomes reliably detectable by the project's total measurement system when Cs-137 activities exceed 1 pCi/g.

Cs-137 Deposition Over Time - An underlying postulate of this work is that the peak Cs-137 levels were deposited downstream in 1969. Based upon this assumption, and drawing upon results obtained in the earlier Ponds report, Figure 39 provides an estimate of the activity deposited versus time. The solid line in the graph represents the actual testing results obtained, without correcting for nuclear decay. The dashed red line represents the Cs-137 activities at the time of deposition, correcting for decay using an Excel spreadsheet program supplied by NASA's Assistant RSO, Rod Case. This figure suggests that the activity in sediment being carried by floods peaked at 18.8 pCi/g in 1969, had dropped to less than 3 pCi/g by 1995, and was approaching a steady-state value just over 1 pCi/g by the year 2000.

Based on this rationale, it was interpreted that 2006 measurements of Cs-137 exceeding 3 pCi/g represented pond deposition during the 11 years between 1969 and 1980. During that time, it was interpreted that the activities in clay being deposited ranged from a high of 18.8 pCi/g, to a low of 5 pCi/g. Following 1990, it appears that values less than 3 pCi/g were deposited. Extending the interpretation cautiously below the PQL, it was estimated that Cs-137 activities of roughly 1 pCi/g continued to be transferred downstream in 2006/2007, where they continued to be widely distributed during flood events.

FIGURE 39 – INTERPRETED DEPOSITION RECORD IN A POND



Location and Significance of Delta – In the Characterization Plan, it was assumed that the final resting place of clays bearing Cs-137 would be a delta, which would occur at the juncture of the stream and the bay. It was assumed that the delta would advance into the bay by laying down deposits of sand over silt, and silt over clay. It was expected that the Cs-137 would be trapped in the clay deposits, at the bottom of the delta sequence. However, no delta was found in the bay. A delta did appear to be present in the middle of the Stream Mouth area, as shown by Figure 40. The delta deposits in the Stream Mouth appeared to be composed only of mixed silt and clay, deposited over peat. Sand was found in other locations, but did not appear to be part of the delta sequence.

The interpretation that the area marked in Figure 40 was a delta was reinforced by the observation that this was the primary area in which the stream channel frequently moved from east (1969 topographic map) to west (2005 airphoto).

Whereas locating the delta postulated in the Characterization Plan was useful in confirming the conceptual model, the expected sequence of deposits, with clay at the bottom, did not appear. Instead, it appeared that sand was mostly deposited in the stream channel further upstream, in the Flood Plain environment. The delta deposit was made only of silt, possibly gradational with clay. At the downstream end of the delta, in the vicinity of transects 3 and 5, this silt + clay deposit appeared to be roughly 2 feet thick. In transect 8 across the delta interval, in which land-derived materials interfingered with bay peat, the delta thickness appeared to increase to about 3 feet. In transect 7, the bottom of the delta interval appeared to be occurring in the deepest interval tested, with Cs-137 detected in some samples at 42-54". Based on Cs-137 detected in the bottom interval of samples SMG6, SMG8 and SMG14, it appears that the delta deposits are thicker than 54" from the SR-6 bridge on the South, to transect 7 on the North. Based upon the preceding interpretations, it appears that the sampling effort likely did not span the entire thickness of the delta between the bridge and transect 7, as shown by the dotted red line on Figure 40. Some deeper samples from this area were retained, available for analysis in the event that this situation should arise. It appears that the sampling effort did penetrate entirely through the delta materials of interest north of transect 7, and on toward the bay.

As shown by Figure 40, the most concentrated amounts of Cs-137 in the Stream Mouth appear to have been deposited in the bottom of the stream channel, between U.S. 6 and the delta.

