DEVELOPMENT OF CONCEPTUAL MODEL AS BASIS FOR CHARACTERIZATION PLAN PLUM BROOK REACTOR FACILITY PERKINS TOWNSHIP, OHIO

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PURPOSE

In May of 2006, the National Aeronautics and Space Administration (NASA) retained Haag Environmental Company (HaagEnviro) to contribute to NASA's evaluation efforts as it decommissioned NASA's Plum Brook Reactor Facility (PBRF) near Sandusky, Ohio.

NASA particularly wished HaagEnviro to assess the potential hydrogeologic distribution of a radioactive isotope of the element cesium, known as ^{137}Cs, or Cs-137. NASA had discovered small amounts of Cs-137 in the sediments of a creek known as Plum Brook, which passed through the NASA property, and extended down to the eastern end of Sandusky Bay on Lake Erie.

The initial HaagEnviro task was to review and evaluate existing data, to form the basis of a Characterization Plan, which would define proposed sampling efforts.

HaagEnviro presented the results of the data review, and the resultant rationale for characterization, in a briefing of NASA on 22-May-06. With NASA concurrence following that briefing, HaagEnviro then prepared the Characterization Plan.

The purpose of the report which follows is to document the data review and conceptual model upon which the Characterization Plan was based.

INTRODUCTION AND BACKGROUND

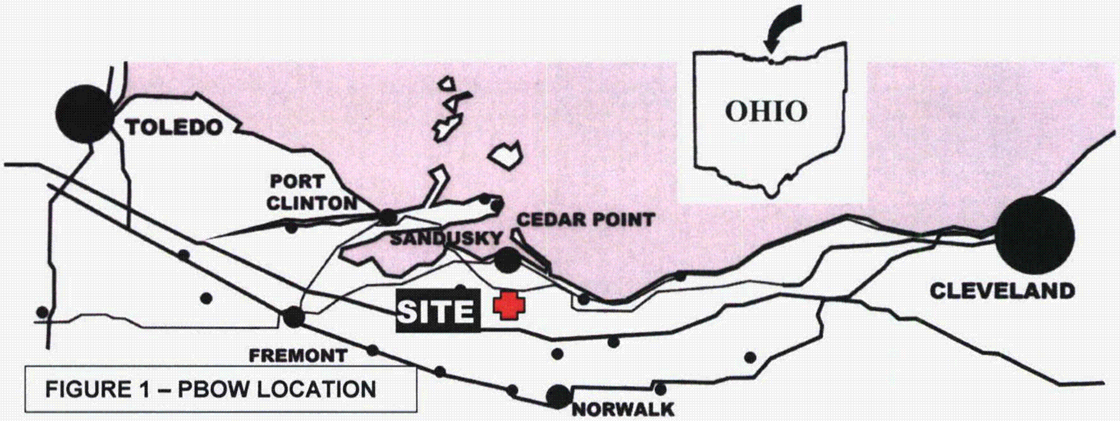


FIGURE 1 – PBOW LOCATION

The site location is shown in Figure 1.

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.

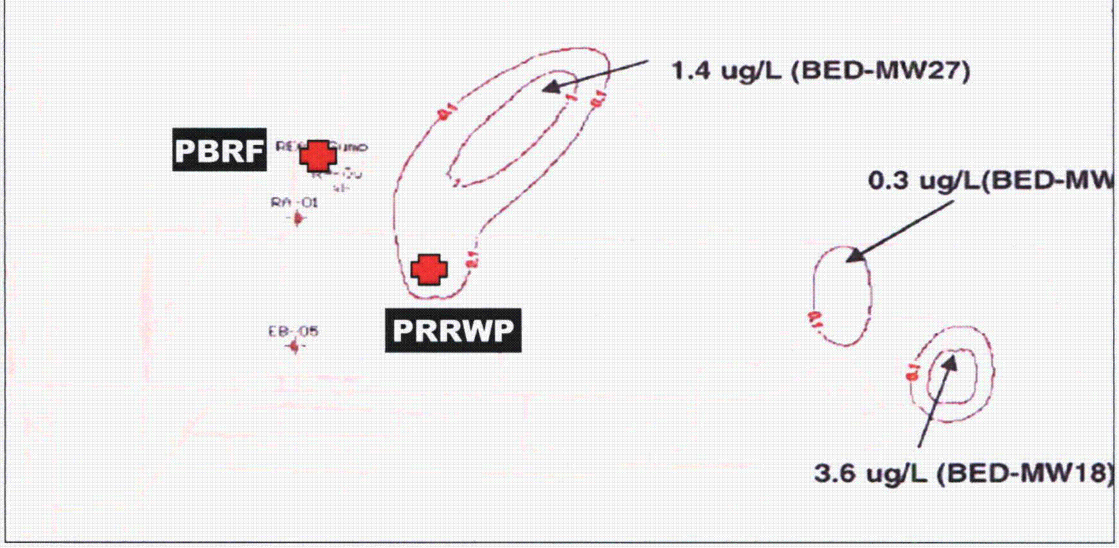
Water was an essential element for nuclear reactor operations. Raw water from Lake Erie was pumped to the site at roughly 400-800 gallons per minute to support plant operations. Most raw water was softened through precipitation, sand filtering and chlorination to become process water. As needed, process 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.

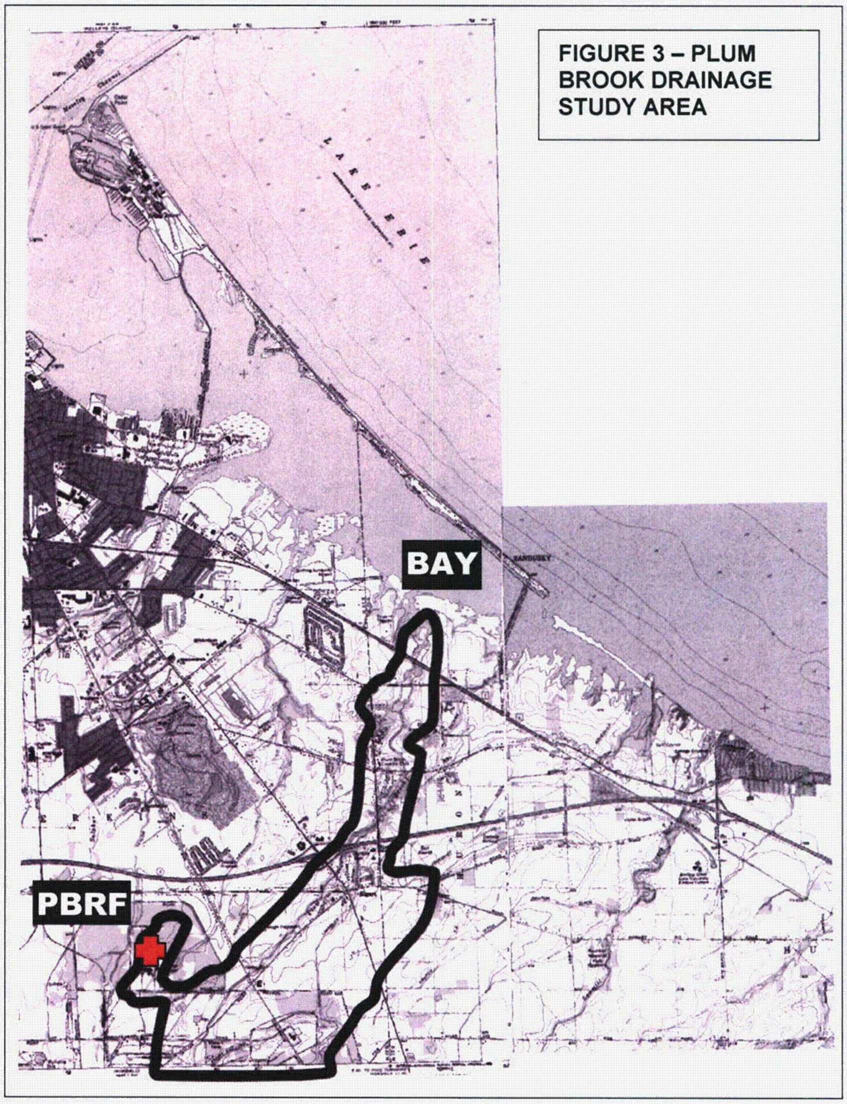
PBRF effluent water was released from the site directly into Pentolite Ditch, which runs along the south side of Pentolite Road. PBRF effluents mixed with drainage from the remains of the contaminated PBOW pond called the Pentolite Road Red Water Pond (PRRWP). This pond was south of Pentolite Ditch, 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.

FIGURE 2 – PRRWP PLUME NEAR PBRF



The U.S. Army Corps of Engineers (USACE) documented groundwater contamination from the PRRWP, as illustrated in Figure 2.

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. The potentially affected drainage basin is shown in Figure 3.



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.

SCOPE OF WORK

This report was intended to document the Conceptual Model presentations that HaagEnviro provided to NASA, showing how the existing-data review led HaagEnviro to develop the Characterization Plan.

The work performed was collected into the following task groups:

1. Obtain data
2. Review and Interpret Data
3. Develop Conceptual Models
4. Prepare Characterization Plan

<u>Obtain Data</u> – included the following efforts:

- Obtain historical culvert data from Erie County (1961-1973)
- Obtain historical airphotos from ODOT* (1961-1973)
- Obtain and plot historical rainfall data (1961-1973)
- Obtain and plot historical stream gage data (1961-1973)
- Obtain wetlands definition data from ODNR
- Obtain Sandusky Bay data from OEPA and ODNR
- Obtain selected trial cores for dating concept evaluation

<u>Review and Interpret Data</u> – included the following efforts:

- Review existing files at Plum Brook Station
- Review GW model report from Plum Brook Station
- Review Sandusky Bay data from OEPA
- Correlate NaI results with laboratory results
- Clarify historical SRO release concept (1961-1973)
- Clarify current SRO release concept (2006)
- Clarify GW release concepts
- Identify available sediment deposit dating concepts
- Identify existing wells useful for GW assessment

<u>Develop Conceptual Model</u> – included the following efforts:

- Define and illustrate SRO concept
- Define and illustrate GW concept

Prepare Characterization Plan – included the following efforts:

- Lay out additional wells for GW assessment
- Lay out NaI screening for Midstream Plum Brook drainage area
- Lay out NaI screening for Downstream Plum Brook drainage area
- Lay out preliminary bay sample screening locations
- Prepare surface and GW assessment plan for regulatory review

*Acronyms, in order of use above:

ODOT – Ohio Department of Transportation
OEPA – Ohio Environmental Protection Agency
ODNR – Ohio Department of Natural Resources
SRO – Surface Run Off
GW – Ground Water
NaI – Sodium Iodide (a sensor for radioactivity)

METHODS

HaagEnviro reviewed available published data, available data from the PBRF and the PBOW facilities, and conducted a few trial sampling experiments. HaagEnviro's observations and interpretations were conveyed to NASA in briefings at the PBRF site.

METHODS OF OBTAINING HISTORICAL CULVERT DATA FROM ERIE COUNTY (1961-1973)

Principal Hydrogeologist Bob Haag visited the offices of the Erie County Engineer, and obtained engineering drawings that documented the design of every culvert through which Plum Brook passed, on its trip from Pentolite Ditch to Sandusky Bay. Copies of these drawings were deposited in the PBRF records center.

METHODS OF OBTAINING HISTORICAL AIRPHOTOS (1961-1973)

Senior Scientist Ben Patterson coordinated with Rick Hentz at the ODOT Office of Aerial Engineering, and ordered photopositive prints of stereo pairs for flights covering Plum Brook from PBRF to Sandusky Bay. Hentz researched the area requested by Patterson, then provided a list of 49 relevant prints, spanning the time before and after the PBRF was in operation. These prints were purchased, reviewed in stereo by Bob Haag, and were then placed in the PBRF records center. In addition, Bob Haag obtained airphoto coverage on compact discs (CDs), from the Erie County auditor. The auditor airphotos were dated 2001, 2003, and 2005. Relevant airphotos were also copied at the Erie County Engineer's office. All of these airphotos were deposited in the PBRF records center. As part of work conducted by the nonprofit organization HaagInsight, Bob Haag had previously obtained a copy of a 1937 airphoto at the City of Sandusky Engineer's office. From this 1937 airphoto, Haag traced land features in the eastern end of Sandusky Bay, and scanned this tracing into a computer file.

METHODS OF OBTAINING AND PLOTTING HISTORICAL RAINFALL DATA (1961-1973)

Ben Patterson reviewed rainfall data available online from the National Oceanographic and Atmospheric Administration (NOAA). Bob Haag and Patterson determined that for-charge hourly data would not be needed, and instead reviewed NOAA's free monthly precipitation records.

