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USE OF THE SITE CHARACTERIZATION AND ANALYSIS PENETROMETER SYSTEM AT GRANDVILLE, MICHIGAN SUPERFUND SITE

by

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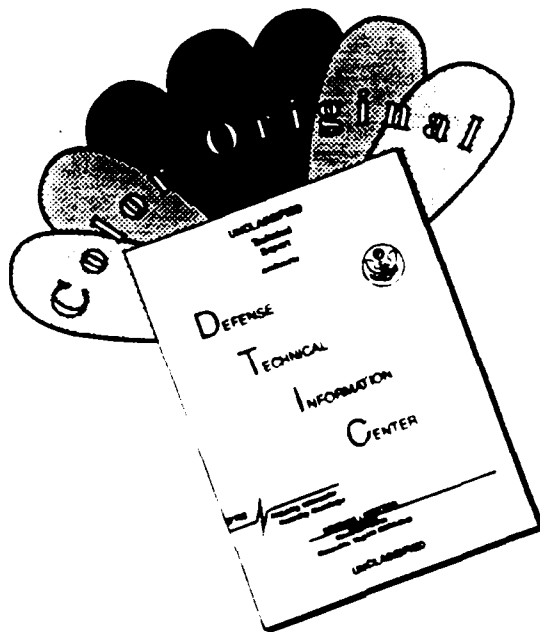
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13. ABSTRACT (Maximum 200 words) This report documents the results of an investigation at the Organic Chemical, Inc. site in Grandville, Michigan. This site is on the National Priority List for cleanup, and is being overseen by the Environmental Protection Agency, Chicago, Region V office. The site was investigated utilizing the Site Characterization and Analysis Penetrometer System, with a fiber optic fluorimeter sensor. This sensor allows the detection of hydrocarbon contaminants in the subsurface. A total of fifty pushes were completed at the site to an average depth of approximately 15 ft, covering approximately 80 acres. A hydrocarbon contaminant plume was located at the site extending from the OCI facility in a northerly direction. This matches the flow of the groundwater in the area as it moves toward the Grand River. The plume was successfully bounded on the North, South, and West sides. The plume boundary on the East side could not be established due to property constraints. The concentrations of contaminants in certain areas of the site exceeded 5000 ppm.				
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Preface

The Earthquake Engineering and Geosciences Division (EEGD), Geotechnical Laboratory (GL), Waterways Experiment Station (WES), was tasked by the Environmental Protection Agency (EPA) and the United States Army Toxic and Hazardous Materials Agency (USATHAMA) to perform an investigation at an EPA superfund site in Grandville, Michigan. The immediate site is owned by Organic Chemicals, Inc., and encompasses approximately 5 acres, with the total anticipated area of contamination encompassing approximately 80 acres. The EPA wished to evaluate and demonstrate the ability of the Site Characterization and Analysis Penetrometer System (SCAPS) to detect and delineate hydrocarbon contaminants at the site. Coordination with the EPA was provided by Mr. Tom Williams, and with USATHAMA by Mr. Wayne Sisk. The investigation was conducted from 8 July to 24 July 1992.

The field work was conducted by Messrs. Michael K. Sharp, Raju Kala, Karl F. Konecny, and Don Harris of the GL, and Messr. Jeff Powell of the Instrumentation Services Division (ISD), WES.

Report preparation was done by Messrs. Michael K. Sharp and Raju Kala, GL, and Jeff Powell, ISD.

The project was under the direct supervision of Mr. Joseph R. Curro, Jr., Chief, Engineering Geophysics Branch, Mr. Mark Vispi, Chief, In Site Evaluation Branch, Dr. A. G. Franklin, Chief, EEGD, and Dr. W. F. Marcuson III, Director, GL.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Leonard G. Hassell, EN.

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CONVERSION FACTOR, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
acres	4,046.873	square metres
Fahrenheit degrees	5/9	Celsius degrees or Kelvins
feet	0.3048	metres
gallons	3.785412	cubic decimetres
gamma	1.0	nanotesla
inches	2.54	centimetres
miles (US statute)	1.609347	kilometres
pounds (mass)	4.448222	newtons
tons (short ton)	907.2	kilograms

* To obtain Celcius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

USE OF THE SITE CHARACTERIZATION AND ANALYSIS PENETROMETER SYSTEM

AT GRANDVILLE, MICHIGAN, SUPERFUND SITE

PART I: INTRODUCTION

Background

1. The Earthquake Engineering and Geosciences Division was tasked by the U. S. Environmental Protection Agency (EPA) and the U. S. Army Toxic and Hazardous Materials Agency (USATHAMA) to perform an investigation at a site in Grandville, MI (Figure 1). The site is owned by Organic Chemicals Inc. (OCI) and is on the National Priority List as a Superfund Site. The facility, through the years, has served many roles, first being an oil refinery and later being converted to an industrial chemical recovery/disposal operation. The plant is now closed pending cleanup activity. The EPA was interested in the ability of the Site Characterization and Analysis Penetrometer System (SCAPS) to detect and delineate hydrocarbon contaminants in the subsurface.

2. Previous work performed at the site includes three investigations done using soil borings and monitoring wells by three different contractors (Black and Veatch Engineers-Architects, Prein and Newhof Engineers-Planners, and Materials Testing Consultants). Both soil and liquid samples were taken and analyzed in the laboratory. In addition, a limited amount of trenching and soil gas surveying was performed at the site. A geophysical electromagnetic survey was also performed. The laboratory results obtained from the samples taken indicate several compounds in the subsurface including benzene, toluene, xylene, styrene, methylene chloride, chlorobenzene, chloroform, acetone, benzoic acid and many others. A complete listing of chemical compounds discovered is contained in a report at the EPA Region V office.

Purpose

3. In addition to the many types of industrial chemicals discovered through laboratory analysis, the EPA wanted to determine whether or not hydrocarbons typical of fuels were also present in the subsurface and if so to what extent. The boring program had indicated that hydrocarbons might be present as evidenced by the color and odor of many samples collected. Due to the complex nature of the conditions at the site, the EPA was having difficulty assimilating the data into a clear representation of site conditions. The objective of the SCAPS work at the site was to develop a data set that could be directly compared to results

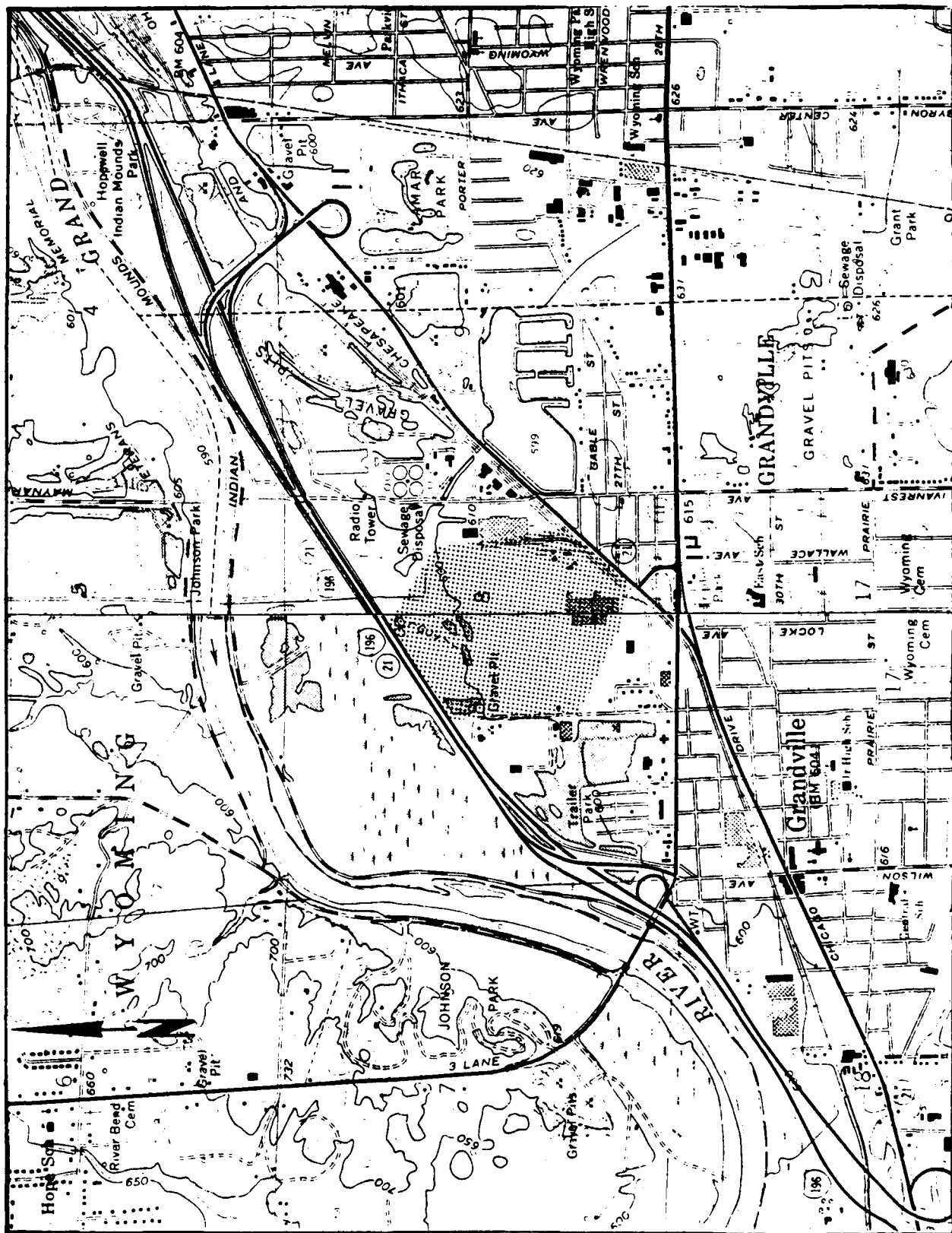


Figure 1. Site map showing the area investigated at Grandville, Michigan.

