CHARACTERIZATION REPORT
FOR
PLUM BROOK SEDIMENT IN EAST SANDUSKY BAY

Prepared for
Keith M. Peecook
National Aeronautics and Space Administration (NASA)
Glenn Research Center
Plum Brook Reactor Decommissioning Program
Plum Brook Station
6100 Columbus Avenue
Sandusky, Ohio 44870

Prepared by:
Haag Environmental Company
315 East Market Street
Sandusky, Ohio 44870

h·a·a·g
environmental company

TABLE OF CONTENTS

FIGURES

APPENDICES

CHARACTERIZATION REPORT
FOR
PLUM BROOK SEDIMENT IN EAST SANDUSKY BAY

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 eastern end of Sandusky Bay near Sandusky, Ohio. The part of the bay that was sampled is a protected wetland known as the Putnam Marsh Nature Preserve. This investigation was conducted to determine whether Cs-137 attributable to a decommissioned reactor facility could be detected there, above the levels attributable to atmospheric atomic bomb testing.

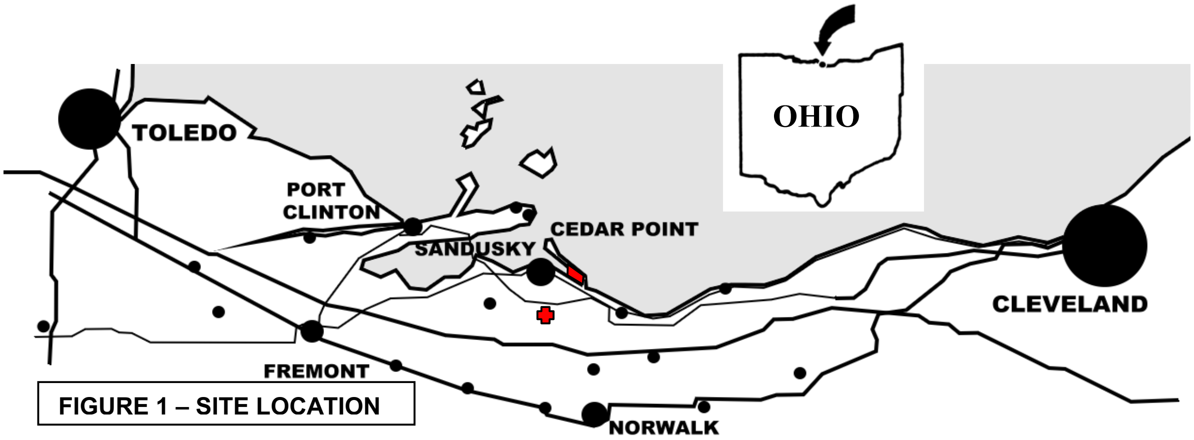


FIGURE 1 – SITE LOCATION

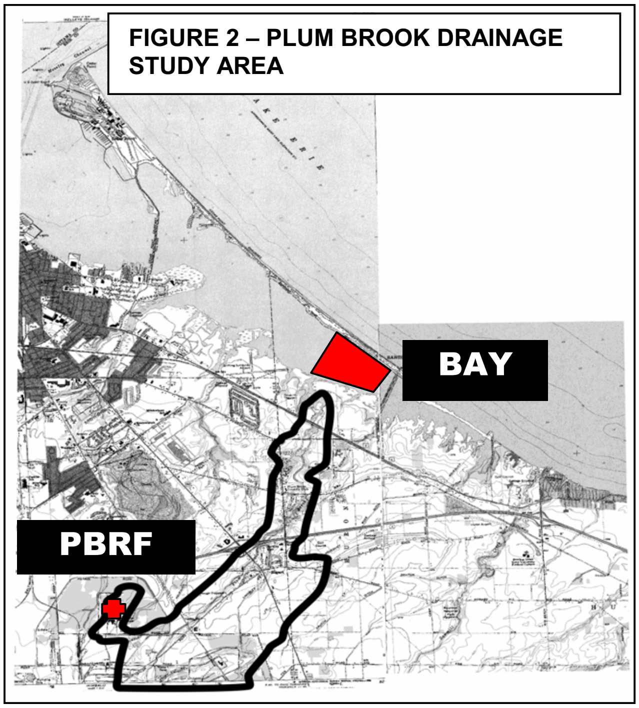


FIGURE 2 – PLUM BROOK DRAINAGE STUDY AREA

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 eastern end of Sandusky Bay are illustrated in 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.

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.

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 bay itself.

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 decision.

PROBLEM STATEMENTS

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

This sampling program was also premised upon the assumption that all of the Cs-137 dissolved in that cooling water was quickly and irreversibly adsorbed by clay minerals in fine sediment. Most of that fine sediment was expected to have been originally located in the bottom of Pentolite Ditch and Plum Brook. 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 1963, 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 1963 and 1973. Once those clays were identified, our goal was to determine where they had traveled since 1973.

Problem Statement for Remediation – If remediation should be needed, the goal would be to remove as much Cs-137 as possible, with the smallest effort 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 Bay 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 removing 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 on the following page.

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

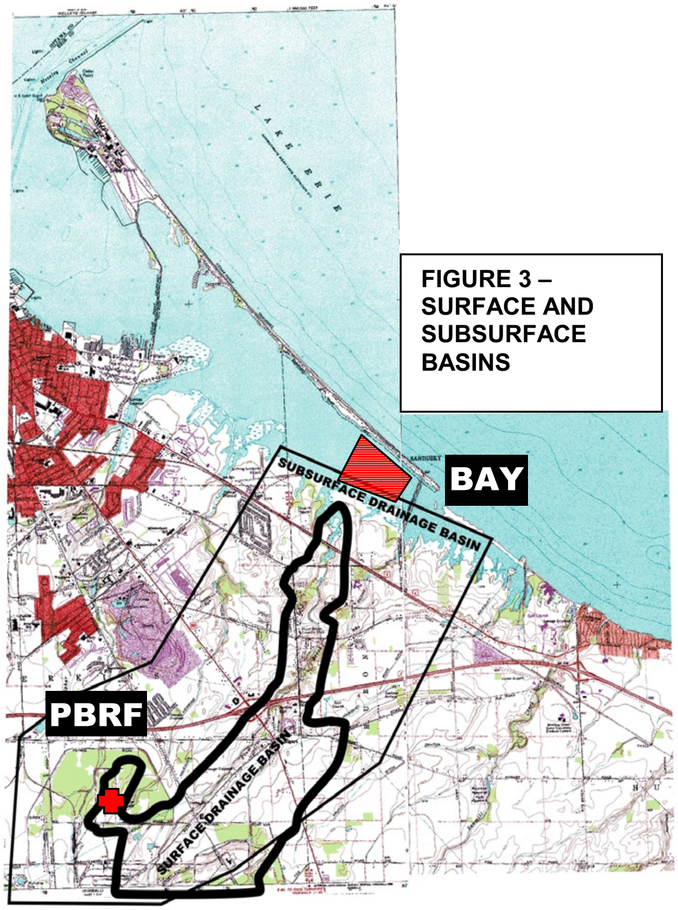


FIGURE 3 – SURFACE AND SUBSURFACE BASINS

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 “Identification of Depositional Environments Potentially Affected by Cs-137 from the Plum Brook Reactor Facility,” 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 evaluated in 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 the 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 bay sampling point in map view, a measurement needed to be reproducible only to within 10 feet.

DATA QUALITY INDICATORS

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

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

RPD is defined here as follows:

RPD = (duplicate 1 – duplicate 2) / average(duplicate 1, duplicate 2)

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

RPD = [log(dup1) – log(dup2)] / average[log(dup1), log(dup2)]

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

In some cases, repeatability must be considered acceptable if presence or absence of the contaminant is the same in the original and duplicate samples. This was the rule applied here to assess the repeatability of laboratory screening analyses, which were performed on unprocessed 3-inch samples still in their sample tubes. This was also the lower-limit rule applied to testing results marked "Qualitative Analysis Only".

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. Investigation was undertaken if the results exceeded the warning limits, and corrective action was taken if the results exceeded the control limits. The warning limits were set at 2 standard deviation 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 ±10% of the known activity.

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.

HaagEnviro assessed the accuracy of the laboratory screening analyses, which were performed on unprocessed 3-inch samples still in their sample tubes, by comparing them with later qualitative and quantitative analyses of composites of those tubes. After the 3-inch samples were screened and photographed, they were composited to yield samples large enough to fill the onsite PBRF laboratory’s standard geometry of at least 100 cubic centimeters (cc). The composite samples were processed following PBRF procedure CS-04, which included drying, grinding, and screening to remove particles over ¼-inch in diameter.

Accuracy of the total measurement system was evaluated based upon log-transformed results. Results were considered to be potential outliers if they were more than 1 order of magnitude greater or less than the best-fit trendline or trend surface.

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 Bay 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 of the type used on this project are typically less than 100%. For clay soils in this project, we employed the rule that sample recoveries of 80% are typical, and clay samples with recoveries less than 50% should be examined further. For organic soils (peat and muck), we employed the rule that sample recoveries of 50% are typical, and peat/muck samples with recoveries less than 30% should be examined further.