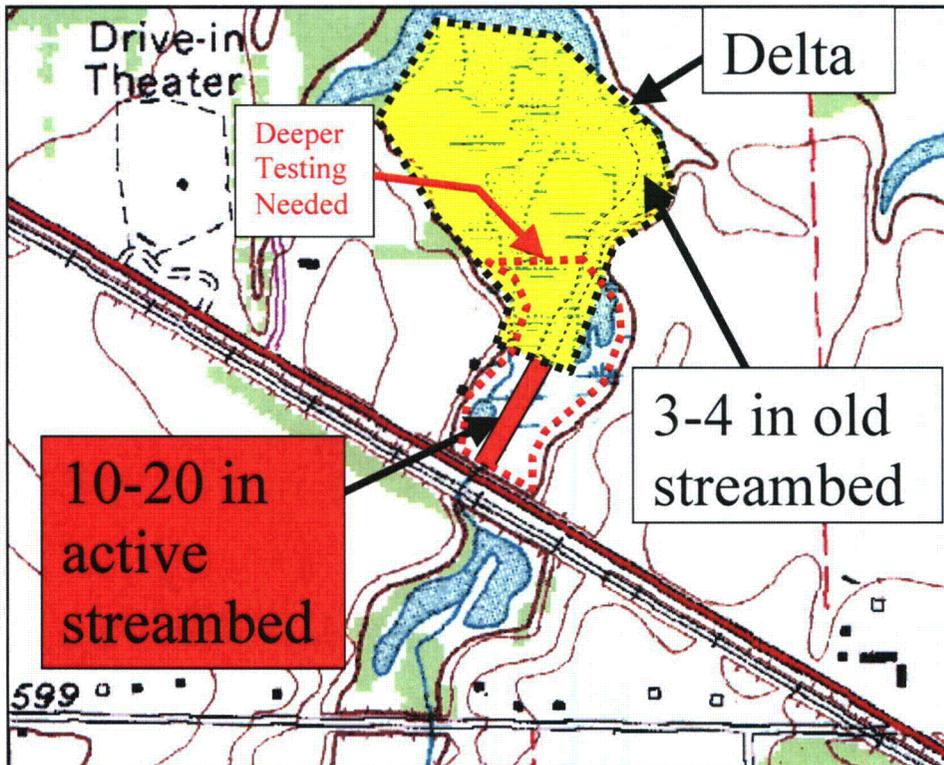
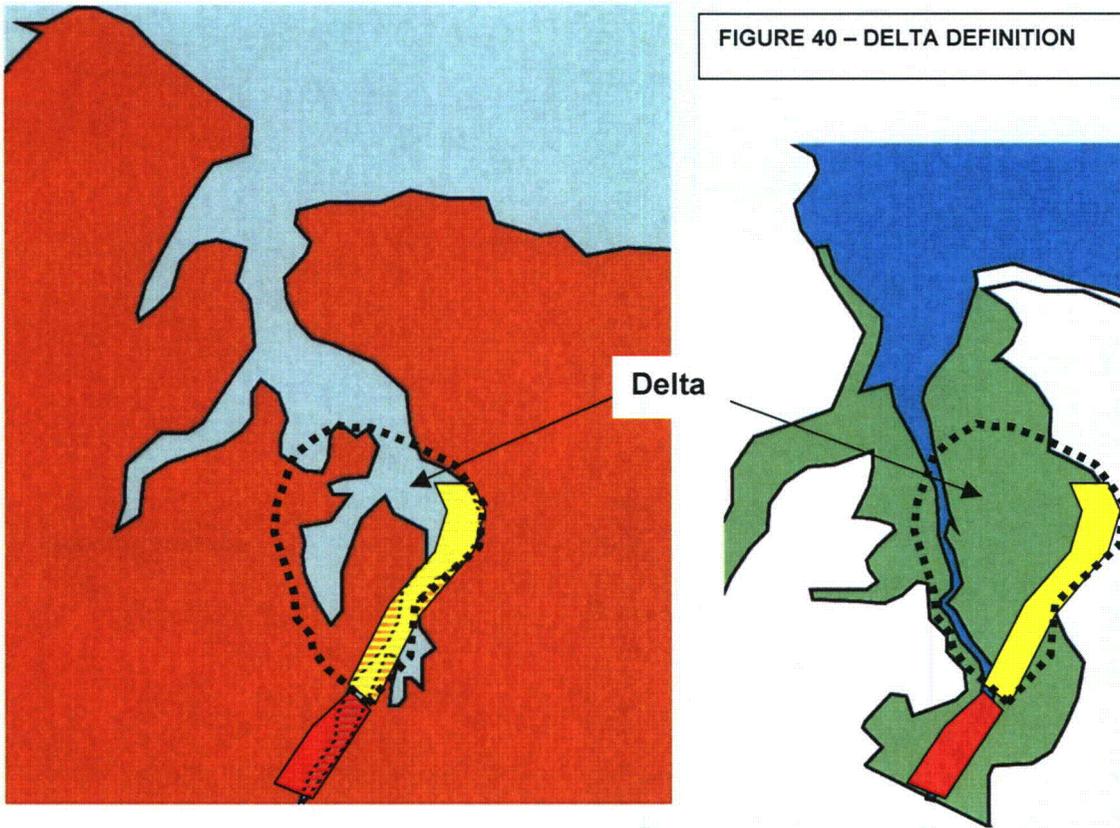
The delta represents the boundary between a normally standing-water environment (the bay), and a normally moving-water environment (the stream). However, depending upon the average and daily level of Lake Erie, the actual boundary between stream deposition and standing-water deposition may move upstream or downstream. Thus, temporary standing-water deposits may have been laid down upstream from the delta, and would then likely be eroded and redeposited downstream during periods of lower lake level.

In particular, it appears that such erosion and re-deposition occurred in the Stream Mouth, in the area labeled "SCOUR AREA" on Figure 13, where there was evidence of scouring in the channel (the water was deeper there). In this area, values of Cs-137

approaching 3 pCi/g were found at greater depths than was typical in most other locations (2.6 pCi/g at 42-56.5" below the stream bottom surface). Thus, it was interpreted that higher levels of Cs-137 were temporarily deposited here during periods of low streamflow or high lake level, then were scoured and re-deposited a short distance downstream during periods of greater streamflow or lower lake level. The downstream location for deposition appears to be where an EMA occurred at location SM6-6. The re-deposition of scoured Cs-137 was spread over part of section A, upstream from the delta. Through the delta, represented by section C and the downstream values of 3.4 and 3.9 pCi/g, the scoured material was also redeposited, with lower Cs-137 activities (3-6 pCi/g).

The clays bearing low levels of Cs-137 appear to have been confined to a channel that extended all the way through the delta, and on out into the Bay. Through the delta and bay, the highest values of Cs-137 encountered appear to be in the range of 3-4 pCi/g.

FIGURE 40 – DELTA DEFINITION



ACCOUNTING FOR CS-137 KNOWN TO BE RELEASED

Inputs to the mass balance for Cs-137 include the amount of Cs-137 per gram of sediment, and the size of areas in which Cs-137 was found. The mass balance assessment is complicated by Cs-137 that is still moving, and by the consideration of radioactive decay.

Two previous reports in this series on Cs-137 in Plum Brook have attempted to assess the total amounts of Cs-137 found. One report assessed the amount of Cs-137 found in 3 ponds; the second report assessed the amount of Cs-137 that might be present in the eastern end of Sandusky Bay. The estimating methods used in each of those reports resulted in the appearance that the amount of Cs-137 found in those environments might have exceeded the total amount estimated to have been released from the PBRF. This could lead to either of the following conclusions:

1. More Cs-137 might have been released than NASA was aware of, or
2. The estimating methods over-estimated the amount of Cs-137 found

Examining the first point more closely, HaagEnviro judged that the original estimate by Jack Crooks was reasonable, but possibly not comprehensive. Although the assessment of Cs-137 distribution focused upon events that occurred in 1968 and 1969, the Crooks calculation of Cs-137 released from the PBRF was not confined to those dates. The Crooks calculation considered water that was discharged during all of the fueling cycles, over the entire duration of the PBRF's operation. However, additional Cs-137 may have been released when the level of radioactivity present was not detectable by the monitoring systems.

