CHARACTERIZATION REPORT
FOR
PLUM BROOK SEDIMENT IN PONDS

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

INTRODUCTION 3

CHARACTERIZATION PLAN OBJECTIVES 8

DATA QUALITY OBJECTIVES 9

EXPECTED CHARACTERISTICS OF POND DEPOSITIONAL ENVIRONMENT ... 17

METHODS 19

OBSERVATIONS 23

INTERPRETATIONS 26

FIGURES
1 – PBRF LOCATION 3
2 – PLUM BROOK DRAINAGE STUDY AREA 3
3 – N. PONDS 5
4 – S. POND 5
5 – PILES IN 2001 6
6 – PILES IN 2003 6
7 – PILES IN 2005 7
8 – SURFACE AND SUBSURFACE BASINS 11
9 – PILE AREAS AS OF 2005 17
10 – SMALLER DREDGED PILE 20
11 – PROBE DRIVER ON BOBCAT 20
12 – SOUTHERN POND 21
13 – CORE SAMPLES FROM S. POND 24
14 – KEY MOUND RESULTS 25
15 – KEY POND RESULT 25

APPENDICES
A - FIELD PROCEDURES 28
B - LABORATORY RESULTS ..... (Computer file 298PondsSpreadsheet.xls)

CHARACTERIZATION REPORT
FOR
PLUM BROOK SEDIMENT IN PONDS

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, related to 3 ponds located on the grounds of the Plum Brook Country Club (PBCC) in 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.

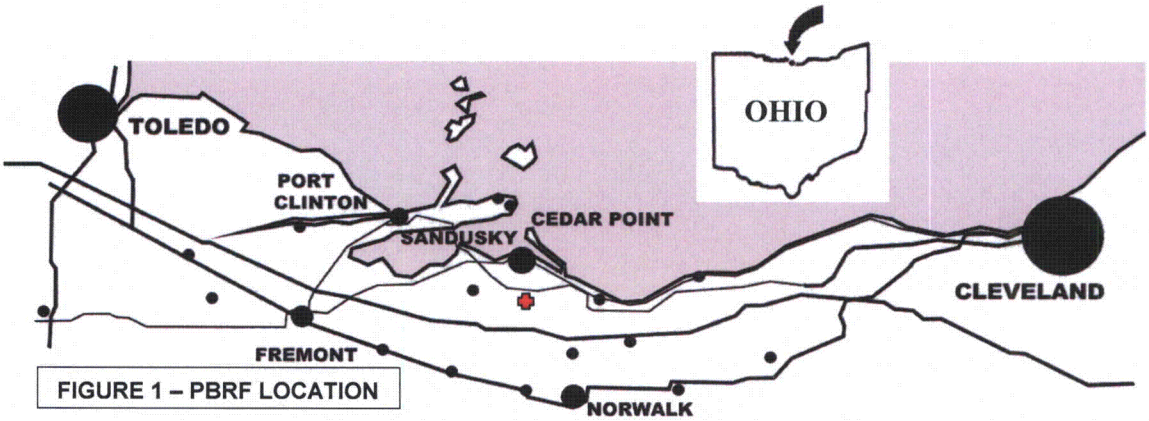


FIGURE 1 – PBRF LOCATION

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 PBCC ponds are illustrated in Figures 1 and 2.

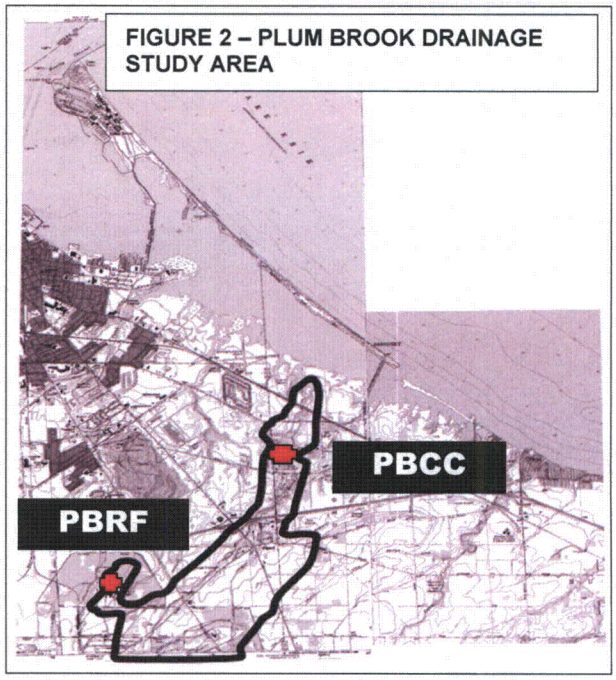


FIGURE 2 – PLUM BROOK DRAINAGE STUDY AREA

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.

NASA constructed its nuclear reactor for research purposes, on the former site of the PBOW's Pentolite manufacturing facility. Pentolite is a high-explosive product. NASA's PBRF operated there for a decade, between 1963 and 1973. Cooling water from the reactor was discharged after testing to a channel named Pentolite Ditch, which ran beside Pentolite Road. Drainage from an explosives-contaminated PBOW pond called the Pentolite Road Red Water Pond (PRRWP) joined Pentolite Ditch, just before the ditch joined the creek named Plum Brook.

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 ponds at the PBCC.

Two pond locations were examined. The northernmost of the group was made of two ponds which had originally been separate, and which had become merged together at some time. Figure 3 illustrates these northern ponds. A third pond was located a short distance to the South, as illustrated by Figure 4.

When HaagEnviro approached the PBCC regarding these ponds, it was learned that at least the northern ponds had been dredged, and the dredged material had been placed in piles, which are outlined in Figures 5, 6 and 7. Sampling the northern ponds was therefore redirected to an effort to sample these piles.