from wells and soils borings and to develop data on the areal and vertical extent of hydrocarbon contamination in the soil above and below the water table. The work of locating the hydrocarbon contamination was done using a cone penetrometer equipped with a fiber optic fluorometer.

PART II: SITE DESCRIPTION

Geology

4. The site investigated lies in Kent county in the west central part of the Lower Peninsula of Michigan. The bedrock in Kent county consists of the edges of bowl-like formations that fill the Michigan Basin. The oldest rock is Marshall Sandstone, which underlies all of the county and is the uppermost bedrock in the southwestern part. Overlapping the Marshall Sandstone in the central and southeastern parts of the county is the Michigan Formation, which is primarily limestone, gypsum, and dolomite interbedded with shale and sandstone. To the northeast, these rocks are progressively overlapped by Bayport Limestone, Parma Sandstone, and finally by the coal-bearing Saginaw Formation in the furthest northeast part of the county. Overlying these rock formations is a mass of glacial drift that was deposited during the Wisconsin glacial period. The county is situated in an area where the Michigan and Saginaw lobes of the Wisconsin ice sheet met. Consequently, a very complex and strongly developed interlobate morainic system developed. The deposits of glacial drift range from less than 10 feet to several hundred feet in thickness within the county. The drift ranges from coarse gravel to fine lacustrine clay. It is the parent material in which many of the soils in the county formed. The present surface features are, for the most part, the results of glacial action. The landscape is an undulating plain in which valleys have been cut. Outwash material was deposited in the valleys by glacial meltwater streams. Three major physiographic regions are recognized in the county. The one that affects the area of investigation consists of a number of outwash plains and lake plains in nearly level valleys having rather definite boundaries. The glacial drift is typically thinnest in these areas, and the bedrock is within a few feet of the surface along the lower reaches of Buck and Plaster Creeks, near Wyoming and Grandville. The elevation in most of Kent county is 750 to 850 feet above sea level. The major outwash channels and plains, however, range from 600 to 750 feet in elevation. The Grand River has an elevation of about 617 feet where it enters the county and of 592 feet where it leaves the county. The water table slopes from 600 ft to 587 ft MSL between the site and the nearby Grand River.

5. The parent material of the soils of Kent county were deposited by glaciers or by glacial meltwater. Some of these materials have been reworked and redeposited by the subsequent action of water and wind. Although the parent materials are of common glacial origin, their properties vary greatly, sometimes within small areas, depending on how the materials were deposited. The dominant parent materials in Kent county were deposited as glacial till, outwash deposits, lacustrine deposits, alluvium, and organic material. The glacial till in Kent

county is calcareous loam, clay loam, or fine sandy loam. From this information and the information obtained from boring logs, it can be determined that there is a substantial clay layer underlying the site. This clay layer occurs at various elevations throughout the site, but tends to occur at lower elevations towards the Grand River. To maintain the integrity of this clay layer, no pushes were made to elevations that would puncture or damage the layer.

General

6. The site once served as an old gravel pit and can be divided in general into two sections. The southern half of the site, where the OCI facility is located, does not appear to have had as much gravel removed as the northern half. The northern half does have a lower surface elevation than the southern half which is in areas as much as 10 ft higher. The northern half of the site has also undergone extensive filling operations in an attempt to raise the surface elevation. The current landowner described the fill material as various types of construction debris. This includes large pieces of concrete, metal pipes, culverts, bricks, blocks, etc. This debris filling operation was not known to WES before the SCAPS work began, and presented quite a problem to the cone penetrometer trying to push through such material. This resulted in many broken probes and rods, greatly hampering progress.

7. The site in general presented a challenge to the cone penetrometer trying to force the push rod through rather large gravels. Four out of six probes on hand were damaged trying to push through the gravel layers. This necessitated the use of a dummy probe in many of the probe locations. The dummy probe is a non-instrumented mechanical device slightly smaller than the instrumented probe used to make a pilot hole. Once the pilot hole was made to the depth required, the instrumented probe was used to collect fluorescence data. This technique does not allow the collection of soils data (cone tip resistance and sleeve friction) for soil classification purposes, but does permit the collection of fluorescence data. Since the main objective of the project was to collect fluorescence data, this technique did not hamper the project.

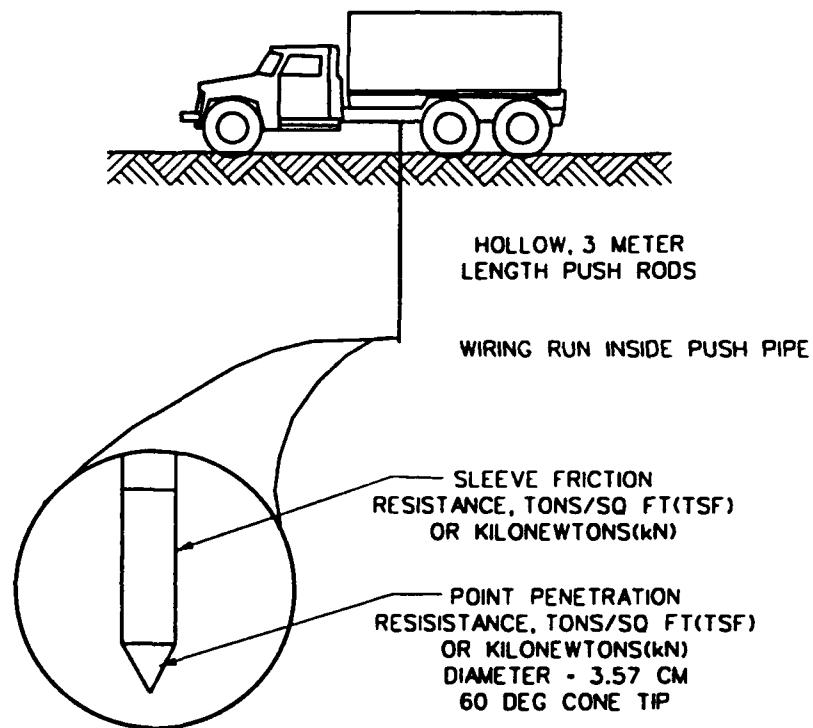
PART III: EQUIPMENT AND METHODS

General

8. The Site Characterization and Analysis Penetrometer System (SCAPS), includes a suite of surface geophysical equipment, survey and mapping equipment, special penetrometers with sensors for contaminant detection, and soil and pore fluid penetrometer samplers. The experimental penetrometer system is mounted in a specially-engineered truck (Figure 2) designed with protected work spaces to allow access to toxic and hazardous sites while minimizing exposure of the work crew. The SCAPS "screening" penetrometers are equipped with sensors that can determine certain physical and chemical characteristics of the soil as the penetrometer tip is forced through the soil. SCAPS includes sensors that can determine the strength, electrical resistivity, and spectral properties, in this case the fluorescence, of soils. All sensors read out in real time, and a computer-based data collection and analysis system permits a display and partial interpretation of data in the instrument compartment on the penetrometer truck. The data analysis system also allows processing of various types of surface geophysical and mapping data collected on site, and integration of data into a unified data base. Fluid and soil samples can be collected using devices such as the commercial "stab type" groundwater and soil samplers that are designed for use with penetrometers. The SCAPS system is also equipped to seal each penetrometer hole with grout as the probe is withdrawn from the hole and the geotechnical investigation proceeds across a site. The SCAPS unit is built so that surfaces and compartments exposed to waste can be thoroughly and completely decontaminated. Post processing of the data to provide a 3-D visualization of site conditions is presently done with a computer work station that can be used at WES or brought to the installation. SCAPS is designed to save time and costs and to minimize exposure of the crew while sensor data or samples are collected. Penetrometer units available commercially do not have this combination of capabilities.

