

**CHARACTERIZATION REPORT
FOR PLUM BROOK SEDIMENT IN
FLOODPLAIN WETLANDS**

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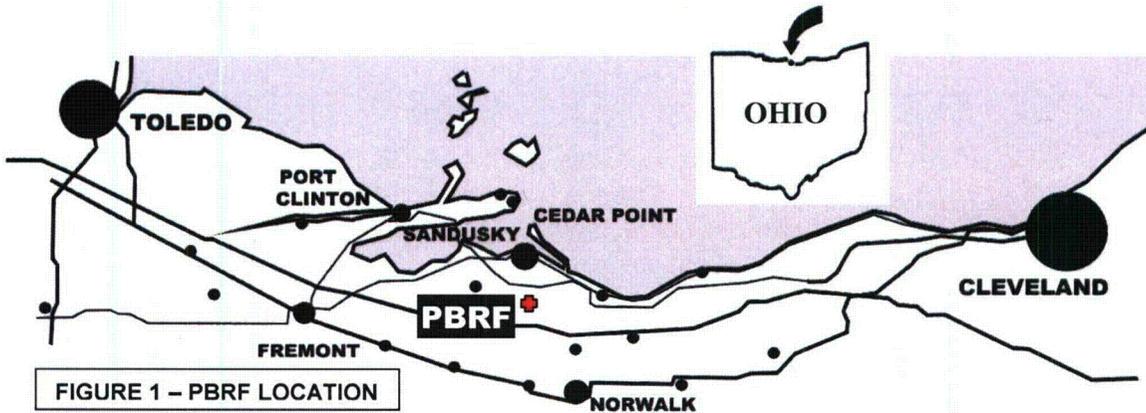
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CHARACTERIZATION REPORT FOR PLUM BROOK SEDIMENT IN FLOODPLAIN WETLANDS

INTRODUCTION

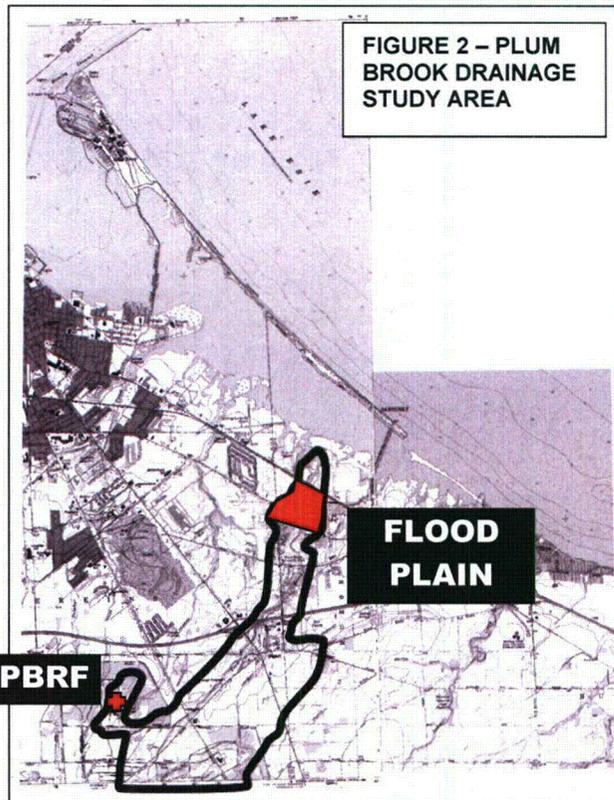
This report documents an investigation of the potential distribution of a radioactive isotope of the element cesium, known as ^{137}Cs , or Cs-137, in the floodplain wetlands of Plum Brook near Sandusky, Ohio. This investigation was conducted to determine whether Cs-137 attributable to a decommissioned 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 floodplain 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 floodplain wetlands, an area where Plum Brook widened from a small, incised channel into a much wider floodplain area.

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. Former NASA employee Jack Crooks estimated 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 could be documented as having been 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), or 2.5 millicuries (mCi) of Cs-137 activity remained to be found in the years 2006 and 2007, when this study was conducted. Subsequent estimates, described in the Stream Mouth report in this series on Plum Brook sediments, reduced that 2.5-mCi estimate to about 2 mCi, due to a closer calculation of radioactive decay. Those subsequent estimates also added about 100 mCi to the amount assumed to have exited the WEMS, with the added amount believed to have been discharged at levels beneath the detection limits of the monitoring methods used at the time.

This sampling program described in this report was also premised upon the assumption that all of the Cs-137 dissolved in the 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 impact 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 floodplain 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:

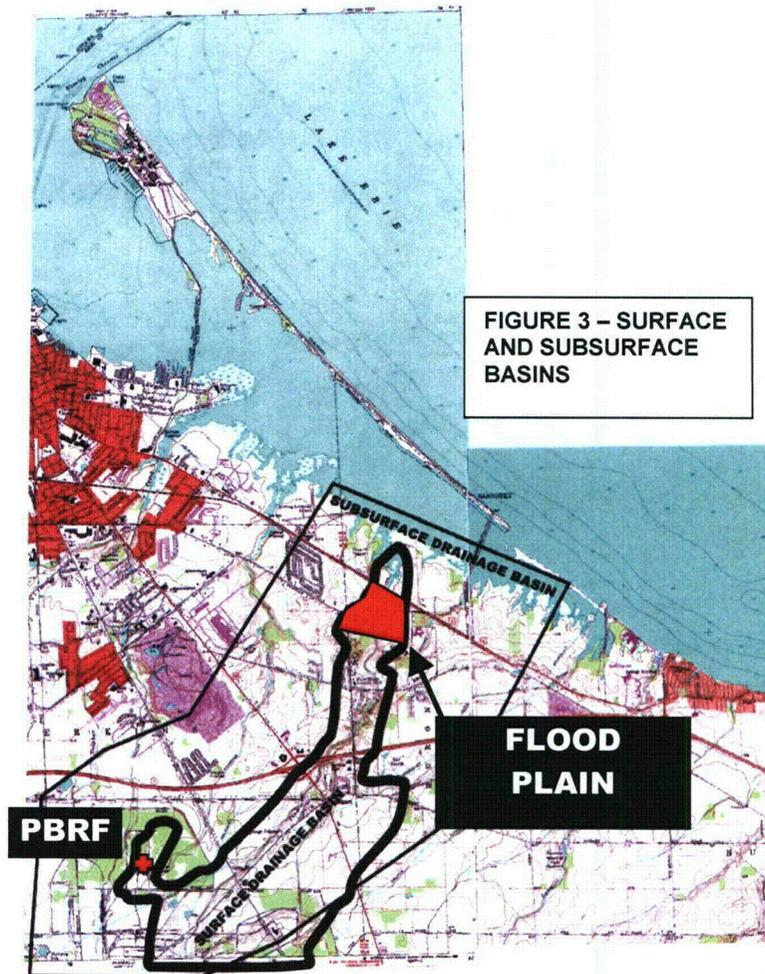
1. Ease of reaching the contaminated sediment with remediation equipment
2. Ease of removing only the contaminated sediment
3. Ease of separating contaminated clay from other materials

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 that hydrogeologist Bob Haag be able to compare the precisions achieved with other hydrogeologic investigations that he had conducted. 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:

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

For this work, quantitative test results for recounted (re-analyzed) samples, and for samples that were “split” during preparation for analysis, were expected to achieve RPDs less than 20%. This was due to the expectation that that the errors measured by comparing these types of sample were due to the analytical process, not to the variability of the soil deposits.

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 might 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. However, it was observed in the Stream Mouth report in this series that this DQI is likely to be achieved only when the “representative” value for a Cs-137 deposit exceeds 9 pCi/g. From observations made in the Stream Mouth report, this means that we can achieve our accuracy target when the range of values is roughly 4.5 pCi/g (50% of representative) to 18 pCi/g (200% of representative). So the RPD of log values should not be employed as a DQI when the Cs-137 activities for a deposit are lower than the 4.5-18 pCi/g range.

In some cases, repeatability must be considered acceptable if detection or non-detection of the contaminant is the same in the original and duplicate samples. This was the rule applied here to assess the repeatability of recount and split 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. This was also the applicable DQI for co-located samples with activities below the 4.5-18 pCi/g range, for which 9 pCi/g was considered the “representative” value.

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 laboratory 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 Floodplain 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 Floodplain 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 sand, silt, and clay soils in this project, we employed the rule that sample recoveries of 80% are typical, and such 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. This was generally achieved on this project, where the pond-like downstream areas were expected to produce the highest activities, and were sampled late in the progression of transects.

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. For analyses performed at PBRF, laboratory blanks were prepared and tested according to the requirements of PBRF procedure RP-021. Testing results for blank samples were 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 had essentially the same meaning.
2. Cs-137 measurements in the natural environment surrounding the PBRF need to be transformed to $\log(\text{measurement})$ 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 procedures employed were PBRF's RP-021, and EPA Method 901.1 Modified.

EXPECTED CHARACTERISTICS OF THE FLOODPLAIN WETLANDS DEPOSITIONAL ENVIRONMENT

The following section describes the expected characteristics of the floodplain 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.

Beginning near the middle of the Plum Brook Country Club, the Plum Brook streambed widens from a deep incised channel, into a floodplain in which the stream is "underfit." This means that the width of the floodplain is larger than a stream of this size would be able to cut. Such widened areas were typically created by past glacial processes and deposits, and not by the underfit stream itself. However, the presence of a wide flat area adjacent to a stream tends to favor marsh vegetation and organic deposits of peat and muck. This type of wetland characteristically holds contaminants in channels and plant hummocks under certain conditions, then releases them when conditions change. The cycles of capture and release may be yearly. Soil deposits may alternate with organic peat and muck deposits. In this type of area, scattered deposits of fine sediment bearing Cs-137, trapped within peat or muck, were sought. It was also considered possible, but less likely, that the peat and muck deposits themselves might have trapped Cs-137.

In prior sampling in the Bay and Stream Mouth depositional environments, it was observed that the bottom soft-sediment deposit was a fine-grained peat/muck, underlain by dense clay till. This peat/muck deposit completely filled the Bay study area, and extended inland into the Stream Mouth environment. Overlying the older peat/muck deposit in the Stream Mouth, HaagEnviro observed alluvial silt/clay deposits judged to represent a delta.

At the time that the Floodplain Characterization Plan was prepared, Cs-137 from PBRF in the Stream Mouth had largely been discovered only in the upper 18 inches of alluvial sediment. A similar pattern was therefore expected at the downstream end of the Floodplain Wetland environment.

However, in the course of performing the Stream Mouth work, it was found that Cs-137 from PBRF had actually been deposited at greater depths, sometimes deeper than the deepest samples tested. Because the Floodplain work was largely performed in parallel with the Stream Mouth work, there was no opportunity to incorporate this finding into the Floodplain plan.

METHODS

HaagEnviro consulted with the Plum Brook Country Club (PBCC) regarding sampling on their property, before and during the sampling effort. Rod Case also obtained access permission from private landowners west of the PBCC.

Based upon the HaagEnviro Characterization Plan for the floodplain wetlands depositional environment, another NASA contractor, MOTA, prepared Survey Request (SR) number 41 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 54. These contractor employees were members of NASA’s Final Status Survey (FSS) Group. SR 54 was designed to find the “representative” activity within an elevated measurement area (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 41, 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 bounding effort, under SR 54, Bob Haag established triangular grid patterns, blanketing the streambed and banks around each of two EMAs.

This area was the first sampled by HaagEnviro in which conditions were dry enough to support surface scanning for Cs-137, in addition to sampling and testing.

In all cases, sample and scanning points were located with the aid of global positioning system (GPS) devices and related mapping software. Sampling methods included a manually driven dual-tube GeoProbe, a power auger using 3-inch-diameter aluminum sample tubes, and a vibrocore system using 3-inch-diameter aluminum sample tubes.

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

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

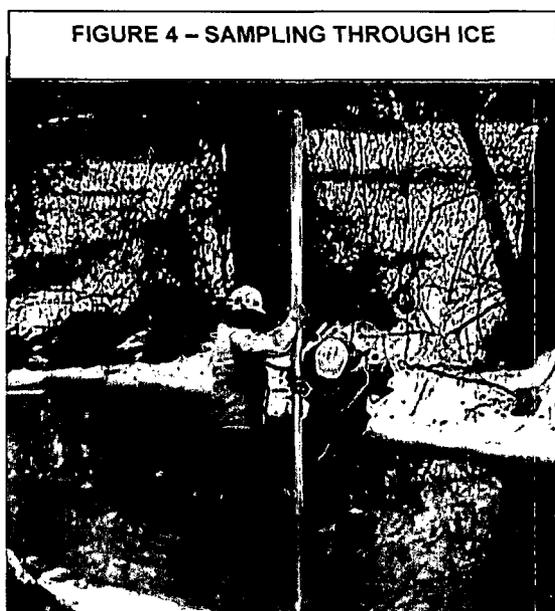
With minor exceptions, the samples were analyzed quantitatively in the PBRF onsite laboratory. Two samples were analyzed at Severn-Trent Laboratories (STL) in St. Louis,

Missouri. Data reduction and review involved comparison of results with DQIs, and a search for trends and patterns.

ACCESS CONSIDERATIONS

Except for those in the stream bottom, all of the samples were obtained on private property. NASA obtained access permissions before the work began. Once HaagEnviro began laying out locations in the field, it was seen that a few samples from planned transects 1, 2, 3, and A were on property for which NASA had not obtained access permission. Work on those properties was delayed until NASA obtained written permission. One of the added landowners, Patrick O'Brien, showed a particular interest in the work, and obtained videotape and photographs of the sampling effort. Mr. O'Brien was employed by a local newspaper, and this led to a request by a newspaper reporter, Tom Jackson, for the testing results obtained on the added landowner properties. In response to that request, NASA made a special effort to transmit those results to the property owners, at the earliest possible time after NASA's data review.

Much of the area sampled in the Floodplain was covered by common reed (Phragmites), cattails, and scrub brush. Roughly one sample out of 6 in each transect was obtained in the streambed of Plum Brook. Access to sampling points was mostly on foot, and somewhat by means of canoes loaned by the nearby Erie MetroParks system, whose land was being sampled at the same time. Some of this work was performed in the winter, and water areas were then accessed through ice, as shown by Figure 4.