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 employed here. 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. The degree of sample cross-contamination is normally measured by obtaining clean, or “blank” samples following sampler decontamination. Testing results for blank samples should show no detection of the contamination found in field samples.

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

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

1. For Cs-137 in the natural environment, the minimum practical quantitation limit (PQL) for the combined sampling/testing measurement system in use on the PBRF Decommissioning Project was 3 pCi/g. All results less than this have essentially the same meaning.

2. Cs-137 measurements in the natural environment surrounding the PBRF need to be transformed to log(measurement) before they are evaluated. After transformation, the results 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 Students 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 FSSP-specified Type I and Type II errors was controlled by 2 main factors: (1) the sample variance, and (2) the distance between the proposed regulatory threshold and the representative value of Cs-137 in the environment, called the "effect size."

6. The conservative maximum variance of log-transformed, trend-removed results identified in the "Minimum Number of Samples" task was 0.40; more samples would be required if the variance of a sample set should exceed 0.40.

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 a 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 that were employed are attached to this plan as Appendix A. The laboratory procedures that were employed are PBRF's RP-021 and EPA Method 901.1 Modified.

EXPECTED CHARACTERISTICS OF THE BAY DEPOSITIONAL ENVIRONMENT

The following section describes the expected characteristics of the Bay environment, one of 7 identified depositional environments. These characteristics were used to guide the field scientists in obtaining representative samples.

Maps, airphotos, and anecdotes indicated that the eastern part of Sandusky Bay, behind the Cedar Point sand bar, had at times been a mostly not-submerged, vegetated area. One anecdote indicated that a nearby area, under water at the time of this writing, was previously used to grow potatoes.

With the higher level of Lake Erie at the time of this study, the bay area investigated had been an open-water environment for many years. However, records indicated that the lake level was quite low when the PBRF began operations in 1963, rose steadily through the reactor's decade of operation, and was at a historically high level at the time of sampling.

Maps and airphotos also suggested that Plum Brook water originally flowed through this bay area to the North, then turned West upon reaching the Cedar Point sand bar, as illustrated by the magenta arrows in Figure 4.

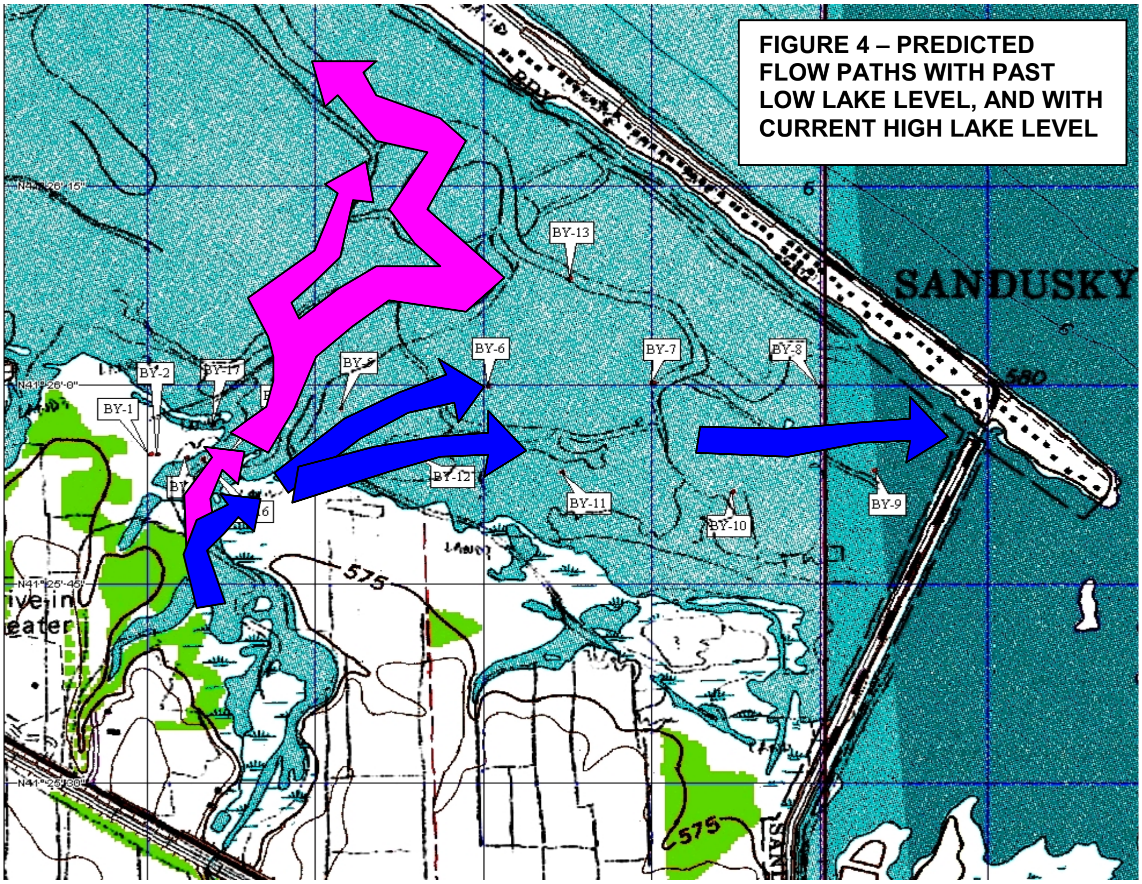


FIGURE 4 – PREDICTED FLOW PATHS WITH PAST LOW LAKE LEVEL, AND WITH CURRENT HIGH LAKE LEVEL

As illustrated by the blue arrows in Figure 4, Plum Brook flow through this bay area in the 5 years preceding this work appeared to be to the East.

At each point to be sampled, fine-grained layers bearing Cs-137 were to be sought. For the earliest part of the PBRF operating period, it was anticipated that Cs-137 might be found in North-trending marsh deposits. For the later part of the PBRF operating period, it was anticipated that Cs-137 might be found in a Northeast-trending delta deposit, in which the fine Cs-bearing sediment would be buried beneath coarser uncontaminated sediments.

In either direction, it was deemed possible that water flow might have carried clays bearing Cs-137 out into still water, where the clays would be deposited as thin layers referred to as varves. Varves often have a nominal thickness of a quarter-inch, or less. For the 10-year period of interest from 1963-1973, a sediment accumulation of as little as 4 inches might therefore be expected to contain all of the targeted Cs-137. It was also considered that a single event involving elevated values of PBRF Cs-137 in 1968, followed by the area’s largest recorded flood in 1969, might contain the most significant values of Cs-137.

The bay deposits were expected to be relatively stable in the short run, but they could be re-eroded if the level of Lake Erie should again fall, which appeared possible. It was therefore considered important to determine the depth of the bay deposits of Cs-137, as compared with the likely lowest level of Lake Erie in the next 100 years. A period of 100 years would represent three Cs-137 half-lives. During that time interval, the Cs-137 activities would be halved after 30 years, halved again after 60 years, and that amount halved after 90 years. Thus, after 100 years, the Cs-137 activities would be 1/8 of the levels found in this study.

METHODS

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

Based upon the HaagEnviro Characterization Plan for the bay depositional environment, NASA's contractor, MOTA, prepared Survey Request (SR) number 34 to cover this work. The NASA Radiation Safety Officer (RSO), Bill Stoner, approved SR 34.

HaagEnviro scientists conducted reconnaissance surveys to plan and guide the location of field samples. A sampling grid was established. Sample points were located with the aid of global positioning system (GPS) devices and related mapping software. Sampling methods included manual dual-tube GeoProbe, powered dual-tube GeoProbe, and depth-to-clay probes. Core samples were field-screened, laboratory-screened, and analyzed quantitatively. Data reduction and review involved comparison of results with DQIs, and a search for trends and patterns.

In the field, two HaagEnviro scientists directed locations, sampled, logged, PID-screened samples, and made field judgments regarding the character of the depositional environments and the need for more or fewer samples. Two MOTA Operations Technicians assisted the scientists in sampling, sampler transport, preparation, and decontamination. Two MOTA Radiation Protection (RP) Technicians scanned core sections with a sodium iodide (NaI) detector, and maintained sample custody according to PBRF decommissioning procedures.

NATURE PRESERVE CONSIDERATIONS

The part of the bay that was sampled was called the Putnam Marsh Nature Preserve, and was protected by Erie MetroParks. Through discussions with park personnel, sampling was planned to avoid times of bald eagle nesting, and to avoid permitted duck and deer hunting. During the bay sampling effort, HaagEnviro maintained contact with the park system's Supervisor of Operational Services, James Lang. Sampling personnel were directed to stay out of stands of American Lotus until the plants had flowered and began to die back. At that point, the samplers were given permission to enter the American Lotus areas.

Standing water with a nominal depth of 3 feet covered the area. Access to sampling points was by means of canoes provided by Erie MetroParks, by means of a floating platform, and by foot.