METHODS OF OBTAINING AND PLOTTING HISTORICAL STREAM GAGE DATA (1961-1973)

Patterson determined that the Huron River was the only river in Erie County with recorded data dating back to the time of PBRF operation. He obtained annual peaks of the Huron River at Milan, Ohio, using the following Internet link:

http://nwis.waterdata.usgs.gov/oh/nwis/peak/?site_no=04199000&

Patterson obtained relevant stream level/flow/gage/peak data from the U.S. Geological Survey (USGS) National Water Information System using the following Internet link:

http://nwis.waterdata.usgs.gov/oh/nwis/measurements?search_station_nm=Huron+River&search_station_nm_match_type=beginning&format=station_list&sort_key=site_no&group_key=NONE&sitefile_output_format=html_table&column_name=agency_cd&column_name=site_no&column_name=station_nm&begin_date=&end_date=&set_logscale_y=1&date_format=YYYY-MM-DD&rdb_compression=file&list_of_search_criteria=search_station_nm

Patterson found crests of the Huron River, from the time of reactor operation to the present, by means of the following Internet link:

http://newweb.erh.noaa.gov/ahps2/hydrograph.phpwfo=cle&gage=milo1&view=1,1,1,1,1,1/US

After a flood in July of 1969 had thus been identified as the highest peak flow on record, Principal Scientist Ruth Haag searched for records of that event in a local newspaper called the Sandusky Register.

METHODS OF OBTAINING WETLANDS DEFINITION DATA FROM ODNR

Ben Patterson conducted online research, then communicated with ODNR geographic information system (GIS) person David Crecelius. Patterson then researched the Ohio Wetland Inventory and the National Wetland Inventory. He used the USGS wetlands mapper to create, view and print wetlands maps of Plum Brook, from the PBRF to the stream mouth in Sandusky Bay. He used the following Internet link for this work:

http://wetlandsfws.er.usgs.gov/wtlnds/launch.html

METHODS OF OBTAINING SANDUSKY BAY DATA FROM OEPA AND ODNR

As part of research conducted by the nonprofit organization HaagInsight, Bob Haag had contacted Brent Kuenzli in OEPA's Surface Water Division. Kuenzli, a former student of Haag's at the University of Findlay, had been instrumental in designing and building a vibrocore sampling system for the OEPA. Due to his sampling work, Kuenzli had collected significant personal experience, and open-file information, relevant to the western part of Sandusky Bay. Kuenzli shared his knowledge and his data, and suggested that Haag also contact the ODNR office in Sandusky. Haag visited that ODNR office, and obtained copies of conventional drilling logs for projects in the eastern part of Sandusky Bay. HaagEnviro drew upon these HaagInsight sources for the PBRF work. Bob Haag also contacted the ODNR's Office of Coastal Management, to clarify the regulatory status of some of the areas to be investigated for the PBRF project.

METHODS OF OBTAINING SELECTED TRIAL CORES FOR DATING CONCEPT EVALUATION

Hydrogeologist Bob Haag anticipated that methods for dating the sediment deposits affected by PBRF would be easier to select if a few trial cores of that sediment could be examined. After reviewing this concept with NASA, Haag selected two locations for test coring, as follows:

1. A narrow stream-alluvium location in the upstream part of Plum Brook, near its juncture with Pentolite Ditch. This location had produced a Cs-137 test value of 50.1 pCi/g in prior work by others.

2. A wide stream-bottom wetland location in the downstream part of Plum Brook, nearer to its mouth into Sandusky Bay

In each trial location, HaagEnviro obtained short GeoProbe cores in plastic tubes. The tubes were cut into short sections, and were screened in the field for Cs-137 radioactivity, by Radiation Protection (RP) Technicians from MOTA Corporation, who used a NASA-provided sodium iodide (NaI) detector. Some of the short core sections were also qualitatively screened for Cs-137 activity in the PBRF onsite laboratory. Qualitative results were supplied to HaagEnviro for consideration.

To obtain a sense of field operation practicality, HaagEnviro also requested that MOTA's RP Technicians perform some surface scanning transects using the continuous data logging capabilities of NASA's NaI device. The results were E-mailed to HaagEnviro for review.

METHODS OF REVIEWING EXISTING FILES AT PLUM BROOK STATION

Bob Haag initially reviewed documents provided by NASA and MOTA. Based on background information gleaned from those documents, Haag requested additional documents from the PBRF records center. Haag was also taken to the document room at the Plum Brook Station Engineering Building. There, Haag was able to review documents prepared by the USACE for remedial work being conducted on the PBOW.

METHODS OF REVIEWING GW MODEL REPORT FROM PLUM BROOK STATION

The Environmental Manager for the NASA Plum Brook Station, Bob Lallier, provided Bob Haag with access to, and copies of, the latest reports that had been prepared for the USACE. Lallier also requested Haag's participation in a planning meeting with the USACE, prior to a public presentation by the USACE. During that meeting, Haag listened to a presentation by the risk assessor for the USACE. Haag asked questions to clarify groundwater issues that might have a bearing on the PBRF issues that Haag was studying. Haag then extracted two figures from the USACE risk assessment report, and used those figures to prepare Figure 2 of this report. Haag placed the USACE risk assessment report in the PBRF records center.

METHODS OF REVIEWING SANDUSKY BAY DATA FROM OEPA AND ODNR

As part of HaagInsight's research, Bob Haag had previously sorted data tables that had been provided by OEPA's Brent Kuenzli, to identify positive chemical results in sediments near Sandusky, on the western side of Sandusky Bay. Haag also noted techniques employed in a study of Ballville Dam, in which Kuenzli had been involved. Haag also reviewed the drilling logs provided by ODNR for the eastern side of Sandusky Bay, to observe the general character of the sediment in that bay area.

METHODS OF CORRELATING NaI RESULTS WITH LABORATORY RESULTS

Ben Patterson obtained selected existing NaI surveys of Plum Brook sediments, from the MOTA RP personnel who had performed or supervised those surveys. Through MOTA, Patterson also obtained corresponding laboratory test results from the PBRF onsite laboratory. Patterson plotted the NaI data against the laboratory results, to observe the degree of correlation between them.

METHODS OF CLARIFYING HISTORICAL SRO RELEASE CONCEPT (1961-1973)

Bob Haag obtained a compact disc (CD) from NASA, on which were recorded PBRF decommissioning drawings that had been prepared by MWH, a prior contractor on the project. Haag reviewed these drawings to obtain an understanding of the potential for spills and other releases of Cs-137 on or near the PBRF site. HaagEnviro later obtained Survey Request (SR) 16 spill information from Rob Marquette of SAIC.

NASA's Radiation Safety Officer (RSO), Bill Stoner, introduced Haag to two retired NASA workers, Jack Crooks and Don Young. Crooks and Young had both been involved in PBRF operations before the facility was shut down. Crooks had been involved with the PBRF from the time of its construction. Crooks and Young explained the following to Haag:

- How Cs-137 was generated by the PBRF
- How Cs-137 could enter reactor cooling water
- How and when cooling water was released to Pentolite Ditch
- How NASA tested and documented Cs-137 levels in cooling water before release

At Haag's request, Jack Crooks prepared a memorandum to Acting Decommissioning Project Manager Keith Peecook of NASA, dated 6-8-2006, and entitled, "Updated Legacy Information on Cs-137 Releases During PBRF Operations". Patterson plotted the Cs-137 in water data provided by Jack Crooks.

Don Young provided Haag with PBRF operating notes during the two largest floods that affected the facility while it was operating. To further assess those flood events, Patterson used the Erie County culvert drawings, and his own field measurements, to calculate the capacities of all culverts from PBRF to Sandusky Bay. Those capacity estimates were based upon the Manning open-channel flow equation.

Patterson then used USGS equations to estimate the amount of water passing through each culvert during the 100-year flood and the 500-year flood of Plum Brook. Patterson used USGS Full-Model Equations from "Techniques for Estimating Flood-Peak Discharges of Rural, Unregulated Streams in Ohio," which he obtained via the Internet at the following link:

www.dot.state.oh.us/research/2003/hydraulics/14740-FR.pdf

Patterson also located and printed pertinent Plum Brook flood maps from the Federal Emergency Management Administration (FEMA). To prepare these maps, he used the following Internet link:

http://msc.fema.gov/webapp/wcs/stores/servlet/CategoryDisplay?storeId=10001&catalogId=10001&langId=-1&categoryId=12001&parent_category_rn=12001&type=CAT_MAPPANEL&stateId=13042&countyId=15049&communityId=352531&stateName=OHIO&countyName=ERIE+COUNTY&communityName=ERIE+CO+*&dfirm_kit_id=&dfirmCatId=null&isCountySelected=&isCommSelected=&userType=G&urlUserType=G&sfc=0&cat_state=13042&cat_county=15049&cat_community=352531

METHODS OF CLARIFYING CURRENT SRO RELEASE CONCEPT (2006)

Before HaagEnviro was retained to work on this project, NASA's Keith Peecook had provided Hydrogeologist Bob Haag with copies of stream sediment testing data that NASA had already released to the public. Bob Haag had performed a cursory review of that data, and the patterns he observed suggested to him that Cs-137 was being distributed by an ongoing low-level release, not a release that had ended 40 years ago. Haag proposed that a long-past release into a mobile medium typically results in a "slug" of contamination that has moved downgradient, so that the highest levels are found distant from the source, while an ongoing release into a mobile medium typically results in a continuum of contamination, in which the highest contaminant levels are near the source, tapering off to lower levels more distant from the source. To further develop this hypothesis after HaagEnviro was retained, Haag conducted several discussions with NASA's RSO, Bill Stoner, and assistant RSO, Rod Case. They provided Haag with the CD containing past soil testing results plotted by MWH. At that time, HaagEnviro also more closely examined the data originally provided by NASA's Keith Peecook, for its bearing on the issue of ongoing versus long-past release patterns.

METHODS OF CLARIFYING GW RELEASE CONCEPTS

NASA's Keith Peecook had provided HaagEnviro with a report prepared by the USACE, dated 17 November 2004, and entitled, "Hydrogeological Report, Plum Brook Reactor

Facility, Sandusky, Ohio". A CD carrying over 3000 pages of prior reports and drilling logs accompanied this report. Patterson reviewed drilling logs from this source, to understand typical well depths and construction types in the PBRF vicinity. Using a site-specific classification of aquifers, aquitards and aquicludes formulated by Bob Haag, Patterson prepared a hydrostratigraphic cross-section of the PBRF vicinity.

Bob Haag contacted the ODNR to discuss karst (limestone solution) areas, and obtained a working potential-karst map of the PBRF area. Both Haag and Patterson conducted Internet searches for additional documents on PBRF-area geology, particularly its karst geology. Patterson went to the University of Toledo's Carlson Library to review and copy pertinent Master's degree theses.

Bob Haag examined PBRF drawings to determine the places in the facility that Haag felt were most vulnerable to leakage of cooling water directly into the Delaware limestone formation.

METHODS OF IDENTIFYING AVAILABLE SEDIMENT DEPOSIT DATING CONCEPTS

Bob Haag supplemented his training in geologic dating concepts with Internet research for additional concepts that might be useful in selecting dating methods for the movement of sediment from the PBRF to Sandusky Bay. Haag also compared meander patterns in a stream adjacent to Plum Brook, to determine the amount of streambed change that could be observed over the 43-year period of time since the PBRF had begun operation. The adjacent stream was used because, unlike Plum Brook, it had been kept clear of vegetation, and stream meanders could be readily observed.

METHODS OF IDENTIFYING EXISTING PBS WELLS USEFUL FOR GW ASSESSMENT

Hydrogeologist Bob Haag and Senior Geologist Phil Weimer re-reviewed key drilling logs, to assess their potential to yield useful data if sampled in the future. Haag also reviewed groundwater-monitoring data provided by NASA's Pete Kolb, who was responsible for environmental monitoring of the PBRF decommissioning project.

OBSERVATIONS

Key information gleaned from the data review and field trials is documented in the following sections.

OBSERVATIONS FROM HISTORICAL CULVERT DATA FROM ERIE COUNTY (1961-1973)

Based on the calculations performed by Ben Patterson, it appeared that all of the culverts between the PBRF and Sandusky Bay should have been capable of passing the 500-year flood. This conflicted with newspaper reports and PBRF operating reports, both of which documented significant backwaters in 1969. The PBRF also experienced a significant backwater event in 1966. In a newspaper account of the 1969 flood, backwaters on Plum Brook were documented at both Bogart Road and Galloway Road. In neither of those flood events was Pentolite Road overtopped. However, some flooding of the reactor facility, itself, did occur.

OBSERVATIONS ON HISTORICAL AIRPHOTOS (1961-1973)

FIGURE 4 – 1937 AIRPHOTO TRACING

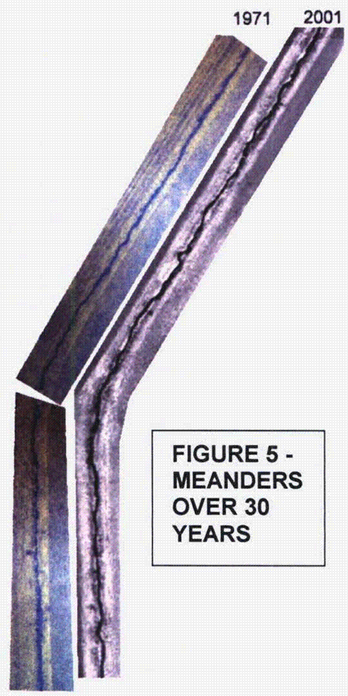


FIGURE 5 - MEANDERS OVER 30 YEARS

The airphoto review revealed 3 ponds on the grounds of the Plum Brook Country Club (PBCC), which were present during and after the period of PBRF operation. The 1937 airphoto, of which a tracing is provided as Figure 4, showed that the eastern end of Sandusky Bay had been a terrestrial wetland, and was not covered by water, in 1937. A 30-year comparison of a section of the Lindsley Ditch channel adjacent to Plum Brook, provided as Figure 5, showed that stream meanders moved position somewhat during that time, indicating that erosion and re-deposition of channel deposits had occurred.