FIGURE 3 –
N. PONDS

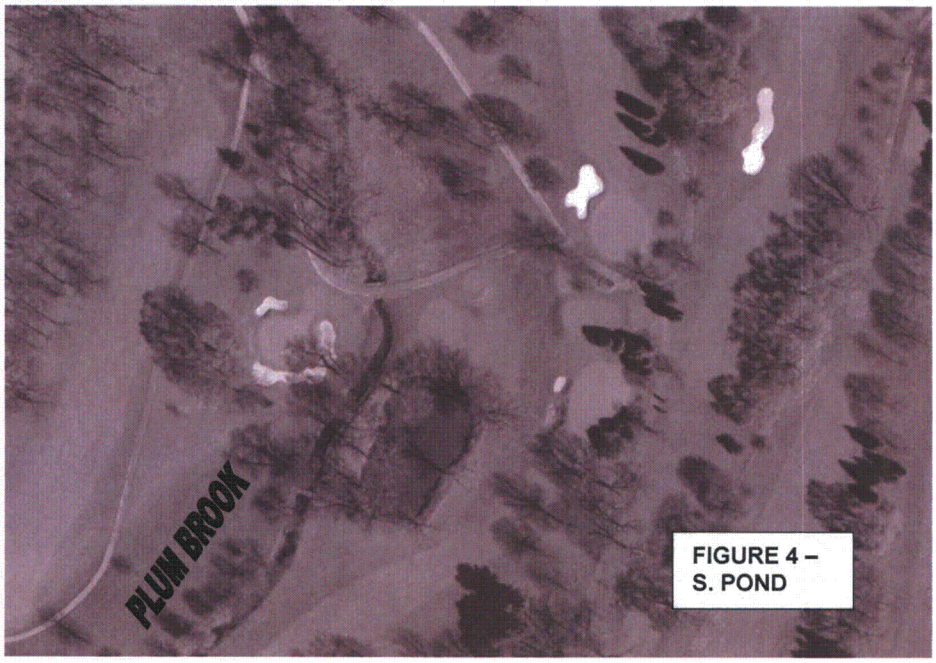


FIGURE 4 –
S. POND

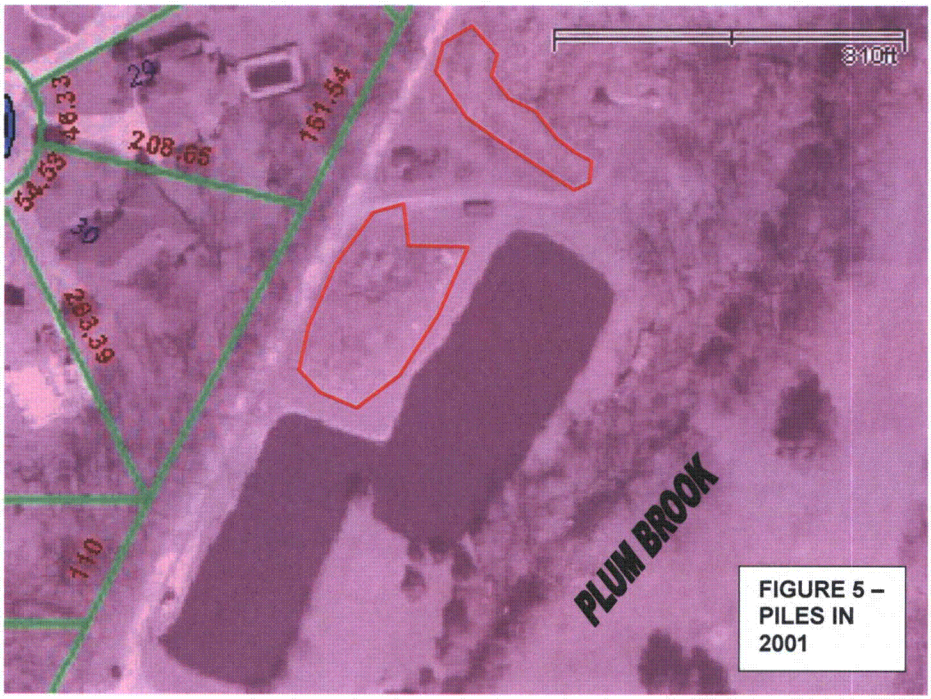


FIGURE 5 – PILES IN 2001

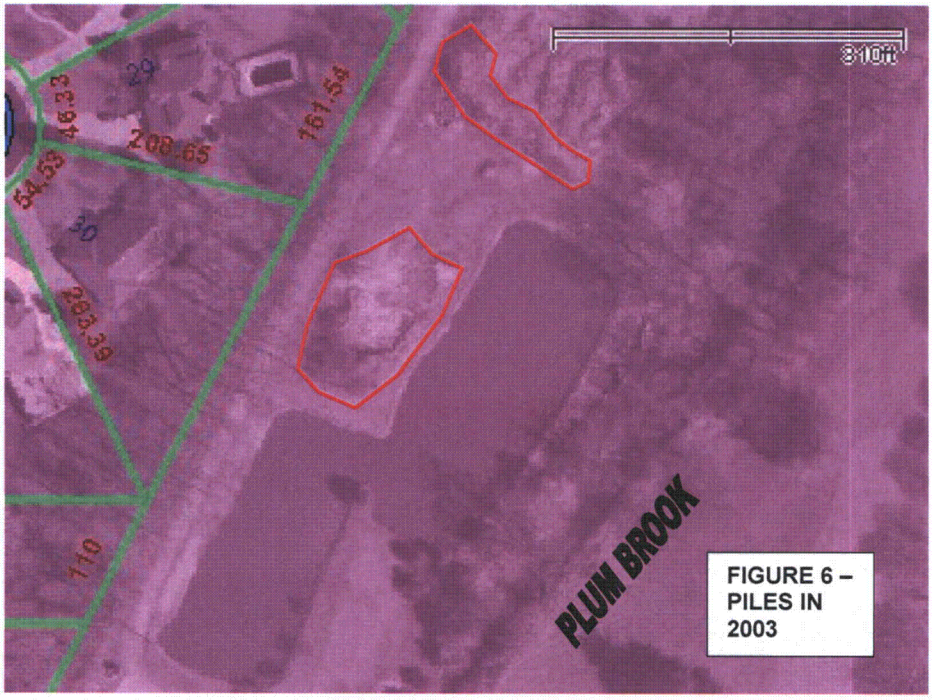


FIGURE 6 – PILES IN 2003

FIGURE 7 – PILES IN 2005

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 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 (Crooks, 2006). 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 1963.