RECONNAISSANCE SURVEYS

The area to be sampled was reconnoitered by HaagEnviro scientists in 3 passes. In a first pass, Hydrogeologist Bob Haag and Senior Scientist Ben Patterson covered the bay area in a canoe, to assess the logistics of sampling. In a second pass, Bob Haag and Principal Scientist Ruth Haag surveyed the area by canoe, to determine the distribution of plant species that were contributing to the peat/muck deposit that appeared to fill most of the bay. In a third pass, Bob Haag and Ben Patterson surveyed the stream mouth area, in an effort to define the boundary between the peat/muck deposit and terrestrial deposits being brought into the bay by Plum Brook.

DEVELOPMENT OF SAMPLING GRID

Based upon the expected characteristics of the bay deposits, sampling for this study was planned to follow a fan-pattern of transects representing possible past flow to the North, later changing to the East. Sampling points within the transects were spaced to yield a triangular grid pattern upon completion. Figures 5 and 6 illustrate the development of the sampling pattern.

FIGURE 5 – INITIAL DEVELOPMENT OF BAY SAMPLING PATTERN

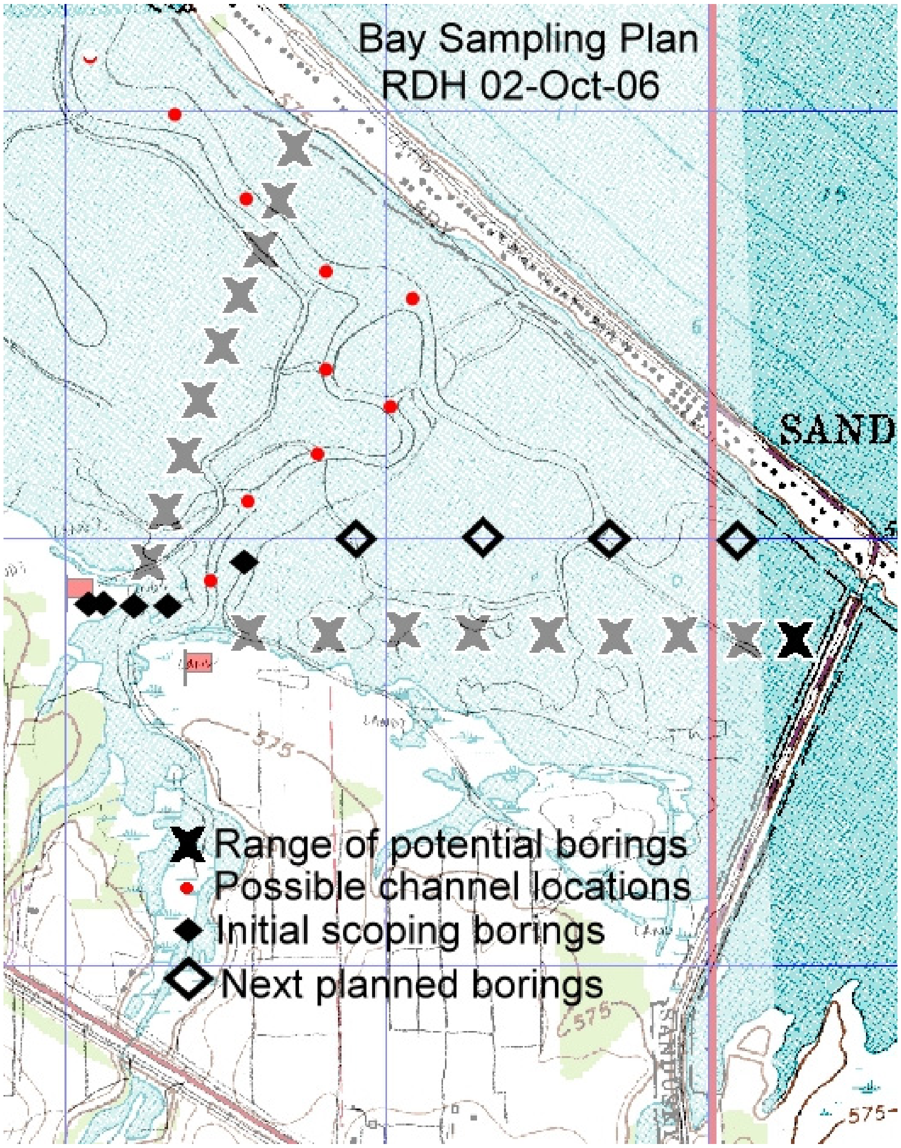
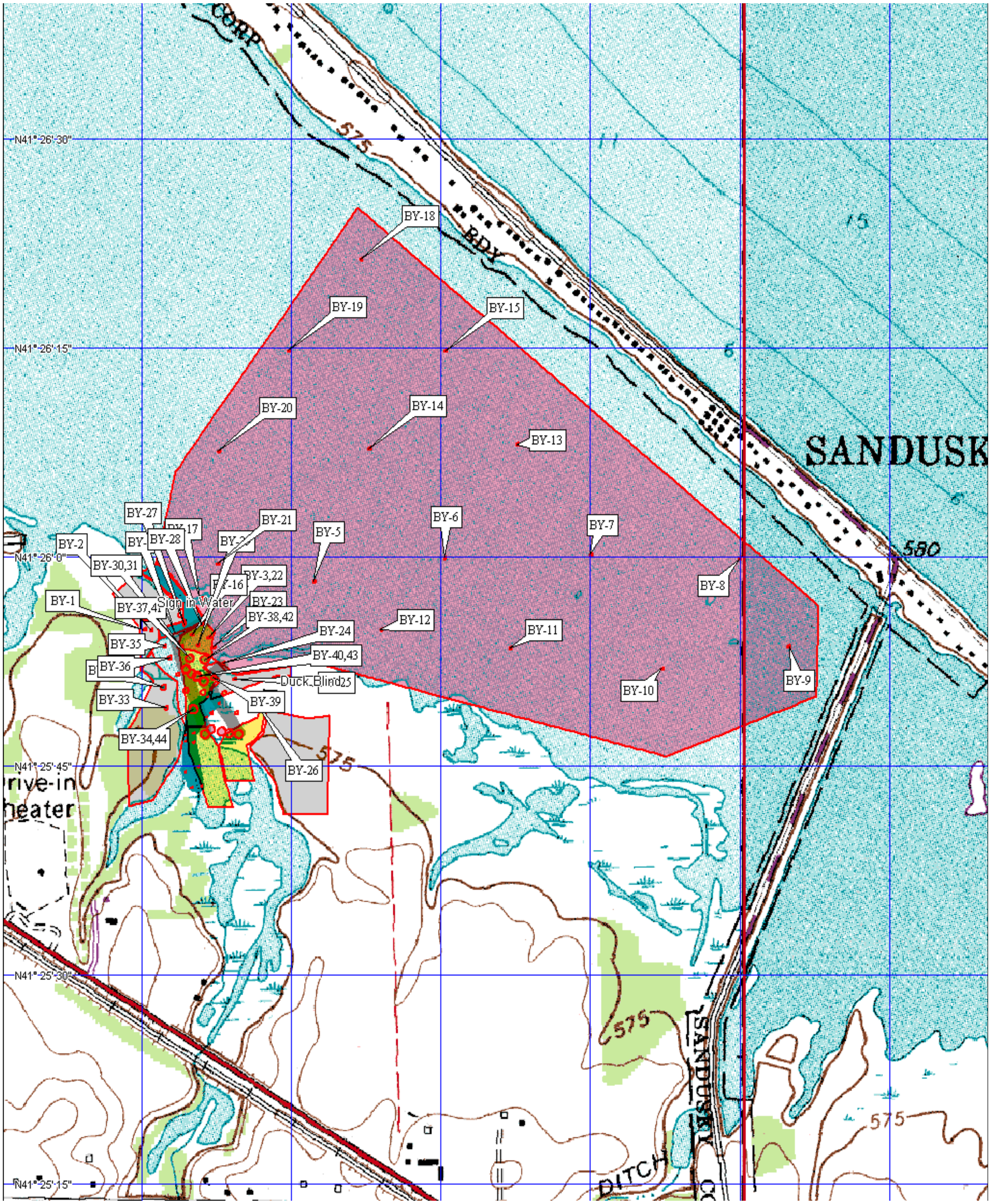


FIGURE 6 – COMPLETED BAY SAMPLING PATTERN



Because it was possible that all of the Cs-137 of interest might have been deposited in a very thin layer, a 3-inch vertical length of sample was selected for screening purposes. After screening was complete, samples were composited to satisfy other requirements of the characterization program, and to obtain quantitative results.

SAMPLE POINT LOCATION

Sampling points were located in the field by means of global positioning system (GPS) instrumentation. Hydrogeologist Bob Haag planned 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, who located them in the bay with HaagEnviro's GPS instrument, a Garmind eTrex Legend. Once the planned locations were found in the bay, they were marked with inflatable buoys attached to anchors. After the samples were obtained, the sample locations were recorded by MOTA RP technicians, using a NASA-provided GPS device, which was a Trimble model TSCe coupled with an integrated GPS/beacon antenna (part number 29653-00).