Site Mapping

9. The locations of penetrometer push points were determined by establishing a grid over the site. The OCI site covers approximately five acres while the total area of investigation covers approximately eighty acres. A grid was established on 300 ft centers (Figure 3) with each location to be surveyed for northing, easting, and elevation. The survey points are based on a local coordinate system provided by EPA, that tied into work performed during the drilling operations. A local Corps District was used for surveying the grid. Additional surveying was performed by the WES crew utilizing a total station



BASIC CONFIGURATION OF SCAPS TRUCK
 MOUNTED ON ALL WHEEL DRIVE TRUCK (MODIFIED M814 MILITARY CHASSIS)
 HYDRAULICALLY POWERED PUSH APPARATUS 178-kN PUSH
 WEIGHT APPROXIMATELY 21,000 KG
 COMPUTER AIDED DATA ACQUISITION
 MEASUREMENTS OF PENETRATION RESISTANCE
 AT 1-INCH (2.5 CM) INTERVALS
 ENCLOSED AIR-CONDITIONED WORKSPACE

Figure 2. Experimental penetrometer system and configuration.

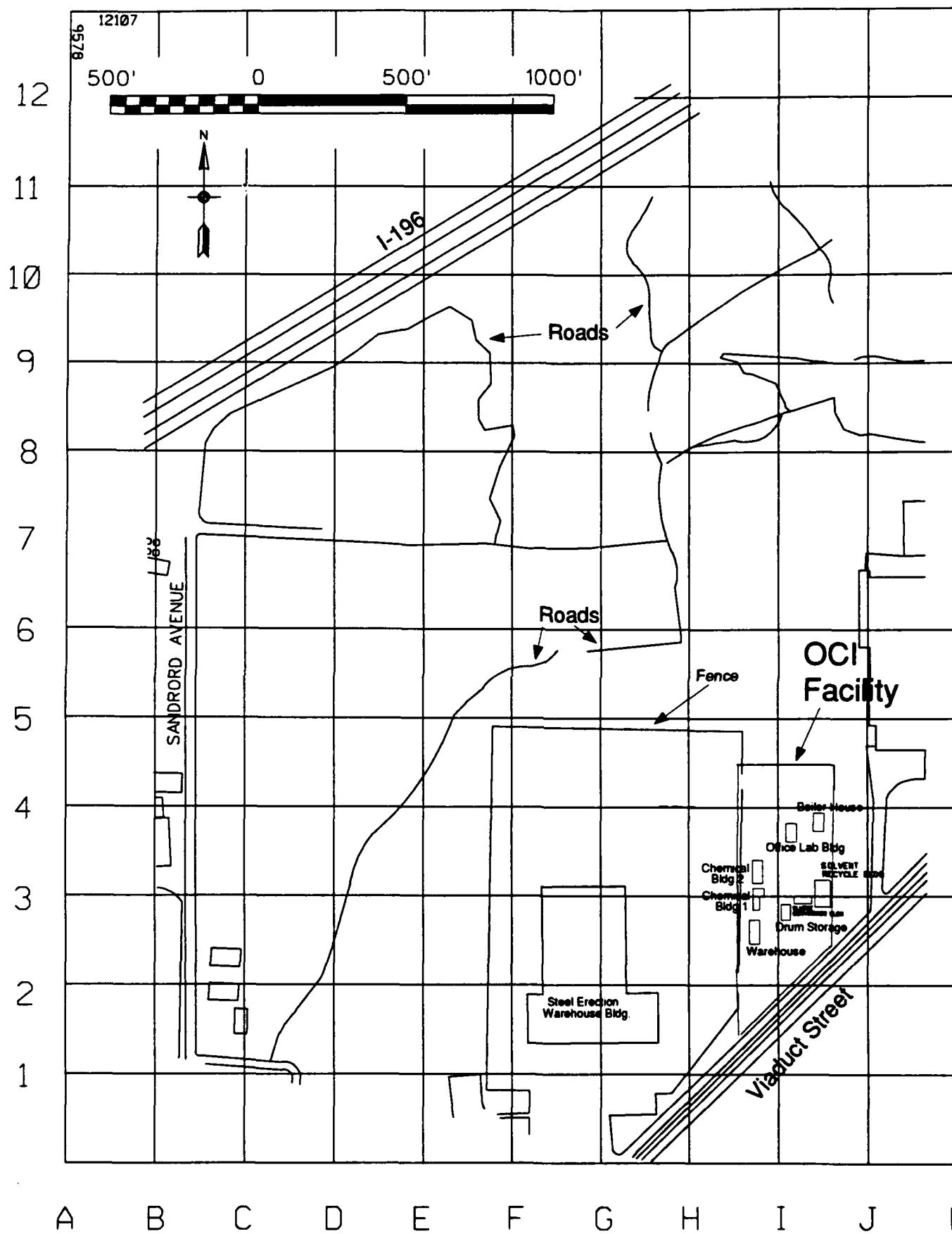


Figure 3. Detail of OCI site and surrounding area showing survey grid established to guide push locations.

electronic distance measuring system (EDM). This additional surveying included points that could not be reached with the push truck due to physical constraints, points investigated between the original 300 ft grid, and points located outside the grid.

Geophysical Investigations

10. Geophysical site surveys were undertaken primarily to determine if there was metallic debris in the area where the penetrometer unit would be operating. The geophysical investigations were simply scans of the area before pushing began to insure that no damage would occur to the probe and that no pipes, barrels, or other such objects would be punctured. The geophysical technique used at the OCI site in conjunction with the SCAPS truck consisted of electromagnetic induction. This technique was selected because of its ease of use, real-time data analysis, and reliability of metal detection to a maximum depth of twenty feet.

11. The electromagnetic induction devices are used to measure the earth's apparent ground conductivity. The responses from the equipment are directly proportional to conductivity and inversely proportional to resistivity. The basic operation utilizes a transmitter coil (Tx) energized with an alternating current at an audio frequency and a receiver coil (Rx) located a short distance away. The time varying magnetic field arises from the alternating current in the transmitter coil inducing currents in the earth. These currents generate a secondary magnetic field which is sensed, together with the primary field, by the receiver coil. In general, this secondary magnetic field is a complicated function of the intercoil spacing, the operating frequency, and the ground conductivity. Under certain constraints, called the low induction condition, the secondary magnetic field is a very simple function of these variables. Under these constraints, the ratio of the secondary to the primary field is linearly proportional to the terrain conductivity. The apparent conductivity indicated by the instruments depends on measurement of the secondary to primary field ratio and assumes low induction conditions. The units of conductivity are the mho (Siemen) per meter or, more conveniently, the millimho per meter.

12. There are two components of the induced magnetic field measured by the instrument. The first is the quadrature-phase component which gives the ground conductivity measurement. The second is the inphase component, which is used primarily for calibration purposes; however, the inphase component is significantly more sensitive to large metallic objects and hence very useful when looking for buried metal containers. Experiments have indicated that the Geonics EM-31 can detect a single 45 gal oil drum at a depth of about 12 ft (3.7m) using

the inphase component of the meter.

13. The instrument has an intercoil spacing of 12 ft (3.7m) and has an effective depth of exploration of approximately 20 ft (6 m). The EM-31 meter reading is a weighted average of the earth's conductivity as a function of depth. A thorough investigation to a depth of 13 ft (4 m) is possible, but below that depth the effect of conductive anomalies becomes more difficult to distinguish as their depth increases. The instrument can be operated in both a horizontal and vertical orientation which changes the effective depth of exploration. The instrument is normally carried such that the transmitter and receiver coils are oriented vertically, which gives the maximum penetration depth. It can be used in either a discrete or continuous-read mode.

Grouting Methods

14. The SCAPS unit is equipped to seal the penetrometer holes using either a liquid (chemical) grout or conventional Portland cement-based grout. The chemical grout system is designed to inject a two-component grout through tubes running down the center of the penetrometer rod and seal the penetrometer hole as the rod is withdrawn. The system uses two high-pressure, positive-displacement pumps feeding into a pressure/volume regulating system that can control the amount of each component dispensed. The chemical grout injection system can handle acrylate, urethane or silicate grouts. The SCAPS equipment also includes a conventional cement/bentonite grout mixer and a low-pressure progressive cavity pump for tremie grouting of penetrometer holes. All holes at the OCI site were grouted utilizing the conventional cement/bentonite grout either poured or tremied into the hole.