OBSERVATIONS ON HISTORICAL RAINFALL DATA (1961-1973)

As it did not prove necessary to extrapolate streamflow from rainfall records, rainfall data were not as directly relevant as streamflow data.

OBSERVATIONS ON HISTORICAL STREAM GAGE DATA (1961-1973)

The largest flooding event was identified as having occurred in 1969. This was confirmed by newspaper accounts, which showed that Plum Brook had flooded dramatically behind the culverts at Bogart Road and Galloway Road.

OBSERVATIONS ON WETLANDS DEFINITION DATA FROM ODNR

It was noted that the coastal management boundary included the stream mouth area north of Route 6, and extended to additional wetlands south of Route 6, adjacent to the Plum Brook Country Club. The wetland area south of Route 6 is shown in Figure 6. It was noted that the eastern part of Sandusky Bay was defined as the Putnam Nature Preserve, and was under the protective management of the Erie MetroParks.

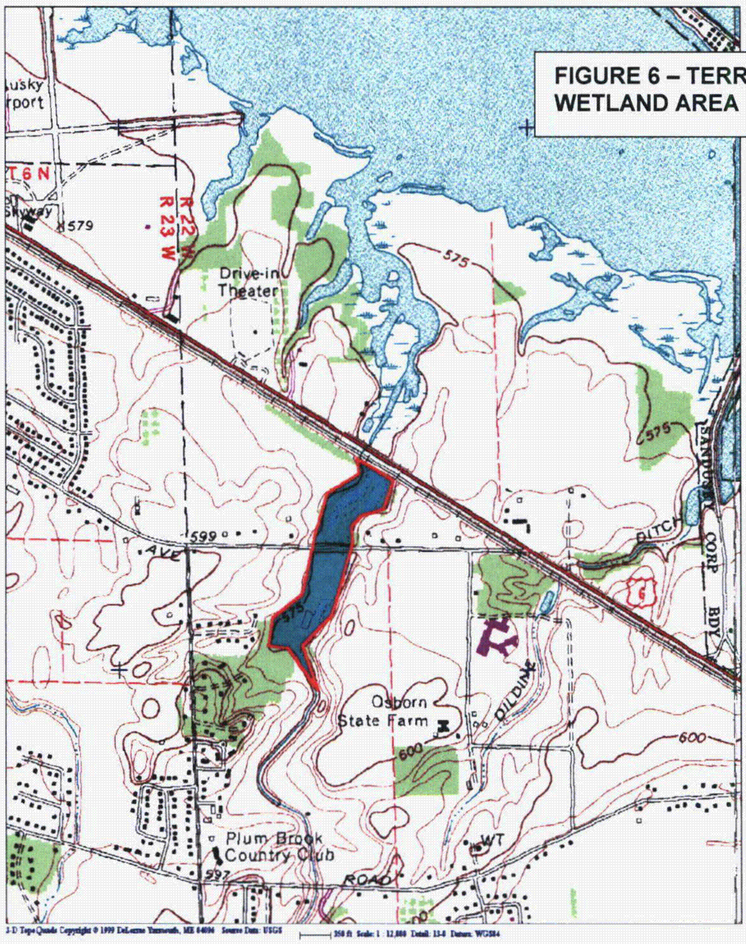


FIGURE 6 – TERRESTRIAL WETLAND AREA

OBSERVATIONS ON SANDUSKY BAY DATA FROM OEPA AND ODNR

The data obtained for the western side of Sandusky Bay was seen to have little relevance to the study area. The significance of peat accumulations documented in some of the eastern-bay drilling logs did not make a clear impression at the time of this review. The drilling was conducted far from the point where Plum Brook entered the bay, and it appeared likely that the peat deposits there were localized features that would not necessarily be found in the PBRF-related studies. Following the HaagEnviro bay sampling work, Bob Haag again reviewed the logs provided by ODNR, and noted the similarities with regard to peat accumulations at the eastern and western ends of East Sandusky Bay.

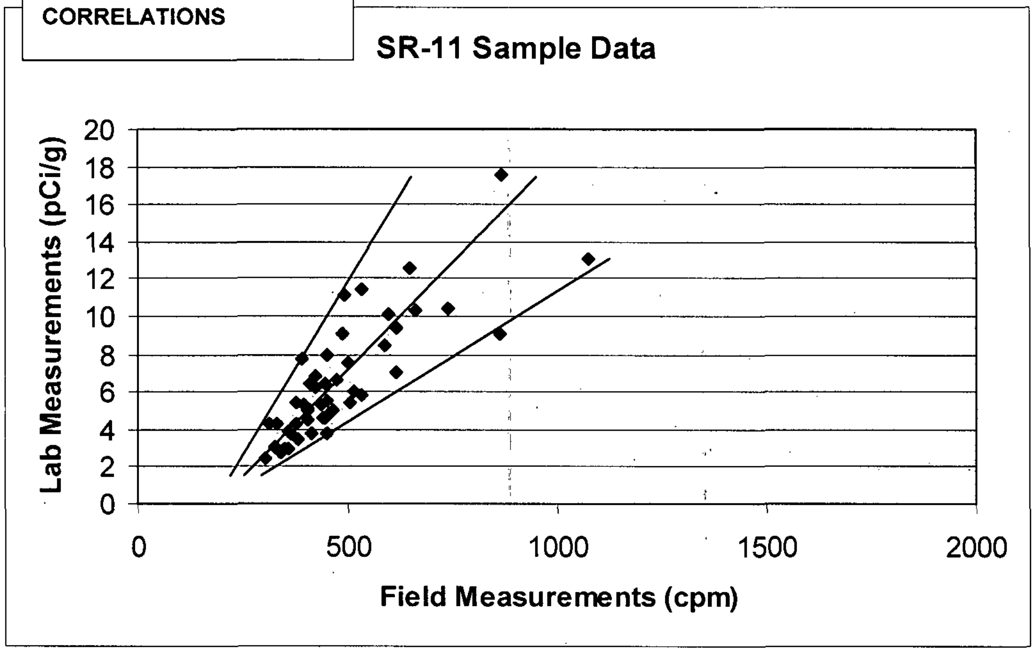
OBSERVATIONS FROM CORRELATING NaI RESULTS WITH LABORATORY RESULTS

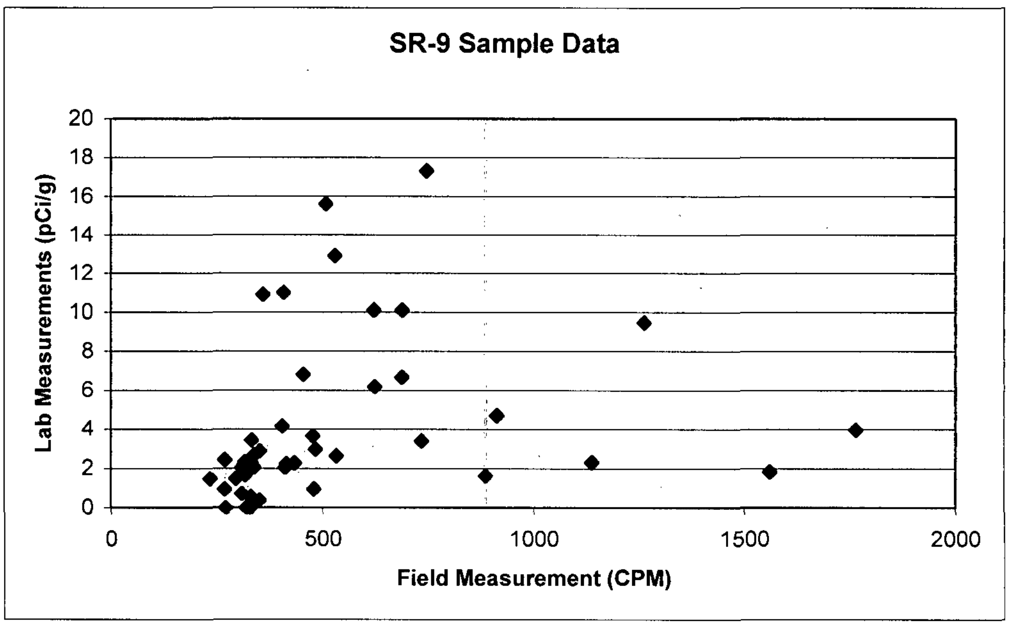
A general, positive, linear correlation between surface scanning results and laboratory testing results for Cs-137 was readily observed in most of the Survey Request (SR) transects reviewed. However, a great deal of scatter around the best-fit line was noted. In Figure 7, an example of one of the better correlations is shown by SR-11. A fairly poor correlation is illustrated by SR-9.

For SR-9, a large departure from linear correlation was noted on the right side of the graph in Figure 7. Interference from natural radionuclides in shale was proposed, as a possible explanation of how field measurements of more than 1000 gross counts per minute (gcpm) could correspond to Cs-137 laboratory measurements of only 2-4 pCi/g. It was determined that the radon daughter radionuclide, bismuth-214 (Bi-214), could have elicited a response from the NaI detector, even when the detector had been configured to limit response to the “Cs window” of gamma radiation energies. However, further evaluation demonstrated that Bi-214 was not actually a factor in this case.

Other potential causes of the discrepancy were considered to be: failure to sample the stratum causing the NaI detector response, unusual contamination geometry causing NaI detector over-response, record-keeping errors, instrument malfunction, human operating errors, or loss of large radioactive particle during sample processing.

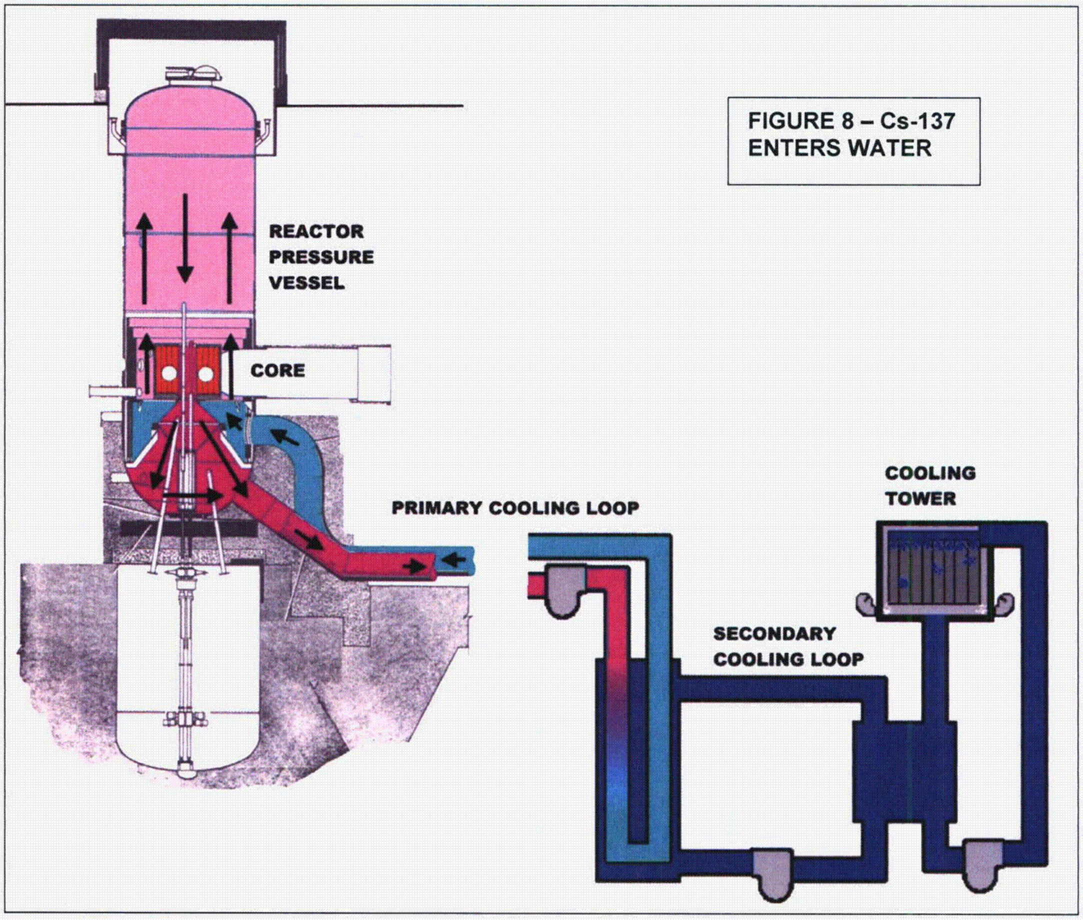
FIGURE 7 – TWO NaI/LAB CORRELATIONS





OBSERVATIONS RELATING TO HISTORICAL SRO RELEASE CONCEPT (1961-1973)

Based upon the explanations of Crooks and Young, HaagEnviro adapted Figure 8 from NASA documents, to illustrate where Cs-137 could enter the cooling water as it passed through the reactor core. The blue colors in this figure show water not impacted by Cs-137, approaching the reactor core. The magenta colors in this figure show water that has passed through the core, and could therefore be carrying Cs-137 in solution.