Other potential pathways of Cs-137 release to Plum Brook, such as water released through the sanitary system, may be evaluated as decommissioning continues. However, at the time of this writing, it is appropriate to maintain the working hypothesis that all of the Cs-137 released to Plum Brook came through the Water Effluent Monitoring System (WEMS).

Examining the second point more closely, HaagEnviro decided that the following three corrections should be made in the Cs-137 estimating process:

1. The magnitude of peat volume reductions should be taken as a factor of 3, not the previously employed factor of 5.
2. Rather than using an average of Cs-137 measurements, the "representative value", as defined in this report, should be employed.
3. The effect of radioactive decay since deposition should be computed in more detail.

Using these concepts, HaagEnviro prepared an estimate of PBRF Cs-137 found in the Stream Mouth as shown in the following table:

Stream Mouth Section	Affected Depth (ft)	Affected Area (ft ²)	Dry Mass (g)	Representative Cs-137 Activity (pCi/g)	Total Cs-137 Activity, (mCi)
B (highest layer)	1	50 x 300 = 15,000	578,850,000	10-BKGND	5.5
B (rest)	1	50 x 300 = 15,000	578,850,000	4.5-BKGND	2.3
A (highest layer)	0.5	(5/14) x (50 x 300) = 5,357	103,363,315	6.3 to 2.5 (use 4.4-BKGND)	0.4
A (rest)	1	(5/14) x (50 x 300) = 5,357	206,726,630	4-BKGND	0.7
C (highest layer)	1	(2/14) x (50 x 300) = 2,143	82,698,370	7-BKGND	0.5
C (rest)	1	(2/14) x (50 x 300) = 2,143	82,698,370	4-BKGND	0.3
Delta Channel (highest layer)	1	50 x 1000 = 50,000	1,929,500,000	2-BKGND	2.9
Rest of Delta	1	24.11 acres = 1,050,232	40,528,452,880	1-BKGND	20.3
Tributaries	1	14.09 acres = 613,760	23,684,998,400	1-BKGND	11.8
Rest of Area	0.5	7.82 + 13.22 acres = 916,502	17,683,906,090	1-BKGND	8.8

TOTAL= 53.6 mCi

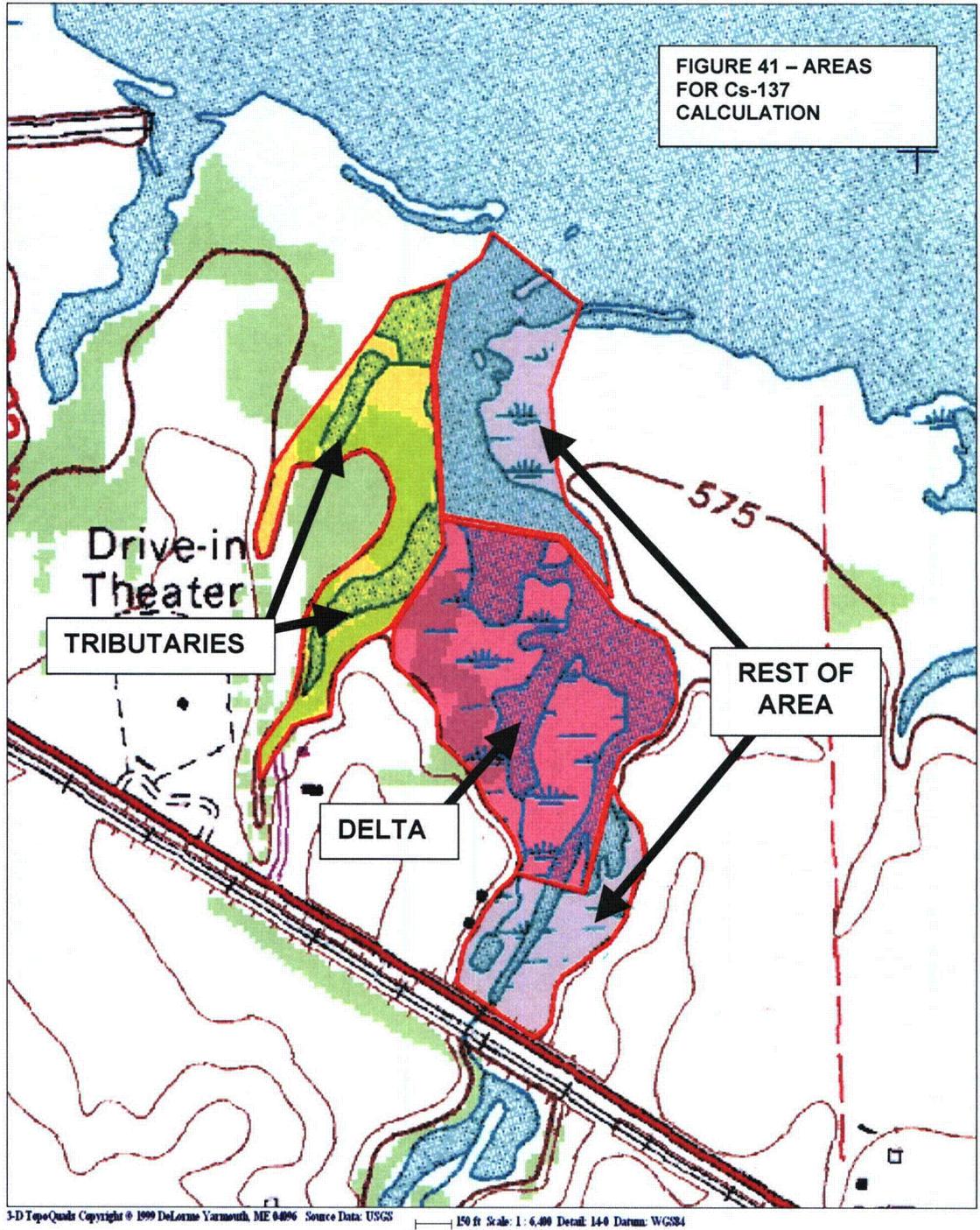
The areas used in the table are illustrated by Figure 41. The following assumptions and conversion factors were used:

Dry weight of soil = 85 pound per cubic foot (PCF)

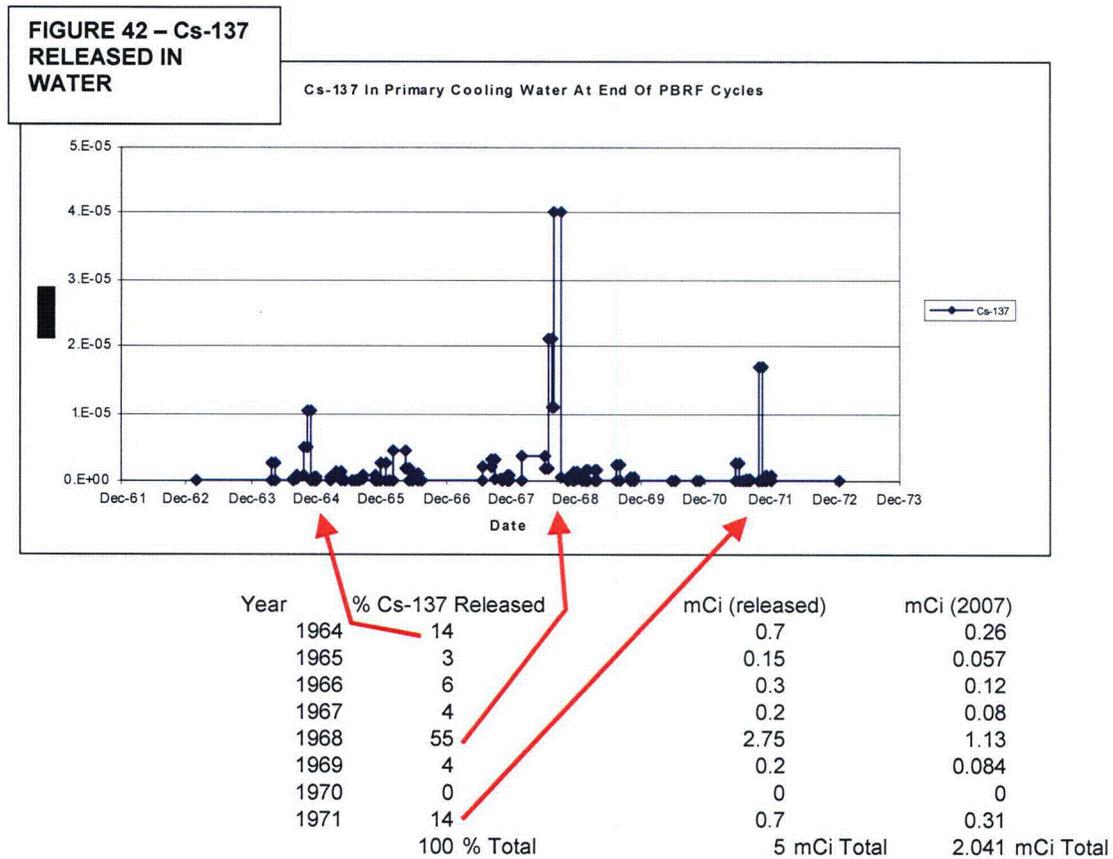
Conversion to grams = 454 g/pound

Conversion to milliCuries (mCi) = pCi/(10⁹)

Conversion to Square Feet (SF) = 43,560 SF/acre



With these assumptions, the total Cs-137 activity found in the Stream Mouth area was 53 mCi . This value of 53 mCi is to be compared with the amount expected to remain from the original PBRF releases, which was roughly estimated as 2.5 mCi.



The amount of Cs-137 that should be expected was computed in more detail as shown by Figure 42.

The result of the more detailed computation is an expected residual radioactivity of 2.04 mCi (round to 2 mCi), a 20% reduction from the prior rough estimate.

With the preceding assumptions, the PBRF Cs-137 that may be located in the Stream Mouth depositional environment (53 mCi) was much larger than the amount accounted for in our release estimates (2 mCi). Even the amount found in the 3 most thoroughly-assessed Stream Mouth areas (9.1 mCi) was 4.5 times the amount attributed to the PBRF releases (2 mCi).

At the time of this writing, HaagEnviro estimated the amount of presently-measurable Cs-137 activity from the PBRF at roughly 100 mCi, distributed approximately as follows:

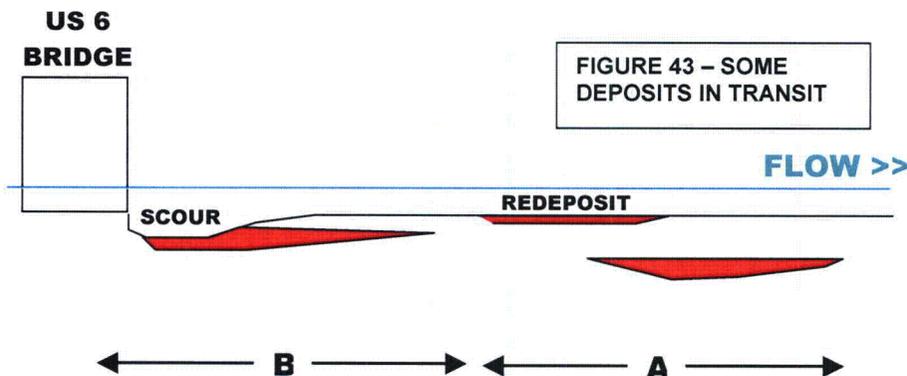
- 37% Excavated from Pentolite Ditch, placed near southern bank
- 9% Stream Mouth Areas A-C
- 42% Stream Mouth other areas
- 10% In front of WEMS
- 1%: Stream Meanders
- 1%: Stream Backwaters
- Not estimated: Flood Plain
- Not estimated: Bay

The estimating assumptions employed are detailed in Appendix C. In the calculation for the Stream Mouth, it should be noted that the largest contribution, by far, came from the assumption of a value of 1 pCi/g, to a depth of 6-12 inches, over the very large areas of the Delta, Tributaries, and Rest of Area.