Site Characterization Methods

15. The major component of the SCAPS system is a 20-ton, all-wheel-drive penetrometer truck that was designed specifically for operations at hazardous waste sites, an overall view of the system is shown in Figure 4. The truck carries a hydraulic power unit and controls to operate the push apparatus, separated push and data acquisition work spaces, a shock-isolated floor for the penetrometer instrumentation, easily decontaminated stainless steel van body, and other personnel protection features. A specially designed trailer is used to carry the grouting pumps, water tank, and a closed-loop steam cleaner to clean the penetrometer rods and tools as they are withdrawn from the soil.

16. The electronics package includes WES-designed and built signal-conditioning hardware and test equipment capable of providing on-site calibrations of



Figure 4. Photograph of penetrometer truck and grouting trailer.

contaminant detectors and load cells used to make penetration resistance measurements. Data acquisition and initial data processing are carried out with an on-board computer with a matching computer used for data management and file integration. The second computer affords redundancy in the event of a computer failure. A view of the data collection compartment of the truck is shown in Figure 5.

Soil Strength and Type Determination

17. A sectional view of a penetrometer equipped to measure soil strength is shown in Figure 6. The point load cell is loaded in compression as the cone tip is advanced. The friction sleeve load cell is in the form of a hollow cylinder and strain gauged on the inside surface of the cylinder. The cell surrounds the tip load cell and is also loaded in compression when soil friction acts on the friction sleeve which jackets the front of the probe. The design employed in this soil strength unit allows the tip penetration resistance and sleeve friction measurement to be made independently and continuously.

18. Two calibration procedures are used with the cone employed in this investigation so that separate calibration curves can be developed for the two load cells. The point resistance load cell is calibrated by cycling the load from zero load to approximately 7272 Kgf (equivalent to 16,000 psi) and back to zero load several times. The cell is then loaded to selected load increments and back to zero. The load cell output is read for each load increment applied and the zero load condition at the beginning and end of each loading increment. The load increments are increased until the compressive force reaches the maximum capacity of the cell. The friction sleeve load cell is calibrated in a similar way. Figures 7 and 8 show typical calibration curves obtained for a strain-gaged penetrometer instrument. Each load cell is calibrated independently but the output of each cell is measured as the calibration proceeds so that any influence of one cell on the output of the other can be determined. Typically neither cell shows any influence on the other. Calibration test responses are generally within 0.5% of the applied load. Load cell calibrations can be done in the field, but are generally completed prior to field deployment.

19. Due to the nature of the site (gravels and construction debris) and the many broken probes, no soils data was collected at the site for any of the probes. Therefore no soils classification information is presented in this report. The depth of penetrometer pushes, selected to extend to the clay layer, was determined from the boring logs in the area rather than from the penetrometer soils information.



Figure 5. View of data collection and processing section of penetrometer truck.

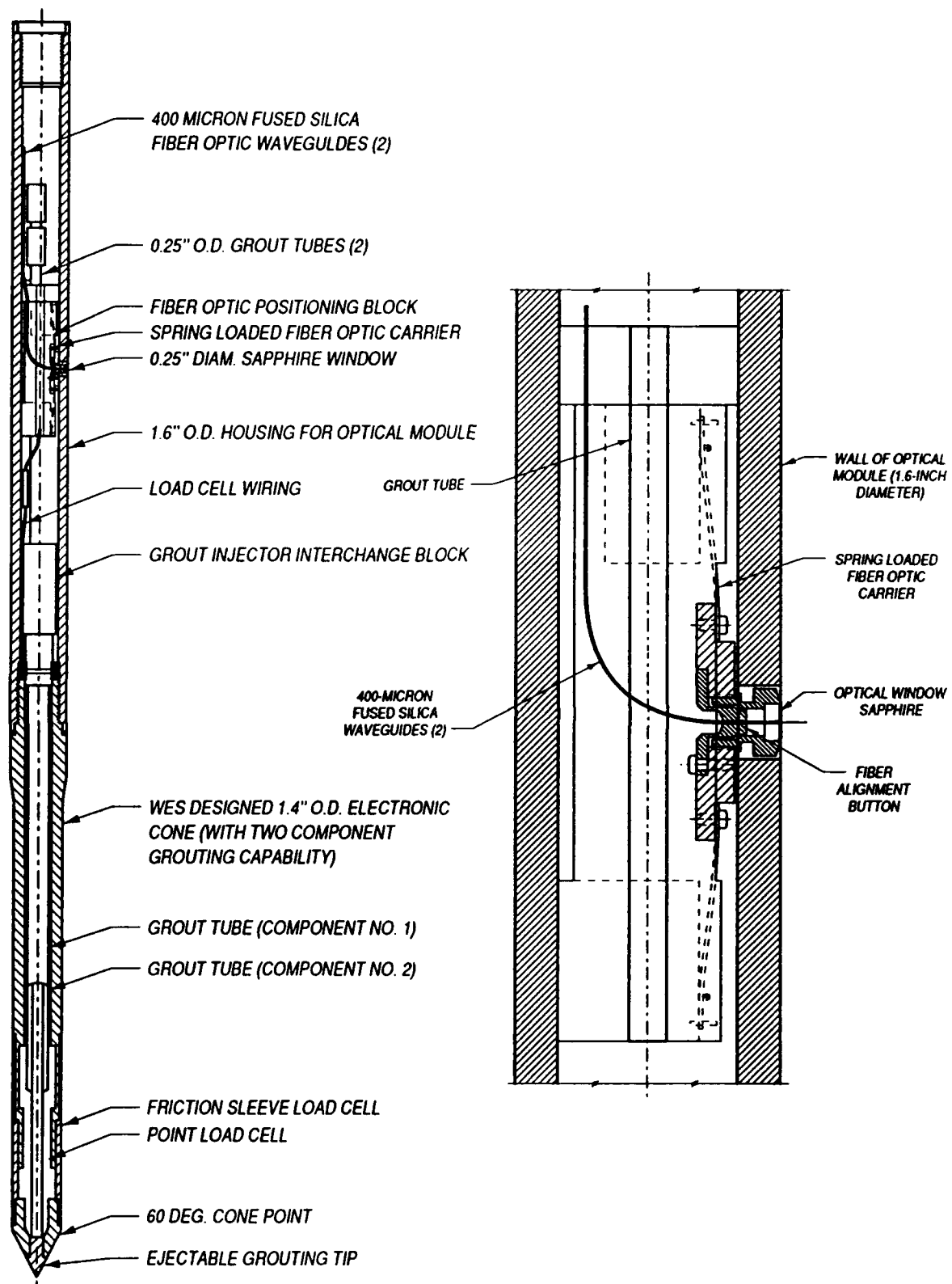


Figure 6. Cross sectional view of penetrometer showing cone, sleeve, and fiber optic components, with close-up of fiber optic window.