HaagEnviro also used its Garmind GPS device to record the locations of certain field observations, such as the limits of channel flow after a storm, and the location of a drum that was partially buried in the bay sediment.

SAMPLING

FIGURE 7 – MANUAL PROBE DRIVING

Core samples were obtained from 44 locations. In the vicinity of the stream mouth, it was observed that core recoveries were consistently low, and core sampling was then replaced by depth probing with metal rods. To perform this depth probing, Geoprobe drive rods with a conical tip were manually pushed until resistance was encountered. An additional 29 locations were depth-probed in this fashion.

Core samples were taken by one of two methods: manual or powered dual-tube GeoProbe.

FIGURE 8 – PROBE DRIVER ON FLOATING PLATFORM

In either approach, the 5-foot-long dual-tube sampler was driven down to the desired depth, or to hard-clay resistance. After the device had been driven 5 feet, the plastic inner sample tube, containing the sample, was pulled out and screened for radioactivity via NaI detector using a Ludlum model 2350 meter with a model 4410 probe, and a gamma-spectrum window set to focus on Cs-137 activity. If a second 5-foot interval was to be sampled, a new inner sample tube was inserted, and the dual-tube assembly was driven an additional 5 feet.

In the manual approach, shown in Figure 7, the sampler was driven with an oversized adaptation of a standard fence-post driver. In the powered approach, shown in Figure 8, HaagEnviro's hydraulic probe driving device was deployed on a floating platform. The metal sampling equipment was 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, as 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.

It was considered that pre-1963 sediments had been reached, and sampling could be terminated, when hard clay was encountered, either in core sampling or in probing with solid rods. One field duplicate borehole was sampled for every 20 field sampling locations.

SAMPLE FIELD-SCREENING AND CHAIN-OF-CUSTODY DOCUMENTATION

Upon extraction from the GeoProbe outer tube, the samples in their plastic tubes were screened by RP technicians for radioactivity, and by environmental scientists for organic compounds. The RP technicians employed the NASA-provided NaI meter. The scientists employed a NASA-provided Mini-RAE 2000 photoionization detector (PID), with a 10.6 eV lamp. The PID meter was calibrated at the beginning of each field day, and the NaI meter was source checked at the beginning and end of each field day, both by MOTA personnel at the PBRF site. After scanning, the plastic sample tubes were cut into 3-inch-long segments, PID-screened, and then capped and taped to seal in their contents. The samples were transported under chain-of-custody (COC) control by the RP technicians to the sample-processing trailer at the PBRF site.

LABORATORY PRE-SCREENING

The 3-inch-long samples were subjected to a laboratory pre-screening process, performed by the PBRF on-site laboratory. The 3-inch-long samples were provided to the laboratory in their tubes, as sealed in the field. The tubes were placed in a holder, and were counted for 900 seconds, or 15 minutes. At least one sample out of every 20 was re-counted by the same method.

As a complete calibration for this geometry was not performed, the results obtained could only be considered qualitative. Accordingly, the numerical results obtained for the 3-inch samples were only to be used to make relative comparisons of activity, for the purpose of identifying the layer(s) with the highest relative activity.

The laboratory screening results were also intended to permit identification of the radioactive isotope(s) present, expected to be almost entirely Cs-137 in the bay samples. The possibility of the presence of 7 other radionuclides of interest was to be considered in those locations, if laboratory screening indicated that this was warranted. It was desirable to assess the possible presence of other radionuclides of interest, particularly Co-60. To this end, the STL testing gamma spectroscopy results were reviewed, as were the PBRF results for composite samples.

COMPOSITING FOR QUANTITATIVE ANALYSIS

After laboratory screening, the 3-inch samples were cut open and photographed. The top two 3-inch sections were then composited, to represent the upper 6 inches of the sediment. Beneath this top 6 inches, the remaining 3-inch sections were composited in groups of 4, to represent one-foot intervals below the surface. In compositing, no consideration was given to the percent recovery, unless a pre-screening result indicated more than 2 pCi/g of activity (this did not occur). After compositing, the samples were dried, sieved, and analyzed in the PBRF onsite laboratory to obtain quantitative results.

QUANTITATIVE LABORATORY ANALYSIS

The composite samples were analyzed by gamma spectroscopy in the PBRF onsite laboratory following PBRF procedure RP-021. As many of the samples were too small or too light to obtain quantitative results, 56 samples were sent to the Severn-Trent Laboratory (STL) in St. Louis, Missouri for further quantitative testing. Tests at STL were performed by gamma spectroscopy using EPA Method 901.1 Modified.

DATA REDUCTION, INTERPRETATION, AND REPORTING

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

HaagEnviro identified possible Cs-137 detections in the pre-screening results by highlighting them in three colors, as follows:

Violet: Possible Cs-137 detection at surface
Yellow: Possible Cs-137 detection in mid-column
Orange: Possible Cs-137 detection at base of bay deposits

These colored columns were evaluated for compatibility with the expected depositional model. The composite-sample test results were coded with the same color system. The composite-sample detections were compared with the pre-screening detections. The colored columns for the composite samples were again evaluated for compatibility with the expected depositional model.

In both pre-screening and composite spreadsheets, laboratory recounts were posted for comparison, and were evaluated. Cases in which the first count was positive for Cs-137, and the second count was negative for Cs-137, were considered “false positives.” Cases in which the first count was negative for Cs-137, and the second count was positive for Cs-137, were considered “false negatives.”

Results were posted on maps and charts, which were reviewed with NASA personnel in weekly briefings.

OBSERVATIONS

NATURE PRESERVE OBSERVATIONS

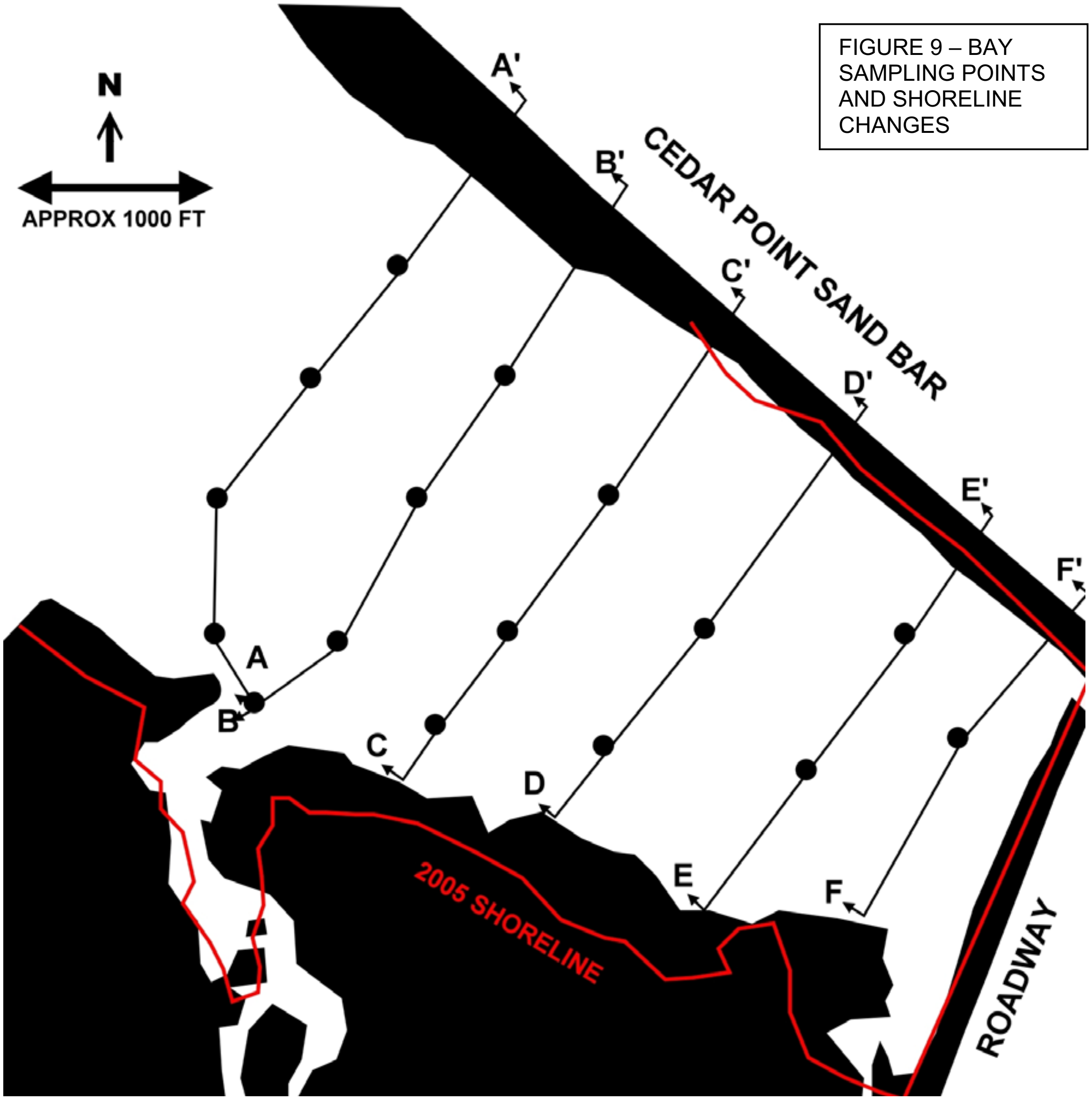
Large stands of blooming American Lotus plants initially prevented sampling very far into the area where Plum Brook entered the bay. By the end of the field effort, however, the American Lotus plants were dying back, and the stream mouth area became accessible. During normal-flow or low-flow periods, it was not possible to observe where the stream water flowed as it entered the bay, because the streamflow passed through a large American Lotus stand. However, one storm event did occur during the time that workers were allowed in the Lotus area, and the limits of observable channel flow were plotted. These channel flow observations are shown as a blue band on Figure 6.