IDENTIFY CS-137 DEPOSITS STILL IN TRANSIT

It appeared that the surface of the Stream Mouth depositional environment was continuing to receive PBRF Cs-137 at low levels (<3 pCi/g, most likely nearer 1 pCi/g). It appeared likely that most of this Cs-137 moved during flood events, when eroded from upstream deposits, and redistributed downstream. The most significant such flood events likely continued to cover the entire Stream Mouth area with water carrying clays with Cs-137.

The immediate downstream side of the bridge over U.S. Route 6 appeared to be a location in which clays bearing Cs-137 were deposited, then scoured out and redeposited. As illustrated schematically in Figure 43 below, the scoured area of the stream bottom appeared to constitute less than a third of Area B, at its southern end. The depositional area for this scoured material appeared to be the upstream half of section A, marked



“redeposit” on Figure 43. The schematic illustrates two buried deposits that would not be expected to move unless they were reached by scour. The deeper deposit, in the

downstream part of section A, was barely revealed in testing results. The deposit illustrated in section B was quite clearly defined by testing results.

The soils bearing Cs-137 that are shown in the area marked "redeposit" would be available to move further downstream. Although this area contained the most elevated Cs-137 activity detected in the Stream Mouth (20.6 pCi/g), the "representative" value for this deposit, defined by the methods in this report, spanned a range of only 6.3 pCi/g (upstream) to 2.5 pCi/g (downstream).

LOCATE FINAL RESTING PLACES OF CS-137 NO LONGER IN TRANSIT

Based upon data presented here, it was interpreted that clays bearing Cs-137 in 1969 were deposited at depths later covered to 30-42 inches below the 2006/2007 stream bottom, in Section A. Those deposits appeared to be beyond the reach of scouring from the stream in 2007.

It was interpreted that, some time after 1969, clays bearing Cs-137 were deposited at depths later covered to 6-18 inches below the 2006/2007 stream bottom in section B. It was considered that those section B deposits may have been contemporaneous with clays bearing Cs-137 in area C and further downstream in the delta, at depths later covered to 18 inches below the in-filled ground surface levels found in 2007. It was considered that these section B, C, and delta deposits may have been derived from deposits further upstream, possibly originating in the part of the Flood Plain that was dredged sometime between 1969 and 2005 (see Flood Plain report).

Subsequent delta deposition covered those deposits with materials of lower Cs-137 activity. When the stream channel changed direction in the delta between 1969 and 2005, many of those deposits were removed from further potential erosion. As a result, low-level deposits of Cs-137 appeared to be trapped in buried parts of this channel that extended through the delta and on out into East Sandusky Bay. Peak Cs-137 activities in the now-buried channels appeared to be in the range of 3-6 pCi/g. It appeared likely that such buried deposits were scattered along the dashed blue line in Figure 44.

The preceding interpretations are summarized as follows:

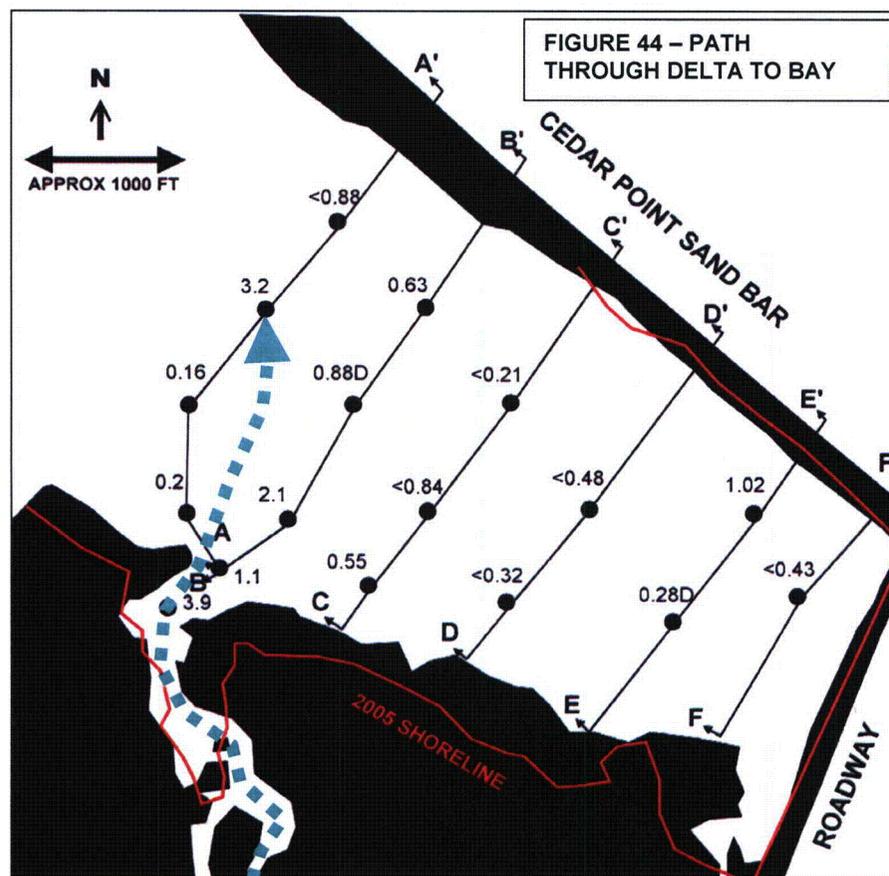
1. 1969 Cs-137 deposition in section A, buried deeper than 30 inches below active stream bottom in 2007
2. 1969 Cs-137 deposition upstream in Flood Plain area
3. Post-1969 dredging of Flood Plain Cs-137, with re-deposition downstream in Stream Mouth sections B, C, delta, and bay
4. Post-1969 dredging re-deposits covered by materials of lesser Cs-137 activity; in 2007 buried deeper than 6 inches in active stream bottom, buried deeper than 18