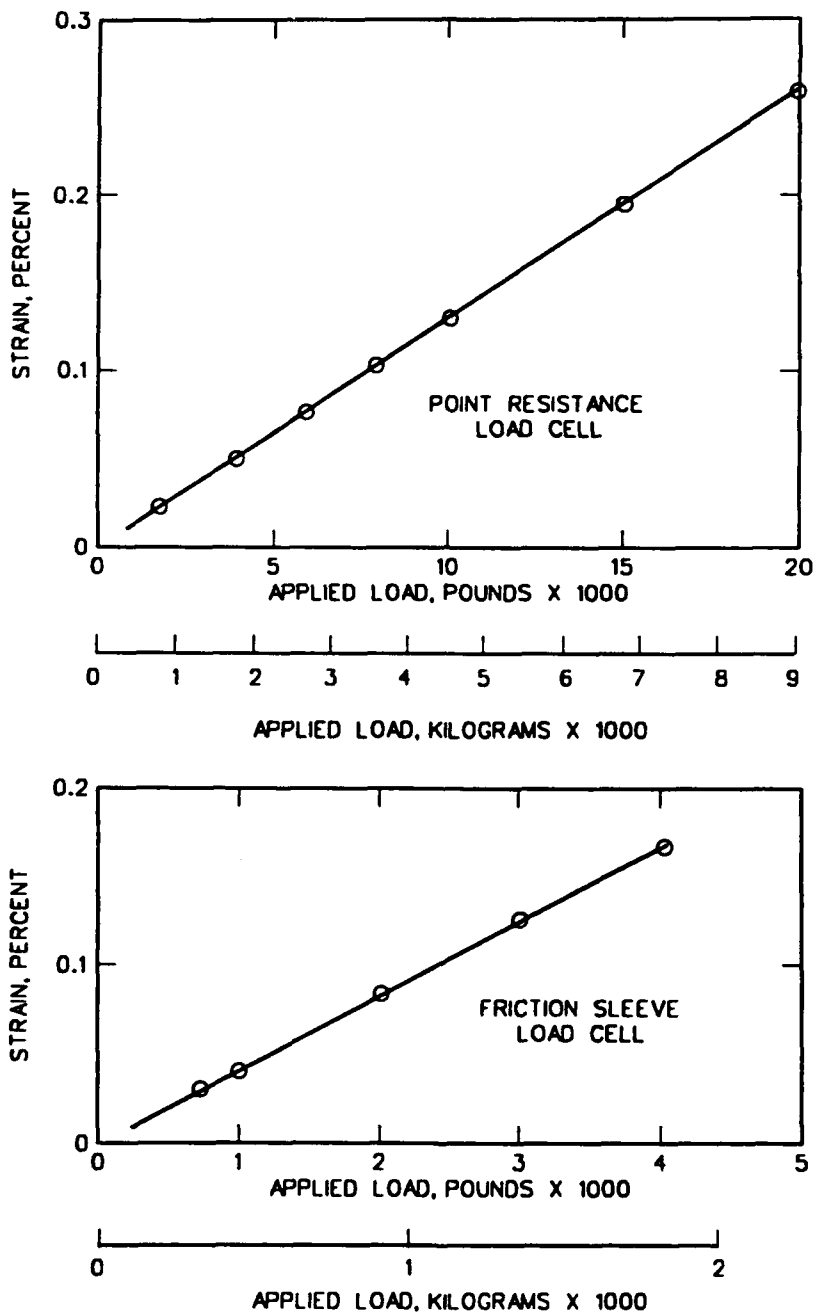


Figure 7 and 8. Calibration curves for point resistance and sleeve friction.

Soil Fluorescence Measurement Methods

20. The in situ fluorometer is described in detail in the U. S. Patent Office (1992). Lieberman, Inman and Theriault (1989) had used a fluorometer for measuring POL fluorescence in seawater, and the fluorescence has been documented as a useful approach in tracking hydrocarbon pollutants. A schematic of the system is presented in Figure 9. In making a measurement, the exciting radiation is produced by firing a pulsed nitrogen laser (emitting wavelengths at 337 nm). The laser light is coupled into two fibers, a timing circuit fiber and the downhole sample irradiation fiber. The light in the timing circuit fiber is used to set the timing window on the detector. The major part of the laser pulse is coupled into a 400-micron optical fiber that passes down the center of the penetrometer rod. The fiber ends at a 6.35-mm sapphire window that passes the light onto the soil surface adjacent to the window. The fluorescence signal that is a response to the ultra-violet excitation is collected by a second 400-micron fiber and is carried back up through the penetrometer rod to a polychromator. In the polychromator the fluorescent signal is dispersed and the energy distribution at the wavelengths of interest is measured using a linear photodiode array. This system is much faster than a scanning spectrofluorometer. Readout of an entire emission spectrum requires only 15 msec. The rapidity of the readout makes it practical to "stack" or add successive pulses and increase the sensitivity of the unit. Time resolve fluorometry is also possible although this may require holding the window in one position for several minutes.

21. The response of the fluorometer is directly related to the concentration of aromatic compounds in the soil. Fluorescence of any aromatic compounds with basic or acid functional groups is usually pH dependent. Ionized aromatic compounds will fluoresce at different wavelengths and at different intensities from the same compounds in a nonionized state. Fluorescing compounds adsorbed on solid surfaces will typically fluoresce with greater intensity than the same compounds in solution. Decomposition or weathering phenomena also change the fluorescence of fuels. Generally the aromatic (ring) compounds that fluoresce are concentrated in the weathering process because the lighter hydrocarbons volatilize and the longer straight-chain hydrocarbons are more easily decomposed by microbial activity.

22. Each fluorescence spectrum consists of photon counts measured at 1024 points (over a wavelength range of 300 to 800 nm) for every 2-cm (0.8-in.) layer of soil investigated. The present data processing system records all spectral intensity measurements and makes corrections for instrument drift during measurement. The corrected data are screened to develop the photon counts for the peak of interest and the background. A file containing the single equivalent

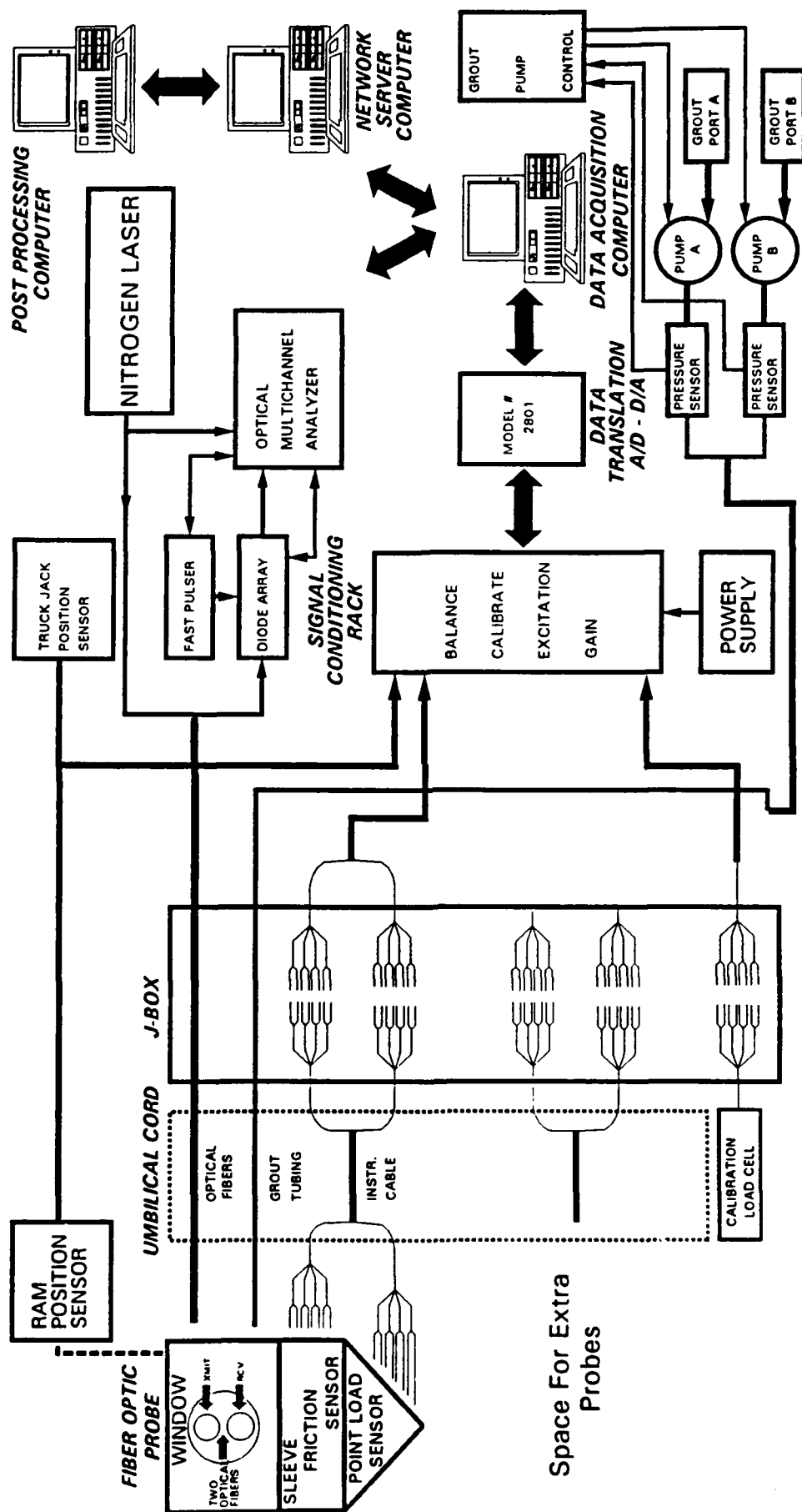


Figure 9. Flowchart of fiber optic system.

normalized counts, the map coordinates, and the depth below a surveyed datum is prepared from the spectral data. The final data file is transformed into a 3-dimensional gridded file and is displayed using a visualization program.

Method of Converting Counts to Probable Contaminant Concentrations

23. Prior to arrival of the SCAPS truck a WES crew visited the OCI site and obtained soil samples at two locations. These samples were collected in areas that were known to contain hydrocarbon contaminants or known to be free of hydrocarbon contaminants based on earlier trenching activity conducted by the EPA. The samples were returned to WES and analyzed in the laboratory for total oil and grease (O&G), total recoverable petroleum and hydrocarbons (TRPH), and total polynuclear aromatics (TPNA). The same samples were investigated with the fiber optic fluorescence system to determine the counts associated with each. The samples were then mixed to form ratios of "clean" to "dirty" at ratios of 25:75, 50:50, and 75:25, respectively. The new samples were then analyzed as described above to produce a set of points for each test. The results of the lab analysis and fluorescence data is presented in Table 1. A plot of O&G, TRPH, and TPNA concentrations of contaminants in ppm versus intensity counts (Figure 10) was then created. The intensity counts axis is a ratio of counts obtained from firing on the soil samples (Table 1) over counts obtained from firing on the rhodamine standard. A best fit line was forced through the data to give three equations. These equations represent a technique to convert counts from the fiber optic system, into predicted concentrations of ppm based on the data collected at the OCI site. The equation used to convert all the counts to ppm in this report is based on the TRPH data. The O&G data should give values that are high because of the inclusion of the greases which do not fluoresce. The TPNA data should give values that are low because it only includes the aromatics. Therefore, the TRPH data is best representative of the soil fluorometer data.