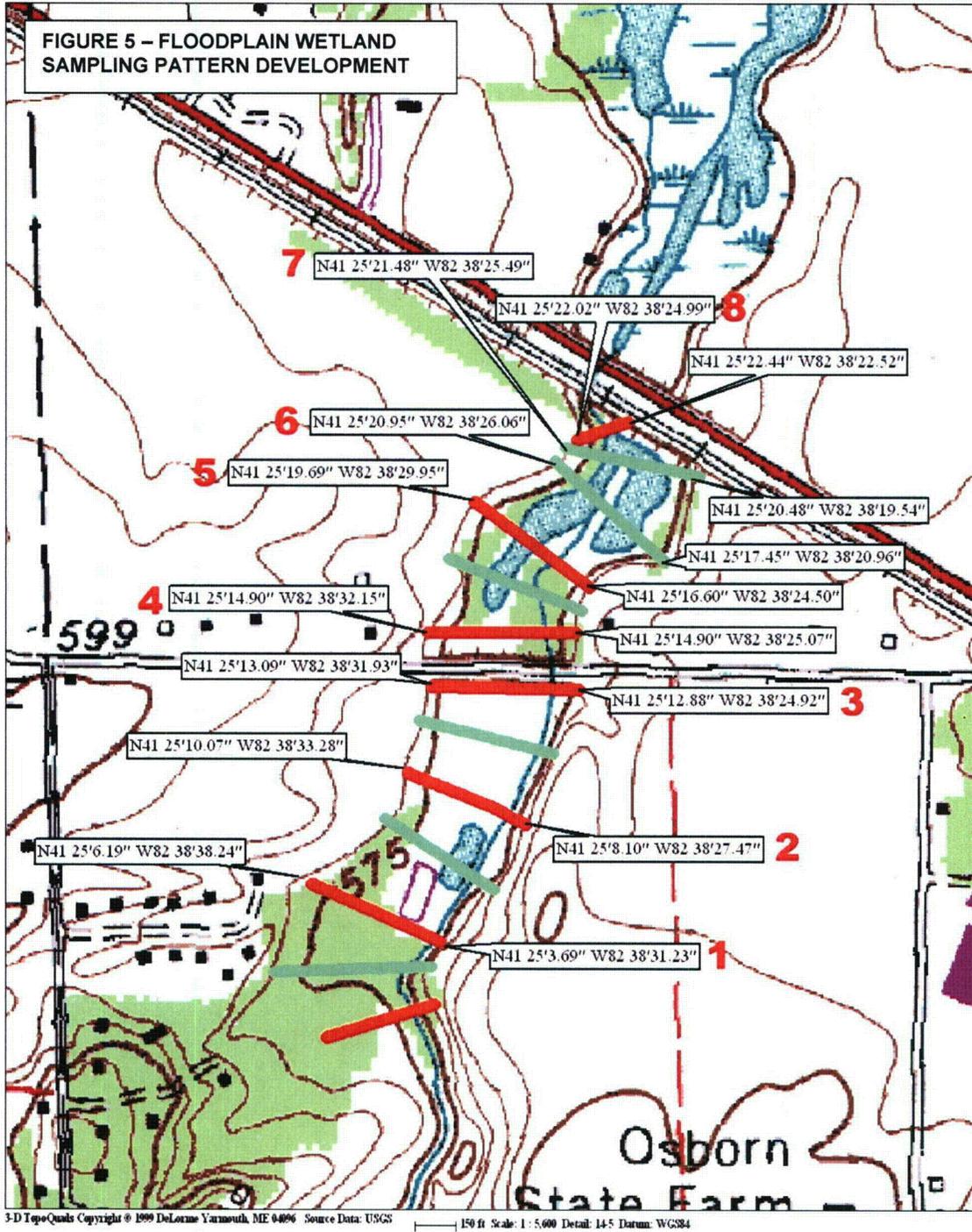


An electric fence blocked a small part of the northeastern corner of the floodplain

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. Figures 5 and 6 illustrate the initial and final layout of transects. Lines marked in red were the primary transects, and those marked in green were possible alternates. 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.



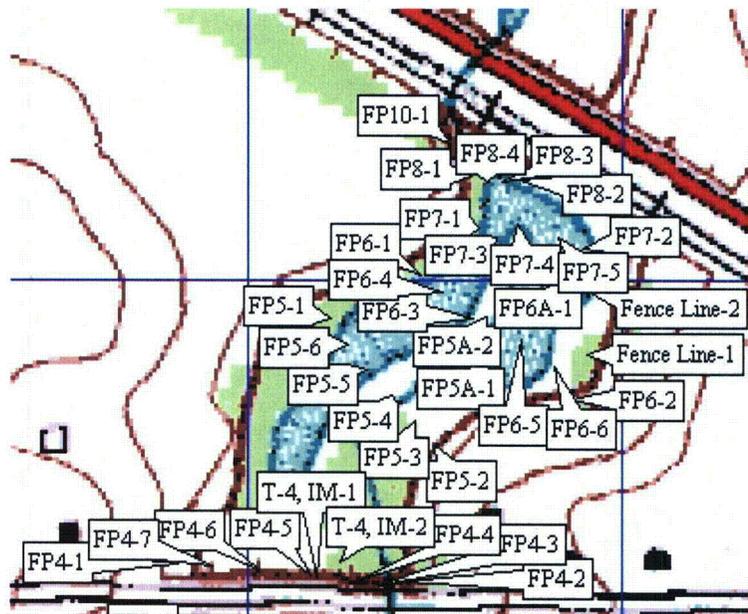
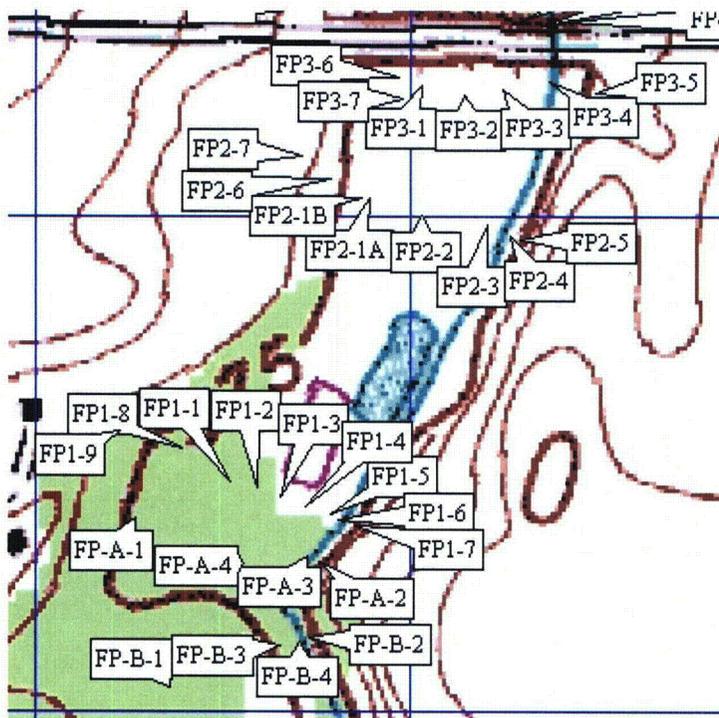


FIGURE 6 – FLOODPLAIN WETLAND TRANSECT SAMPLING LOCATIONS, IN NORTHERN FLOODPLAIN (ABOVE) AND SOUTHERN FLOODPLAIN (BELOW)



DEVELOPMENT OF BOUNDING GRIDS

After sampling and testing along the transects was complete, two elevated measurement areas (EMAs) had been identified. The EMAs were found at sampling locations IM-2 and FP7-3, illustrated on Figure 7. These EMAs were further investigated as described below.

The key assumption underlying the bounding investigation was that any EMA represented a continuum of lognormally distributed values. The size of each survey area was based upon the maximum size for a Class 1 survey area, as defined in the FSSP. The spacing of each triangular grid was based upon guidance in the FSSP. The starting points for each grid pattern were selected along the stream, by means of a random number generator. Using these concepts, the sampling patterns shown in Figure 8 were developed.

The first grid area, labeled Area A, was centered on an EMA on the stream bank, which had produced a peak Cs-137 measurement of 10.3 pCi/g (rounded to 10 in some figures). The second two survey areas, labeled B and C, flanked an EMA that had produced a peak Cs-137 measurement of 14.2 pCi/g (rounded to 14 in some figures). Figure 7 illustrates the relationships between areas A, B and C. Figure 7 also shows, by means of very small yellow dots, the locations of the original transect samples.

FIGURE 7 – BOUNDING SAMPLING AREAS

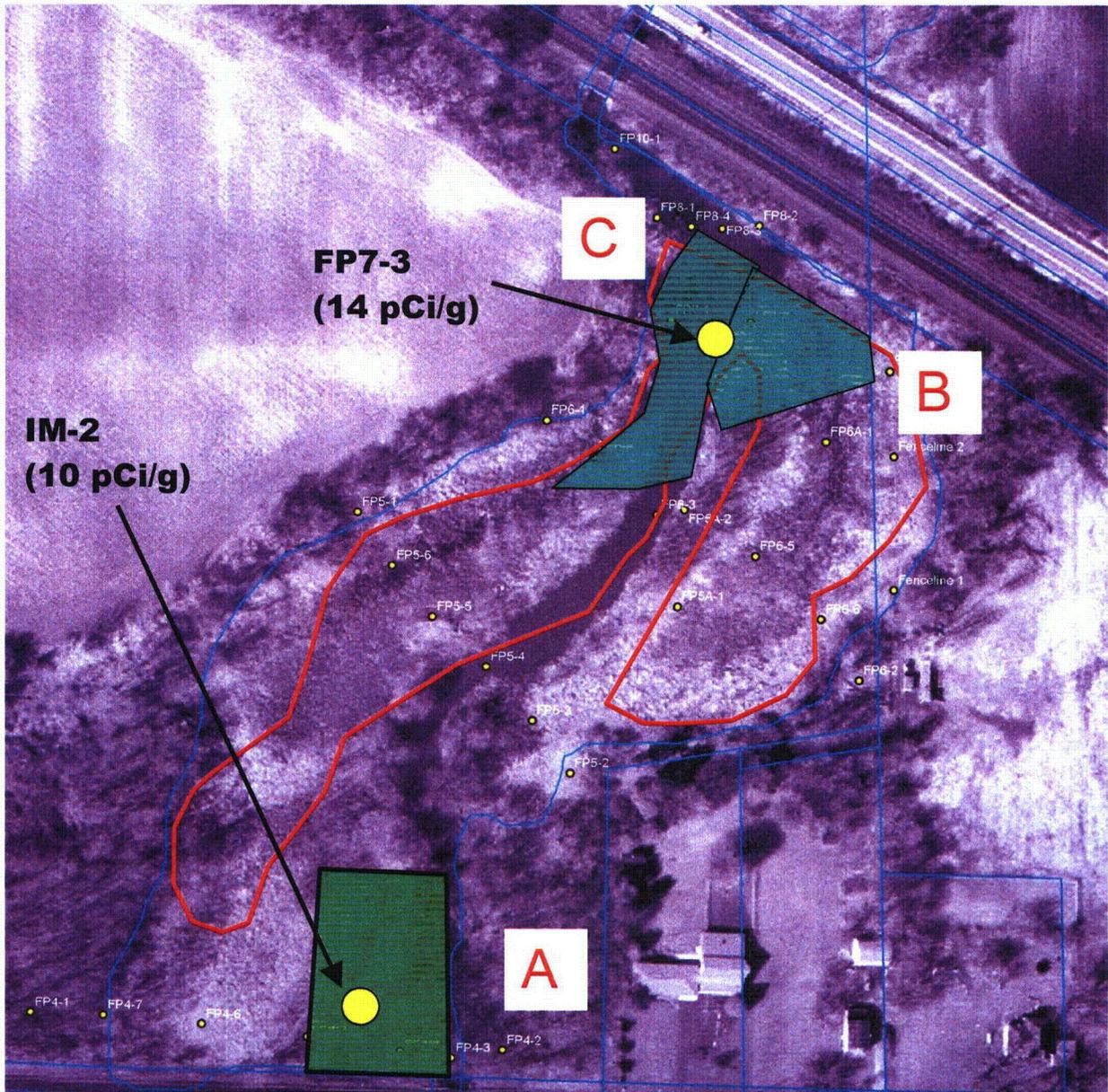
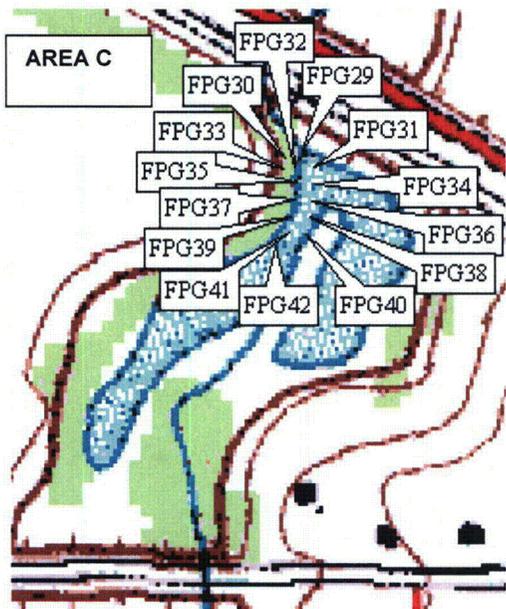
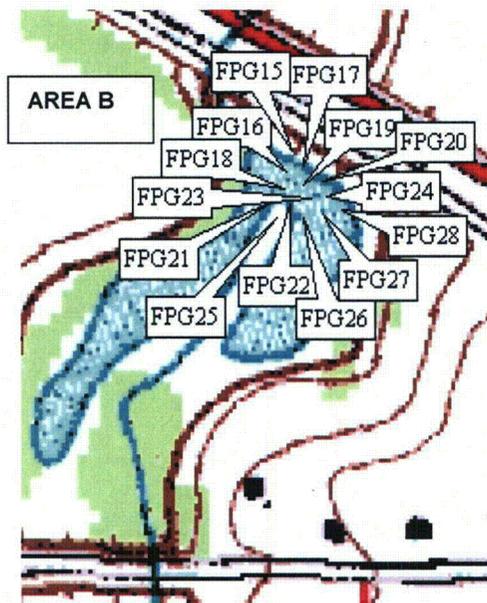
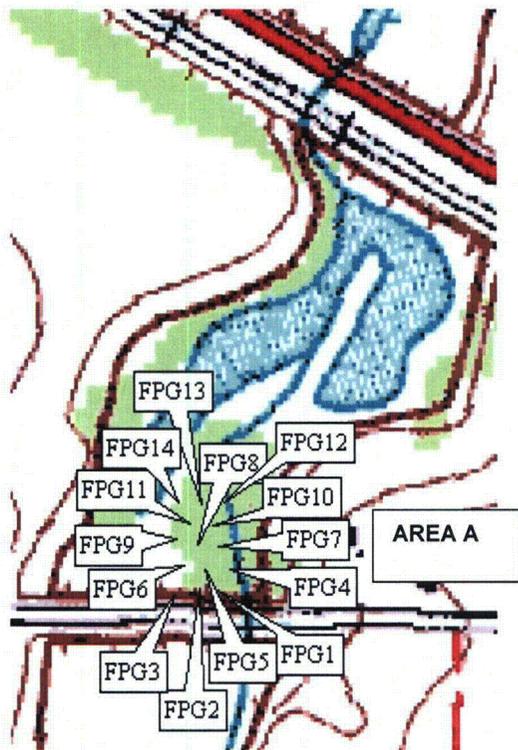


FIGURE 8 – SAMPLING LOCATIONS WITHIN BOUNDING AREAS A, B AND C



LOCATION OF SAMPLING 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 transect 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, Haag located a few key points, then measured the grid pattern from those points. The MOTA RP Technician then used a NASA-provided GPS device to post the measured locations on a map on a handheld computer, and adjusted those locations to obtain a more uniform grid, in consultation with Bob Haag. The NASA-provided GPS device was a Trimble model TSCe coupled with an integrated GPS/beacon antenna (part number 29653-00).

SAMPLING METHODS

HaagEnviro core samples in the initial transects were obtained from 63 locations. HaagEnviro core samples were taken by one of three methods: manual dual-tube GeoProbe, power auger, or vibracore.

MOTA reported on soil samples from 2 additional locations, called IM-1 and IM-2.

HaagEnviro did not observe MOTA methods, but it is assumed that their methods complied with PBRF Procedure CS-01, "Survey Methodology to Support PBRF License Termination".



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

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

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

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



FIGURE 10 – VIBRACORE SAMPLING

By either sampling method in the initial transects, it was considered that pre-1961 sediments had been reached, and sampling could be terminated, when hard glacial till

was encountered. In the later bounding work, it was considered that either refusal at hard till, or 6 feet of sample depth would be sufficient to achieve the objectives of the FSSP.

At 3 of the initial transect locations, a gasoline-powered auger was used to spin a short section of aluminum vibracore sample tube past frozen soil, until refusal or the desired depth was reached. The sample was then handled like any other vibracore sample. A Geoprobe sample was then taken in the open hole left by the auger, until GeoProbe refusal was obtained.