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 pond 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 8.

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

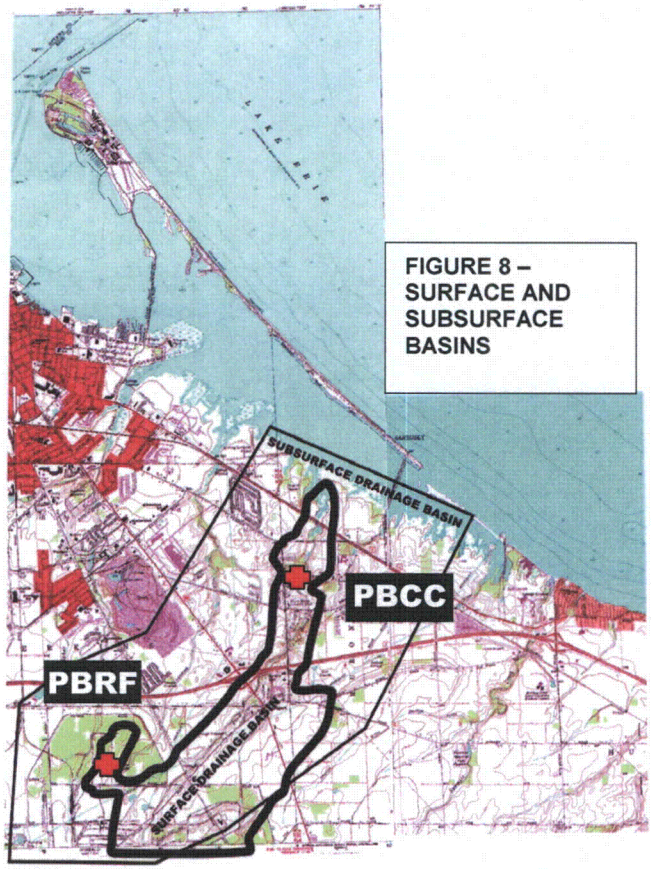


FIGURE 8 – SURFACE AND SUBSURFACE BASINS

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

DATA QUALITY INDICATORS

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

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

RPD is defined here as follows:

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

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

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

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. 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.

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.

Assessing the accuracy of the total measurement system was difficult, because there were no spatial trends about which to observe scatter. To the degree that an evaluation could be made, it was based upon the assumption that the results conformed to a lognormal distribution. Results would therefore not be considered as potential outliers unless they were more than 1 order of magnitude greater or less than the values for samples immediately above or below them.

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 Pond 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, or between tests in the laboratory. Testing results for blank samples should show no detection of the contamination found in field samples.

Three laboratory blanks tested during the ponds investigation were all below the MDA. Blank results are included in the spreadsheet provided as Appendix B.

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 employed are attached to this plan in Appendix A. The laboratory procedure that was employed was PBRF's RP-021.

EXPECTED CHARACTERISTICS OF THE POND DEPOSITIONAL ENVIRONMENT

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

Historical maps and airphotos indicated that 3 ponds were located beside Plum Brook on the grounds of the PBCC, and had been present there prior to 1963. Therefore, during past flooding of Plum Brook, floodwaters transporting Cs-137 on clays might have overflowed into these 3 ponds. The clays might then have settled out in layers at the bottoms of these ponds.

For the 10-year period of interest, from 1963-1973, it was expected that a sediment accumulation of as little as 4 inches might contain all of the targeted Cs-137. It was also considered that a single annual layer, involving elevated levels 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. Thus, the most significant Cs-137 activity might occur in a layer less than one inch thick.

FIGURE 9 – PILE AREAS, CIRCLED IN RED, AS OF 2005

But a one-inch layer bearing Cs-137 would not be detectable in the northern ponds, as PBCC maintenance superintendent Marc Bauer reported that those two ponds had been

dredged at least 10 years prior to this 2006 investigation. Bauer indicated that the soil removed from the two connected northern ponds was mounded in two general pile areas, which he pointed out. One pile area was to the West of the two ponds, and the second pile area was to the North of the joined ponds. The two pile areas are circled in red on Figures 5, 6, 7 and 9.

Since the dredging, Mr. Bauer reported that soil from the pile located west of the ponds was gradually used throughout the golf course as fill dirt, mostly along cart paths. The reduction in pile size is illustrated on Figure 9.

Mr. Bauer indicated that the southern pond had not been dredged, and he indicated that the samplers should expect it to have a depth of roughly 3 feet of water.

When asked about a nearby pile of light tan sand, and a large pile of dark brown soil, Mr. Bauer indicated that neither came from the ponds.

METHODS

HaagEnviro consulted with the PBCC staff, before and during the sampling effort. Bob Haag and Ben Patterson visited the country club on several occasions before sampling. Maintenance superintendent Marc Bauer was the main site contact. HaagEnviro scientists and MOTA staff members also visited the PBCC site together, to view the ponds and to plan and guide the location of field samples.

Based upon the HaagEnviro Characterization Plan for the pond depositional environment, MOTA prepared Survey Request (SR) number 33 to cover this work. NASA's Radiation Safety Officer (RSO), Bill Stoner, approved SR 33.

In the field, one HaagEnviro scientist directed locations, operated the sampling devices, PID-screened and logged the samples, and made field judgments regarding the character of the depositional environment and the need for more or fewer samples. Two MOTA Operations Technicians assisted the scientist in sampling, sampler transport, preparation, and decontamination. MOTA Radiation Protection (RP) Technicians scanned samples and surfaces for radioactivity, and maintained sample custody according to PBRF decommissioning procedures.

HaagEnviro obtained samples using a GeoProbe dual-tube system. MOTA RP Technicians performed surface scans following PBRF procedure CS-01. In one area of interest, identified by surface scanning, MOTA RP Technicians obtained a soil sample following PBRF procedures.