Table 1. Results of calibration testing for the OCI site.

	Dirty	75% Dirty 25% Clean	50% Dirty 50% Clean	25% Dirty 75% Clean	Clean
Fluorescence Counts	1115	731	402	170	45
Laboratory O&G, ppm	4500	3100	1600	800	230
Laboratory TRPH, ppm	3900	2600	1200	600	45
Laboratory TPNA, ppm	1.4	1.0	0.6	0.06	0

Soil Calibration Study

Laser Intensity Counts vs Lab Results

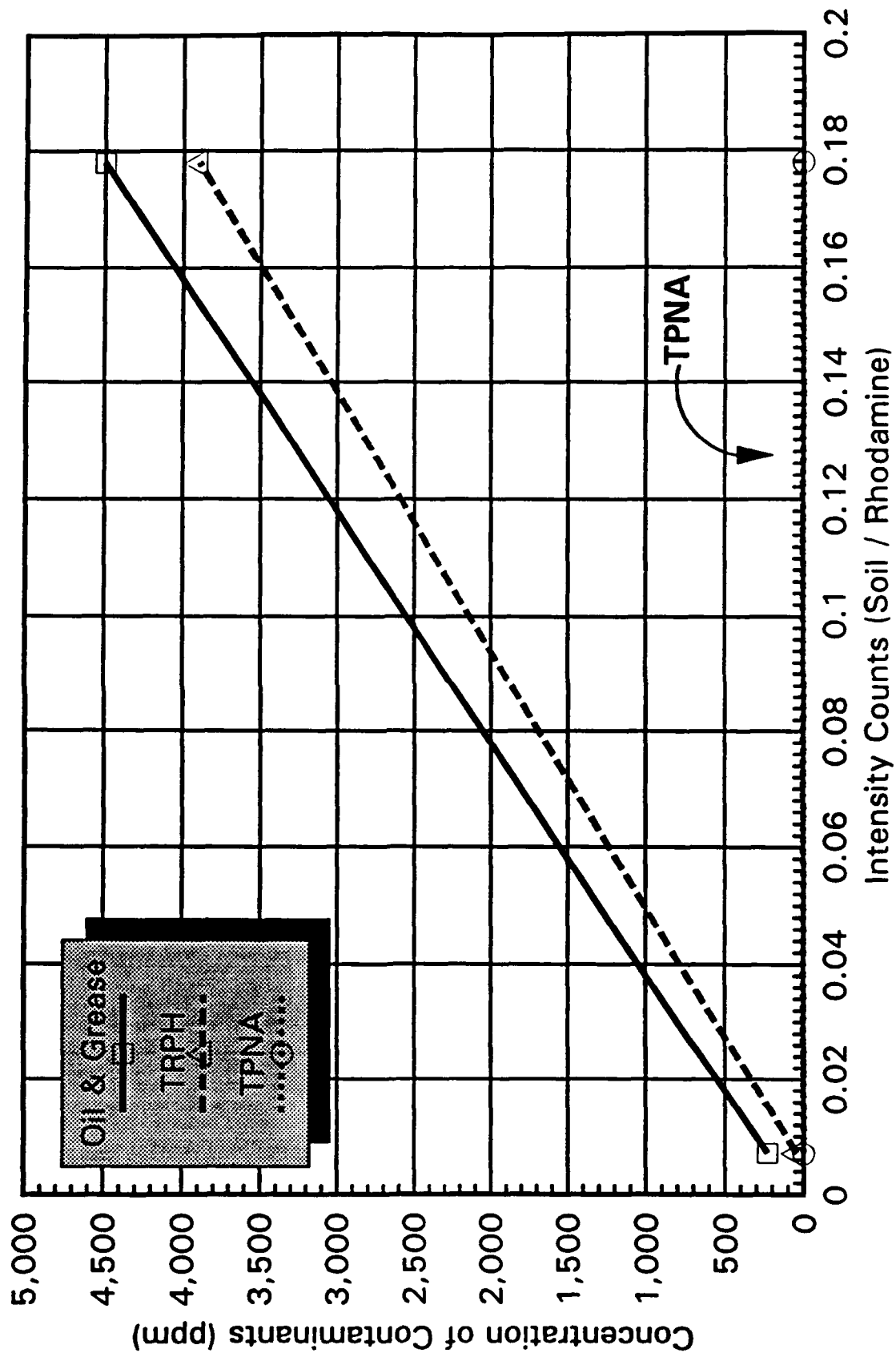


Figure 10. Calibration curves established for the OCI site showing counts versus ppm for three different laboratory test.

Data Acquisition

24. The data acquisition system and the post processing system each have a separate control computer. The two computers are linked by a network so that data can be exchanged during and after the penetration testing. During the penetration test the data acquisition computer controls all systems and stores the data on a hard disk. The major block of data is generated by the soil fluorometer system in the optical multichannel analyzer (OMA). The OMA is a separate computer that is controlled by the data acquisition computer through a general purpose interface bus. The data acquisition is also interfaced directly with; the amplifier/filter components for the measurement of strain on the cone tip and sleeve and a variable potentiometer that reads out the position of the hydraulic rams (data used to calculate the depth of the penetrometer tip). After the completion of each push, the data are transferred via the network link from the data acquisition computer to the post processing computer where two dimensional plots of the data can be produced. In addition to this, the data are continuously displayed in the form of two dimensional plots on the computer screen during each push.

Data Visualization

25. Penetrometer data were interpreted on-site with the help of 3-dimensional visualization software (Interactive Volume Modeling, IVM) developed by Dynamic Graphics, Inc. on a Silicon Graphics workstation. The IVM program accepts scattered data files in ASCII format and creates a uniform 3-dimensional grid. Smooth extrapolation and interpretation for points is used to create grid values within and near the existing data. A lateral clipping plane is created to clip extrapolated data outside the bounds of the original data. The basic data controls the location of each known value but the aspect of the final 3-dimensional shapes produced from a data set can be altered by varying the weighting on the 3-dimensional grid derived from the original data. Typically the weighting values for the derived grid are selected by examining 3-dimensional volume plots and observing which spacing combination produces a plot that most closely agrees with the original data points. The software is referred to as "modeling" by the vendor. In the opinion of the authors, these are interpolation and extrapolation processes rather than modeling of a physics to science based process.

26. A completed 3-dimensional visualization model is presented as a series of surfaces that represent specific values of the variable under study. The plot of the surfaces can be presented as a series of drawings of the site or as a

computer-generated video that shows the soil volume with the data boundaries presented in varying colors. The IVM software can rotate the volume so that the limits of the parameter can be observed from all sides. Subprograms are available that allow the volume model to be sliced at various points so that the variation of the parameter can be observed inside the projected volume. All data collected at the OCI site was processed in this manner each day to help in directing the next day's probe siting.

PART IV: RESULTS AND DISCUSSION

General

27. The location of each probe conducted at the OCI site is shown in Figure 11. The results for each probe are presented as a series of panels in two dimensional form and as a three dimensional volume representation. The two dimensional figures each contain four panels presenting the fluorescence data. As previously discussed, due to the use of pilot holes, geotechnical data were not collected for any probe.

28. The four panels represent the fluorescence data collected at the site. The first panel is a plot of fluorescence intensity single equivalent normalized counts. At each depth of data collection (every 2 cm) the fluorescence intensity returned from the soil being sampled is recorded in terms of counts. Low counts referring to very little fluorescence and high counts referring to high fluorescence. The counts are then normalized by adjusting them to the calibration data recorded at the start and end of every push. In addition the counts are referenced to a standard (Rhodamine calibration of 10,000 counts) so that every probe regardless of the site conditions can be compared one to another. The panel shows the minimum resolution of the SCAPS fluorescence system, which is approximately 100 single equivalent normalized counts. Values below this range are attributable to resolution difficulties and can not be considered representative of conditions in the sub-surface.

29. The second and third panels convert fluorescence intensity single equivalent normalized counts into predicted parts per million (TRPH). Panel two presenting the data on a linear scale and panel three on a logarithmic scale. This data is based on the conversion technique as discussed in paragraph 22. The fourth panel is the wavelength that corresponds to the counts.