Crooks and Young explained that the cooling water was periodically drawn down to perform maintenance on the reactor. Water that was drawn down was held for testing in large tanks in the Hot Retention Area (HRA). After the water was shown to contain no radionuclides, including Cs-137, at levels above those permitted by regulations, the water was discharged to Pentolite Ditch through a structure referred to as the Wastewater Effluent Monitoring Station (WEMS). Crooks indicated in his memorandum that the limits for Cs-137 releases in water during PBRF were likely 2×10^{-5} uCi/ml (soluble) and 4×10^{-5} uCi/ml (insoluble). He noted that the release limit in 2006 was 1×10^{-6} uCi/ml.

Crooks' calculations led him to conclude that approximately 5 millicuries of Cs-137 activity were released in total, with a worst-case figure of 7.2 millicuries.

Graphs of Crooks' data are provided in Figures 9 and 10. Both scales of the first graph are linear, while the vertical scale of the second graph is logarithmic. In these graphs, a value of 1×10^{-8} uCi/ml was used when the laboratory analysis indicated a result below the minimum detectable activity.

FIGURE 9 – Cs-137 IN WATER (LINEAR)

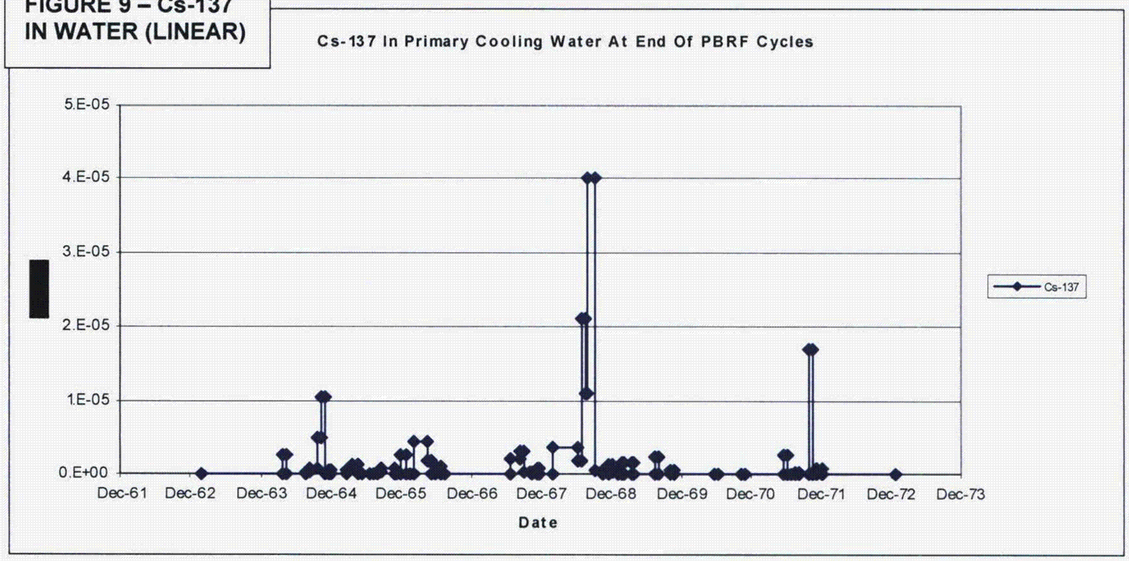
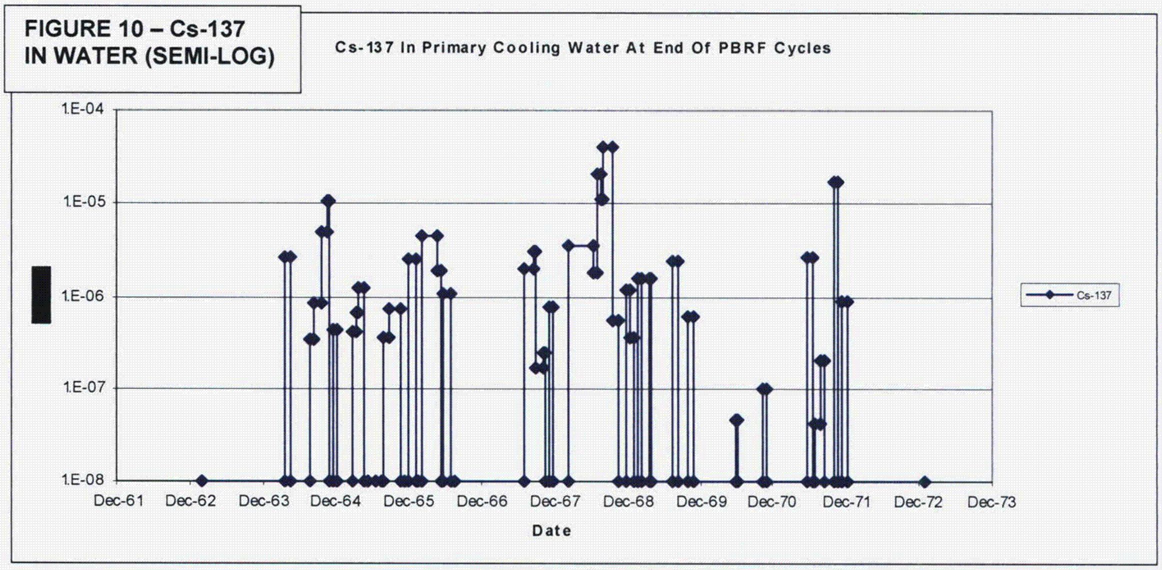


FIGURE 10 – Cs-137 IN WATER (SEMI-LOG)



To illustrate locations in which it was known that Cs-137 had been found in surface or near-surface spillage, HaagEnviro adapted Figure 11 from a MWH drawing. All of the surface drainage features shown drain to the WEMS.

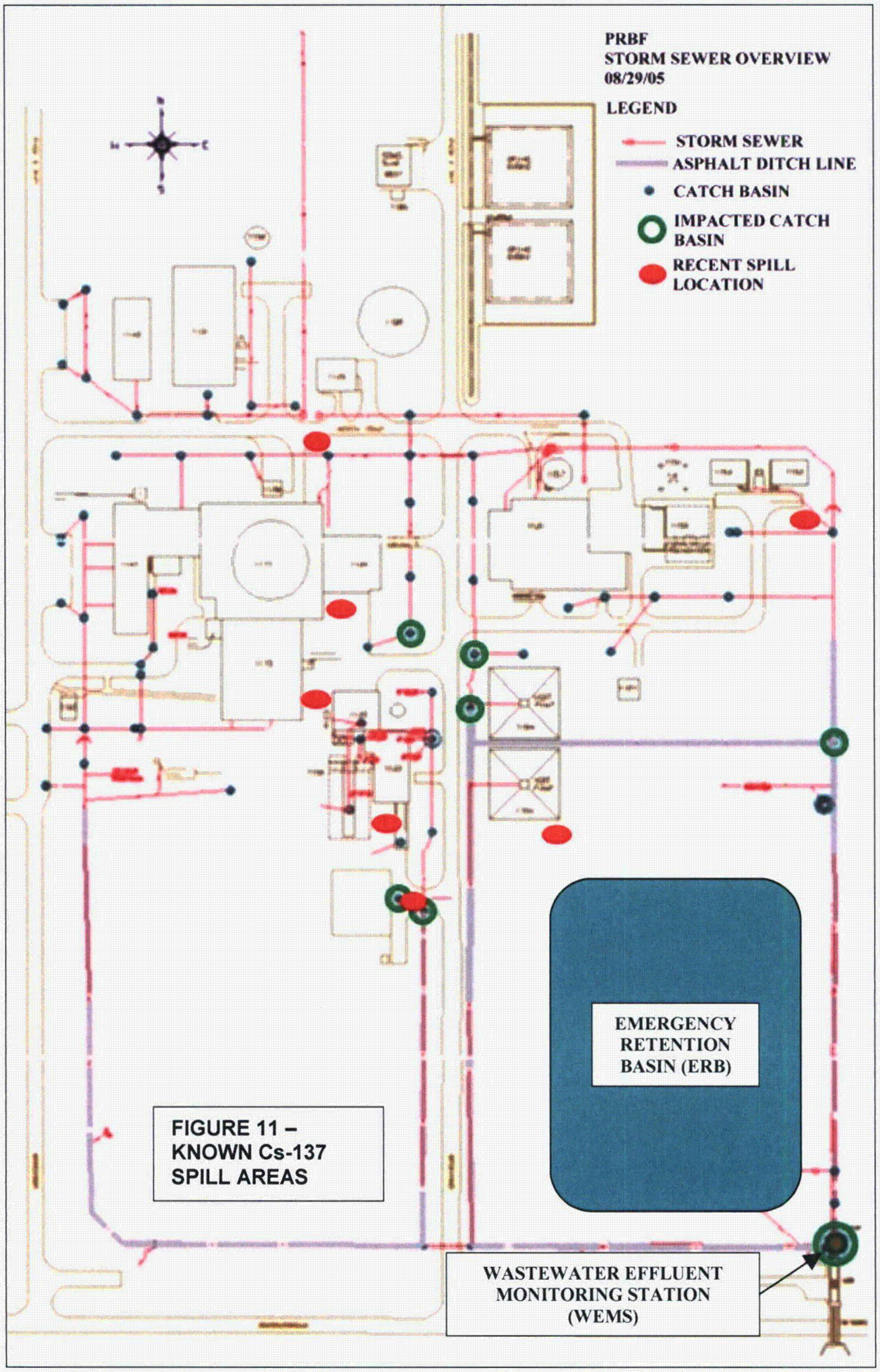


FIGURE 11 – KNOWN Cs-137 SPILL AREAS

To illustrate the highest Cs-137 activities that had been found in sediment dredged from Pentolite Ditch, HaagEnviro adapted Figure 12 from a MWH drawing. It was reported to HaagEnviro that the HaagEnviro averages shown below were based on "targeted" locations, identified by surface scanning. This figure also shows the location of the soil sample for which the highest Cs-137 activity, 1020 pCi/g, was reported.

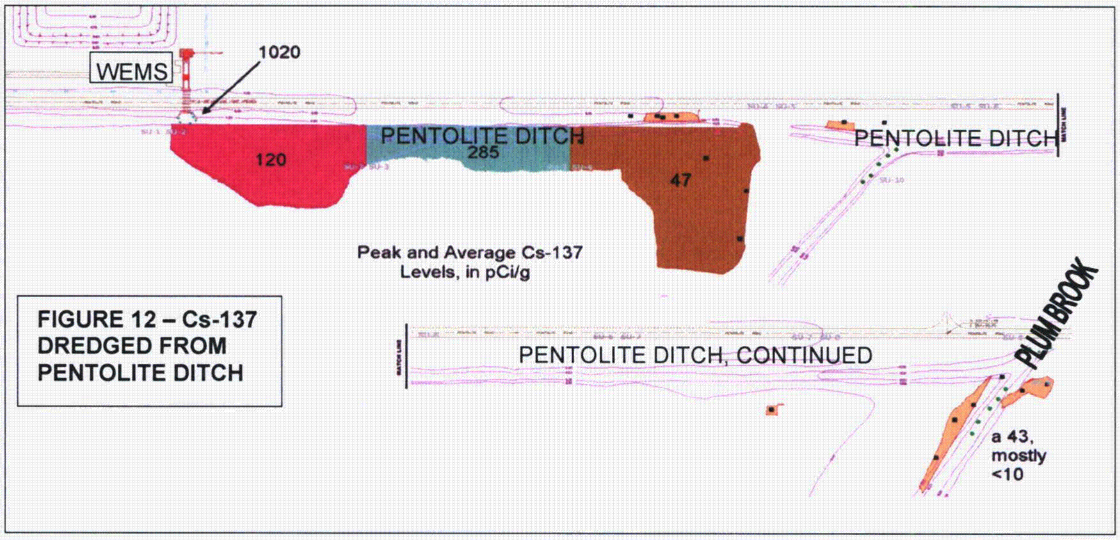


FIGURE 12 – Cs-137 DREDGED FROM PENTOLITE DITCH

Figure 13 provides a continuation from Figure 12, and shows the location of the sediment sample that produced a Cs-137 activity result of 50.1 pCi/g.