Samples were analyzed quantitatively in the PBRF onsite laboratory. Data reduction and review involved comparison of results with DQIs, a comparison with the proposed action level of 12 pCi/g, and a comparison of log-transformed results with a classification system developed by HaagEnviro for the project.

PLUM BROOK COUNTRY CLUB (PBCC) CONSIDERATIONS

HaagEnviro initially consulted with PBCC maintenance superintendent Marc Bauer, who assisted in obtaining access permission through the club's attorney and the club's president. There were few golfers on the course during this late October sampling event. The samplers were asked to stay off the golf course itself, but were given access to dirt maintenance roads, and were provided with a PBCC johnboat for sampling of the southern pond, as well as PBCC golf carts.

SAMPLE POINT LOCATION

In the original plan, 3 sampling points had been allocated to each of the 3 ponds, for a planned total of 9 locations. For the southern pond, this plan was followed, and 3 points were distributed across the center of the pond's long axis. The remaining 6 planned points were allocated according to the footprint size of the two pile areas. Two points were allocated to the western pile, which was the smaller of the two as of 2006. The

remaining 4 points were allocated to the larger northern pile. Two surface sampling locations were added by MOTA, based upon their surface scanning results. After the samples were obtained, the sample locations were recorded by MOTA RP technicians, using a NASA-provided global positioning system (GPS) device, which was a Trimble model TSCe coupled with an integrated GPS/beacon antenna (part number 29653-00).

SAMPLING METHODS

The soil piles were sampled from top to bottom using HaagEnviro's Bobcat-mounted probe driver on top of the piles. The smaller of the two piles is illustrated in Figure 10, and the probe driver is shown in Figure 11.

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. 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, or to hard-clay resistance. For the pile work, the core samples were cut into a top 6-inch segment, followed by 12-inch segments down to the bottom of the tube.

FIGURE 10 - SMALLER DREDGED PILE, WITH TREES, BEHIND UNRELATED PILE IN FOREGROUND

The MOTA RP Technicians performed surface scanning for Cs-137 on accessible pile surfaces, and in the excavated open area shown in Figure 10, where a worker is standing behind a green rolloff container. The scanning action level, that would cause the MOTA RP Technicians to obtain a sample, was 300 gross counts per minute (gcpm). Based upon data from stream meander survey SR-11, as presented in Figure 7 of the Concept Report, it appears that a field scanning measurement of 300 gcpm would correspond to a laboratory measurement of 3.5±1 pCi/g.

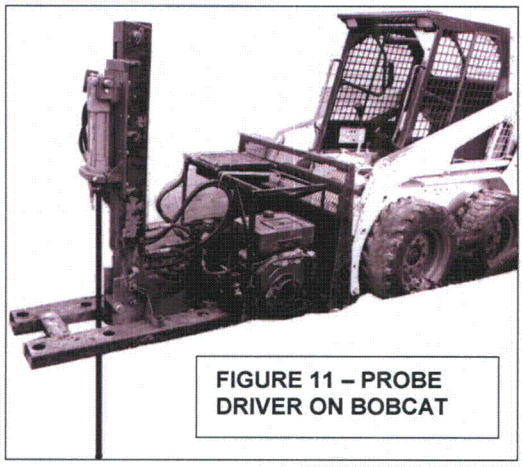


FIGURE 11 – PROBE DRIVER ON BOBCAT

The MOTA RP Technicians also performed surface scanning for Cs-137 on odd-numbered golf holes, except hole #5, on the fairway side of the cart path. Fifty yards per hole were scanned between the white 150-yard line and the red 100-yard line. An additional quality control (QC) scan was performed along 50 yards of the cart path at golf hole #17.

For one area of interest near the piles, with readings exceeding 300 gcpm in the surface scan, MOTA technicians obtained two samples by digging to 6 inches with a shovel.

To sample the sediment at the bottom of the southern pond, shown in Figure 12, the inner plastic tube of the dual-tube sampler was pressed to the bottom. In the pond, it was considered that pre-1963 sediments had been reached, and sampling could be terminated, when hard resistance was encountered. The sequence of steps was as follows:

1. Move boat to pond sample location.
2. Press string of solid steel GeoProbe inner drive rods into pond-bottom sediment until refusal is reached.
3. Attach a 5-foot-long inner plastic GeoProbe sampler to a second string of GeoProbe inner drive rods.
4. Using the first set of solid rods to anchor the boat, press the 5-foot-long inner plastic tube down into sediment, until refusal is reached.
5. Retrieve sampler for scanning and logging.

FIGURE 12 – SOUTHERN POND

The metal sampling equipment was decontaminated before each borehole was started. Each 5-foot-long sample was captured in a new plastic tube. For the pond work, the core samples were cut into 3-inch segments.

FIELD-SCREENING AND CHAIN-OF-CUSTODY DOCUMENTATION

Upon extraction, the sampling devices were screened by the RP technician for radioactivity, and by the environmental scientist for organic compounds. The RP technician employed a NASA-provided Ludlum model 2350 meter with a model 4410 probe, and a gamma-spectrum window set to focus on Cs-137 activity. The scientist 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.

The plastic sample tubes were cut into 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.

SAMPLE PREPARATION FOR QUANTITATIVE ANALYSIS

In the course of sample processing, the pond samples were cut open and photographed. As dredging would have destroyed any stratigraphic information, the pile samples were not photographed. After they were photographed, the samples were composited as follows: (a) the top 6 inches of each sample core were combined, and (b) successive 12-inch lengths of sample core beneath the top were each combined. When an additional core segment remained at the bottom of the core, it was combined with the composite above it. The composite samples were then dried, sieved, and analyzed in the PBRF onsite laboratory to obtain quantitative results.

QUANTITATIVE LABORATORY ANALYSIS

The tube samples were analyzed by gamma spectroscopy in the PBRF onsite laboratory following PBRF procedure RP-021. Three samples were recounted once and one sample was recounted twice.