At 4 of the initial transect locations, and one of the grid locations, the vibracore sampler was used until refusal, then the Geoprobe was used to carry the hole deeper, until either GeoProbe refusal or a 6-foot depth was obtained.

SAMPLE SCREENING AND CHAIN-OF-CUSTODY DOCUMENTATION

Samples were transported under chain-of-custody (COC) control by the RP Technician, to the sample-processing trailer at the PBRF site.

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 datalogger with a model 44/10 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.

Screening for organic chemicals during the processing of some of the initial transect 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. The NASA PID was initially fitted with a 10.6 eV lamp, which was later changed to an 11.7 eV lamp. A HaagEnviro employee calibrated the HaagEnviro PID each day. A MOTA employee calibrated the NASA PID each day. In each case, calibration was performed using isobutylene gas with a concentration of 100 parts per million (ppm).

To determine whether there might be any organic compounds of concern in the samples with elevated PID readings, further investigations by chemical testing were conducted. Two Floodplain soil samples were tested at STL for the following parameters: volatile organic compounds (VOCs) by SW846 Method 8260B, semivolatile organic compounds (SVOCs) by SW846 Method 8270C, organochlorine pesticides by SW846 Method 8081, chlorinated herbicides by SW846 Method 8151A, and nitrate fertilizer indicators by MCAWW Methods 350.1 and 353.1. The testing for VOCs and SVOCs included a search for tentatively identified compounds (TICs). The two samples sent to STL due to

elevated PID readings were FP3-1, 42"-54", and FP3-5, 6"-18". STL also performed gamma spectroscopy testing on these samples using EPA Method 901.1 Modified.

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, as shown by Figure 11. 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. After testing, the processed samples were also retained at PBRF.

QUANTITATIVE LABORATORY ANALYSIS

The processed samples were analyzed by gamma spectroscopy in the PBRF onsite laboratory following PBRF procedure RP-021. Samples sent to STL were processed by STL, and were analyzed by EPA Method 901.1 Modified.



**FIGURE 11 – SAMPLE PROCESSING
(ABOVE) AND SCREENING/SAMPLING
FOR ORGANICS (BELOW)**



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 here 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 the top 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), results for QC duplicates, or "split" samples, 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. One co-located sample was obtained, labeled FP2-1A and FP2-1B.

The highest initial transect results were posted in map view, and reviewed for patterns of elevated Cs-137 levels. The bounding results were assessed in a similar fashion. Histograms of the bounding results were also prepared, to allow assessment of the Cs-137 distributions.

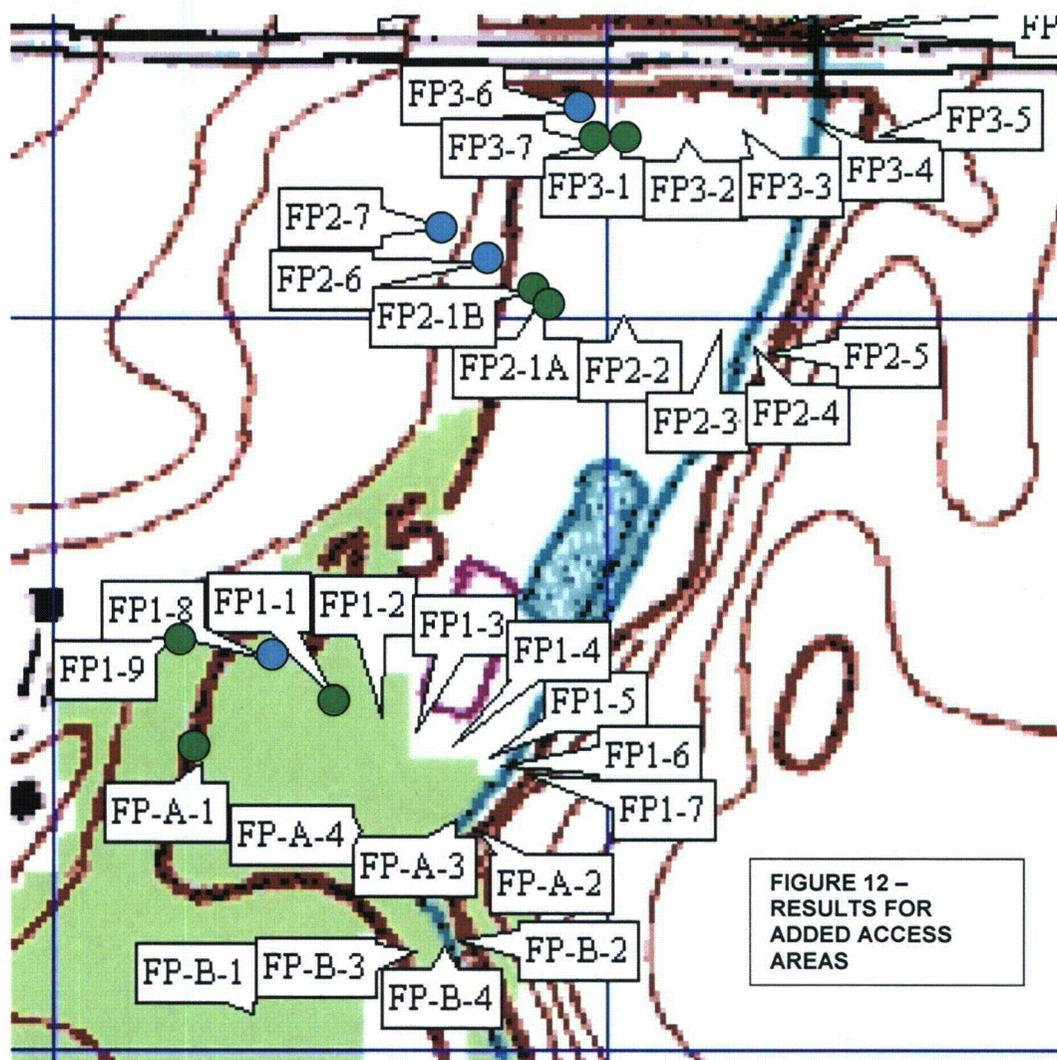
Results and interpretations were posted on graphics that were presented to NASA personnel in weekly briefings.

OBSERVATIONS

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

ACCESS OBSERVATIONS

The sampling locations for which results were transmitted to property owners in response to a newspaper reporter's request are illustrated by Figure 12. All of the results transmitted to these added-access private property owners were relatively low, being closer to a background value of 1 pCi/g, than to the proposed effective DCGL of 12 pCi/g. The highest result observed among these sampling locations was 1 pCi/g, at location FP-A-1.



● Cs-137 not detected

● Cs-137 detected

INITIAL TRANSECT SAMPLING AND TESTING OBSERVATIONS

General Sediment Patterns – Based on the photographs obtained after the samples were extruded from the core tubing, the dominant sediment types were seen to include fine sand, silt, and dense cemented silt. There were also some occurrences of soft gray clay, some peat, and an anomalous layered sand/peat deposit. The dense cemented silt, found near the bottom of the cores, was judged to be glacial till. Like glacial till, which is laid down beneath a glacier, the observed fine sand and silt could also have been contemporaneous with the glaciers. When this material was re-worked and re-deposited by the post-glacial stream, it became sand or silt alluvium. The soft clay and peat sediments were considered to be post-glacial. Figure 13 illustrates the character of the deposits that were found in the Floodplain wetland environment.

Figure 14 summarizes the results obtained. A cross-sectional plot of the sediment deposits along transect 1, in the upper Floodplain area, is provided in Figure 15. Figure 16 is a composite cross-section of downstream sediments in the lower Floodplain area. Figure 16 also provides Cs-137 results, including the only two notable EMAs (locations IM-2 and FP7-3). The composite Figure 16 shows the stream in two different locations, relative to each of the EMAs.

Sand and Silt Deposits – Most of the sand observed exhibited an appearance associated with wind-blown dune deposits, being light-colored (yellow and yellow-brown) and very fine-grained, often grading into a similar-colored silt. Sand of this type was observed in samples obtained at the eastern and western extremes of transects, where the land surface was rising up out of the wetland.

An anomalous type of sand deposit was observed in most of the grid samples obtained in area A. The 18-30" depth samples from area A generally contained a yellow sand interbedded with a black material, the latter having the appearance of peat. The sand in these deposits had the size and character of a typical mason's sand, much coarser than the fine sand found in the surrounding areas. One occurrence of this type of sand deposit was seen upstream from area A, at location FP2-3, and four occurrences were seen downstream from area A, in samples FP7-4, FP8-4, FPG32, and FPG37.

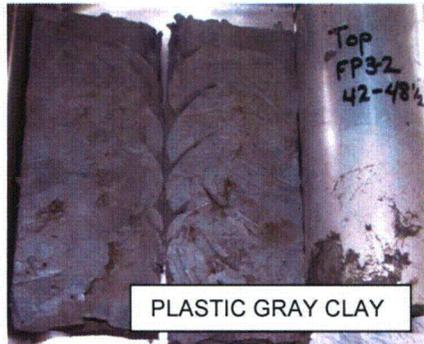
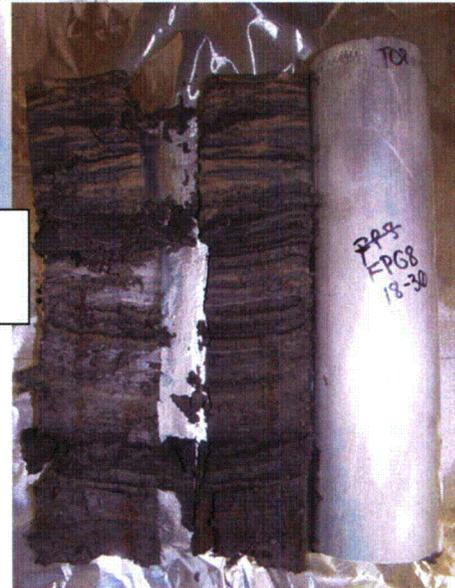
Dense Silt (Till) Deposits – The bottom samples in most locations showed a very dense silty material, which evidenced a blocky fracture pattern when the cores were cut in half, and the halves were pried apart. Most of these samples showed oxidized colors such as yellow and yellow-brown.

Plastic Clay Deposits – A very plastic gray clay was seen in the bottom samples at a few locations.

Peat Deposits - Peat deposits were relatively rare, by comparison with the Stream Mouth and Bay environments downstream. Peat deposits were seen at the northernmost (downstream) end of the study area, in grid-sampling areas B and C. In those areas, a fairly uniform depth to peat was noted, which was nominally 30-36 inches.

FINE SAND
AND SILT

FIGURE 13 – FLOOD PLAIN
SEDIMENTS



Cs-137 Results in Initial Transects – Initial transect results are summarized in Figure 14. This figure demonstrates that, in the southern half of the area, no values approached the DCGL of 12 pCi/g, except in the materials excavated from the ponds, shown by two yellow dots in the center of the South Floodplain figure.

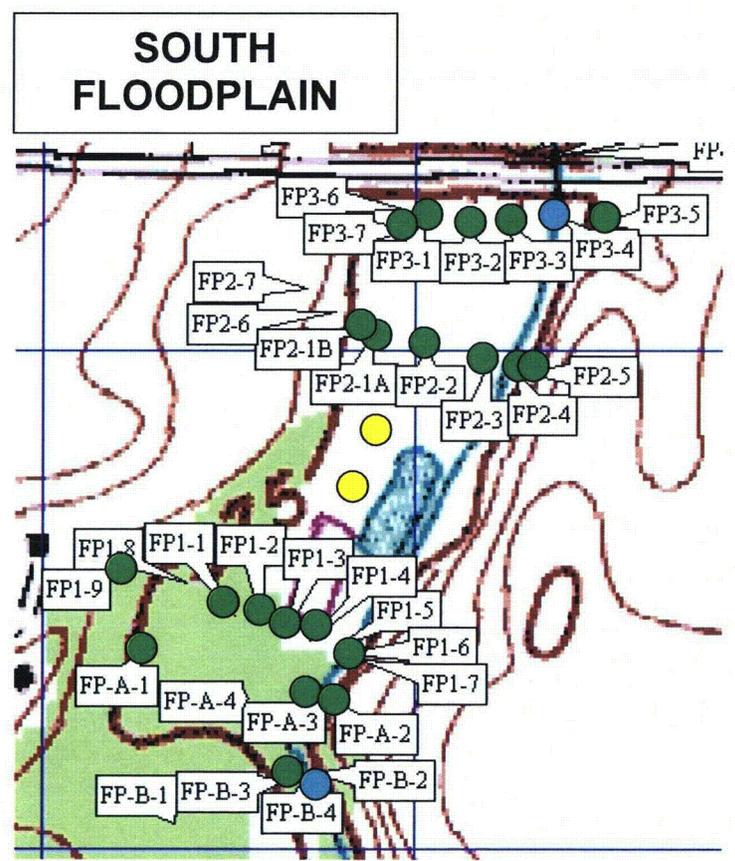
The only other EMAs found were in the North Floodplain area. Only 1 EMA had a Cs-137 result above the DCGL of 12 pCi/g. Location FP7-3 had a Cs-137 laboratory testing result of 14.2 pCi/g at a depth of 0"-6". This sample was obtained within the present stream channel. The second EMA, with a peak Cs-137 laboratory testing result of 10.3 pCi/g at a depth of 0"-6", was found adjacent to the present stream channel, at location IM-2.

The second EMA was found in the course of field trials that were being conducted to develop a NaI scanning system with continuous GPS location and logging. When those trials produced readings approaching 300 gross counts per minute (gcpm), MOTA RP technicians returned to investigate the area by means of NASA procedure CS-01, using scanning and sampling approaches defined in that procedure.

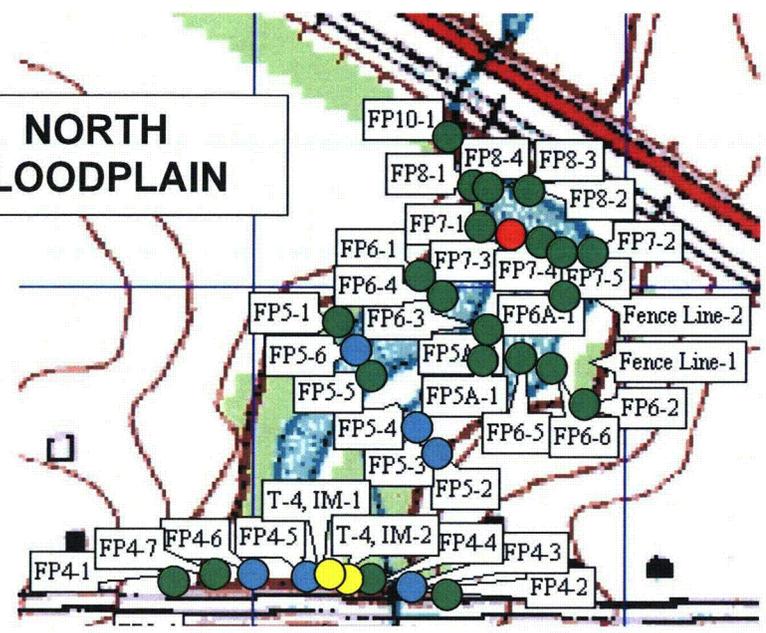
Cs-137 Results from Ponds Investigation – Three ponds, used by the Plum Brook Country Club (PBCC), were located within the Floodplain area. The investigation of those ponds was discussed in a separate report in this series. The key results are illustrated by Figure 17. The most elevated Cs-137 results in the ponds area were related to piles of sediment that had been dredged from the bottom of a complex of 2 joined ponds. These ponds were connected to Plum Brook by means of a pipe. The irrigation system for the PBCC drew water from the 2-pond complex, which in turn drew its make-up water from Plum Brook.