30. On each of the two dimensional figures presenting the results of a single probe (four panels), a legend is located at the bottom containing information about the probe. The values that appear for North, East, and Elevation are referenced to a local coordinate system. In the lower left corner of the legend is located the probe name. The probe name is a WES naming convention that is tied to the initial grid established by the surveyors. For example, "OCIC70" is the name identifying cone penetrometer push at the OCI site at location C7 on the grid (Figure 11).

31. The data are also presented in the form of three dimensional volumetric models representing sub-surface conditions. The field data are analyzed by

sophisticated three dimensional data interpolation algorithms. The gridded data are then formed into a three dimensional volumetric image of the subsurface soil conditions or of the body of contaminated soil. Varying properties of the material (contaminant concentrations) are displayed as different color zones. The image can easily and rapidly be manipulated in a number of ways to allow viewing the object from all angles. The location of all data points used to create the gridded data are displayed on the figure. Due to the large data set collected (every 2 cm) the posted data appear as a solid line. A two-dimensional plan map of the site investigated can be added to the figure to aid in feature locations. In the lower left corner of the figure is a legend presenting the color zones and corresponding values represented.

Fluorescence Data

32. The two dimensional panel plots of the fluorescence data from each individual probe conducted at the site are presented in Appendix A, and are summarized in Table II. Figures 12 through 22 are the volumetric representations of the data. Figure 12 is a view of the site looking east to west, that shows each probe location. The probe locations have been presented as elongated rectangles that have been color coded, with the legend located in the upper left corner of the plot. From a simple presentation like this, one can see the locations of contaminants extending from the south to north end of the site. The probes extended from Viaduct Street at the south end to Interstate-196 at the north end of the site. The east west boundaries were established by the property boundaries of adjacent landowners. A total of 49 probes were completed at the site.

33. A more detailed presentation of the data is given in the remaining figures. Figures 13 through 16 are all views of the site looking from southwest to northeast. Figure 13 shows all the data obtained at the site with TRPH concentrations of 100 ppm and above. Figure 14 shows the data with concentrations of 400 ppm and above, Figure 15 with concentrations of 1000 ppm and above, and Figure 16 with concentrations of 5000 ppm and above. These figures all show that the contaminants are spread out from the OCI site (where the buildings and tanks are located) northward toward the Interstate.

Organic Chemicals Inc.
TRPH, ppm

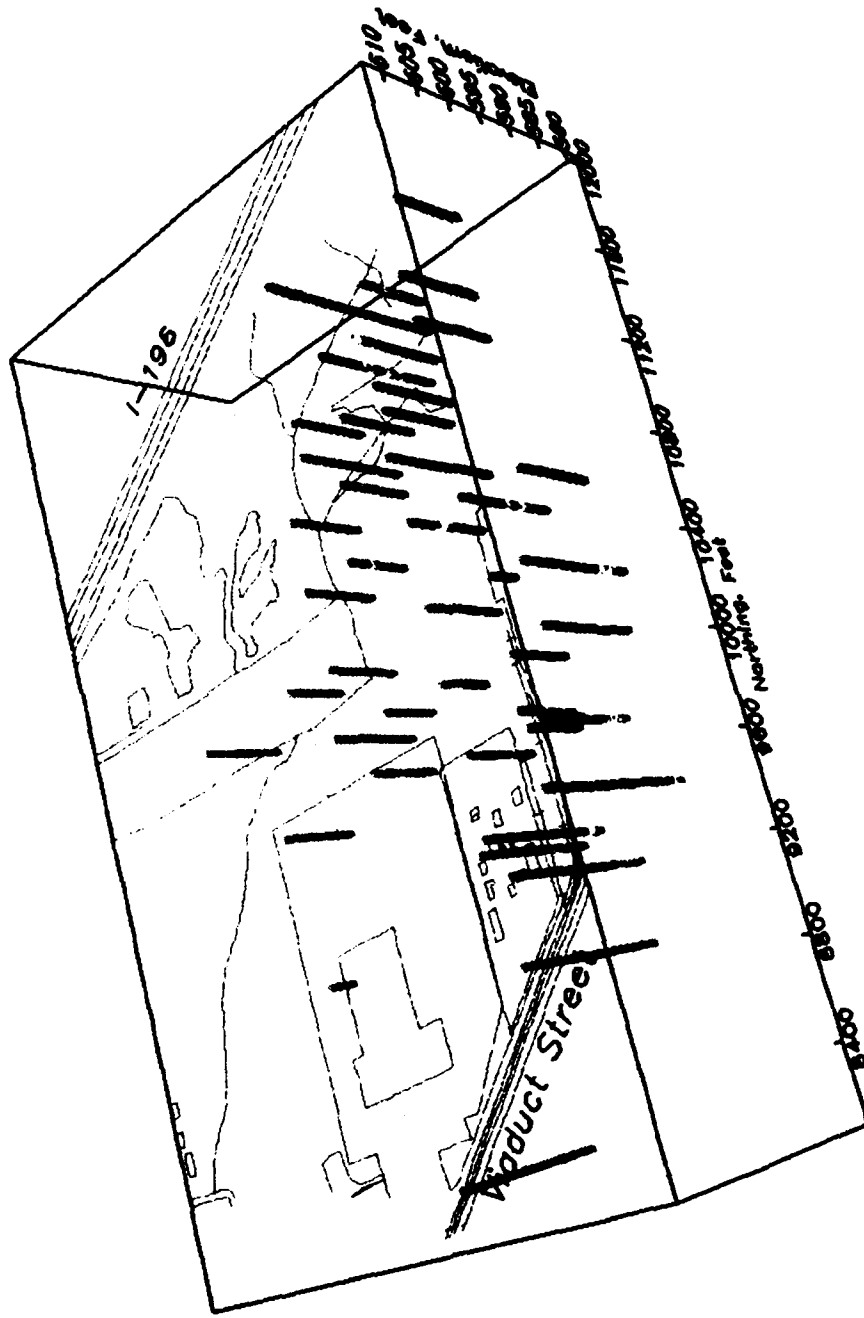
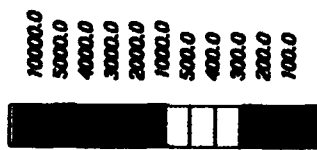


Figure 12. Three dimensional representation of site showing all probes presented as green rectangles, with the data color coded to reveal varying concentrations as varying colors.