DATA REDUCTION, INTERPRETATION, AND REPORTING

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

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

OBSERVATIONS

FIELD SAMPLING AND SCANNING OBSERVATIONS

Surface scans of the two soil piles, themselves, produced no areas exceeding the action level of 300 gcpm. Soil samples from the piles produced sample recoveries of 58-100%, and the soil was generally characterized as "light brown clay with minor sand." All soil or sediment samples obtained from the two piles produced PID screening results and NaI scanning results at background levels.

The flat area, where soil had been excavated from the pile west of the two merged ponds, had several places in which surface scans exceeded the 300 gcpm action level. One reading was reported to be 541 gcpm, with a background of approximately 50 gcpm. A QC recount of this location yielded a count of 489 gcpm, with a background reading similar to the first. This caused the MOTA RP Technicians to obtain soil samples COC-7EAST and COC-7WEST in this area. The area of elevated activity at COC-7EAST was approximately 5 square feet (SF) and COC-7WEST was approximately 10 SF. The soil samples from these areas were identified as SP-1 and SP-2. SP-1 was associated with COC-7WEST, and SP-2 with COC-7EAST. Due to the presence of dense brush and debris, the MOTA RP Technicians could not scan an area of approximately 300 SF that was adjacent to COC-7EAST and COC-7WEST.

The measured depth of the southern pond, expected to be approximately 3 feet deep, was effectively about 9 feet deep. The water depth to the top of very soft sediment, that would not support a person wading, was typically only about 3-4 feet, with the very soft sediment below extending another 5 feet in depth. This caused a change in the planned sampling approach. The originally planned sampling approach had involved workers wading into the pond, and driving the dual-tube sampler into the sediment. The approach was revised so that the inner tube of the sampling device was lowered over the end of a johnboat provided by the PBCC, and was manually pressed into the soft bottom sediment.

Sediment samples from the southern pond were generally characterized as "light tan or gray fine sand" at the bottom, grading up into "dark gray or brown soft clay," and finally grading up into "minor organics" at the top of the section. Sample recovery was difficult to estimate, as the material at the top was very loose, almost liquid. The 5-foot-long sampling device was pushed through approximately 6 feet of increasingly-dense sediment. The typical sample length recovered from such a pass through 64-90 inches of sediment was 20-25 inches of sample, so recovery might be estimated at 22-39%.

All soil or sediment samples obtained from the southern pond produced PID screening results and NaI scanning results at background levels.

The surface scans along the cart path to odd-numbered golf holes produced no readings exceeding the action level of 300 gcpm.

OBSERVATIONS FROM PREPARING SAMPLES FOR QUANTITATIVE ANALYSIS

Representative photographs, from the center of the southern pond, are provided in Figure 13.

FIGURE 13 – CORE SAMPLES FROM MIDDLE OF S. POND

OBSERVATIONS FROM LABORATORY ANALYSES

Laboratory results are compiled in Appendix B. In general, they can be summarized as follows:

Un-Excavated Part of Dredged Pile North of 2 Joined Ponds: Peak Cs-137 activity of 7.5 pCi/g; some values ranging from 3.3-4.7 pCi/g in the middle of the pile.

Un-Excavated Part of Dredged Pile West of 2 Joined Ponds: Cs-137 activity mostly <0.1 pCi/g; some values of approximately 0.3 pCi/g are scattered through the pile.

Excavated Area of Dredged Pile West of 2 Joined Ponds: Cs-137 activity approximately 2-10 pCi/g, on the ground surface where this pile was, before it was excavated for use on the golf course.

Sediment in Bottom of Single Southern Pond: Cs-137 activity approximately 1-3 pCi/g; with the slightly higher levels occurring at the bottom of the sediment.

All RPDs from laboratory recounts were less than 20%.

Key, or highest, values are posted on Figures 14 and 15.