RECONNAISSANCE OBSERVATIONS

During the first “recon” survey, the position of the shore was measured by GPS, on each side of the stream mouth. When these two shore locations were posted on the latest USGS 7.5-minute topographic map (photorevised 1979), the points located by GPS in 2006 were seen to be approximately 200-500 feet inland on the 1979 map. Subsequent observations confirmed that the shoreline had indeed moved inland by this amount, in the 27 years between 1979 and 2006. The shoreline change is illustrated by Figure 9. The first recon survey also allowed the observation that most of the bay study area was filled with a thriving crop of submerged vegetation.

During the second recon survey, the submerged vegetation was noted in a series of cross-bay canoe transects. The submerged vegetation community out in the bay was seen to be dominated by sedge and milfoil, growing together as a community. Plant communities in shore areas were dominated by American Lotus and Common Reed (Phragmites), with some areas of cattails. A few scattered areas of Lotus were observed across the middle of the bay.

The third recon survey sought to locate the boundary between bay-bottom areas covered by peat/muck deposits, and bay-bottom areas covered by terrestrial sediment deposits such as gravel, sand, silt, and clay. The objective was to delimit an expected delta, built of sediment brought down from upland areas by Plum Brook. No such delta was located. Instead, the peat deposit appeared to be nearly ubiquitous, covering almost the entire bay bottom, and extending far up the stream mouth, beyond the limits set for this part of the study. During this recon survey, clay was noted in bay-bottom areas that had become water-covered when the shoreline moved inland between 1979 and 2006. In those areas, the water was very shallow (6-12 inches deep). Clay brought up in grab samples often exhibited a blocky structure, with blocks the size of pea-gravel or smaller. A few small pebbles were found within some of these clay grab samples. In all, such clay samples exhibited the appearance of a glacial till being reworked in the shallow water.



SAMPLING OBSERVATIONS

The samples retrieved from cores were almost uniformly field-classified either as peat/muck, or as clay/silt. As the samples were kept in their tubes until they had been laboratory-screened for Cs-137, no stratification could be observed. After the samples had been screened, extruded from the tubes and photographed, it could be seen that there were some minor variations. A few clays contained notable sand, and a few clays exhibited varves, although most were massive. Occasional pebbles were seen in the clay samples, but many more pebbles became visible when the samples were dried and sieved in preparation for quantitative analysis.

The distribution of post-glacial sediment deposits in the bay is illustrated by Figure 10. In the cross-sections on this figure, blue represents water, black represents peat, and white indicates clay. The cross-sections have a 30x vertical exaggeration.

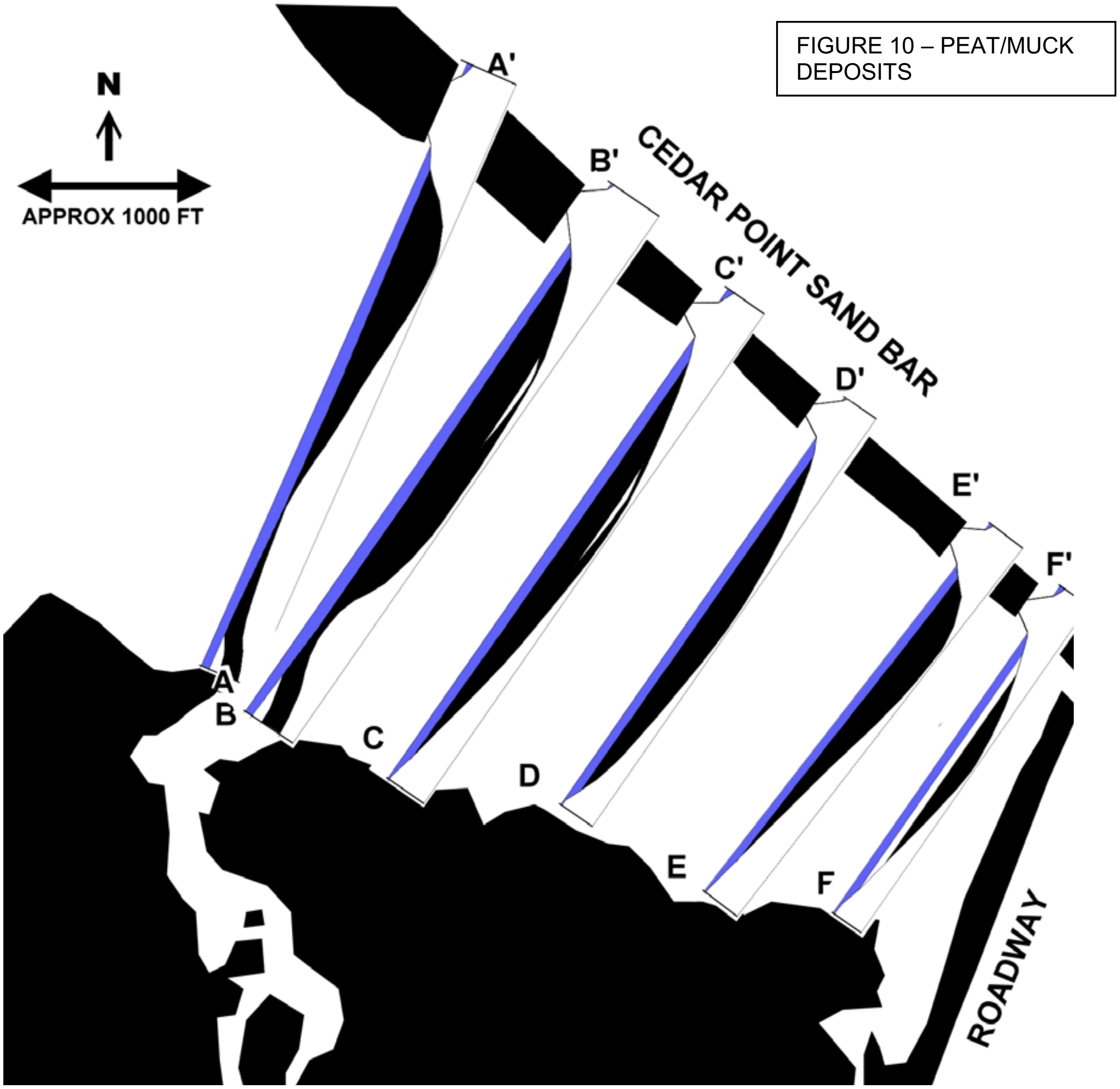


FIGURE 10 – PEAT/MUCK DEPOSITS

Neither the field-scanning for radioactivity, nor the field-screening for organic chemicals, produced readings sufficiently above background to warrant concern or further inquiry. The posting of field-screening results, in Appendix B, allowed HaagEnviro to observe the sample recoveries achieved by the GeoProbe dual-tube sampling approach. One table is provided in the Appendix for each bay location that was sampled. In every table, the potential total sampling depth of 120 inches (10 feet) is shown at the left. The sampling device was advanced in 60-inch increments, and the resulting sample was cut up into 3-inch segments, beginning at the bottom of each tube. A laboratory pre-screening result for each 3-inch segment is posted in the table in Appendix B. To observe the recovery for any 60-inch tube, observe the number of 3-inch intervals for which results are posted, beginning at 60 inches for the shallow core run, and beginning at the deepest result posted for the deeper core run. To use BY-1 as an example:

1. The sampler was pushed to 39 inches before hard clay was encountered.
2. Screening results were reported for each 3-inch interval, beginning at the bottom with interval 36-39, and continuing up to interval 9-12 at the top.
3. Of 13 three-inch intervals possible, 9 of them had sample results.
4. Nine three-inch intervals contained sediment, out of a possible total of 13 three-inch intervals, yielding a recovery of 9/13 x 100% = 69%.
5. Visually, one can observe that most of the chart, from 36-39 up, had numbers, so one can see that recovery was acceptable. (Acceptable is defined as recovery >30% in peat, and >50% in clay)