inches in abandoned channel, and buried deeper than 54 inches in near-bay end of Stream Mouth

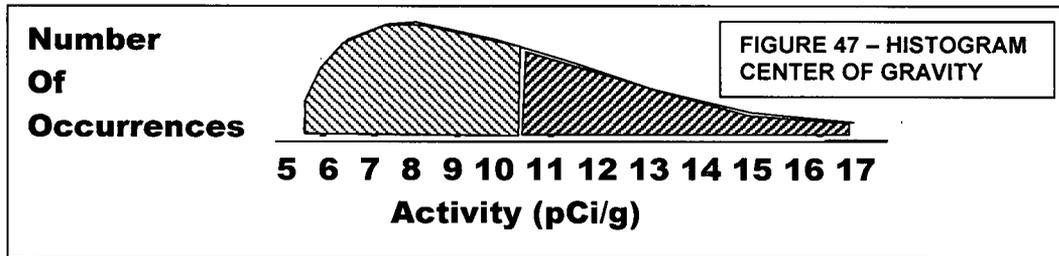
- 2006/2007 scour from section B, with re-deposition in section A, responsible for highest Stream Mouth activity, found in upper 6 inches of stream bed

Reinterpretation of Bay Results - In light of the Stream Mouth interpretations, it became reasonable to interpret that Cs-137 values equaling or exceeding 3 pCi/g, found in the Bay, were a continuation of the pattern described in the Stream Mouth. Re-examining the data from the Bay report led to the interpretation that the main part of Cs-137 deposition in the Bay followed a channel to the west, as shown in Figure 44. The values found continued to be well below 12 pCi/g, and the conclusions of the Bay report continued to be valid, except that it did appear that PBRF Cs-137 might actually be distinguishable from background Cs-137 in the bay. The original bay report had concluded that a distinction between background and PBRF Cs-137 could not be made.

The fact that the bay value marked 3.2 pCi/g in Figure 44 occurred in the upper 6 inches of a bay sample indicates that some of the material eroded from Stream Mouth section B may have been delivered to the Bay as recently as 2006/2007.

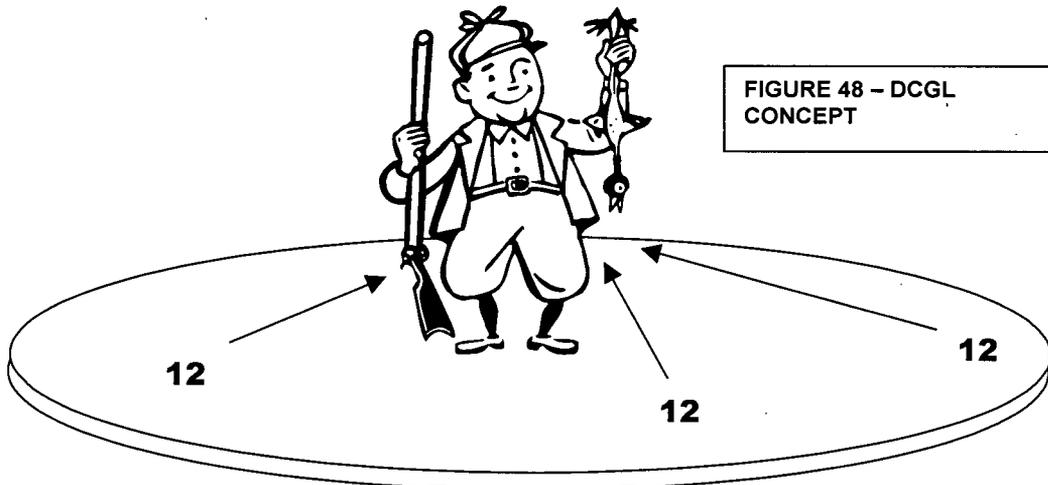


Without the original observations, we have the following curve, which we can divide into equal areas to the left and right of the “center of gravity” of the area under the curve.