The highest Cs-137 value found in the ponds investigation was 9.5 pCi/g, obtained in a surface sample in the center of an area that had previously held dredged sediment. The PBCC reported that sediment from that pile had been used for fill around the club, particularly along the edges of the paved golf cart paths.

FIGURE 14 – HIGHEST RESULTS IN INITIAL TRANSECTS



NORTH FLOODPLAIN



- Cs-137 \geq 12 pCi/g
- Cs-137 6-11 pCi/g
- Cs-137 = 3-5 pCi/g
- Cs-137 0.2-2 pCi/g

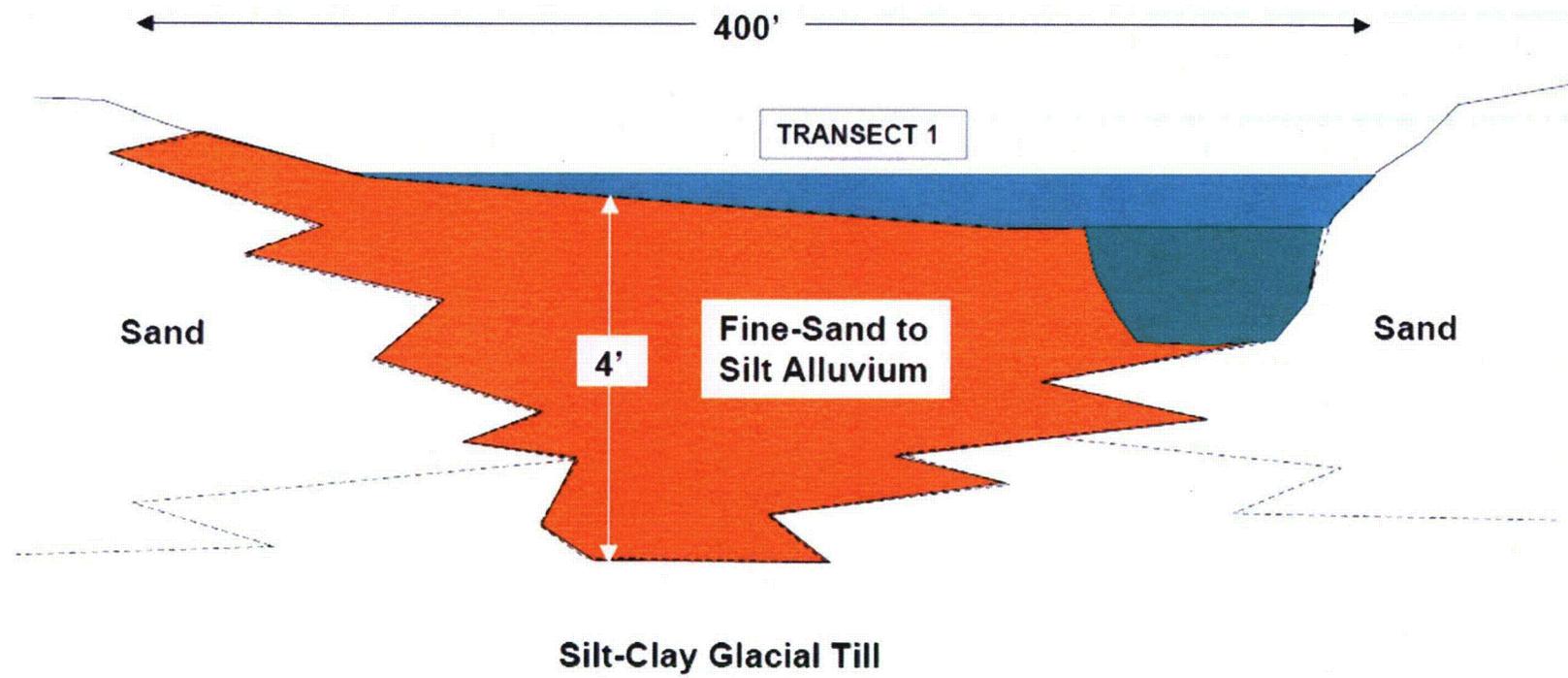


FIGURE 15 – SOUTHERN FLOODPLAIN CROSS-SECTION

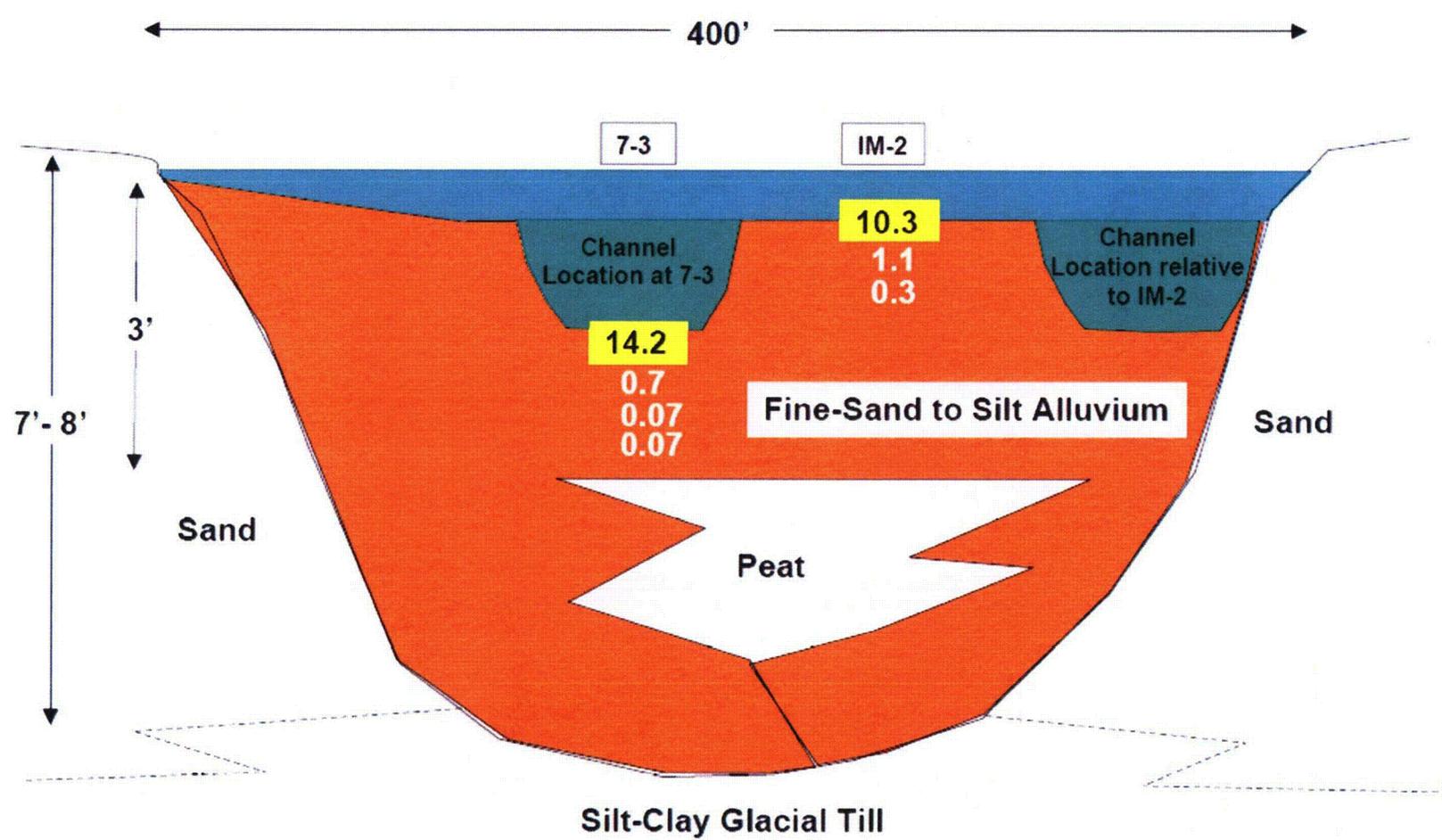


FIGURE 16 – NORTHERN FLOODPLAIN AREA COMPOSITE CROSS-SECTION, WITH MOST ELEVATED RESULTS POSTED (THIS IS A COMPOSITE, SHOWING THE STREAM IN TWO DIFFERENT LOCATIONS, RELATIVE TO EACH OF THE EMAS)

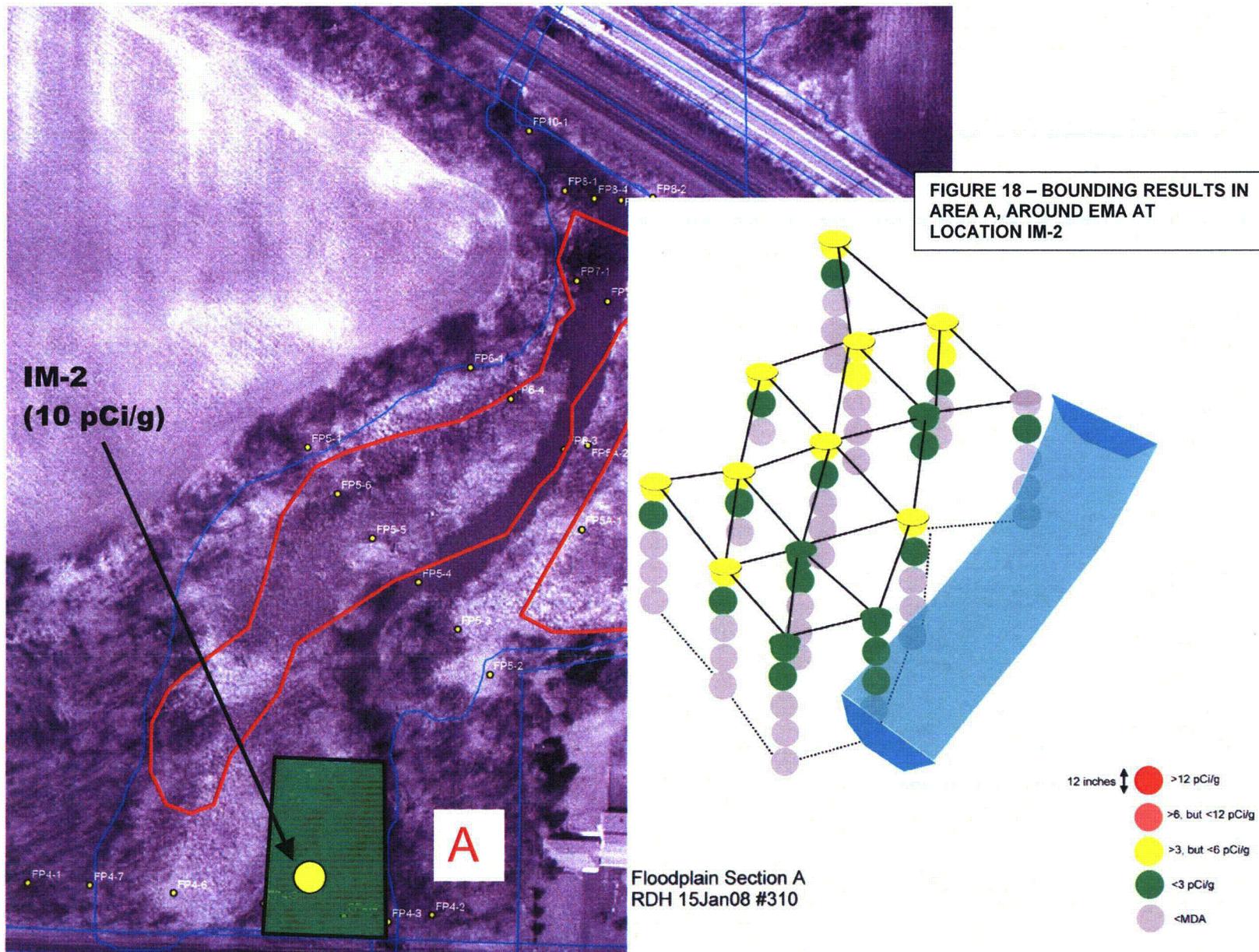
BOUNDING SAMPLING AND TESTING OBSERVATIONS

The results obtained from the bounding effort are depicted by Figures 18 through 23.

Area A – As shown by the figures, none of the results obtained from the area A grid sampling approached the prior EMA result of 10.3 pCi/g. Instead, the area results showed a bimodal lognormal distribution, with the most frequent results at approximately 1 pCi/g and 4.5 pCi/g. With one exception, all of the area A results >MDA were found in the upper 18 inches of soil. None of the area A samples were taken in the current streambed.

Area B – In area B, adjacent to the in-stream EMA of 14.2 pCi/g, none of the positive Cs-137 results exceeded 3 pCi/g. Those that were > MDA were all within the upper 18 inches of soil. None of the area B samples were taken in the current streambed.

Area C – In area C, which included the current streambed and its western bank, three in-stream samples reflected the EMA of 14.2 pCi/g. One of those results was 12 pCi/g, found in the 0"-6" interval of location FPG38. The second was 7.67 (rounded to 8) pCi/g, found in the 0"-6" interval of location FPG34. Between these two stream locations, a value of 4.68 (rounded to 5) pCi/g was noted, in the 6"-18" interval of location FPG36. All of the results >3 pCi/g were in the current streambed. The most elevated results were in the top 6 inches of sediment in the streambed.