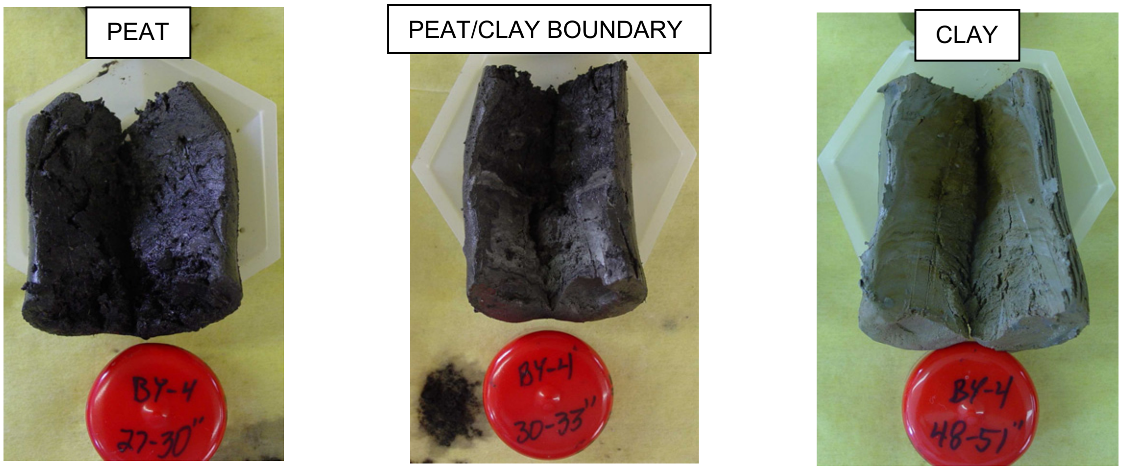
LABORATORY PRE-SCREENING OBSERVATIONS

Pre-screening results are presented in Appendix B. An assessment of duplicate screening analyses demonstrated that the screening approach was subject to a very high level of false positives. Virtually all of the samples that indicated the presence of Cs-137 on first screening, did not show Cs-137 to be present upon re-screening. On the other hand, most of the samples that indicated a lack of Cs-137 on first screening, also showed a lack of Cs-137 on re-screening, so the rate of false negatives was much lower than the rate of false positives.

OBSERVATIONS FROM COMPOSITING FOR QUANTITATIVE ANALYSIS

Samples of organic peat/muck lost a great deal of their volume and weight when they were dried, ground, and sieved for analysis. A typical weight reduction, for composite sample BY-7-83, was a gross starting weight, including tubes and caps, of 108.8+109.0+105.1+103.9 = 426.8 g, and a processed weight of 64.9 g. Allowing perhaps 40 g for the tubes and caps, the reduction in weight would be from 386.8 down to 64.9, so that the final weight was only 17% of the starting weight. This reduction in weight could cause a significant increase in apparent Cs-137 activity, because that activity, in pCi, is reported per gram of soil. Assuming that the typical weight reduction between the wet pre-screening samples and the dried composite samples is 5-to-1, then the resultant activity, per unit weight of the soil, could be magnified 5 times between pre-screening and composite analysis.

Some samples of clay yielded a significant volume of pebbles, suggesting that the material was a glacial till. Most clays exhibited a massive structure without varves, although a few clay samples did exhibit varves. Three examples are shown in Figure 11.


PEAT

PEAT/CLAY BOUNDARY

CLAY

FIGURE 11 - BAY CORE SAMPLES

COMPOSITE LABORATORY ANALYSIS OBSERVATIONS

Composite laboratory testing results are presented in Appendix B. In general, patterns suggested by the pre-screening analyses were not confirmed in the composite testing results. Because of the significant loss of sample volume upon processing, most of the composite results from the PBRF onsite laboratory were judged to be qualitative. In general, this was due to a composite sample volume that was less than the standard container geometry for which the testing system was calibrated. The data reviewer indicated that this condition typically leads to overstatement of activity.

Of 20 samples sent to STL, for which the PBRF laboratory had reported qualitative Cs-137 detections:

- 3 of 20 were confirmed as detections by STL
- 12 of 20 were not confirmed as detections by STL
- 5 of 20 did not have an STL MDA low enough to compare with the PBRF result

Most of the STL results for the composite samples from the bay were less than 1 pCi/g. Of the 56 Bay results received from STL, 4 had been requested by HaagEnviro to evaluate specific questions. Two of those STL tests, intended to confirm some of the higher PBRF laboratory results, did not achieve the 1 pCi/g MDA needed. The other two STL tests confirmed the conclusions drawn from the PBRF laboratory results.

STL reported 3 results for Cs-137 blank spike recoveries, which were 105%, 109%, and 102%, respectively. All of these recoveries were within the acceptable ranges set by STL, and by HaagEnviro. As all of the spike recoveries were >100%, one might note that the reported results tended to be slightly higher than the known amounts of Cs-137 inserted into the laboratory control samples.

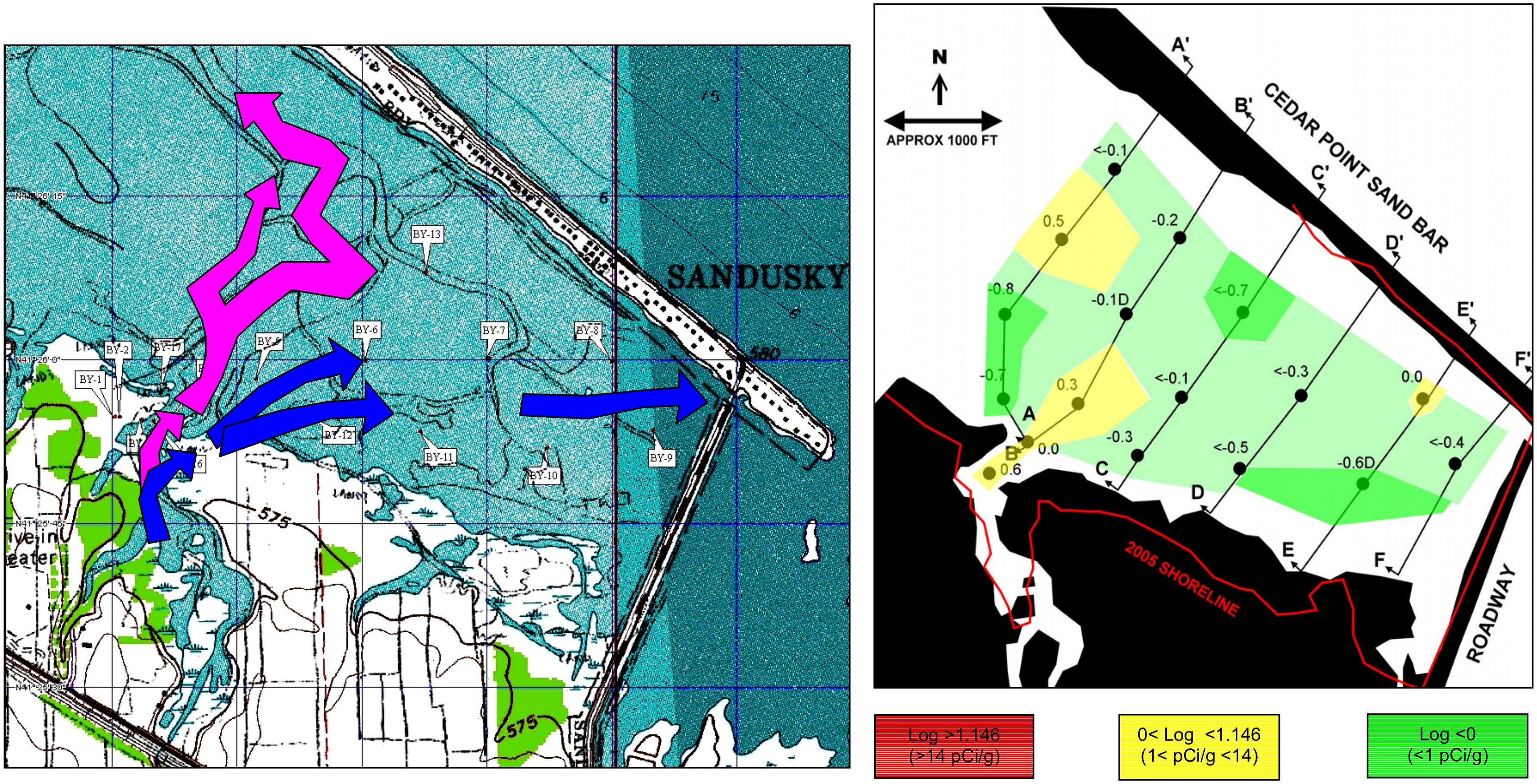
Within the PBRF onsite laboratory results, Co-60 was reported in only 4 samples, at activities ranging from 0.21-0.94 pCi/g. All but one of those results was labeled "qualitative." The single quantitative PBRF laboratory result was 0.35 pCi/g, for sample BY-15-188. For the other 3 PBRF detections of Co-60, there were corresponding STL quantitative results, none of which confirmed the Co-60 detections. Two of the 3 STL duplicates had sufficiently low MDAs to make the comparison; one of the STL duplicate tests had an MDA slightly above the qualitative result reported by the PBRF laboratory, so no comparison could be made. In all, STL reported no Co-60, but did report several instances of Europium-154, which was not indicated by the PBRF onsite laboratory.