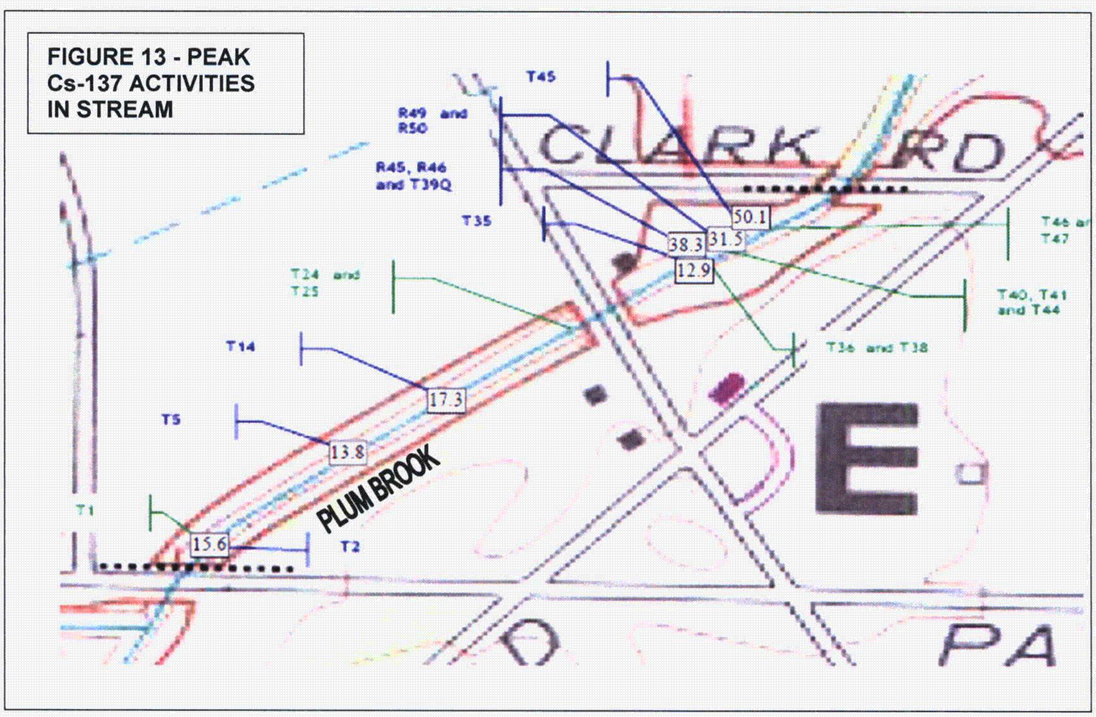


FIGURE 13 - PEAK Cs-137 ACTIVITIES IN STREAM

To illustrate the most significant flood event of record, HaagEnviro produced Figure 14 from flood peak data, and reproduced Figure 15 from the July 7, 1969 issue of the Sandusky Register.

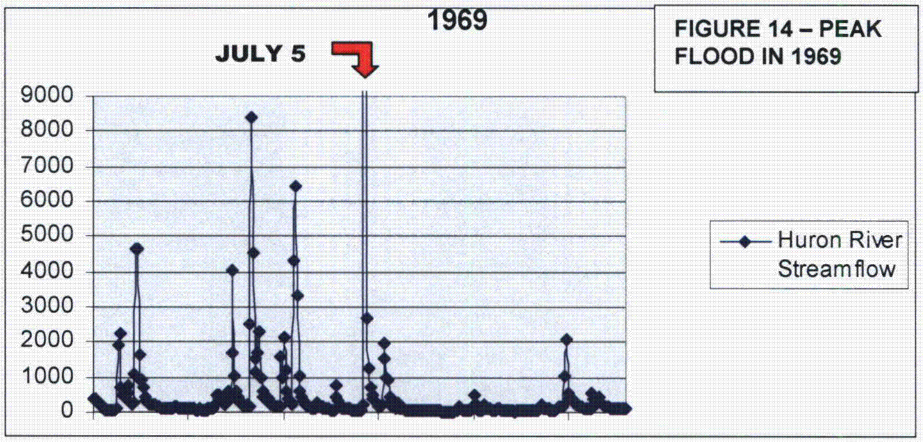
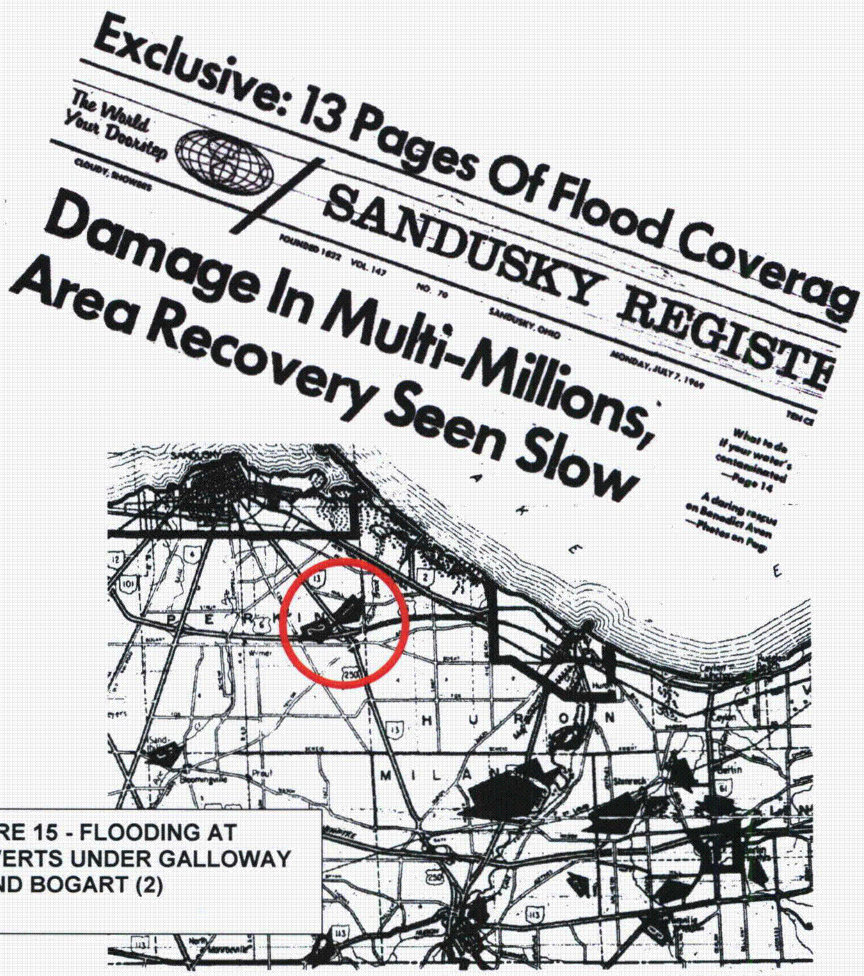


FIGURE 14 – PEAK FLOOD IN 1969


Exclusive: 13 Pages Of Flood Coverag

SANDUSKY REGISTE

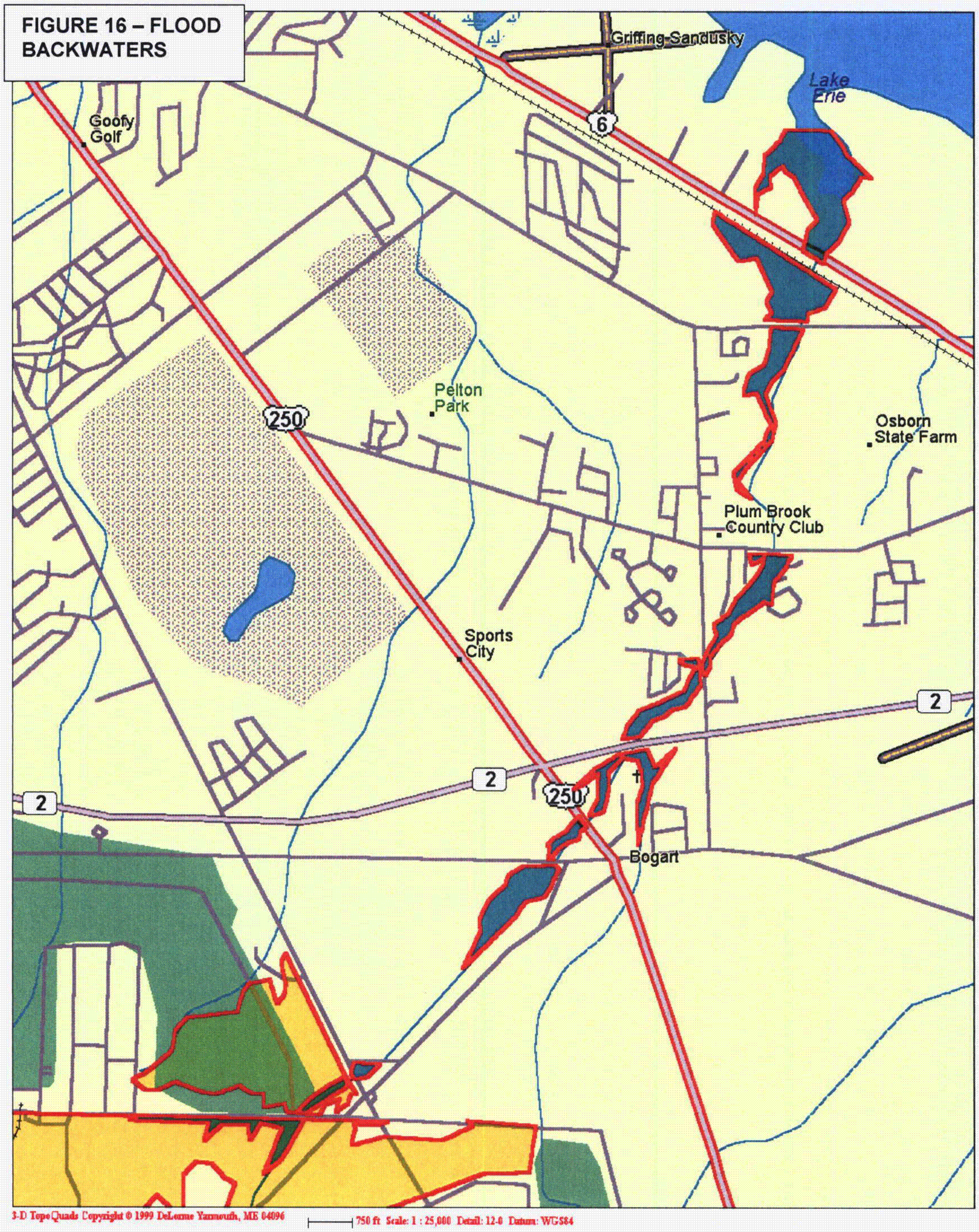
Damage In Multi-Millions, Area Recovery Seen Slow

THE ARROWS IN THE ERIE COUNTY MAP ABOVE DETAIL IMPASSABLE ROADS AND KNOCKED OUT BRIDGES AS OF NOON TODAY. (Register

FIGURE 15 - FLOODING AT CULVERTS UNDER GALLOWAY (1) AND BOGART (2)

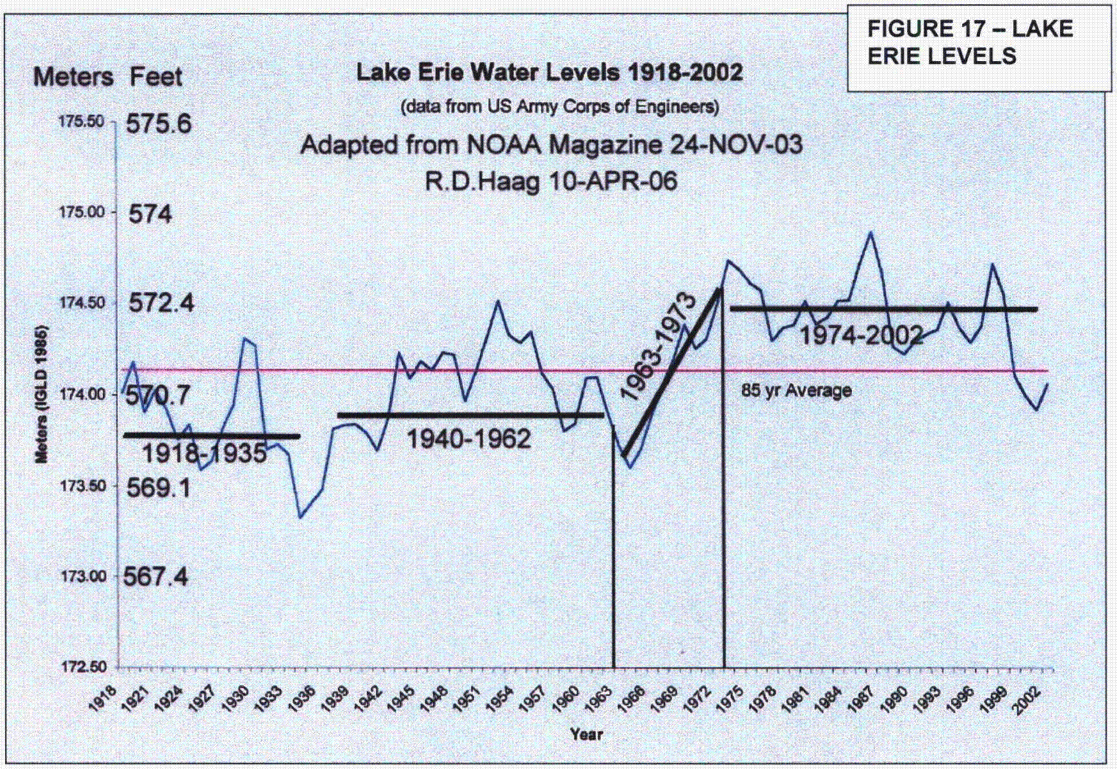
To illustrate areas in which flooding was expected to have created backwaters, that might have distributed sediment bearing Cs-137, HaagEnviro produced Figure 16. In this figure, the areas marked in dark blue represent HaagEnviro's predicted maximum backups along Plum Brook. The areas highlighted in yellow were part of a search to determine how high the water would need to rise in order to spill over into other streams besides Plum Brook.