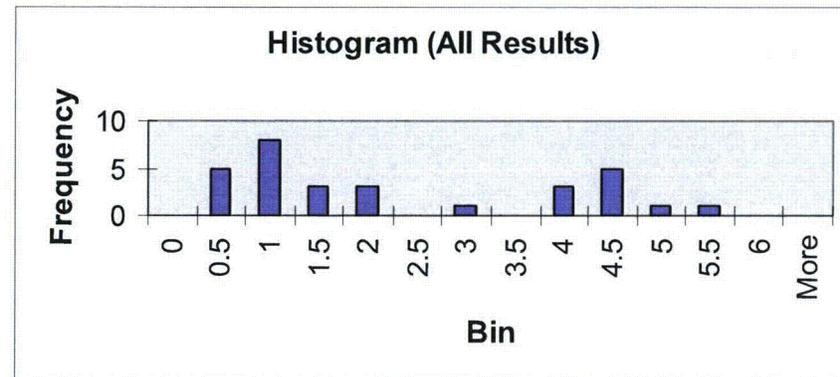
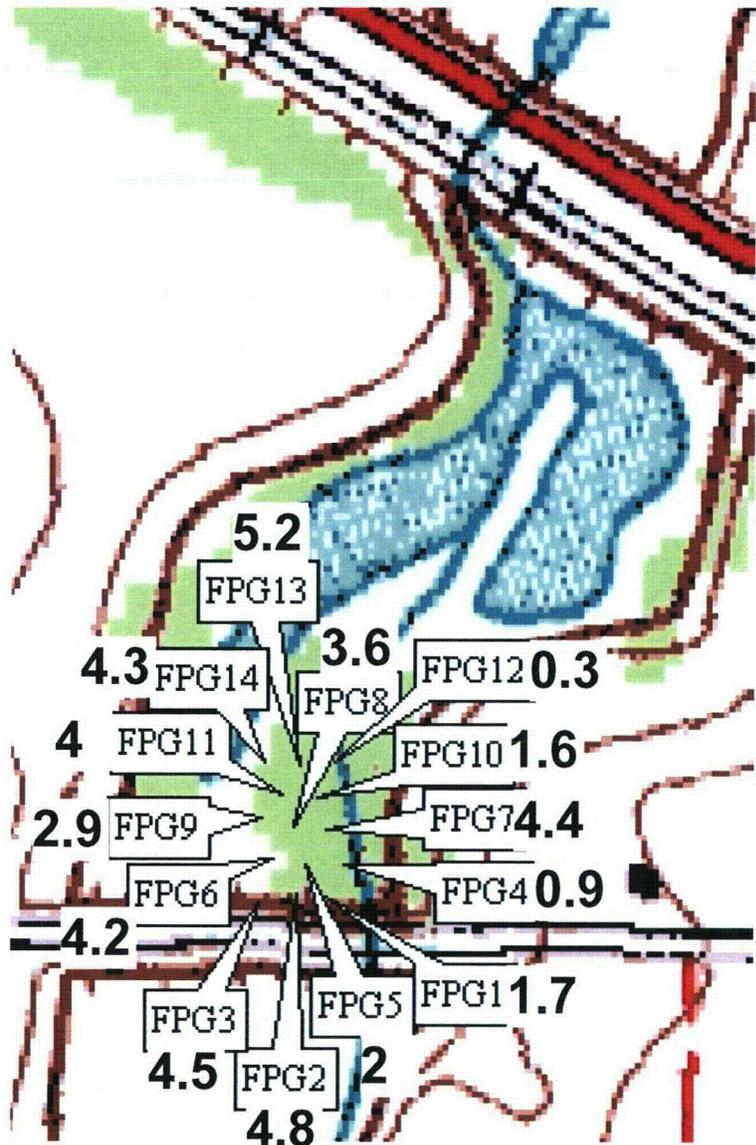
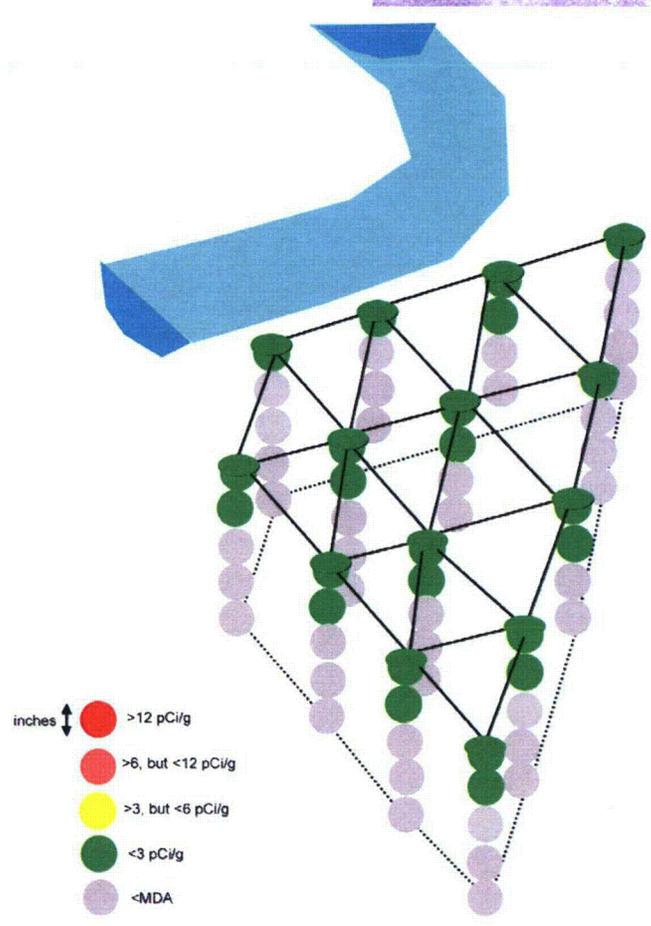
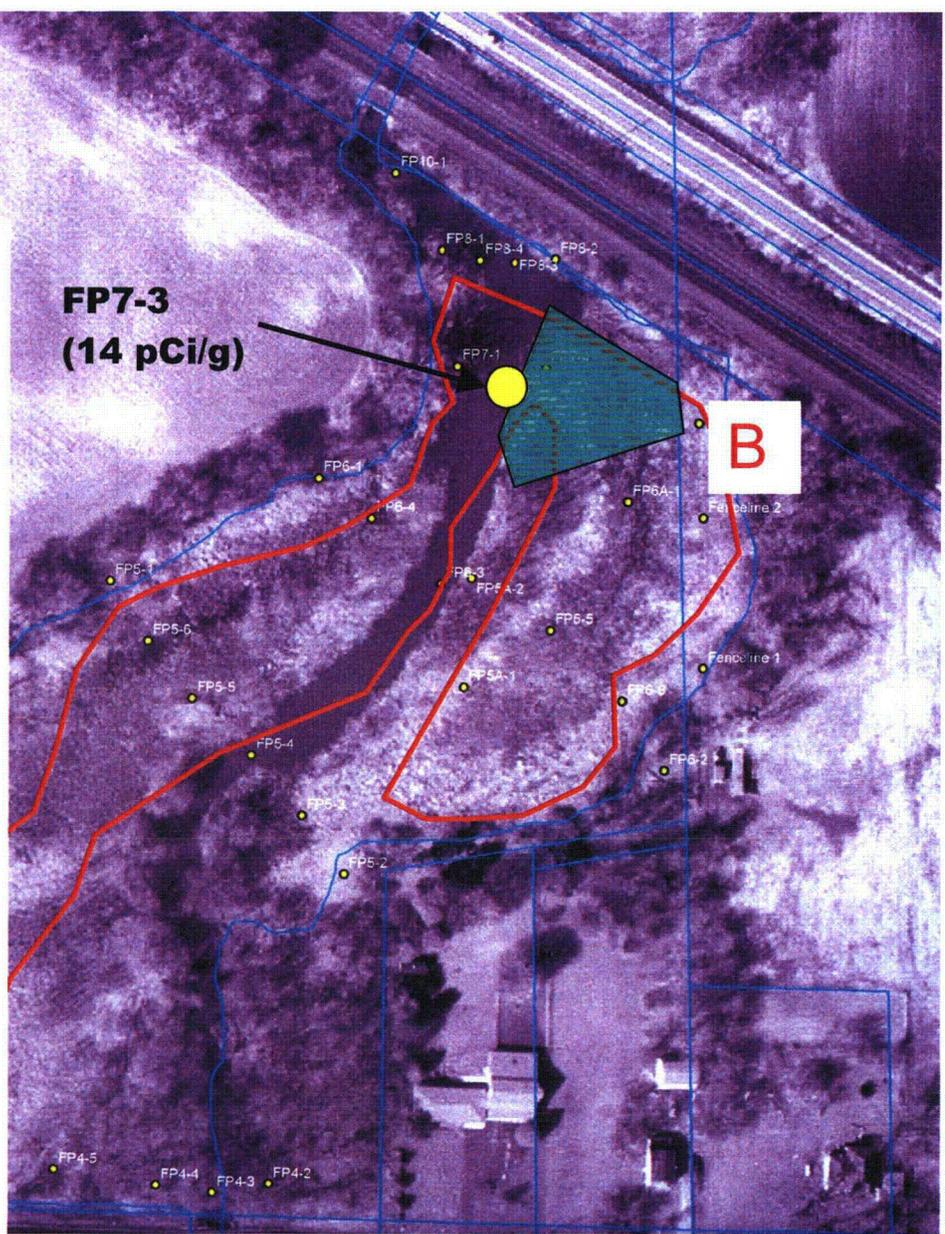


FIGURE 19 – HIGHEST BOUNDING RESULTS IN AREA A. ALL RESULTS IN pCi/G.

FIGURE 20 – BOUNDING RESULTS IN AREA B, NEAR EMA AT LOCATION FP7-3



**Floodplain Section B
RDH 15Jan08 #310**



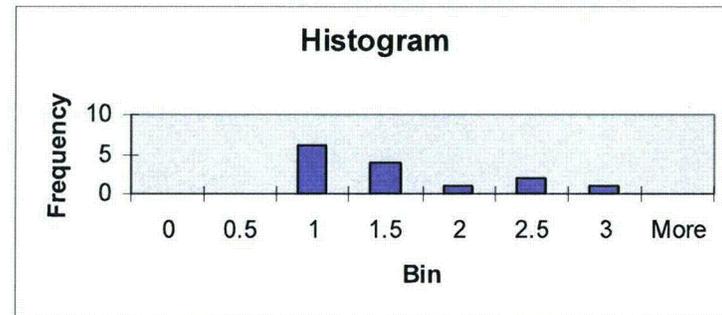
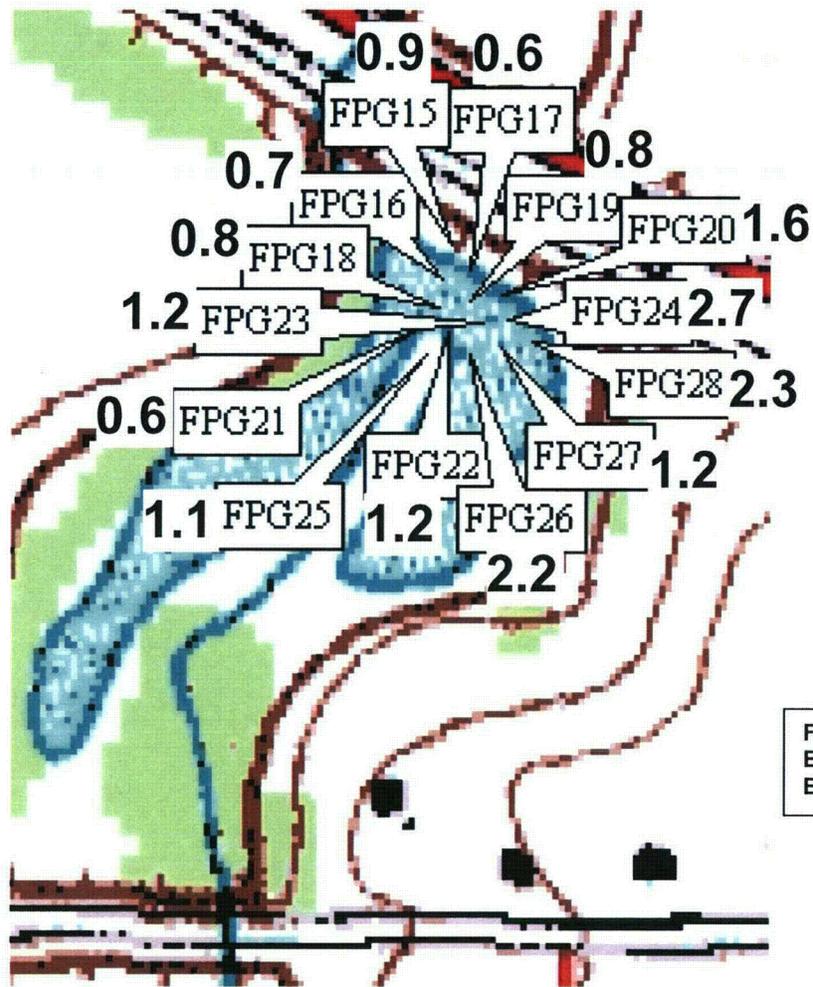
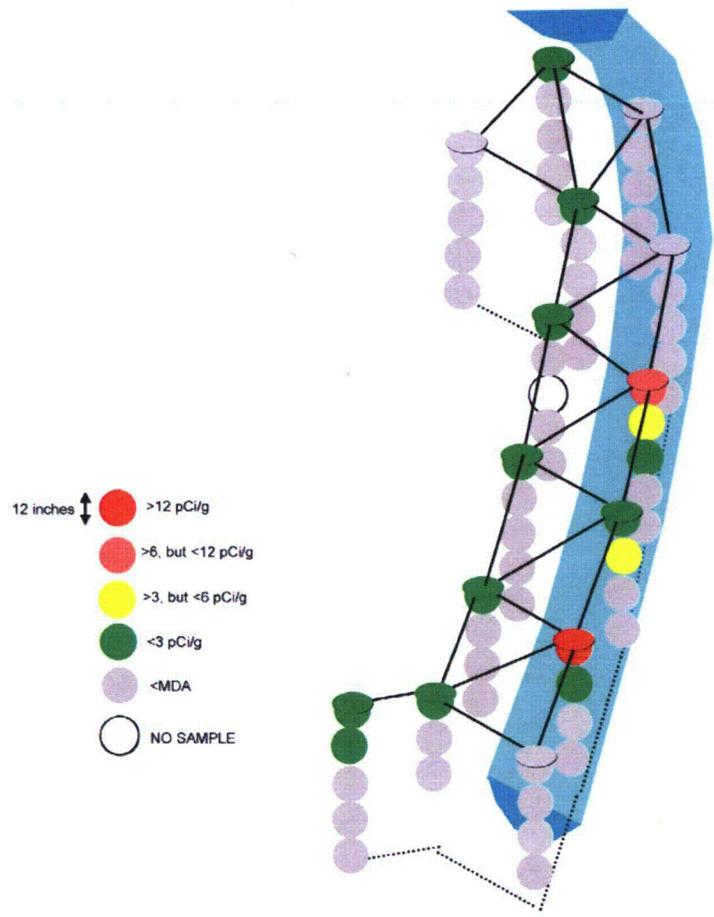
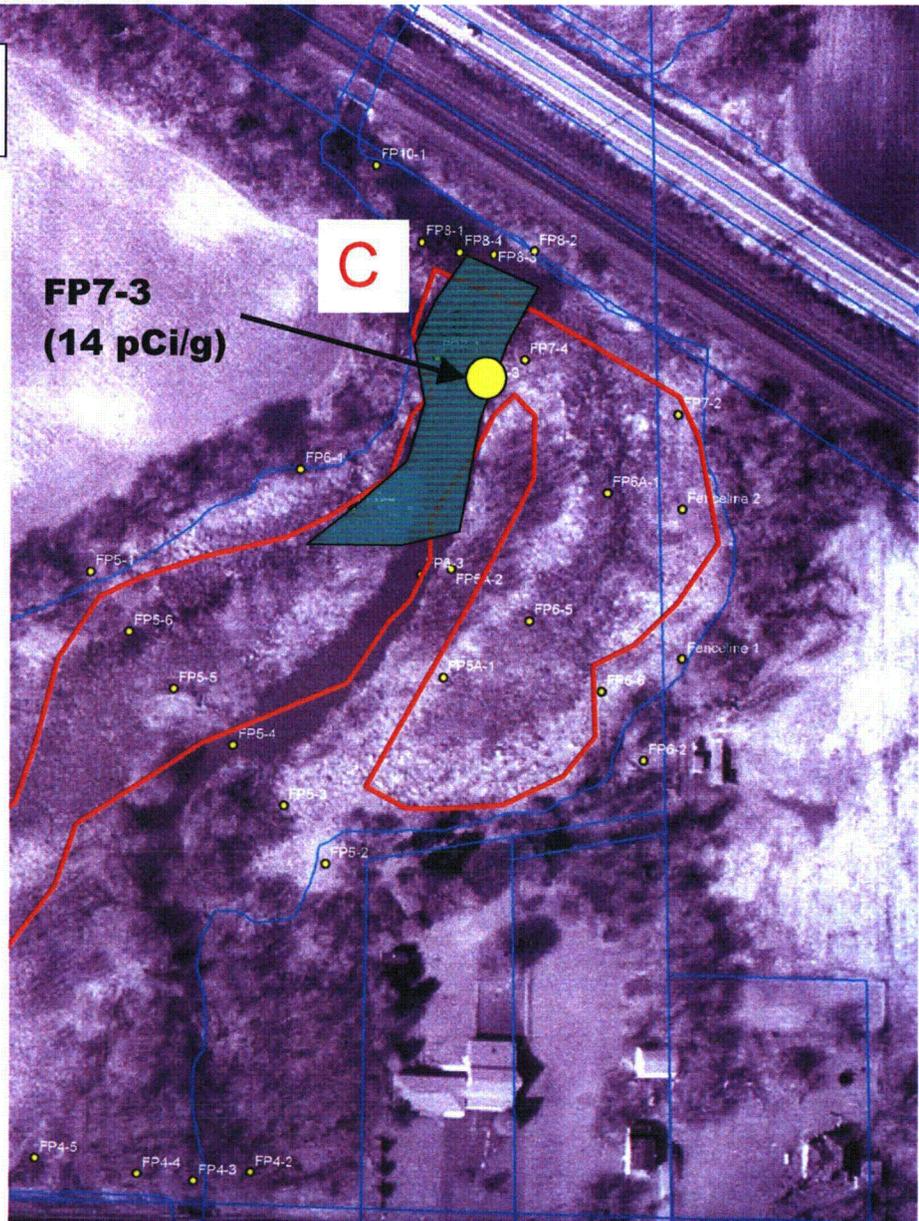


FIGURE 21 – HIGHEST BOUNDING RESULTS IN AREA B. ALL RESULTS IN pCi/G.