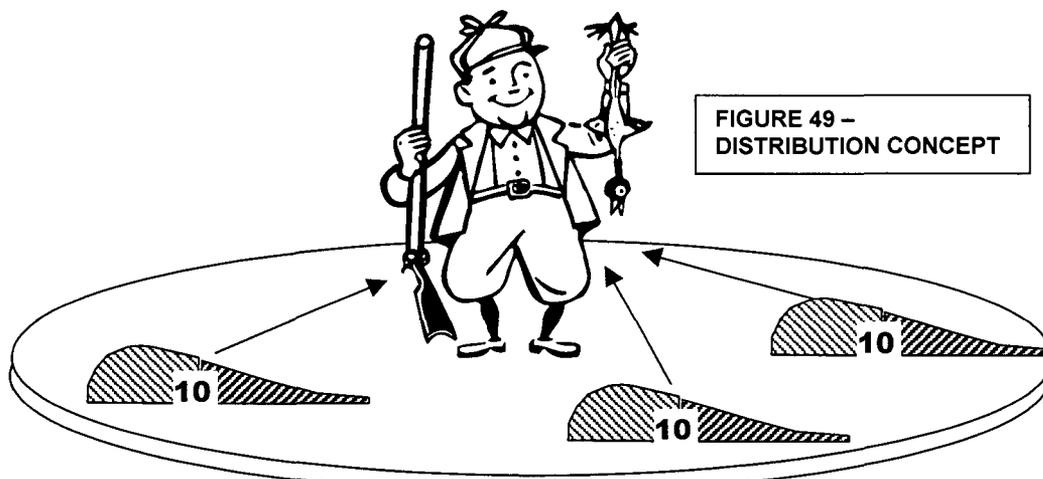


By this analysis, the “representative” activity in the Area B sediment layer with the highest Cs-137 activities would be slightly greater than 10 pCi/g. Note that the “representative” value determined for this section, by fitting a line to the logs of the measurements, was 10 pCi/g (fairly close, considering the simplicity of this example).

The direct exposure aspect of the DCGL calculation assumes that all of the soil in the area surrounding the maximally exposed individual has the same Cs-137 activity, as illustrated in Figure 48 for a DCGL of 12 pCi/g:



However, when the Cs-137 distribution is lognormal, and not uniform, the same individual might walk over individual activity measurements as high as 17 pCi/g, but be exposed to an equivalent radioactivity of only 10 pCi/g, as illustrated by Figure 49.



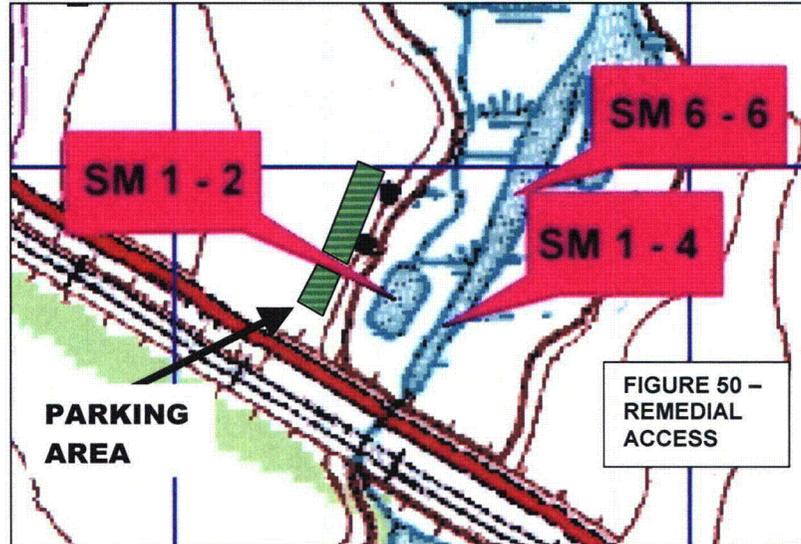
One way in which this discrepancy might be overcome would be to take a dose approach to determining what sediment should be removed, rather than employing the DCGL concept. Another approach might be to compare the “representative” value, as defined in this report, to the DCGL. Yet another approach would be to use a Cs-137 input with a lognormal distribution in the RESRAD computer model, to define the input that delivers a dose of 25 mRem/year. If any of these approaches were employed, it appears likely that the conclusion would be that removal of many sediment deposits would not be necessary in order to achieve the required dose <25 mRem/year.

Precision and Accuracy – It has been observed in prior studies in this series that the practical quantitation limit (PQL) for testing values in this project is 3 pCi/g. Below that value, the precision DQI of $\pm 20\%$ cannot be reliably achieved. In such cases, the differences between one result and another are only approximations, and cannot be relied upon as meaningful. Based upon the graph provided in the current study as Figure 37, it appears that the accuracy DQIs of 80-120% can only be achieved when the measured values span the range at least as high as 4.5-18 pCi/g, with a “representative” value at least as high as 9 pCi/g.

Number of Samples Required – As the “representative” value approaches the current remedial target of 12 pCi/g, the number of samples required to achieve 95% confidence, that the “representative” value is less than the target, increases. A trial calculation suggested that, when the variance of the log-transformed values is 0.15, the power of the statistical test is 1.0, and the “effect size” is $|12-9|$ pCi/g, the number of samples required to achieve 95% confidence would be at least 25. These preliminary calculations employed only the most elevated activity values at each sampling location. If all of the samples containing Cs-137 from PBRF were employed, then it is possible that there would be a sufficient number of samples to support the conclusion at the 95% confidence level.

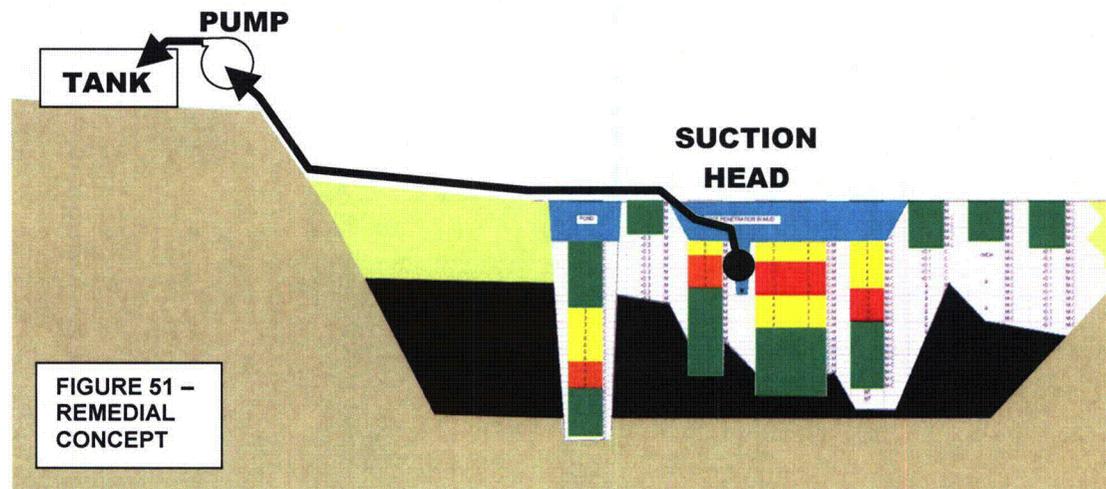
Ease of reaching the contaminated sediment with remediation equipment – Overland access to key parts of the Stream Mouth would be relatively straightforward. Overland access can be achieved from an Erie MetroParks parking area, illustrated in Figure 50. If fixed equipment could remain in that paved area, hoses could be extended roughly 200 feet to the stream, without significant impact to the vegetation.