FIGURE 16 – FLOOD BACKWATERS



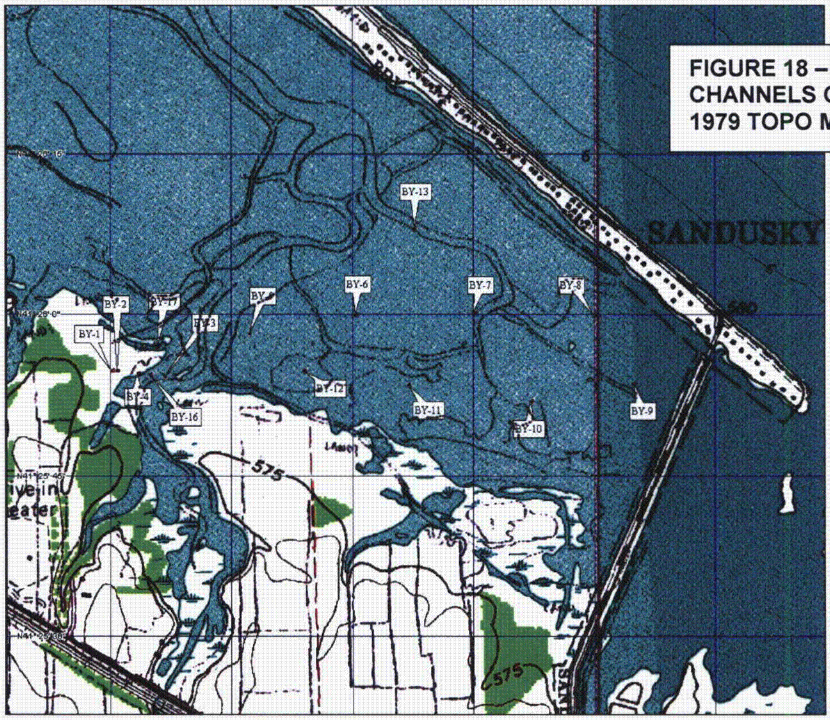
To illustrate historical trends in the level of Lake Erie, which affected the direction of flow in the bay, HaagEnviro adapted Figure 17.

FIGURE 17 – LAKE ERIE LEVELS



By superimposing the 1937 channels over the area that was completely water-covered on the1979 topographic map, Figure18 was created to illustrate the changes that the lake level wrought on the eastern part of Sandusky Bay.

FIGURE 18 – 1937 CHANNELS ON 1979 TOPO MAP

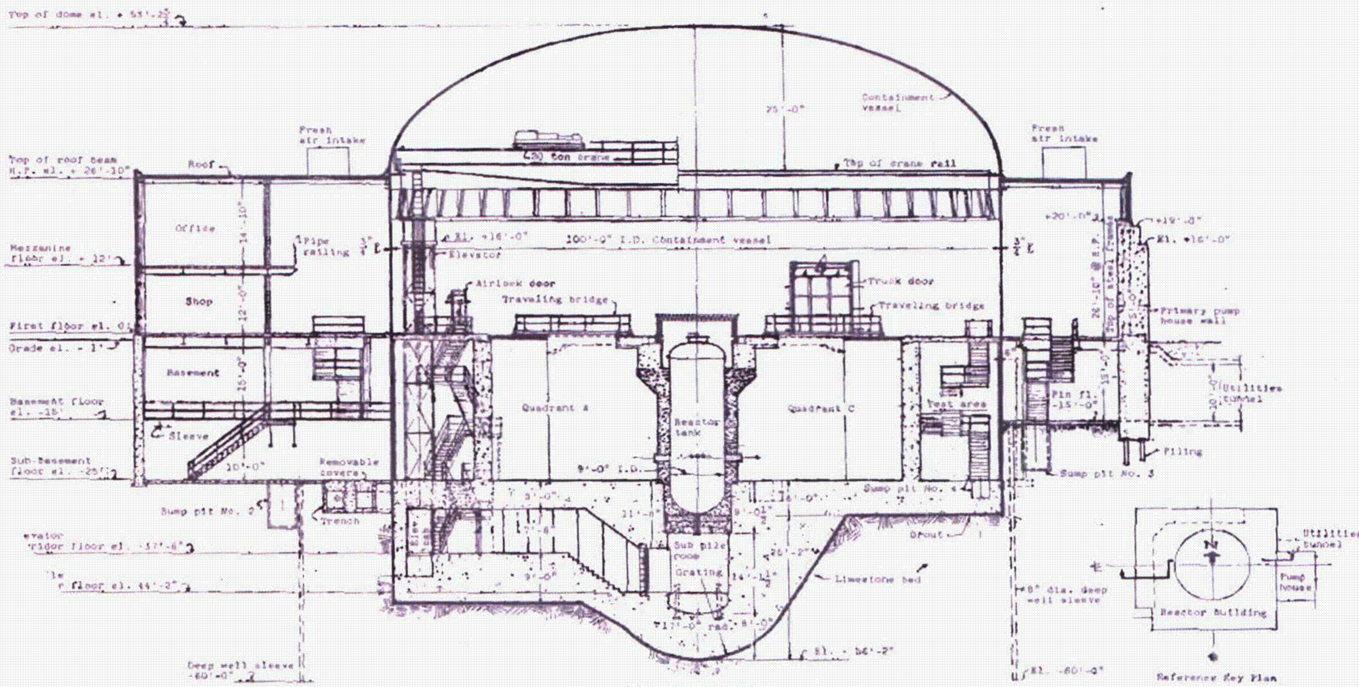


OBSERVATIONS RELATING TO CURRENT SRO RELEASE CONCEPT (2006)

In discussions with the staff working on PBRF decommissioning for NASA, Bob Haag noted frequent reference to a Cs-137 activity measured at the edge of Pentolite Ditch. The highest Cs-137 activity measured there was 1020 pCi/g, as shown on Figure 12. This result was obtained along the ditch very near to the WEMS, where cooling water was discharged into the ditch. This was the highest-known Cs-137 activity outside the PBRF radiation control area (RCA). In the Pentolite Ditch bottom near this highest activity, a peak Cs-137 activity of 473 pCi/g was reported at a depth of 18-30 inches. The next-highest Cs-137 activities associated with Pentolite Ditch sediment were 72.8 and 58.9 pCi/g. Outside the PBOW, the next-highest-known Cs-137 activity measured was 50.1 pCi/g. This was found in Plum Brook stream sediment just outside the PBOW gate, roughly 0.9 mile from the WEMS, as shown on Figure 13. The farthest-downstream Cs-137 detection reported in early NASA studies was 2.64 pCi/g, near the Plum Brook stream mouth, just upstream of Sandusky Bay. That location was roughly 4 miles downstream from the WEMS.

OBSERVATIONS RELATING TO GW RELEASE CONCEPTS

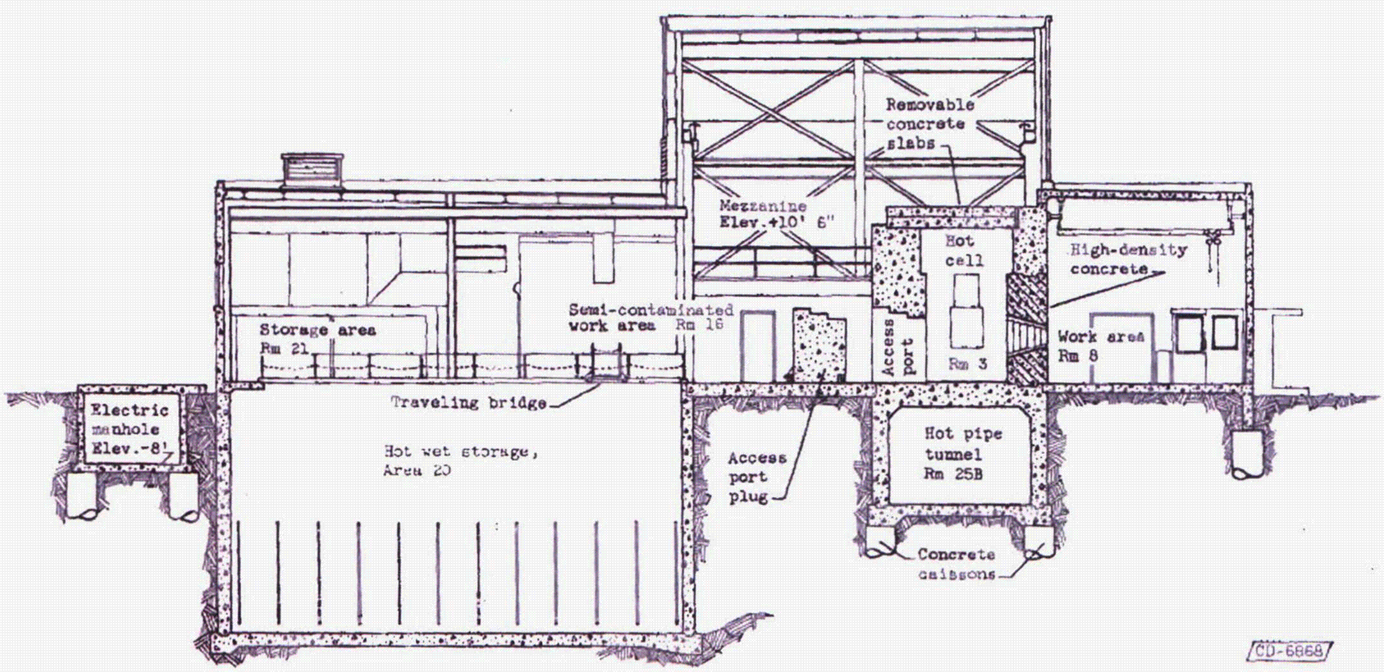
It was evident that a large thickness of concrete surrounded the reactor core, and the chamber below the core, as illustrated in Figure 19 and in other NASA drawings of the PBRF design. However, HaagEnviro also used Figures 19 and 20 from NASA to illustrate where there might be areas where cooling water carrying Cs-137 might be in transit, but the concrete thickness was less than that surrounding the core.



(a) East-west section.

Figure 2.12. - Vertical section of the reactor building.

FIGURE 19 – MUCH CONCRETE AROUND REACTOR CORE



(e) Section D-D.

FIGURE 20– LESS CONCRETE UNDER HOT STORAGE

HaagEnviro used NASA Figure 21 and USACE Figure 22 to illustrate the relationship of the PBRF to the water-bearing Delaware formation. HaagEnviro adapted Figure 22 slightly, extending the bottom of Plum Brook down into the Delaware Limestone, to illustrate the possibility that such a configuration might be present, somewhere along the stream course.