FIGURE 22 – BOUNDING RESULTS IN AREA C, AROUND EMA AT LOCATION FP7-3



Floodplain Section C
RDH 15Jan08 #310



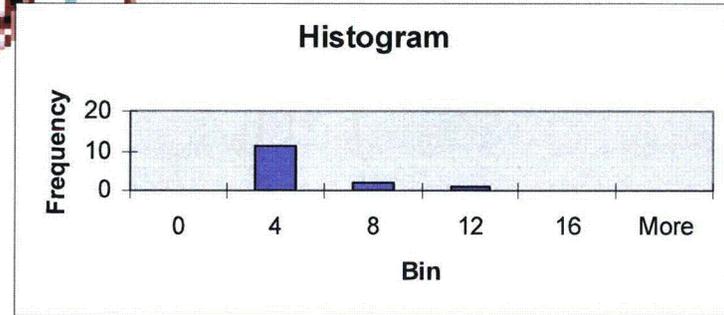
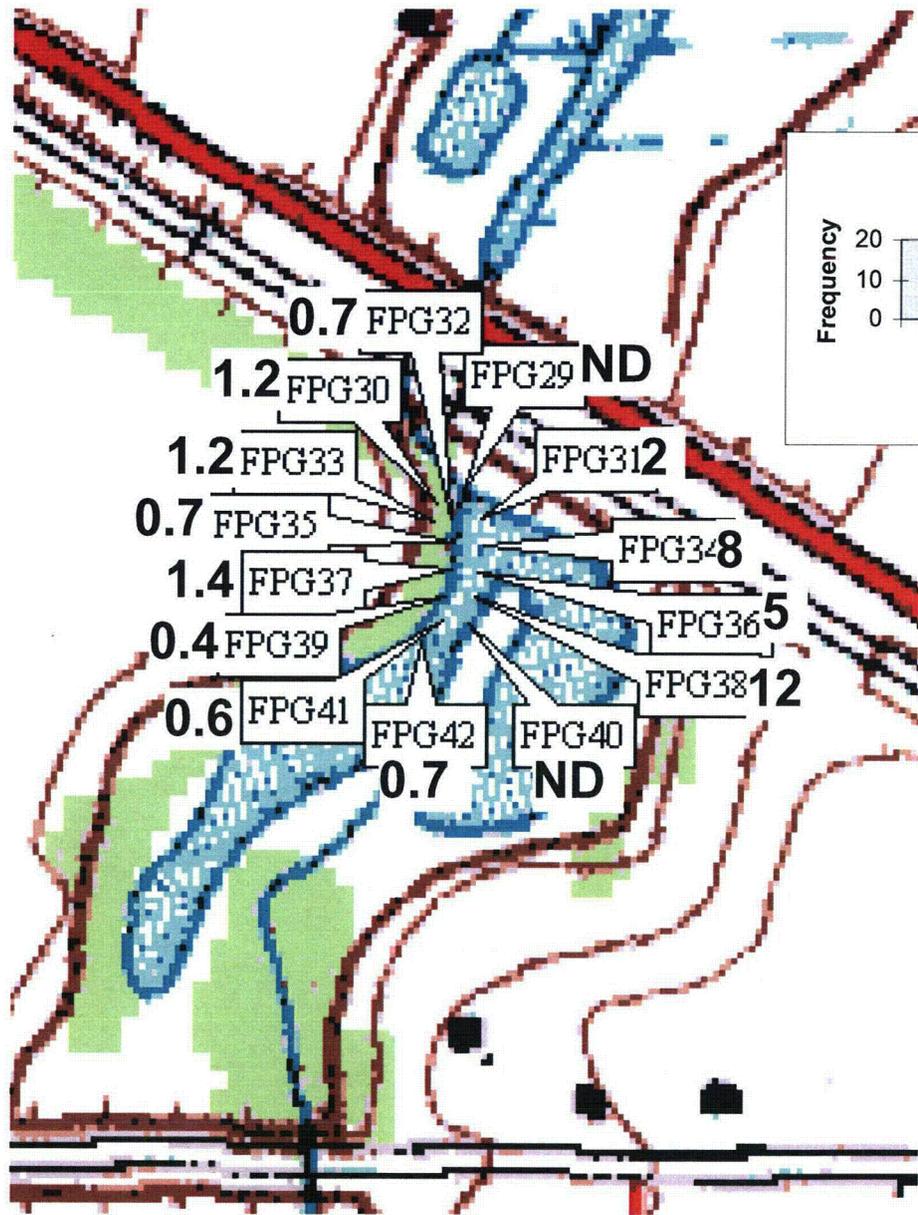


FIGURE 23 – HIGHEST BOUNDING RESULTS IN AREA C. ALL RESULTS IN pci/g. (ND=NOT DETECTED)

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 Floodplain report.

DQI observations more specifically related to the Floodplain work are discussed below.

Precision – Following the FSSP, NASA must employ the criteria in Section 12.7.2 of NRC Inspection Manual 84750 to determine the agreement between duplicate samples. That approach allows a greater margin for error when the statistical uncertainty underlying a result is large compared with the result itself.

As noted in the preceding methods section entitled “Data Quality Indicators”, it was also important that hydrogeologist Bob Haag be able to compare the precisions achieved here with other hydrogeologic investigations that he had conducted. 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 RPD parameter, defined in the DQI methods section.

In all of the cases where the RPD exceeded 20%, the original and the duplicate results were less than about 3 pCi/g. RPD comparison after log transformation yielded values over the 20% limit, so this criterion was set aside as not useful. This was expected when the value measured was less than 9 pCi/g. When Rod Case applied the NRC Inspection Manual 84750 criteria to the samples that did not achieve the 20% RPD criterion, he found that all of those samples successfully passed the Manual 84750 test.

In the original transects, a total of 285 original field samples were tested. Recounts were performed on 2 of those samples, or 1 in 143. Results from the two transect recounts were both similar to their original results.

In the original transects, quality control (QC) duplicates or “splits,” were prepared for 20 samples, or 1 in 14. Results from 16 of these 20 duplicates were acceptably similar to the results from the original samples. Only the following 4 sample comparisons produced differing conclusions: In sample FPB-4, 0”-6”, the original result was a rejected value of 0.175 pCi/g, while the split result was an unrejected value of 0.296 pCi/g. The following 3 samples had RPDs that exceeded 20%: FPB4 6”-18” (41%), FP5-3 0”-6” (25%), and FP2-4 0”-6” (22%).

One co-located sample was taken in the original transects. Geoprobe sample location FP2-1A had low recovery and was re-sampled with the vibracore device (labeled FP2-1B). Results from the vibracore sample (FP2-1B) and the original Geoprobe sample

(FP2-1A) had the same detect/non-detect pattern. However, the RPD achieved between the two surface results (38%) did not achieve the 20% RPD criterion.

In the 3 grid sampling areas, a total of 187 original field samples were tested. Laboratory recounts were performed on 12 grid samples, or 1 in 16. Of the RPDs calculated for these, all but 1 met the criterion that the original and the duplicate should be within 20% of one another. The recount result for sample FPG21 0"-6" produced an RPD of 50%.

QC duplicates, or "splits" were prepared for 20 grid samples, or 1 in 9. Of the RPDs calculated for these 20 samples, only 2 exceeded the criterion that the original and the duplicate should be within 20% of one another. The RPD for sample FPG41 0"-6" and its duplicate was 36%. The RPD for sample FPG1 0"-6" and its duplicate was 27%.

One recount revealed a false negative. Sample FPG33 0"-6" produced an initial result of <0.520 pCi/g. Upon recounting, the first recount yielded a positive result of 1.16 pCi/g, and the second recount produced a result of 1.22 pCi/g.

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

Accuracy – For the two samples analyzed by STL, the laboratory reported a spike recovery of 112% for Cs-137, which was in the acceptable accuracy range of 80%-120%.

Because no trends in Cs-137 activity were noted, it was not possible to estimate the scatter of measurements about a trend line fit to log-transformed results.

The sample variance for all of the log-transformed results in the upper 6 inches of area A was 0.16. For the next 12 inches below that, plus two samples in the 12 inches below that, the area A sample variance was 0.11. The sample variance for the highest log-transformed results in area B was 0.046. The sample variance for the highest log-transformed results in area C was 0.29. All of these variances were acceptably less than the target of 0.4, so that criterion for accuracy was met.

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. "Representative" values, provided in the Interpretations section of this report, were also inserted in this test, in place of the mean of the log-transformed results.

This test of accuracy 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 represented a 95% confidence interval. The concept is illustrated by Figure 24. The question being asked was essentially: "Is the scatter of results around the mean (or the "representative") value tight enough, so that 95% of the results will always be less

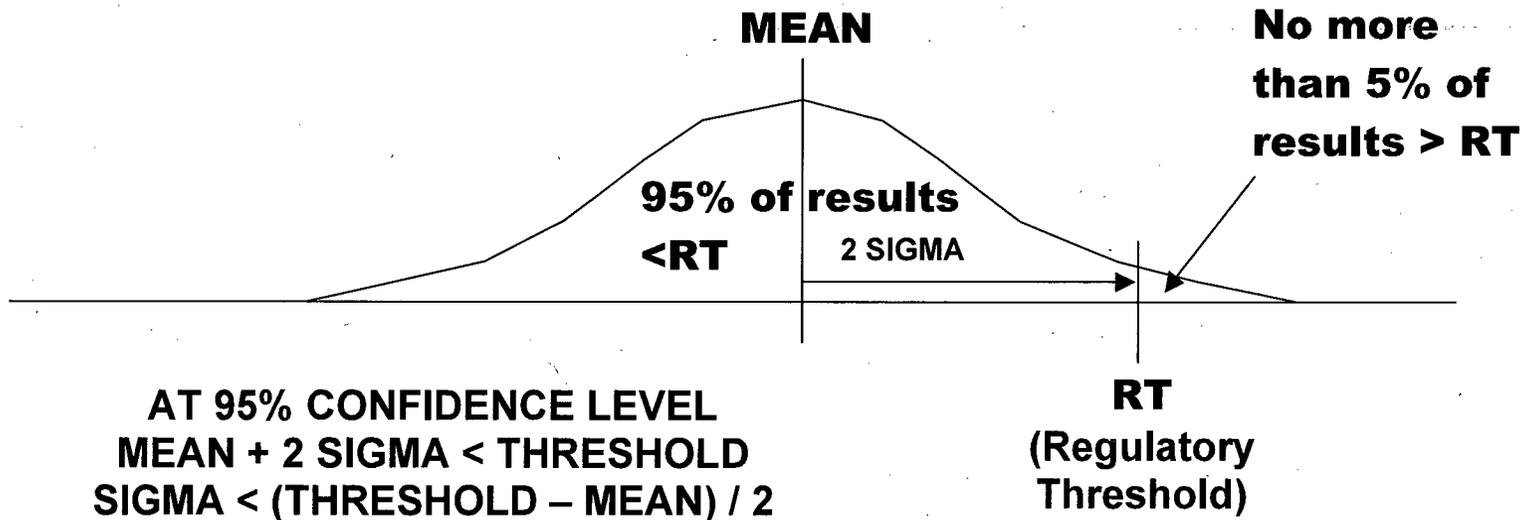


FIGURE 24 – CONCEPT FOR ASSESSING ACCURACY

than the Regulatory Threshold (RT) of 12 pCi/g?” If the answer to this question was “Yes,” then the accuracy was sufficient to support the decision that the “representative” value was less than 12 pCi/g.

In the data set for the top 6 inches of section A, the interpreted “representative” value was 5 pCi/g, the standard deviation of the log-transformed results was 0.4, and the mean of the log-transformed results was 0.38. To apply the test above to determine whether accuracy was sufficient, the following question was answered using the mean:

Is $s(\log \text{ transformed results}) < (\log(12\text{pCi/g}) - \text{mean}(\log \text{ transformed results}))/2$
Is $0.4 < (1.08-0.38)/2$?
Is $0.4 < 0.35$? **[NO, but close]**

Using the log of the “representative” value (0.7); instead of the mean of 0.38, the question was as follows:

Is $0.4 < (1.08-0.7)/2$?
Is $0.4 < 0.19$? **[NO]**

In both trials, the answer was no, so this test of accuracy suggested that the scatter about the “representative” log value of 0.7 was too large to support a conclusion that the “representative” log value of 0.7 was less than the regulatory threshold log value of 1.08, at a 95% confidence level. This could be re-phrased to say that a “representative” value of either 5 pCi/g or $10^{0.38}$ (2.4 pCi/g) could not be shown to be less than the regulatory threshold of 12 pCi/g at the 95% confidence level, with the samples obtained.

In the data set for area B, the interpreted “representative” value was 2 pCi/g, the standard deviation of the log-transformed results was 0.21, and the mean of the log-transformed results was 0.056. To apply the test above to determine whether accuracy was sufficient, the following question was answered using the mean:

Is $s(\log \text{ transformed results}) < (\log(12\text{pCi/g}) - \text{mean}(\log \text{ transformed results}))/2$
Is $0.21 < (1.08-0.056)/2$?
Is $0.21 < 0.51$? **[YES]**

Using the log of the “representative” value (0.3), instead of the mean of 0.056, the question was as follows:

Is $0.21 < (1.08-0.3)/2$?
Is $0.21 < 0.39$? **[YES]**

In this case, the answer was “Yes” in both trials, so this test of accuracy suggested that the scatter about the “representative” log value of 0.3 was tight enough to support a conclusion that the “representative” log value of 0.3 was less than the regulatory threshold log value of 1.08, at a 95% confidence level. This could be re-phrased to say that a “representative” value of either 2 pCi/g or $10^{0.056}$ (1.14 pCi/g) could be shown to be

less than the regulatory threshold of 12 pCi/g at the 95% confidence level, with the samples obtained.

In the data set for area C, the “representative” value was postulated as 9 pCi/g, the standard deviation of the log-transformed results was 0.54, and the mean of the log-transformed results was 0.056. To apply the test above to determine whether accuracy was sufficient, the following question was answered using the mean:

Is $s(\log \text{ transformed results}) < (\log(12\text{pCi/g}) - \text{mean}(\log \text{ transformed results}))/2$
Is $0.54 < (1.08-0.056)/2$?
Is $0.54 < 0.51$? **[NO, but very close]**

Using the log of the “representative” value (0.95), instead of the mean of 0.056, the question was as follows:

Is $0.54 < (1.08-0.95)/2$?
Is $0.54 < 0.065$? **[NO, not very close at all]**

The answer was “No” in both trials, so this test of accuracy suggested that the scatter about the “representative” log value of 0.95 was too large to support a conclusion that the “representative” log value of 0.95 was less than the regulatory threshold log value of 1.08, at a 95% confidence level. This could be re-phrased to say that a “representative” value of either 9 pCi/g or $10^{0.056}$ (1.14 pCi/g) could not be shown to be less than the regulatory threshold of 12 pCi/g at the 95% confidence level, with the samples obtained.