TREND AND PATTERN OBSERVATIONS

For the most part, the Cs-137 detections reported for the composite samples were in peat, in the upper part of the sample column. Sample point BY-14 deviated from this pattern. At that sample location, the bottom sample, spanning an uncorrected depth range of 102-111”, produced a qualitative Cs-137 result of 0.88 pCi/g at the PBRF laboratory. The STL result for this sample was 1.04 pCi/g. The PBRF laboratory also analyzed a BY-14 composite sample spanning an uncorrected depth range of 54-102”, and produced a qualitative result of 0.82 pCi/g. There was no STL duplicate for that test. For the upper 6 inches at BY-14, both the PBRF and STL laboratories produced results less than their MDAs, which were 0.49 and 0.34 pCi/g, respectively. Sample point BY-14 appears on Figure 12 with the label, “-0.1D”.

Figure 12 illustrates the pattern of log-transformed detections in composite samples tested in the PBRF onsite laboratory. Figure 12 also compares these Cs-137 patterns with the expected past and recent flow patterns. It appears from Figure 12 that the slightly more-elevated Cs-137 results tend to follow the magenta arrows, which represent low-lake-level conditions, expected near the start of PBRF operations.

FIGURE 12 - Cs-137 DETECTIONS COMPARED WITH PREDICTED FLOW PATHS



INTERPRETATIONS

HaagEnviro makes the following interpretations based upon the data presented.

INTERPRETATIONS REGARDING Cs-137 EXTENT IN BAY

Cs-137 from PBRF Reached the Bay - Some Cs-137 from the PBRF is present in peat deposits in the eastern part of Sandusky Bay.

Bay Deposition Mechanism Involves Peat – PBRF Cs-137 was adsorbed on clay minerals upstream. Clay particles carrying this Cs-137 were suspended in water that traveled out into the bay, and eventually settled on the vegetation growing underwater in the bay. The clay that settled on the vegetation became part of the peat/muck deposit that had filled the bottom of the bay. The peat/muck deposit that filled the bay was judged to be thousands of years old, with initial deposition beginning some time after the last glacial retreat exposed the bay area, and water began to accumulate there. The Cs-137, which could only have been deposited in the past 40-50 years, was therefore generally found in the upper part of the peat deposit. When Cs-137 was detected at the bottom of the peat deposit, it was inferred that either (a) the area was dredged or otherwise exposed preceding Cs-137 deposition, or (b) the Cs-137 detected was a false positive sampling/testing result. Sample point BY-14 appeared to represent an area that was excavated or dredged at the time of Cs-137 deposition by the PBRF.

Cs-137 in the Bay is Not Currently Moving - The Cs-137 deposited in the bay environment was not in transit at the time of this study, but it could be eroded and redeposited if the level of Lake Erie should fall to the low levels seen in 1935 and 1965. Those levels were 3-4 feet lower than those seen in 2006 at the time of this study.

Cs-137 Activity in the Bay Study Area Could Account for Much Released from PBRF – With the assumptions that were used, one might estimate that the Cs-137 activity in the Bay study area could account for more than that released from the PBRF. Some of the estimating assumptions should probably be refined.

In-Situ Volume Affected - The Bay study area in which Cs-137 activity was reported to exceed 1 pCi/g was identified as the area colored in yellow in Figure 12. That area was estimated as approximately 1.7×10^6 square feet (SF). The thickness of the sediment carrying Cs-137 was estimated at 1 foot (or less). Using these numbers, the in-place peat volume was estimated at $1.7 \times 10^6 \times 1 = 1.7 \times 10^6$ cubic feet (CF), or 62,963 cubic yards (CY).

Volume and Density Upon Drying for Testing - Making the estimating assumption that, upon drying, the affected peat volume was reduced by a factor of 5, then the dry volume of the affected area would be 12,593 CY. Based on the observation that the peat did not float, the dry density of the peat was estimated at 1.1 grams per cubic centimeter (g/cc), or 0.85×10^6 g/CY. It was assumed that the average Cs-137 activity in this dried material was 1 pCi/g. These assumptions are illustrated in Figure 13.

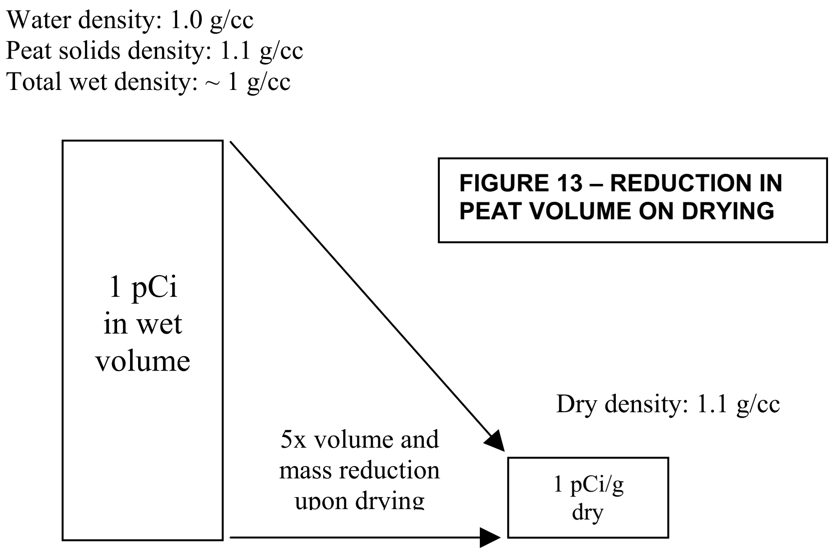
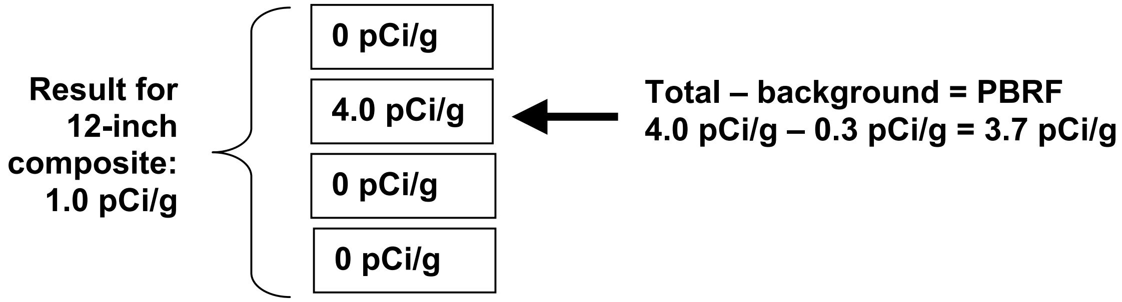


FIGURE 13 – REDUCTION IN PEAT VOLUME ON DRYING

<u>Framework for Considering Potential Background from Atmospheric Testing</u> – Although a consideration of background activity might not enter into regulatory considerations, it was considered important to determine whether background activity could have been a significant factor in the mass-balance evaluation. The following discussions suggest that background activity would not likely be a major factor in the assessment.

It was assumed that atmospheric testing during the same time that the PBRF operated contributed a Cs-137 background, which was assumed to be 0.3 pCi/g. This was based on soil testing by others on Star Island in nearby Old Woman Creek, where the upper 4 inches of soil contributed roughly 0.3 pCi/g, and the soil below 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). These estimates are illustrated in the Concept Report.

The assumed contributions are illustrated below for a 12-inch composite sample with a test result of 1 pCi/g:



The result of this particular set of assumptions would be a PBRF contribution of 3.7 pCi/g, over a 3-inch layer within the peat. Averaging 3.7 pCi/g over the 12-inch sample would yield an overall result of 3.7/4 = 0.925. These assumptions reduce the average for the 12 inches by just under 0.1 pCi/g.

If one were to deduct 0.1 pCi/g from the Bay area results, then the Cs-137 attributable to the PBRF would be approximately 0.9 pCi/g x 0.85×10^6 g/CY x 12,593 CY = 0.963×10^{10} pCi. With these assumptions, it would appear that the Cs-137 activity in the bay study area would be slightly less than four times the total Cs-137 activity believed to have been discharged in PBRF cooling water. We previously estimated that 0.25×10^{10} pCi of Cs-137 activity from the PBRF remained to be found in the year 2006.

Balance to within an Order of Magnitude - As noted in the section entitled "Limits on Decision Errors," one must consider masses to be "adequately balanced" when the amount of Cs-137 activity accounted for is within one order of magnitude of the amount estimated to have been released. In the Bay Study area exercise, it appears that the amount of Cs-137 found could account for more than all of the Cs-137 believed to have been released from the PBRF. But the results do balance to within one order of magnitude, if no other areas contribute to the total found.

Sensitivity of Estimate to Each Parameter - This estimating exercise serves to identify the elements of the estimate that may need to be examined more closely, which are as follows:

1. Actual atmospheric-testing background activity of Cs-137 in peat deposits (current estimate is approximately 0.3 pCi/g over 4 inches, or 0.1 pCi/g over the top 12 inches of peat in situ)

2. Actual total Cs-137 activity within peat layer affected by PBRF (current estimate is 1 pCi per gram of dried peat)

3. Actual thickness of peat layer carrying Cs-137 from PBRF (Current assumption is upper 12 inches, while the actual thickness seems more likely a 4-inch layer buried within the upper 12 inches; this only becomes an issue if we try to refine the background contribution.)