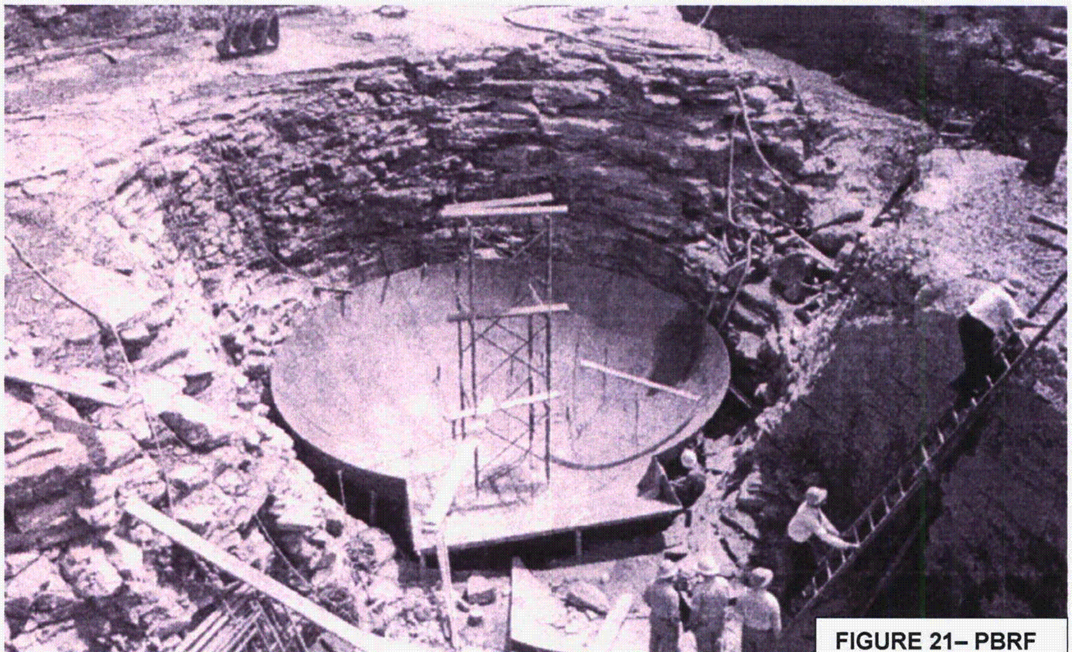
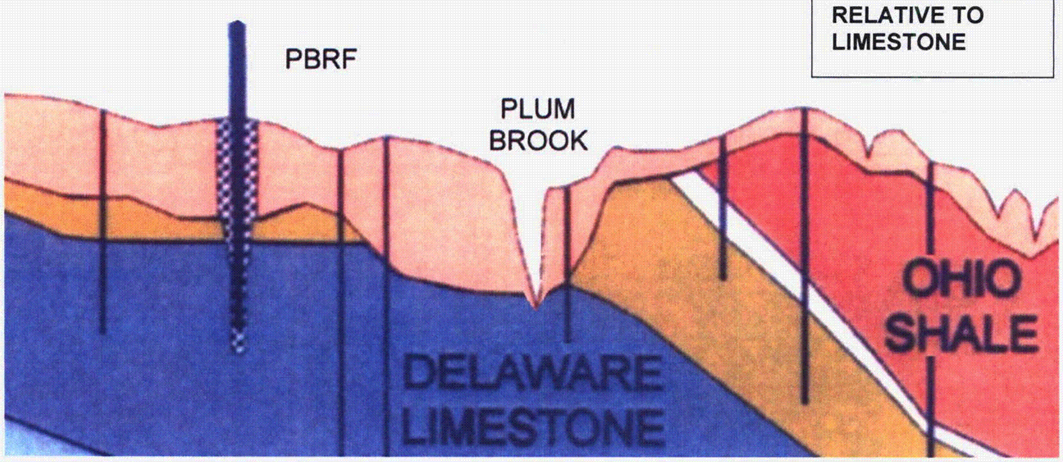


FIGURE 21– PBRF CONTACT WITH LIMESTONE

FIGURE 22– PBRF RELATIVE TO LIMESTONE



To illustrate limestone fractures and possible karst features anticipated in the area, HaagEnviro adapted Figure 23 from the USACE, and Figure24 from a working map provided by ODNR.

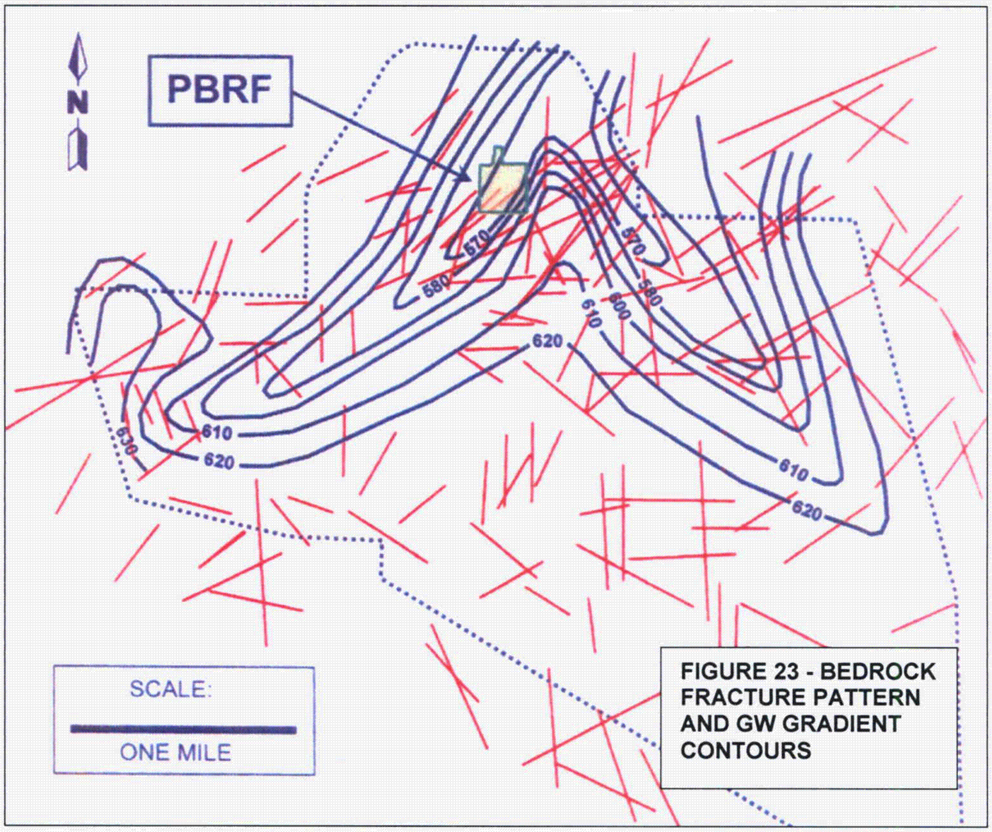


FIGURE 23 - BEDROCK FRACTURE PATTERN AND GW GRADIENT CONTOURS

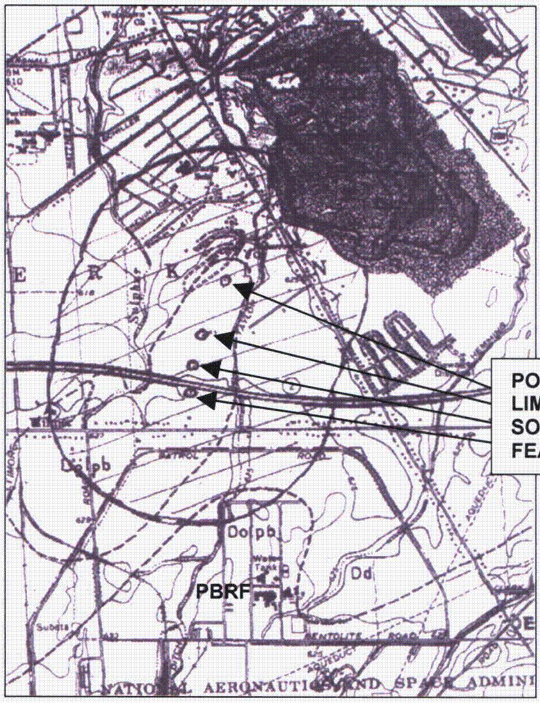
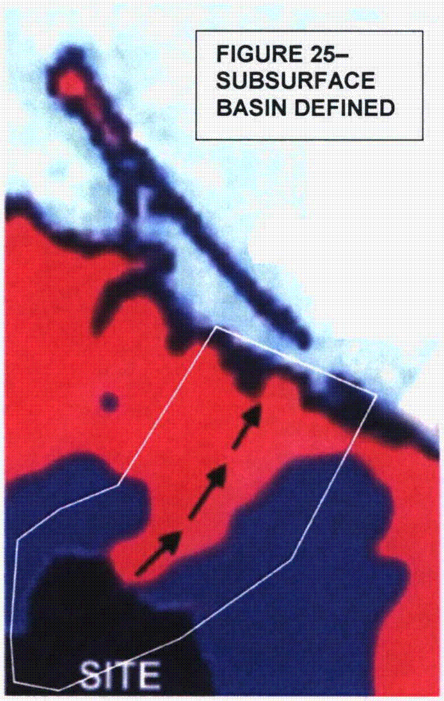
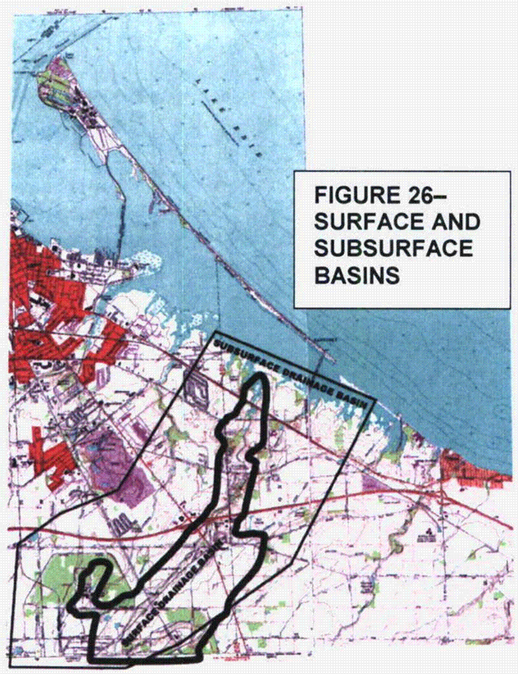


FIGURE 24 - ODNR PRELIMINARY MAP OF POSSIBLE LIMESTONE SOLUTION FEATURES

To illustrate the relationship between Plum Brook's surface drainage basin, and the subsurface drainage basin expected to control groundwater flow, HaagEnviro adapted Figures 25 and 26. The figure on the left, adapted from an ODNR bedrock topography map, illustrates the shape of the surface of the bedrock, beneath the covering of glacial deposits. The figure on the right illustrates the subsurface basin that is defined by the bedrock surface, superimposed on the surface drainage basin created by the topography of the land surface.





To illustrate the expected dominating effect of Wagner Quarry upon groundwater flow directions in the area, HaagEnviro adapted Figure 27 from the USACE. Figure 28 illustrates the expected effect in map view.