Considering the possibility that only the elevated results from the stream bottom might actually represent the Cs-137 deposit, the calculation for Floodplain area C was repeated using only the highest results from locations FPG31, 34, 36, and 38.

In this area C scenario, the interpreted “representative” value was again 9 pCi/g, but the standard deviation of the log-transformed results was 0.31, and the mean of the log-transformed results was 0.77. To apply the test above to determine whether accuracy was sufficient, the following question was answered using the mean:

Is $s(\log \text{ transformed results}) < (\log(12\text{pCi/g}) - \text{mean}(\log \text{ transformed results}))/2$
Is $0.31 < (1.08-0.77)/2$?
Is $0.31 < 0.16$? **[NO]**

Using the log of the “representative” value (0.95), instead of the mean of 0.44, the question was as follows:

Is $0.31 < (1.08-0.95)/2$?
Is $0.31 < 0.065$? **[NO]**

The result remained unchanged, as the answer was again “No.” This implied that the results from the 4 in-stream samples did not provide sufficient accuracy to assess the

question of whether the representative value of 9 pCi/g was less than the regulatory threshold of 12 pCi/g. This could be re-phrased to say that a “representative” value of either 9 pCi/g or $10^{0.77}$ (5.9 pCi/g) could not be shown to be less than the regulatory threshold of 12 pCi/g at the 95% confidence level, with the samples obtained.

In each of the preceding evaluations, it was noted that the interpreted “representative” values for the Cs-137 deposits was roughly twice the value derived by raising 10 to the power of the mean of the log-transformed values.

Completeness – Defining completeness is an assessment of whether one has a sufficient number of samples to support a determination that the “representative” value is less than the regulatory threshold. The preceding assessment of accuracy suggested that the number of samples obtained in area B was sufficient to make that determination. However, the preceding assessment of accuracy suggested that the number of samples obtained in areas A and C were not sufficient to make that determination.

One characteristic of the statistics used here is that it takes more samples to prove that a “representative” value is less than 12 pCi/g, as the representative value gets closer to 12 pCi/g. Thus, it takes fewer samples to prove that 2 pCi/g is less than 12 pCi/g, than it takes to prove that 9 pCi/g is less than 12 pCi/g. That is part of the reason that there were a sufficient number of samples to prove that the representative value of 2 pCi/g in area B was less than 12 pCi/g. That is one reason that the available samples were insufficient to prove that any of the representative values of 2.4, 5, 5.9, and 9 pCi/g were less than the regulatory threshold of 12 pCi/g.

A second important characteristic of the statistics used here is the scatter of results, which is represented by the sample variance (s^2), or its square root, the standard deviation (s). As s or s^2 become larger, more samples are required to prove that the “representative” value is less than the regulatory threshold. While all values of s^2 here met the basic criterion of $s^2 < 0.4$, the values of s^2 was relatively large for area C (0.29), but not so large for area A (0.16). Thus, it may take fewer samples to prove that area A meets the 12 pCi/g criterion, that it will take to prove that area C meets the same criterion. The calculation for determining the appropriate number of samples, in either case, is discussed in the Stream Mouth report.

Representativeness – The posting of field-screening results, in Appendix B, allowed HaagEnviro to observe the sample recoveries achieved. One Geoprobe sample, out of 13 samples taken, was below 50% recovery (40% was achieved). This location, FP2-1A, was re-sampled with the vibracore device, and the sample was labeled FP2-1B.

All of the vibracore samples achieved the desired 50% recovery. This is granting that one recovery of 49.6%, at FP6-2, rounds to 50%.

All three of the short samples taken with a gasoline-powered auger, using the same 3” diameter tube as the vibracore, had 100% recovery.

Location FPG10 was sampled with both the vibracore and GeoProbe samplers. The bottom part of the hole had recovery less than 50%.

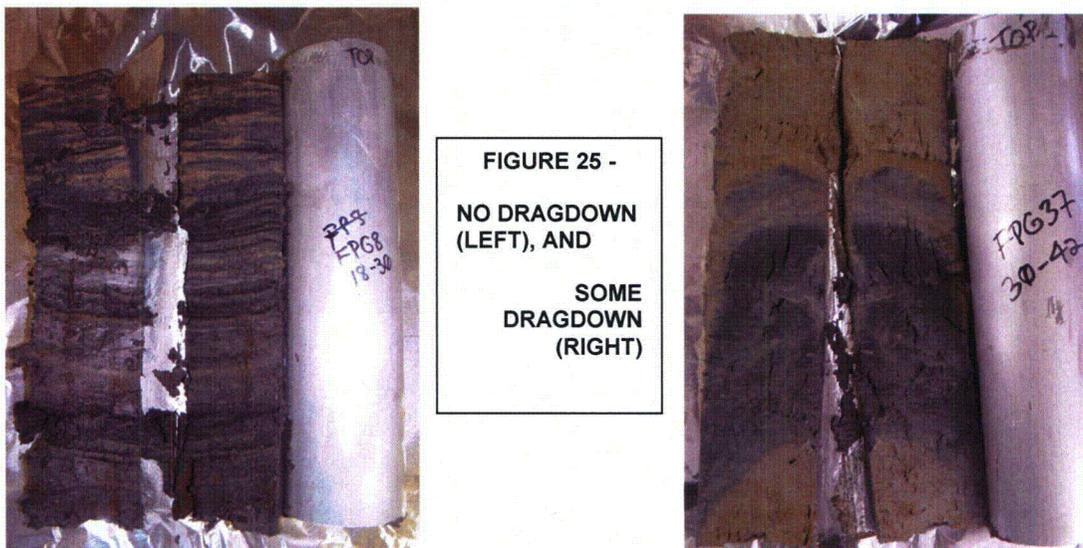
Two sampling tubes became stuck in the bed of Plum Brook. These were either pulled out or broken off flush with the streambed, using a tractor supplied by the PBCC, and no samples were recovered.

Two samples were taken by MOTA at elevated scan locations near transect 4. One shale sample was taken by MOTA, at an elevated scan location on the railroad embankment near location FP8-4.

Recoveries from the remaining Floodplain samples met the relevant criteria.

Blank results are included in the spreadsheet provided in Appendix B. One blank yielded a positive result, which was not found again upon recounting. This was a blank with lab ID PB07-03375, which produced a positive result of 0.052 pCi/g. A longer-duration recount of this blank, with lab ID PB07-03375-R, produced an acceptable result, <0.022 pCi/g. A blank with lab ID PB07-03542 produced a positive result of 0.041 pCi/g, but the data reviewer rejected this result.

Review of core photos and corresponding testing results suggested that carry-down generally did not occur to any significant extent. Examples in which drag-down did and did not occur are shown in Figure 25. Based on the testing results for samples obtained at locations IM-1 and IM-2, near transect 4, some top-to-bottom cross contamination may have occurred there.



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 Dzvonnar 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 10.6 eV PID, the highest reading obtained was 40 ppm at the 42" depth in sample location SM6-4. The highest reading with the NASA 10.6 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.

When elevated PID readings were first obtained, while processing samples from Floodplain transects 3 and 4, two samples were sent to STL for chemical testing for organic parameters. The samples selected for testing were FP3-1 42"-54" and FP3-5 6"-18". The 42"-54" sample from FP3-1 had produced readings on the HaagEnviro 11.7 eV PID that exceeded its upper scale of 2000 ppm. The shallower samples from this location had produced readings of only 1-4 ppm using the same meter. The 6"-18" sample from FP3-5 had also produced 11.7 PID results >2000 ppm. Readings of the same sample obtained with the NASA 10.6 eV PID produced results of 0.0 ppm.

The laboratory testing of these two samples resulted in some detections, with the highest values coming from the 42"-54" sample at FP3-1. The following were the highest detections reported:

- 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 semivolatile organic 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

Acetone was not detected in the laboratory method blank, at a detection limit of 20 ug/kg. Phenol was not detected in the method blank, at a detection limit of 330 ug/kg.

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

OBSERVATIONS ON OTHER RADIONUCLIDES

Besides Cs-137, other radionuclides of interest were defined in FSSP Table A-7, and included 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 all of the Floodplain results, no occurrences of these “other radionuclides” were reported.

In the results provided by STL, only 1 radionuclide from FSSP Table A-7, other than Cs-137, was reported. That was Eu-154, reported in sample FP3-5 6”-18” at 3.4 E-07 uCi/g. The total two-sigma uncertainty for this result was 4.8 E-07 uCi/g, and the MDC was 1.1 E-07 uCi/g. Because the result was not more than two-sigma greater than the MDC, this result should be rejected.

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 Floodplain 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.

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 were 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 possible way to distinguish Cs-137 attributable to PBRF from background Cs-137 was to look for other radionuclides characteristic of PBRF. Among the other radionuclides listed in FSSP Table A-7, only Co-60 appeared offsite. When Co-60 did appear, it was always in association with elevated levels of Cs-137. This was not consistent with the expected behavior of Co-60, which was expected to behave like calcium. There was no reason to expect Co-60 to adsorb to clay minerals, as was expected for Cs-137. Based on this assumption, a strong correlation between Cs-137 and Co-60 results would not be expected. However, in testing results reported nearer the PBRF, it did appear that Co-60 and Cs-137 were positively correlated, with Co-60 activities 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 was interpreted that the mechanism of Co-60 migration must be similar to that for Cs-137. If Cs-137 was adsorbing on clay minerals, this means that Co-60 was also adsorbing on clay minerals.

Because Co-60 was only reliably detected by the project's total measurement system when Cs-137 activities significantly exceeded the background level of 1 pCi/g, the presence of Co-60 was often not a useful way to distinguish PBRF Cs-137 from background Cs-137.

Cs-137 Deposition Over Time - An underlying postulate of this work was that the peak Cs-137 levels were deposited down Plum Brook in 1969. Based upon this assumption, and drawing upon results obtained in the earlier Ponds report, the top of Figure 26 provides an estimate of the activity deposited versus time, in a pond near Plum Brook, in the Stream Mouth depositional environment. 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.

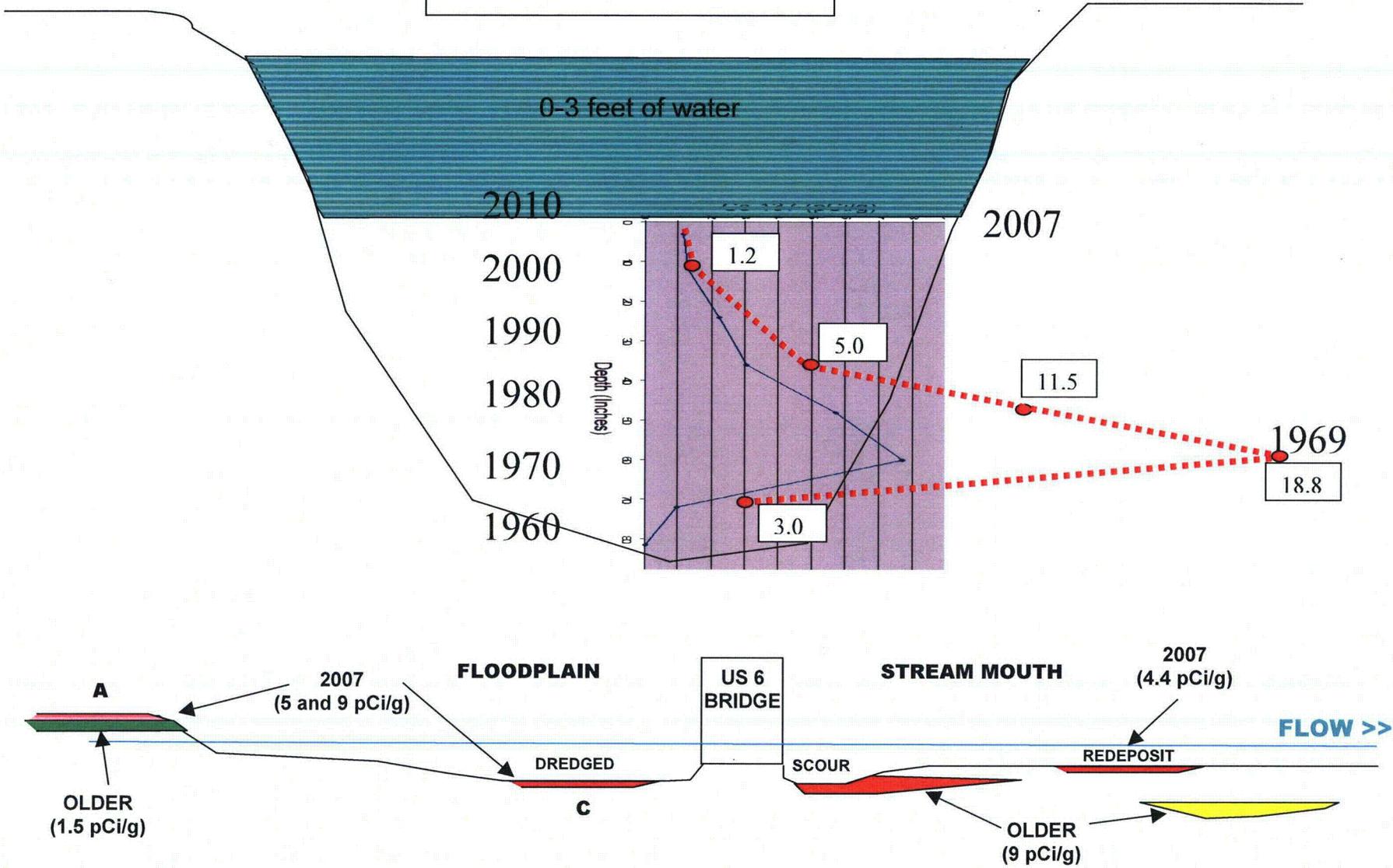
Based on this rationale, it was interpreted that 2006 measurements of Cs-137 exceeding 3 pCi/g in the pond represented pond deposition during the 11 years between 1969 and 1980. During that time, it was interpreted that the activities in clay being deposited in that pond ranged from a high of 18.8 pCi/g,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

The results obtained in Floodplain areas A, B, and C appeared to tell a different story, but one that did not necessarily conflict with the pond deposition interpretation. HaagEnviro interpreted that the bimodal distribution of Cs-137 results within Floodplain area A represented two episodes of deposition. The distribution with a peak around 1 pCi/g was deeper, and therefore earlier, than the distribution with a peak around 4.5 pCi/g.

The distribution of Cs-137 results in Floodplain area B peaked around 1 pCi/g, and HaagEnviro therefore interpreted that this deposit was associated with the deeper deposit found in area A. The distribution of Cs-137 results in Floodplain area C peaked around 4 pCi/g, and HaagEnviro therefore interpreted that the Area C deposit was associated with the upper deposit found in Floodplain area A. The deposits peaking around 4-4.5 pCi/g in Floodplain areas A and C occurred in the top 6 inches of soil, and thus represented current and ongoing conditions.

The relative times of deposition in stream areas are illustrated at the bottom of Figure 26.