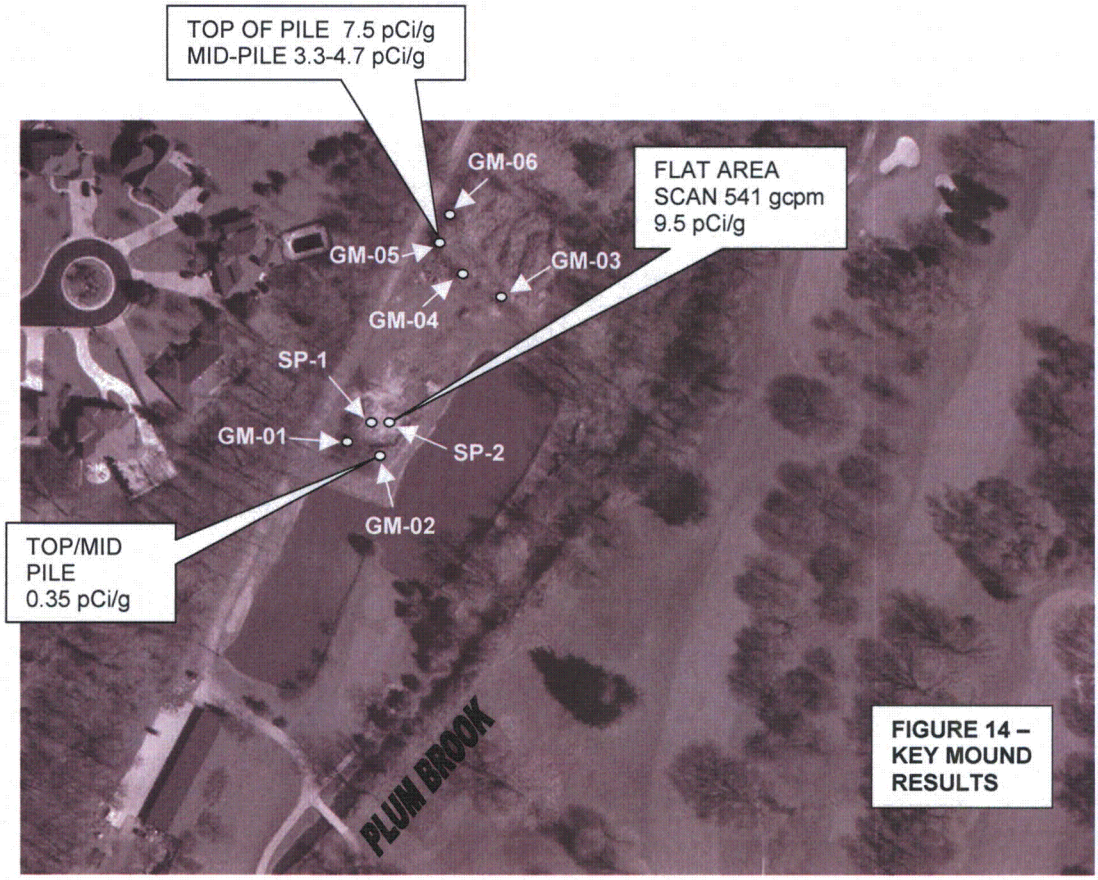


FIGURE 14 – KEY MOUND RESULTS

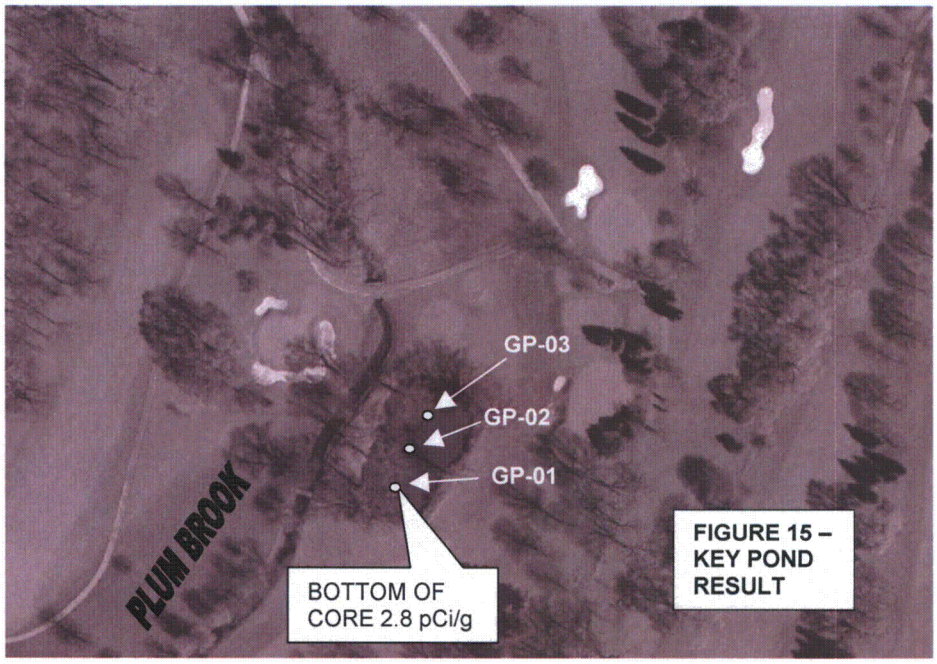


FIGURE 15 – KEY POND RESULT

INTERPRETATIONS

MECHANISM OF CS-137 TRANSPORT

The proposed mechanism of transport appears to be confirmed by this work. It does appear that clays bearing Cs-137 from the PBRF were deposited by flooding that reached the 3 ponds at the PBCC. Pumping from the northern ponds, with makeup water obtained from Plum Brook, may have increased the potential for Cs-137 accumulation there.

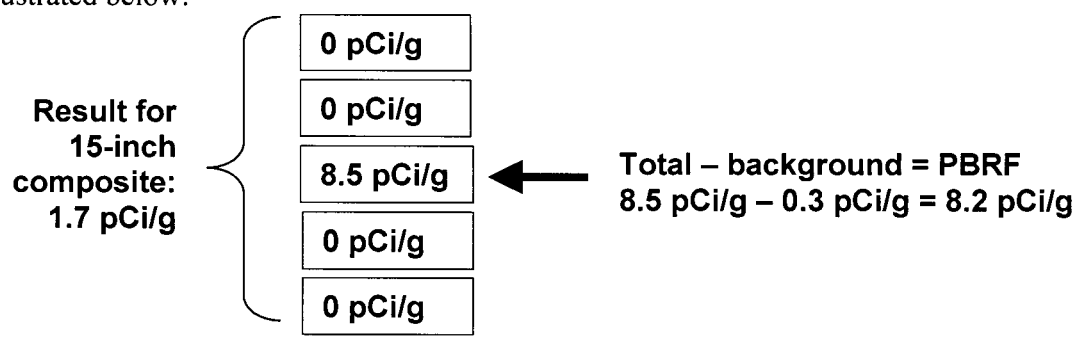
ACCOUNTING FOR CS-137 KNOWN TO BE RELEASED

HaagEnviro interprets that all of the Cs-137 found in this pond/pile study was originally contained within the 3 ponds. HaagEnviro interprets that the PBRF Cs-137 was deposited in a layer that was thinner than the composite samples, which each represent either the top 6 inches of sediment, or successive 12-15-inch sections below that top 6 inches.

The Cs-137 testing results from the pond bottom were all below 3 pCi/g, which is considered the practical quantitation limit for this study. For purposes of illustration, however, we employed some figures less than 3 pCi/g. If necessary to support the evaluation, PBRF will perform investigational surveys and sampling to better quantify the activity.

To illustrate the relative magnitudes of potential contributions to the overall Cs-137 mass balance, we considered that the average Cs-137 activity reported for the southern pond might actually have been concentrated in a 3-inch layer within a 15-inch sample. For this evaluation, we assumed that the remaining 12 inches of the sample contributed no activity. For the 3-inch layer, we used the average of the peak values from 3 pond-bottom samples (the average of 2.8, 1.3, and 0.9 = 1.7).