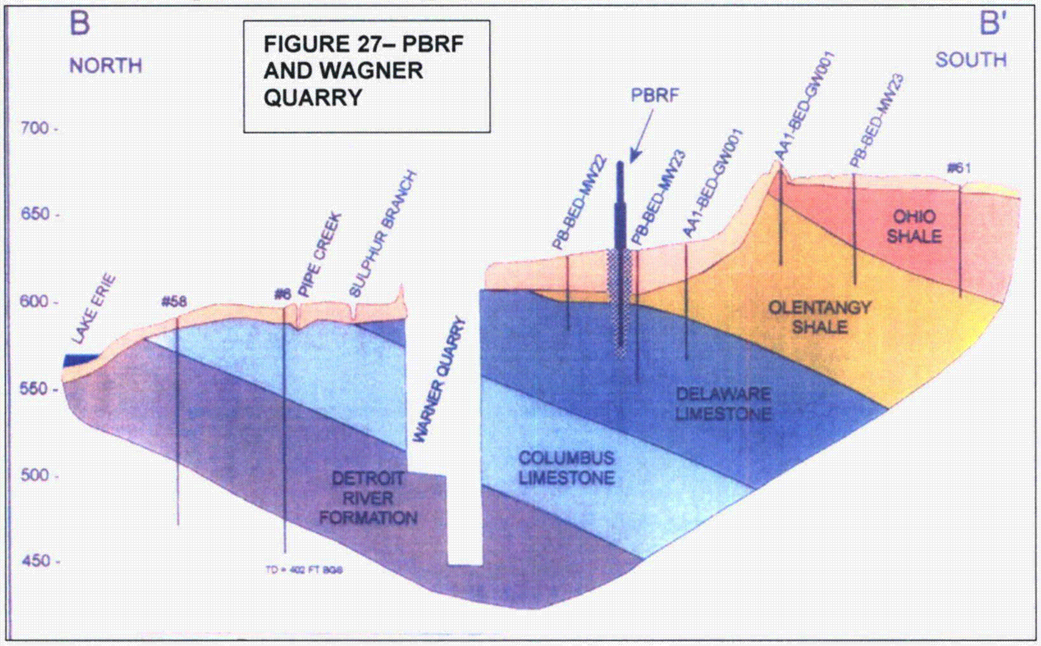


FIGURE 27– PBRF AND WAGNER QUARRY

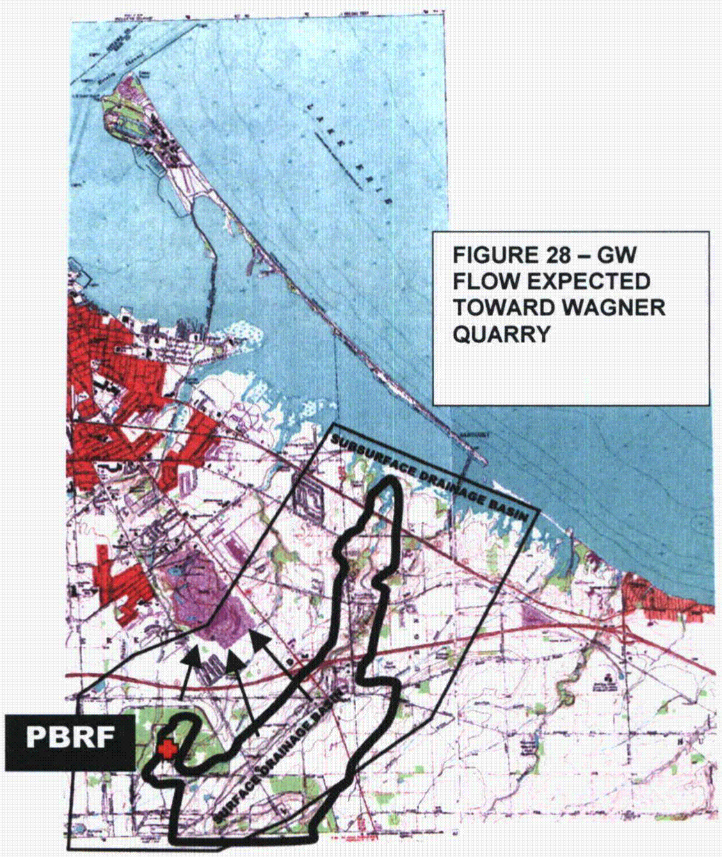
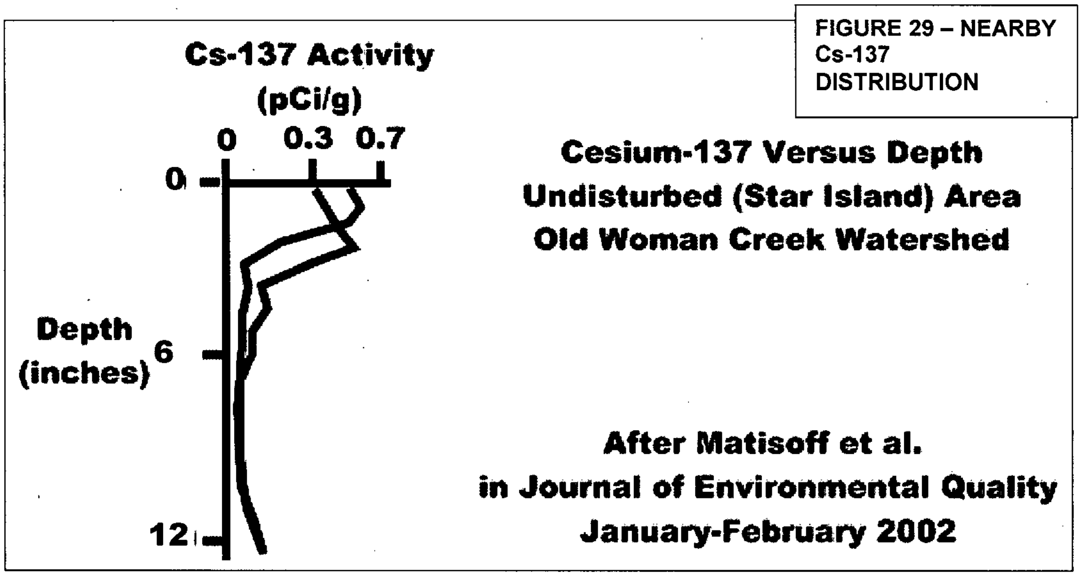


FIGURE 28 – GW FLOW EXPECTED TOWARD WAGNER QUARRY

OBSERVATIONS ON AVAILABLE SEDIMENT DATING CONCEPTS

Cs-137 had been used extensively for dating recent sediment movements, but the dating concept was based upon the assumption that the Cs-137 detected had been deposited from atmospheric bomb testing. The studies reviewed lead HaagEnviro to the conclusion that a typical background level of Cs-137, in the top 4 inches of an undisturbed soil, would peak at about 0.6 pCi/g, and would have an average level of about 0.25 pCi/g, as illustrated in Figure 29.

FIGURE 29 – NEARBY Cs-137 DISTRIBUTION



Carbon-14 dating was briefly considered. Other dating concepts available were fairly simple geologic observations, including the following:

- Recent alluvium carried by Plum Brook was generally a soft, brown silt
- Pleistocene glacial till in the area was typically a hard, gray clay, with included pebbles
- The last glacial retreat in this area was several thousand years ago
- Some sediment studies in other areas encountered human artifacts, such as pieces of aluminum, that marked the deposits as being of very recent age

OBSERVATIONS ON EXISTING WELLS USEFUL FOR GROUNDWATER ASSESSMENT

Existing wells identified, in order of downgradient proximity to the PBRF, were as follows:

1. Rx-25 (inside the reactor building)
2. Rx-15 (inside the reactor building)
3. Rx-01 (just outside the reactor building, cross-gradient)
4. RA-07S (shallow well downgradient from reactor building)
5. RA-07D (deep well downgradient from reactor building)
6. RA-02 (downgradient, but off gradient centerline from reactor building)
7. Rx02 (slightly upgradient from reactor building)
8. Rx03 (slightly upgradient from reactor building)
9. Rx04 (slightly upgradient from reactor building)
10. MW-03 (slightly up-gradient from reactor building, but off gradient centerline)
11. RA-03 (cross-gradient from reactor building, but off gradient centerline)
12. IT-MW06 (far downgradient from reactor building)
13. PB-BED-MW-22 (farthest downgradient from reactor building, at outer fence)
14. EB-RA-01 (directly upgradient from reactor building)
15. PB-BED-MW-23 (directly upgradient from reactor building)
16. PB-BED-MW-15 (upgradient from reactor building, but off gradient centerline)

INTERPRETATIONS

HaagEnviro had set out to develop opinions on two issues that were key to its understanding of the expected extent of Cs-137 distribution: (1) the nature and distribution of the original release of Cs-137 during the time of PBRF operation, and (2) the possible ongoing release of Cs-137 suggested to HaagEnviro by the pattern of contamination detected in prior NASA investigations. In addition, NASA had posed five specific questions to be addressed in the course of this and subsequent work.

INTERPRETED HISTORICAL SRO RELEASE CONCEPT (1961-1973)

Based upon the data reviews documented here, HaagEnviro interpreted that Cs-137 was dissolved in water in the reactor's primary cooling system. It was estimated that Cs-137 producing a total of 5 millicuries, or 5 x 10^9 piocuries (pCi) 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 2.5 x 10^9 pCi of Cs-137 activity would remain to be found, more than 30 years later.

It was considered reasonable to make the assumption that all of the Cs-137 dissolved in the discharged cooling water was quickly and irreversibly adsorbed by clay minerals in fine sediment, although it was felt that this assumption should be tested. Most of the Cs-137 was expected to have been captured by the clays in the bottom of Pentolite Ditch. However, some of the Cs-137 could have been captured by clays in the PBRF drainage systems, and in bedrock fractures.

It was considered reasonable to make the assumption that, wherever the contaminated clay was transported since the reactor began operating in 1963, the Cs-137 was also transported. The sedimentary environments that would have carried or received the clay bearing Cs-137 were judged to include the following:

Pentolite Ditch – which would be viewed as a long, thin pond, with an overflow to Plum Brook.

Meandering Stream Parts of Plum Brook - in which HaagEnviro judged that a proposed action level of 12 pCi/g was exceeded at an average rate of 1 exceedance per 500 feet of streamcourse. Most of those exceedances were distributed by the brook in a scattered pattern, as would be expected for deposits that are constantly being eroded and deposited, particularly during large flood events. Two of the exceedances offsite were concentrated at two pipe effluent points, which might warrant further investigation of those pipes.

Backwaters – were considered relevant in two ways (1) Cs-137 should be sought where backwaters might have risen high onto the stream banks, and (2) Cs-137 should be sought just upstream of each culvert, where there would be the greatest potential for deposits that would not be re-scoured.

Ponds – were considered relevant if floods of Plum Brook might have risen to a level that inundated the ponds. As the floodwaters receded, fine-sediment deposits bearing Cs-137 could have been left behind. A wide, thin sediment layer (3 inches or less) would be expected, at a depth proportional to the year of deposition. Flood events in 1966 and 1969 were of particular interest.

Terrestrial Wetlands – were identified beginning near the northern end of the Plum Brook Country Club, where the streambed widened from a deep incised channel, into a wide floodplain. It was expected that this type of wetland would hold contaminants in channels and plant hummocks under certain conditions, then might release them when conditions changed. In this type of area, scattered deposits of fine sediment bearing Cs-137, trapped within peat or muck, would be sought. It was also considered possible, but less likely, that the peat and muck deposits themselves might have trapped Cs-137.

The Mouth of Plum Brook – had at times been a marshy braided distributary channel environment, and at other times had been mostly covered by water. It was hoped that a pattern of layers corresponding to the years 1963 to present could be identified. Within such a pattern, layers bearing fine sediment with Cs-137 would be sought.

East Sandusky Bay – was expected to contain Cs-137 from the earliest part of the PBRF operating period in a West-to-North trending fan, in marshy braided distributary deposits. For the later part of the PBRF operating period, it was anticipated that Cs-137 might be found in the bay in a North-to-East trending fan, in deltaic deposits in which the fine Cs-bearing sediment would be buried beneath coarser uncontaminated sediments.

Groundwater Sediment - evaluations would do best to initially focus upon sediment collected in existing wells onsite, on the assumption that Cs-137 would have accumulated at the bottom of such wells. Wells drilled near the PBRF and to the north of the facility should be sought. Particular emphasis should be placed upon wells drilled before 1963, if any should be found to exist. Depending upon the results obtained very near to the reactor, a decision could be made on whether to pursue sediment in the groundwater environment at greater distances.

INTERPRETED CURRENT SRO RELEASE CONCEPT (2006)

Based upon the data reviewed, HaagEnviro interpreted that the primary release of Cs-137 had occurred in 1968, and was distributed far downstream by the flood of 1969. HaagEnviro initially interpreted that no further releases from the facility itself could occur following the shutdown of the PBRF four years later, in 1973. However, the PBRF Radiation Safety Officer, William Stoner, indicated that monitored low-level releases did occur after 1973. Examples included draining of the Cold Retention Areas in 2005, and a building-flooding event that occurred in December of 2006. The project RSO also noted that the decommissioning project released sump water with low-level radioactivity on a day-to-day basis, and indicated that there were probably several other known releases. He noted that these releases were all minor, and were not considered to have added measurably to the Cs-137 accumulation in Plum Brook.

Therefore, any releases that might be occurring in 2006 and later, as suggested to HaagEnviro by the reported distribution of contamination, would be due to Cs-137 being eroded from surface soil deposits, such as the sediment along Pentolite Ditch.

ANSWERS TO SPECIFIC NASA QUESTIONS

Based upon the work that had been performed at the end of the existing-data evaluation, HaagEnviro developed the following opinions regarding the five questions of specific interest to NASA:

1. WHERE CS-137 WAS MOST LIKELY TO HAVE SETTLED

HaagEnviro felt that the largest fraction of Cs-137 released from the PBRF between 1963 and 1973 was likely to have been distributed between the following 3 depositional environments:

1. In sediment in the bottom of Pentolite ditch, which was then excavated and spread on the ground within the site controlled by NASA
2. In intermittent deposits within the meandering-stream portions of Plum Brook
3. Beneath delta deposits in the eastern side of Sandusky Bay

It was unknown whether detectable amounts of Cs-137 might have been distributed on land and in ponds during extreme floods, might have been trapped within wetland deposits near the mouth of Plum Brook, or might have been distributed by clays within cracks in a groundwater aquifer. In each of those depositional environments, it was considered reasonably possible that no Cs-137 would be detected. It was also considered reasonably possible that no Cs-137 would be detected in the bay, if dilution from other sources of sediment had been significant.

2. DEPTH AT WHICH Cs-137 WAS LIKELY TO HAVE BEEN DEPOSITED

In sediments dredged from Pentolite Ditch and spread overland, HaagEnviro expected that the Cs-137 might all lie within 3-6 inches of the land surface.

In the meandering-stream deposits of Plum Brook, HaagEnviro anticipated that most of the Cs-137 would be found in very thin layers at depths greater than 6 inches, but less than 24 inches.

Within the bay, HaagEnviro expected the Cs-137 deposits to be found in thin layers at depths less than 10 feet below the top of sediment, which itself was beneath 0-3 feet of water.

3. INTERFACE BETWEEN PLUM BROOK AND GROUNDWATER

HaagEnviro suggested that there were two primary groundwater pathways of interest for Cs-137: (a) transport of affected clays in fractures in the Delaware Limestone, and (b) transport of affected clays in shale fractures at the base of Plum Brook. Of these two possibilities, HaagEnviro felt that detectable transport in limestone was somewhat likely, while detectable transport in shale appeared quite unlikely.

4. HOW FAR DOWNSTREAM CS-137 WAS LIKELY TO HAVE MOVED

Based upon the data reviewed in this study, HaagEnviro found it likely that Cs-137 had moved to the bay, more than four miles downstream from the PBRF.

5. MEANS TO CONTROL STREAM FLOW DURING REMEDIATION (IF NEEDED)

HaagEnviro indicated that, if any further Cs-137 were to be removed from the bottom of Pentolite Ditch, drainage could readily be routed around this feature, which was quite similar to a long, thin pond.

In the stream meander environment, HaagEnviro indicated that the Cs-137 appeared to be located in deposits beside the stream's low-flow level, thus no flow control might be needed so long as removal were to be conducted during dry weather.

In the bay and marsh environments, HaagEnviro anticipated that Cs-137 would be buried, would be thinly distributed, and would be diluted by the addition of sediment from other streams. Accordingly, it appeared unlikely to HaagEnviro that remediation activities would be necessary in the bay depositional environment.