Water access can be achieved from East Sandusky Bay, but water depths in the Stream Mouth become very shallow, such that boats can draw only a few inches in some places. For this reason, MetroParks canoes were used to transport the sampling equipment for this study. The



nearest commercial boat access is roughly 2 miles to the west, and is the point at which HaagEnviro put in its pontoon boat for bay sampling.

Ease of removing only the contaminated sediment – The lateral limits of deposits that contain individual results that may exceed cleanup standards can be defined by the methods used in this study. As illustrated by Figure 51, the parts of the sediment that



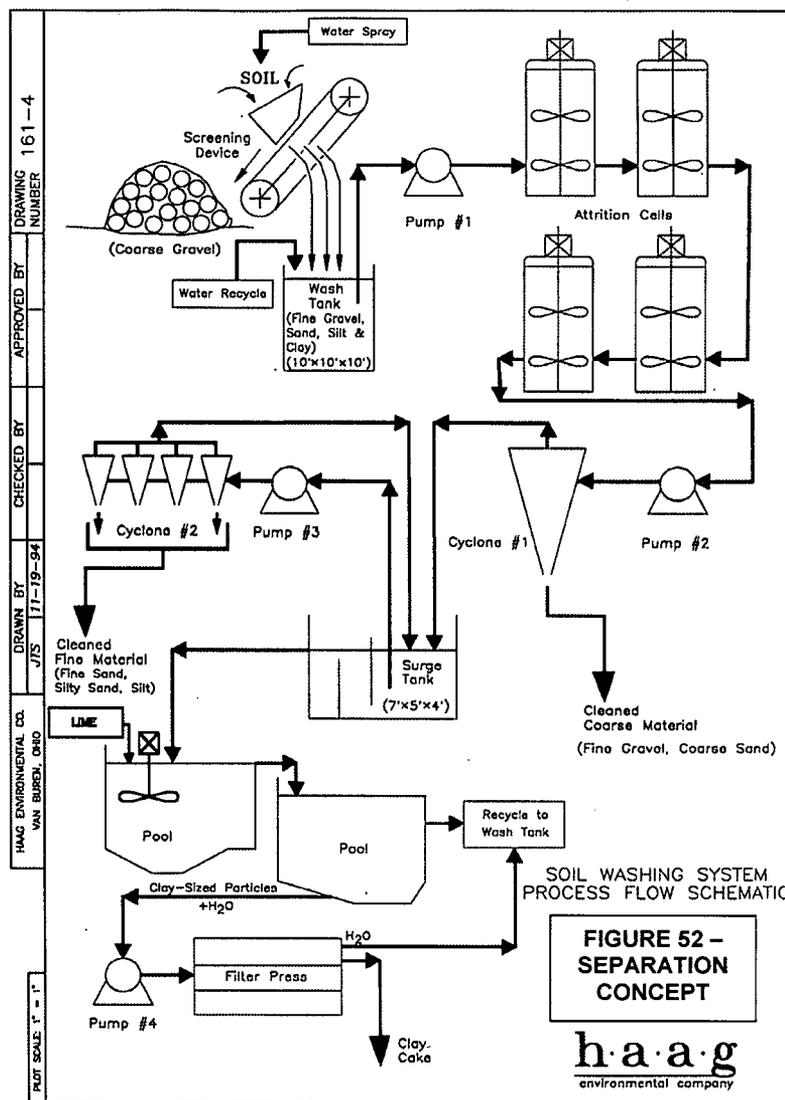
exceed those criteria often occur in layers that underlie materials that might not exceed the standards. Segregation of these layers would not likely be feasible. Once the key layers are removed, it is likely that the combined material removed would no longer

exceed the cleanup criteria, due to mixing of the layers, and due to mixing of the lognormally distributed Cs-bearing particles.

Removal of contaminated layers, in the Stream Mouth setting, would most likely be performed using land-based hydraulic dredging equipment, such as that illustrated in Figure 51. This approach would generate a slurry of water and sediment. The sediment slurry would then be processed to remove water, at a minimum. Potentially, the processing could also segregate the Cs-bearing soils from the balance of the material.

Ease of separating contaminated clay from other materials –

NASA has not studied segregation of clay particles from coarser materials on this project. However, others have performed such work, on other projects in the past. For example, HaagEnviro set up and operated a trial system of this type in 1994, as illustrated by Figure 52. The primary function of the system illustrated here was to segregate contaminated clays from other soil types, and to concentrate those contaminated clays in a dry cake, for disposal.



Summary of Interpretations – Cs-137 from the PBRF was found in the Stream Mouth depositional environment, at levels that appeared unlikely to deliver a dose >25 mRem/year to the maximally exposed individual. In some cases, Co-60 from the PBRF was also present. The most elevated levels of Cs-137 detected were in transit, through a process of sediment erosion and re-deposition. The highest Cs-137 activity in transit was 20.6 pCi/g, but the “representative” value for this deposit was a range of only 2.5-6.3 pCi/g. Downstream from the most elevated deposit, the erosion and re-deposition process was seen to have moved levels of Cs-137 in the stream mouth and bay that peaked in the range of 2-4 pCi/g.