We assumed that atmospheric testing during the same time that the PBRF operated contributed a Cs-137 background, which we 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 assumed contributions are illustrated below:



The result of this particular set of assumptions would be a PBRF contribution of 8.2 pCi/g, over a 3-inch layer within the southern pond. If we assume that the same layer was originally present in all 3 ponds, and we estimate their collective surface area at 80,000 square feet (SF), then we could estimate the PBRF Cs-137 activity that was captured by the ponds as follows:

$$80{,}000\ ft^2 \times 0.25\ ft = 20{,}000\ ft^3$$
$$20{,}000\ ft^3 \times 100\ lbs/\ ft^3 = 2{,}000{,}000\ lbs$$
$$2{,}000{,}000\ lbs \times 454\ g/lb = 9.08 \times 10^8\ g$$
$$9.08 \times 10^8\ g \times 8.2\ pCi/g = 0.74 \times 10^{10}\ pCi$$

Comparing this to the 0.25×10^{10} pCi of PBRF Cs-137 activity that we estimated as remaining to be found in the year 2006, the Pond study area would be the resting place for three times the amount assumed to have been released from the PBRF.

Based upon the limited data obtained in this study, it would be premature to conclude that the computed amount of 0.74×10^{10} pCi of Cs-137 is actually present in these ponds. Rather, the purpose of this calculation exercise is to illustrate the relative magnitude of measurements needed to support a mass-balance evaluation.

Balance to within an Order of Magnitude - As noted in the section entitled "Limits on Decision Errors," we 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. That is achieved in this estimate. However, in this Pond study area exercise, we can see 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.

IDENTIFY CS-137 DEPOSITS STILL IN TRANSIT

Except for the dredging process, the Cs-137 trapped in these pond sediments would not be expected to be mobile.

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

In the un-dredged southern pond, the Cs-137 deposited there is expected to remain in place. With regard to the sediment dredged from the other two ponds, the Cs-137 that was originally deposited there has apparently been distributed across the golf course.

CHARACTERISTICS OF CS-137 DEPOSITS THAT AFFECT REMOVAL

If Cs-137 should be found on PBCC property at levels of concern, it does not appear that the clay carrying that Cs-137 could easily be separated from other sediment.

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 SAMPLING WITH INNER TUBE OF GEOPROBE DUAL-TUBE SYSTEM

Sampling soft sediment with a total recoverable thickness of up to 5 feet will be accomplished with the inner plastic tube of a Geoprobe dual-tube system.

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
- Geoprobe adapter from sampler to 1" drill rod
- 3' long by 1" diameter drill rods
- 10.6 eV photoionization detector (PID), for explosives
- Sodium Iodide (NaI) detector, for Cs-137 activity
- Sharpie fine point marker
- Tape measure
- Utility knife

PROCEDURE

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

1. Warm up and calibrate PID
2. Decontaminate all metal parts
3. Allow parts to air dry, or dry with paper towel
4. Obtain background readings with PID and NaI meters
5. Assemble sampler consisting of inner plastic tube, adapter, and drill rods
6. Allow weight of rods to drive sampler into sediment, then press down gently so as not to bend or break the plastic tube
7. Extract plastic tube, with sample inside
8. Use PID to screen bottom of sample
9. Cap bottom of clear tube with red cap
10. Measure 3" from end of core and cut with utility knife, label plastic tube with sample location and depth interval
11. Cap the top of the 3" core with a black cap
12. Screen next "bottom" section and cap with red cap
13. Measure 3" from end of "new" core and cut with utility knife, label plastic tube with sample location and depth interval
14. Continue steps 11 through 13 until every section is screened and capped.
15. Perform NaI screening on every 3" sample, using a one-minute count
16. Record findings

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
- One red and one black sampling tube end caps per 6" or 12" sub-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
- 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. Cut off top of tube where recovered sample ends; measure down 6" from top of recovered core and cut with decontaminated hacksaw.
8. Use PID to screen bottom of sample
9. Cap the top of the 6" core with a black cap, bottom with a red cap
10. Label bottom tube cap with sample location and bottom depth interval
11. Measure down 12" from top of remaining core and cut with hacksaw
12. PID-screen bottom of sample
13. Cap top of 12" core with a black cap, bottom with a red cap
14. Label bottom cap with sample location and depth interval
15. Continue steps 11 through 14 until every section is screened and capped.
16. Record findings in notebook.

APPENDIX B

LABORATORY RESULTS
(Provided as a separate computer file named 298PondsSpreadsheet.xls)

17-Apr-07 GM-01

Sample Number	Depth (inches)	CS-137 Result (pCi/g)	MDA (pCi/g)	Lab Flag	Uncertainty 2 Sigma (%)	2 Sigma (pCi/g)	(Result - 2 Sigma) - MDA (+ = good, - = bad)	R.Case Note	Haag Note	Recount (pCi/g)
SR-33-1	0-6	~~0.125~~	0.105	#	**74.4**	0.093	**-0.073**	NO		
SR-33-2	6-18	<	0.12	B<						
SR-33-3	18-30	<	0.076	B<						
SR-33-4	30-42	0.309	0.114	#	44.72	0.138	0.057	OK		
SR-33-5	42-52	~~0.128~~	0.135	#A	**75.59**	0.097	**-0.104**	NO		
SR-33-6	60-72	<	0.139	B<						
SR-33-7	72-78	<	0.126	B<						

COLOR KEY

magenta	Detection at top
yellow	Detection in middle
orange	Detection at bottom

17-Apr-07 GM-02

Sample Number	Depth (inches)	CS-137 Result (pCi/g)	MDA (pCi/g)	Lab Flag	Uncertainty 2 Sigma (%)	2 Sigma (pCi/g)	(Result - 2 Sigma) - MDA (+ = good, - = bad)	R.Case Note	Haag Note	Recount (pCi/g)
SR-33-8	0-6	0.345	0.118		42.12	0.146	0.081			
SR-33-9	6-18	~~0.153~~	0.173	#A	**93.58**	0.144	**-0.164**	NO		
SR-33-10	18-30	<	0.12	B<						
SR-33-11	30-42	<	0.13	B<						
SR-33-12	42-49.5	<	0.102	B<						
SR-33-13	60-75.5	<	0.163	B<						