4. Actual surface area of PBRF Cs-137 deposits (current estimate in Bay study area is 1.7×10^6 SF, could be much less if it is confined to old channels)

5. Actual peat volume/mass reduction upon drying (current estimating assumption is a 5:1 reduction)

6. Actual peat dry density (current assumption is 1.1 grams per cubic centimeter (g/cc), or 0.85×10^6 g/CY)

Only the measurement of actual Cs-137 activity contributes order-of-magnitude variations to the estimate. Among the remaining parameters, those with the greatest ability to affect the mass-balance appear to be as follows, in order of importance: The actual peat volume reduction could affect the results by a factor of 5. The actual thickness of the layer carrying PBRF activity could be overestimated by a factor of 4. The actual surface area could be overestimated by a factor of 4, if the deposits are confined to old channels. The actual atmospheric-testing background activity of Cs-137 in peat deposits appears to contribute less than 10% to the amount being considered in the mass balance.

INTERPRETATIONS RELATED TO REMEDIATION

Levels of Cs-137 Found in Bay Not a Health Concern - Cs-137 has not been detected in the bay at the level of interest, currently defined as 12 pCi/g or greater.

Evaluating Cs-137 activity based on mass (grams) is an overly conservative approach for these peat/muck soils. When water is removed from these soils, both their volume and their mass are greatly reduced. Further, the mass of a sample of dried peat will be much less than the mass of an equal volume of dried clay. This will cause a ratio of activity (pCi) to mass (g) to be higher for the peat than it is for the clay. These two effects, the reduction in volume upon loss of water from peat, and the lesser density of peat, will cause a magnification of the Cs-137 activity reported for a peat sample, as compared with a clay sample.

In this report, the potential magnification is roughly approximated as a factor of 5. If correct, this would imply that a person standing on peat soil with a measured Cs-137 activity of 100 pCi/g would only receive one-fifth of the dose that they would receive if they were standing on clay soil with a measured Cs-137 activity of 100 pCi/g.

Cs-137 not Easy to Remove from Bay - If removal were to be considered, the clay carrying Cs-137 could not easily be separated from the peat/muck material in which it is trapped. However, drying to remove water could easily reduce the volume of removed material. The volume of removed material could be further reduced by incineration of the organic matter.

UNCERTAINTIES AND DATA GAPS

The following issues are identified as contributing uncertainty to the interpretations given above:

1. **Precision:** Most of the Bay results were less than the 3 pCi/g limit at which repeatability can be reliably assessed. The PBRF laboratory reported most of the results over 1 pCi/g as qualitative, and STL was not able to achieve a low enough MDA to support an RPD calculation. Accordingly, the only useable measure of repeatability has been to note whether detection/non-detection was the same in both duplicates. Most of the negative lab-screening results were confirmed upon recounting, but almost none of the positive lab-screening results were confirmed upon recounting. The screening approach therefore had an unacceptably high false-positive rate, and this approach should be discontinued. The false-positive rate for the qualitative PBRF analyses, checked by the STL tests, was approximately 60%. This is an improvement over the screening results, but is still less than ideal. A 10% false-positive rate would be ideal. A 25% false-positive

rate would still meet project guidelines established in the Final Status Survey Plan (FSSP).

2. **Accuracy:** Three phenomena combined to make it difficult to state what was the true amount of Cs-137 present: (a) the low Cs-137 levels in the Bay, (b) the fact that the results were distributed log-normally, and (c) the magnification of results due to sample processing. For the same reasons, the ability to separate PBRF Cs-137 from background Cs-137 was also limited.

3. **Representativness:** Peat/muck sample recovery was less than the desired 30%, or clay recovery was less than the desired 50%, in 22 out of 64 five-foot core runs. Thus, about one-third of the core runs needed careful scrutiny for interpretation. Upon review, the mid-bay core runs were judged acceptable for use, but the results obtained where the Stream Mouth entered the Bay could not be considered to represent the deposit. As a result, a new peat sampling method should be adopted for the next phase of this study, which will continue up the Stream Mouth.

4. **Completeness:** The minimum criterion of at least 3 valid samples to represent a plane was easily met. A statistically based minimum of 14 samples, to represent Cs-137 variability in the bay depositional environment, was also achieved.

5. **Comparability:** Compliance with procedures was maintained, except for appropriate deviations called for by field conditions. Both compliance and appropriate deviations were recorded in two sets of documents: the HaagEnviro field notes, and the MOTA RP Technicians' chain-of-custody documentation.

It may be appropriate to address the following data gaps:

1. In order to assess the total amount of Cs-137 being held in the Bay, the pattern of Cs-137 detections may have to be followed to the West.

2. Some Stream Mouth samples should be duplicated using methods that produce better peat recovery (A vibrocore approach is planned for the Stream Mouth phase of sampling).

3. In order to assess the actual potential for human exposure to Cs-137 activity in peat/muck deposits, a standard other than activity per dry weight should be employed. Activity per volume in-situ might be more meaningful.

4. In order to obtain quantitative results from the PBRF onsite laboratory, peat sample volume should be increased in future efforts (this is planned in the Stream Mouth phase of sampling).

5. In order to obtain quantitative results from the PBRF onsite laboratory, the analytical system should be calibrated for a smaller geometry (A 100-cc geometry is to be implemented).

6. In order to obtain quantitative results from the PBRF onsite laboratory, the analytical system might need to be calibrated for a less-dense material.

7. If it were desired to clearly separate PBRF activity in the Bay from background atmospheric testing activity, it would be necessary to obtain and quantitatively analyze very small samples, from depth intervals of one inch. Alternatively, it might be possible to identify PBRF activity by means of the ratio between Cs-137 and Co-60. While this would not require samples on a one-inch interval, it might require quantitative results with low MDAs, which might be obtained from larger samples and longer count times. These approaches are not currently considered necessary.

APPENDIX A
FIELD PROCEDURES

PROCEDURE FOR SAMPLING EQUIPMENT DECONTAMINATION

This procedure describes the general method to be used for decontamination of sampling devices such as water level indicators or sampling pumps. The purpose of decontamination is to remove all solid and liquid residues from prior samples before taking a new sample.

PRIOR PROCEDURES REQUIRED

- None

EQUIPMENT REQUIRED

- Metal wash tub
- Boot sprayer
- Distilled water
- Detergent
- Sample gloves
- Paper towels
- Trash bag
- Knife or scissors
- Plastic sheeting

PROCEDURE

1. Don sample gloves, use knife or scissors to detach all sample string, and completely disassemble the sampling device.
2. Place device in tub, with a small amount of detergent and 1 gallon of distilled water.
3. Scrub all parts with detergent and distilled water to remove visible solid residues.
4. Run detergent and water through interior of sampling equipment.
5. Remove equipment and rinse off detergent with distilled water.
6. Place equipment on clean plastic sheeting.
7. Dry equipment with paper towels, or allow to air dry.
8. Place all solid waste (sampling gloves, paper towels, string, etc.) into trash bag, to return to PBRF. Discard water on ground after screening with NaI meter.

PROCEDURE FOR GEOPROBE DUAL-TUBE SAMPLING

This procedure is for sampling soils using Geoprobe tools, and a manual or powered driving device.

PRIOR PROCEDURES REQUIRED

- Sampling Equipment Decontamination

EQUIPMENT REQUIRED

- Clear 60” Geoprobe sampling tubes
- Four red and four black sampling tube end caps per 12” of sample
- 60” Geoprobe dual-tube sampler
- Geoprobe adapter from sampler to 1” drill rod
- Geoprobe drive cap
- 3’ long by 1” diameter drill rods
- Manual driver, or hydraulic probe driver
- 10.2 or 11.7 eV photoionization detector (PID), for organics
- Sodium Iodide (NaI) detector, for Cs-137 activity
- Decontamination supplies
- Tape measure
- Hacksaw
- Field notebook, Sharpie fine point marker

PROCEDURE

For each 60-inch depth sampled, the following steps will be performed.

1. Warm up and calibrate meters
2. Obtain background meter readings
3. Assemble sampler by inserting inner plastic tube inside outer steel tube
4. Drive sampler into sediment
5. Extract inner plastic tube, with sample inside
6. Use NaI meter to screen outside of entire plastic tube
7. Use PID to screen bottom of sample
8. Cap bottom of clear tube with red cap
9. Measure 3” from end of core and cut with decontaminated hack-saw
10. PID-screen next “bottom” section and cap with red cap
11. Label tube cap with sample location and bottom depth interval
12. Cap the top of the 3” core with a black cap
13. Measure 3” from end of “new” core and cut with hacksaw, label plastic cap with sample location and depth interval
14. Continue steps 11 through 13 until every section is screened and capped.
15. Record findings in notebook.

APPENDIX B
LABORATORY TESTING RESULTS
(Provided as a separate computer file named 298BayResultsSpreadheet.xls)