FIGURE 26 – INTERPRETED DEPOSITION RECORD IN A POND, AND IN THE STREAM



ACCOUNTING FOR CS-137 KNOWN TO BE RELEASED

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

Previous reports in this series on Cs-137 in Plum Brook have made a series of refinements in the methods used to assess the total amounts of Cs-137 found. Several of those refinements are detailed in the Stream Mouth report in this series. Following are key assumptions at the time of this writing:

- It was appropriate to maintain the working hypothesis that all of the Cs-137 released to Plum Brook came through the Water Effluent Monitoring System (WEMS).
- Based upon a computation of radioactive decay, the Cs-137 known to have been released from the WEMS, estimated at 5 mCi by Jack Crooks, was expected to have a remaining activity of 2.04 mCi (round to 2 mCi).
- In the Stream Mouth report, the total Cs-137 activity released from the WEMS was estimated at just over 100 mCi. Most of this was attributed to Cs-137 that passed through the system at activities below the detection limits of the instrumentation used at the time of PBRF operation.

The range of results obtained in Floodplain area C, particularly in the stream bottom, was very close to the prescribed range of 4.5-18 pCi/g, at which the accuracy DQI could be achieved. This area C distribution was quite similar to that obtained immediately downstream from State Route 6, as documented in the Stream Mouth report. Based upon this observation, it might be inferred that the "representative" Cs-137 value for the stream bottom in Floodplain area C was 9 pCi/g. However, based on the calculations performed to assess accuracy, the representative value might have been only 5.9 pCi/g.

Based on the results histogram for Floodplain area A, a representative value of 5 pCi/g was assigned to the top 6 inches of area A. However, based on the calculations performed to assess accuracy, the representative value there might have been only 2.4 pCi/g. The next 12 inches of area A was assigned a representative Cs-137 value of 1.5 pCi/g.

Based on the results histogram for Floodplain area B, the top 18 inches of area B was assigned a representative Cs-137 valued of 2 pCi/g. However, based on the calculations performed to assess accuracy, the representative value there might have been only 1.14 pCi/g.

It was considered conservative to use the higher estimates in calculations of the amount of Cs-137 in the Floodplain area.

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

Floodplain Section	Affected Depth (ft)	Affected Area (ft ²)	Dry Mass (g)	Representative Cs-137 Activity (pCi/g)	Total Cs-137 Activity, (mCi)
A (highest layer)	0.5	29,847	575,897,865	5-BKGND	2.6
A (rest)	1	29,847	1,151,795,730	1.5-BKGND	1.2
B	1.5	17,535	1,015,013,475	2-BKGND	1.5
C (highest layer, in stream)	1.5	(50 x 146) = 7,300	422,560,500	9-BKGND	3.6
C (entire area)	0.5	15,812	305,092,540	1-BKGND	0.2
Rest of North Floodplain	0.5	5.46 acres = 237,838	4,589,076,492	2-BKGND	6.9
Rest of South Floodplain	0.5	7.84 acres = 341,510	6,589,443,168	1-BKGND	3.3

TOTAL= 19.2 mCi

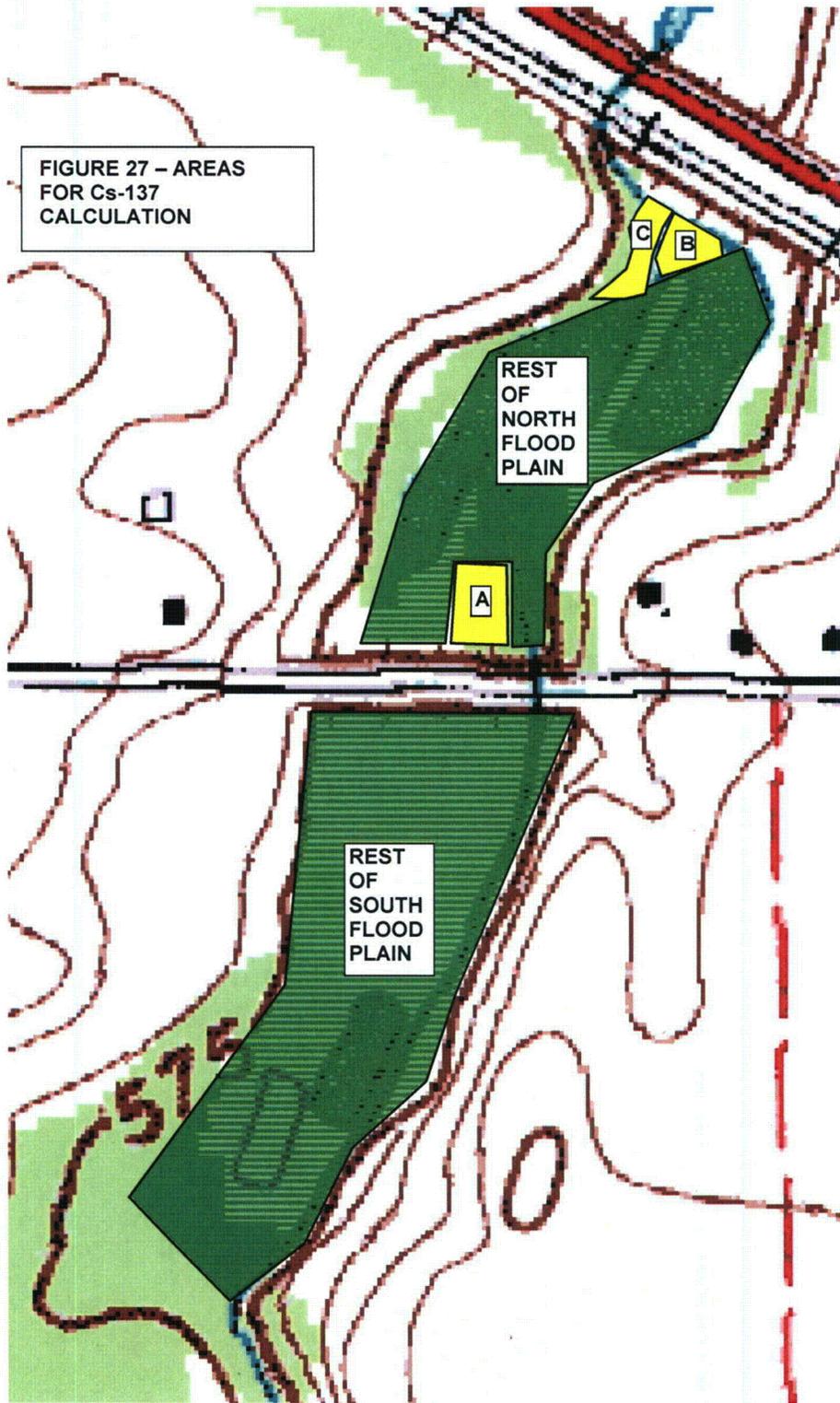
The areas used in the table are illustrated by Figure 27. The following assumptions and conversion factors were used:

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



At the time of this writing, HaagEnviro updated its estimate of the amount of currently measurable Cs-137 activity from the PBRF to roughly 120 mCi, distributed approximately as follows:

- 8% In front of WEMS
- 31% Excavated from Pentolite Ditch, placed near southern bank
- 1% Stream Meanders
- 1% Stream Backwaters
- 7% Flood Plain Elevated Measurement Areas A+B+C
- 9% Flood Plain large areas
- 7% Stream Mouth Elevated Measurement Areas A+B+C
- 36% Stream Mouth large areas
- Not estimated: Bay

The estimating assumptions employed are detailed in Appendix C.

IDENTIFY CS-137 DEPOSITS STILL IN TRANSIT

The deposits peaking around 4-4.5 pCi/g in areas A and C occurred in the top 6 inches of soil, and thus represented current conditions.

The upper 6-inch deposits in Floodplain areas A and C, with most frequent Cs-137 activities of 4-4.5 pCi/g, appeared to be in active motion at the time of this writing. Similar activities, in the 3-4 pCi/g range, also appeared to be in active motion in the Bay (this was first interpreted in the Stream Mouth report.) Peak levels for these actively moving deposits are known to reach up to 20.6 pCi/g (see Stream Mouth report), and have "representative" values ranging from 4-10 pCi/g.

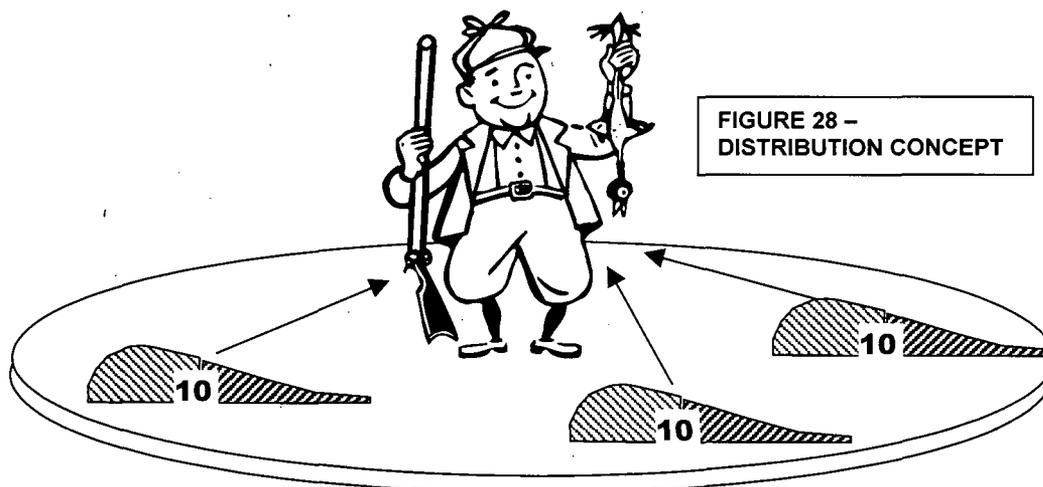
LOCATE FINAL RESTING PLACES OF CS-137 NO LONGER IN TRANSIT

No permanent deposits of Cs-137 were found in the Floodplain depositional environment.

CHARACTERISTICS OF CS-137 DEPOSITS THAT AFFECT REMOVAL

Lognormal Distribution – The distribution of Cs-137 testing results affects the decision on whether or not sediments should be removed. A key issue is that lognormally distributed results cannot be directly compared to a Derived Concentration Guideline Limit (DCGL) value. This is because the assumption that underlies the DCGL calculation is a uniform distribution, not the lognormal distribution observed in the field.

The key problem to be solved to make a reasonable comparison is to determine what is the “representative” activity emanating from a deposit that contains Cs-137 in a lognormal distribution. In evaluating the radiation dose delivered by a lognormal distribution, the “representative” activity should be considered the center of gravity of the distribution. This center of gravity is not determined by the arithmetic mean of the measurements. It can be determined by finding the equation of the distribution’s histogram curve, then finding the activity at which half the area under the curve lies to either side of that activity. An example was provided in the Stream Mouth report, in which the area under a lognormal distribution curve was divided into equal areas to the left and right of the “center of gravity” of the area under the curve. Figure 28 illustrates that concept.



Thus, one approach by which this discrepancy might be overcome would be to compare the “representative” value, as defined in this report, to the DCGL. Another way in which this discrepancy might be overcome 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. Yet another approach would be to take a dose approach to determining what sediment should be removed, rather than employing the DCGL concept. 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. In particular, it does not appear that any of the sediments bearing Cs-137 in the Floodplain depositional environment would be candidates for removal.

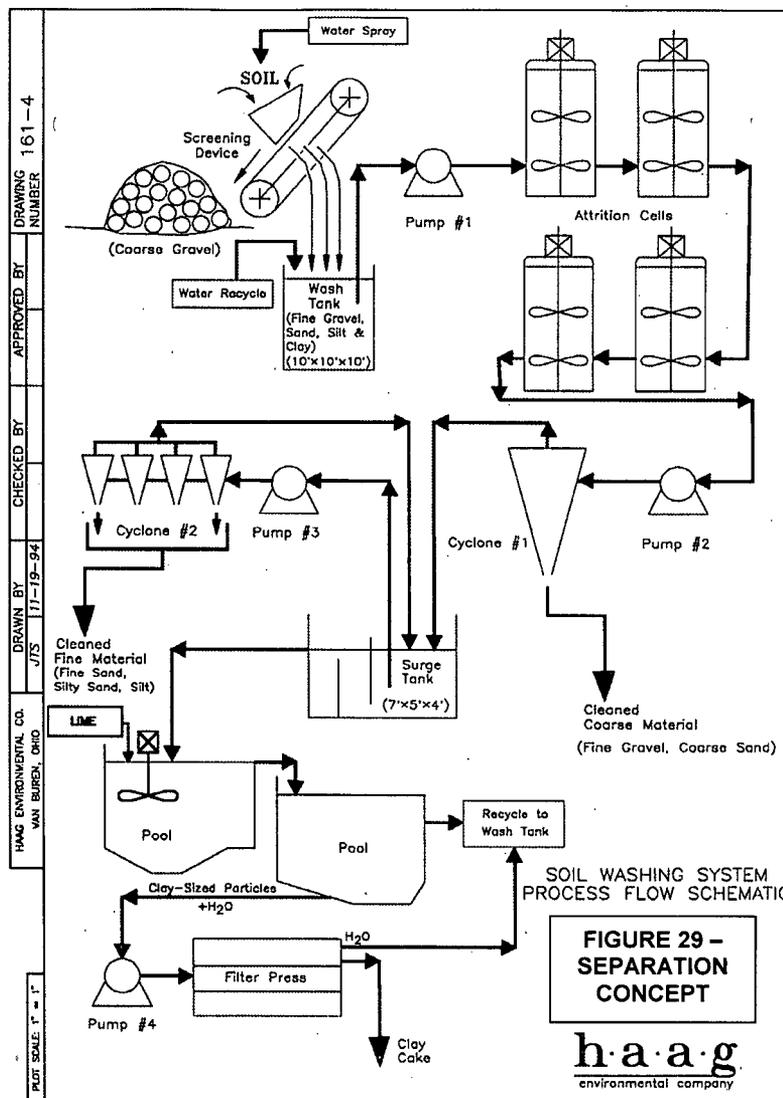
Precision, Accuracy and Number of Samples Required – It has been observed in prior studies in this series that the practical quantitation limit (PQL) for testing values in this project is 3 pCi/g. Below that value, the precision DQI of $\pm 20\%$ cannot be reliably achieved. In such cases, the differences between one result and another are only approximations, and cannot be relied upon as meaningful. In the current Floodplain study, it appears that sampling and testing methods generally produced acceptable precision for results > 3 pCi/g.

Based upon results reported in the Stream Mouth study, it has appeared that the accuracy DQIs of 80-120% can only be achieved when the measured values span a range at least as high as 4.5-18 pCi/g, with a “representative” value at least as high as 9 pCi/g. Most of the results obtained in the Floodplain were below this range. On the other hand, when the “representative” values for a Cs-137 deposit were found to be less than 2 pCi/g, it appeared possible to demonstrate that the representative value was less than the target of 12 pCi/g, with a 95% confidence. With a sufficient number of samples, it should also be possible to demonstrate that higher levels of “representative” activity are also < 12 pCi/g.

Ease of reaching the contaminated sediment with remediation equipment – Overland access to key parts of the Floodplain depositional environment would be relatively straightforward with suction hoses extended from land-based vacuum equipment. Access with conventional excavation equipment would be quite difficult in some areas.

Ease of removing only the contaminated sediment – In the Floodplain depositional environment, the key deposits containing Cs-137 were found in the upper 6 inches of soil or stream-bottom sediment. 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 lognormally distributed Cs-bearing particles.

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 29. 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 Floodplain depositional environment, at levels that appeared unlikely to deliver a dose >25 mRem/year to the maximally exposed individual. No Co-60 was found. 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 found in transit was 14.2 pCi/g, but the “representative” value for these deposits was a range of only 4 to 10 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 produced a most frequent result in the range of 4 to 4.5 pCi/g.