17-Apr-07

GM-03

Sample Number	Depth (inches)	CS-137 Result (pCi/g)	MDA (pCi/g)	Lab Flag	Uncertainty 2 Sigma (%)	2 Sigma (pCi/g)	(Result - 2 Sigma) - MDA (+ = good, - = bad)	R.Case Note	Haag Note	Recount (pCi/g)
SR-33-14	0-6	2.254	0.164		11.96	0.277	1.813			2.255
SR-33-15	6-18	0.885	0.199		28.35	0.252	0.434			
SR-33-16	18-30	1.245	0.155		20.83	0.262	0.828			
SR-33-17	30-38	0.323	0.125	#	45.88	0.148	0.05	OK		
SR-33-18	60-65	<	0.177	B<						

17-Apr-07

GM-04

Sample Number	Depth (inches)	CS-137 Result (pCi/g)	MDA (pCi/g)	Lab Flag	Uncertainty 2 Sigma (%)	2 Sigma (pCi/g)	(Result - 2 Sigma) - MDA (+ = good, - = bad)	R.Case Note	Haag Note	Recount (pCi/g)
SR-33-19	0-6	0.713	0.173	#	29.63	0.212	0.328	OK		
SR-33-20	6-18	4.739	0.085		9.89	0.493	4.161			
SR-33-21	18-30	2.142	0.14		11.65	0.259	1.743			
SR-33-22	30-39	2.155	0.143		15.67	0.343	1.669			
SR-33-23	60-72	~~0.232~~	0.158		**66.49**	0.154	**-0.08**		Reject	

17-Apr-07

GM-05

Sample Number	Depth (inches)	CS-137 Result (pCi/g)	MDA (pCi/g)	Lab Flag	Uncertainty 2 Sigma (%)	2 Sigma (pCi/g)	(Result - 2 Sigma) - MDA (+ = good, - = bad)	R.Case Note	Haag Note	Recount (pCi/g)
SR-33-24	0-6	7.451	0.233		6.81	0.554	6.664			
SR-33-25	6-18	1.703	0.168		18.22	0.315	1.22			
SR-33-26	18-30	3.257	0.193		12.67	0.423	2.641			
SR-33-27	30-40	1.388	0.183		20.37	0.285	0.92			
SR-33-28	60-64	0.333	0.145		48.98	0.163	0.025			

17-Apr-07 GM-06

Sample Number	Depth (inches)	CS-137 Result (pCi/g)	MDA (pCi/g)	Lab Flag	Uncertainty 2 Sigma (%)	2 Sigma (pCi/g)	(Result - 2 Sigma) - MDA (+ = good, - = bad)	R.Case Note	Haag Note	Recount (pCi/g)
SR-33-29	0-6	0.717	0.199	#	34.88	0.251	0.267	OK		
SR-33-30	6-18	2.286	0.138		11.35	0.268	1.88			1.953
SR-33-31	18-30	2.05	0.12		14.57	0.306	1.624			
SR-33-32	30-36	1.581	0.187		19.64	0.315	1.079			
SR-33-33	60-65	0.553	0.129		29.02	0.161	0.263			

17-Apr-07

SP1 & SP2 (COC-7)

Sample Number	Depth (inches)	CS-137 Result (pCi/g)	MDA (pCi/g)	Lab Flag	Uncertainty 2 Sigma (%)	2 Sigma (pCi/g)	(Result - 2 Sigma) - MDA (+ = good, - = bad)	R.Case Note	Haag Note	Recount (pCi/g)
SR-33-34, Flat-SP1	0-6	2.209	0.188		13.03	0.295	1.726			2.17, 2.58
SR-33-35, Flat-SP2	0-6	8.52	0.128		7.46	0.691	7.701			9.49

17-Apr-07 GP-01

Sample Number	Depth (inches)	CS-137 Result (pCi/g)	MDA (pCi/g)	Lab Flag	Uncertainty 2 Sigma (%)	2 Sigma (pCi/g)	(Result - 2 Sigma) - MDA (+ = good, - = bad)	R.Case Note	Haag Note	Recount (pCi/g)
SR-33-36	109-115	1.122	0.312		31.62	0.356	0.454	Qualitative		
SR-33-37	115-130	2.761	0.16		10.68	0.305	2.296			

17-Apr-07 **GP-02**

Sample Number	Depth (inches)	CS-137 Result (pCi/g)	MDA (pCi/g)	Lab Flag	Uncertainty 2 Sigma (%)	2 Sigma (pCi/g)	(Result - 2 Sigma) - MDA (+ = good, - = bad)	R.Case Note	Haag Note	Recount (pCi/g)
SR-33-38	93-99	~~0.529~~	0.451	#	**73.18**	0.388	**-0.31**	NO, **Qualitative**		
SR-33-39	99-114	1.321	0.153		16.42	0.221	0.947			

17-Apr-07 GP-03

Sample Number	Depth (inches)	CS-137 Result (pCi/g)	MDA (pCi/g)	Lab Flag	Uncertainty 2 Sigma (%)	2 Sigma (pCi/g)	(Result - 2 Sigma) - MDA (+ = good, - = bad)	R.Case Note	Haag Note	Recount (pCi/g)
SR-33-40	86-92	1.12	0.314		31.63	0.356	0.45	Qualitative		
SR-33-41	92-110	0.915	0.188		28.01	0.258	0.469			

17-Apr-07

BLANKS

Sample Number	Depth (inches)	CS-137 Result (pCi/g)	MDA (pCi/g)	Lab Flag	Uncertainty 2 Sigma (%)	2 Sigma (pCi/g)	(Result - 2 Sigma) - MDA (+ = good, - = bad)	R.Case Note	Haag Note	Recount (pCi/g)
PB06-03603		<	0.103	B<						
PB06-03604		<	0.11	B<						
PB06-03605		<	0.138	B<						