Organic Chemicals Inc.
TRPH, ppm

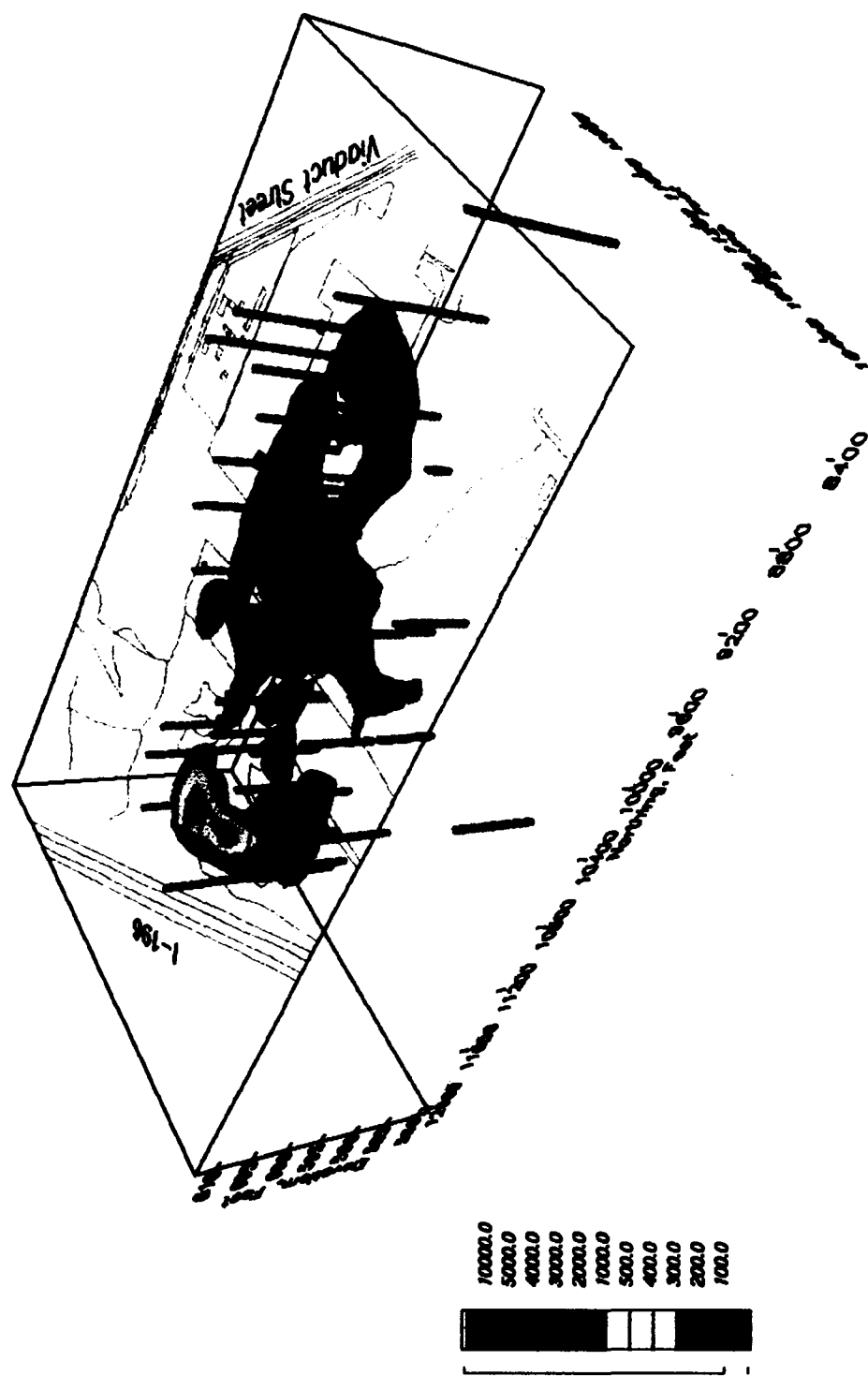


Figure 13. Volumetric representation of data looking southwest to northeast showing all concentrations of 100 ppm and greater.

Organic Chemicals Inc.
TRPH, ppm

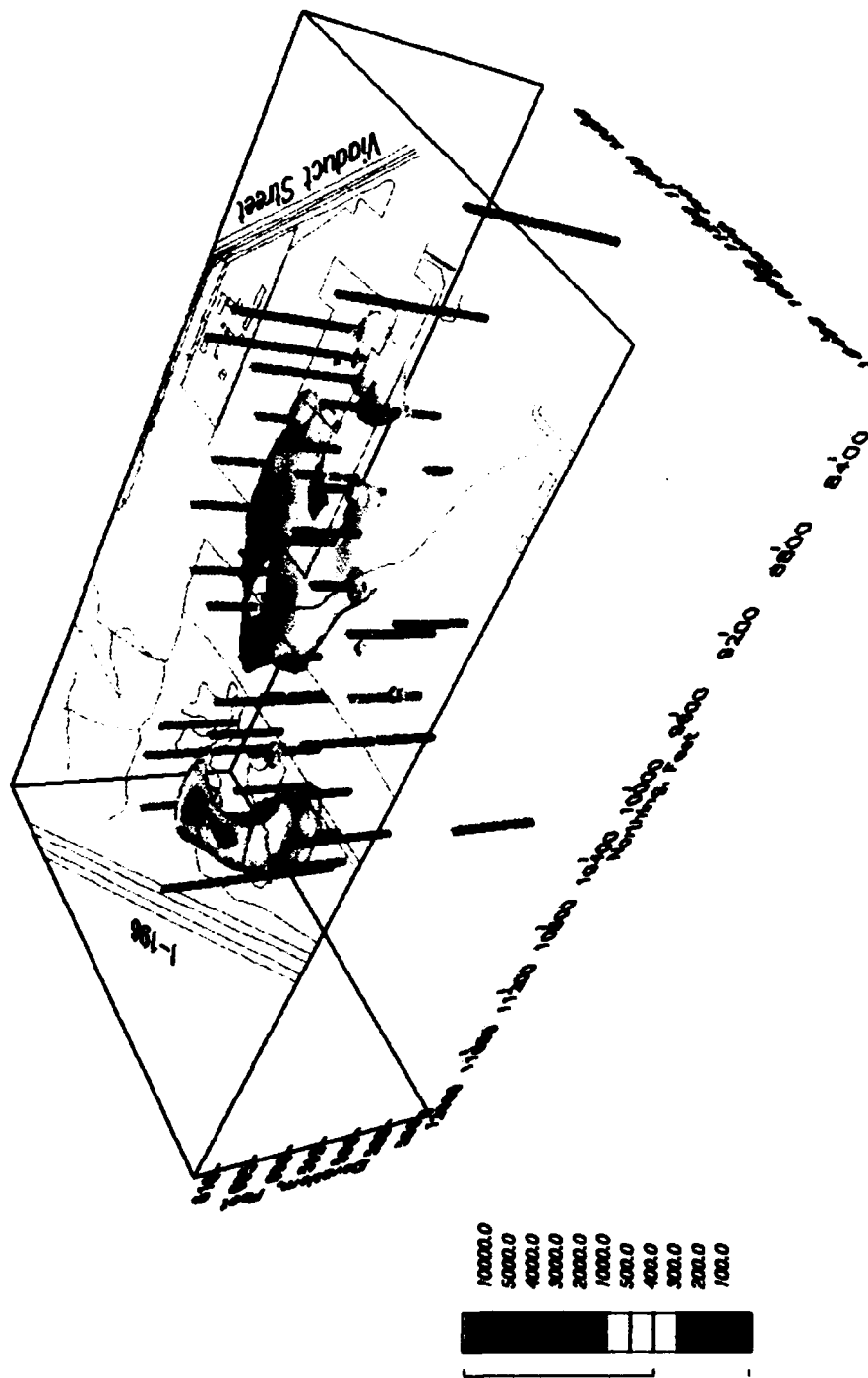


Figure 14. Volumetric representation of data looking southwest to northeast showing all concentrations of 400 ppm and greater.

Organic Chemicals Inc.
TRPH, ppm



Figure 15. Volumetric representation of data looking southwest to northeast showing all concentrations of 1000 ppm and greater.

Organic Chemicals Inc.
TRPH, ppm



Figure 16. Volumetric representation of data looking southwest to northeast showing all concentrations of 5000 ppm and greater.

Table II. Summary of probes at OCI site

PROBE NAME	PROBE LOCATION	ELEV INVESTIGATED ABOVE MSL	PRODUCT ENCOUNTERED AT ELEV ABOVE MSL
OCIC70	C7 on survey grid	600.1 - 587	none
OCIE50	E5 on survey grid	606.2 - 595	none
OCIE60	E6 on survey grid	602.9 - 594	none
OCIE70	E7 on survey grid	600.2 - 591	none
OCIF60	F6 on survey grid	603.6 - 590	none
OCIF70	F7 on survey grid	600.3 - 588	598, 594 - 590
OCIF80	F8 on survey grid	602.5 - 591	none
OCIF90	F9 on survey grid	602.1 - 590	none
OCIF100	F10 on survey grid	597.8 - 580	none
OCIF105	Between F10 & F11 on survey grid	597.8 - 585	none
OCIG50	G5 on survey grid	608.8 - 598.5	605 - 603
OCIG60	G6 on survey grid	603.9 - 594	597 - 594
OCIG80	G8 on survey grid	603.8 - 594	602 - 598
OCIG90	G9 on survey grid	600.3 - 590	599.7, 598 - 597
OCIG100	G10 on survey grid	600.3 - 588	589 - 588
OCIG511	Between G11 & H11 on survey grid	600 - 583	598 - 596, 594
OCIH50	H5 on survey grid	602.7 - 591	596 - 593
OCIH60	H6 on survey grid	603.7 - 595.5	599, 595.5
OCIH70	H7 on survey grid	603 - 591	601-599, 597-592
OCIH80	H8 on survey grid	602.4 - 589	597 - 589
OCIH90	H9 on survey grid	601.7 - 585	none
OCIH92	Between H9 & H10 on survey grid	601.7 - 589	none
OCIH100	H10 on survey grid	601.7 - 588	600-597, 594, 591.5
OCIH110	H11 on survey grid	602.3 - 590	none
OCII40	I4 on survey grid	610.3 - 592	607, 596 - 592
OCII50	I5 on survey grid	601 - 593	599.5, 593.5
OCII55	Between I5 and J5 on survey grid	601 - 594	596 - 594.5
OCII60	I6 on survey grid	600.1 - 591	600, 598.5, 597-591
OCII70	I7 on survey grid	600.6 - 596.5	597.25

PROBE NAME	PROBE LOCATION	ELEV INVESTIGATED ABOVE MSL	PRODUCT ENCOUNTERED AT ELEV ABOVE MSL
OCII80	I8 on survey grid	602.3 - 591	602-600, 595.5-591
OCII100	I10 on survey grid	603 - 590	none
OCII110	I11 on survey grid	603.4 - 590	none
OCII120	I12 on survey grid	600.8 - 589	none
OCIJ40	J4 on survey grid	607.5 - 601	none
OCIJ50	J5 on survey grid	603 - 591	601-600, 598-592
OCIJ60	J6 on survey grid	604.4 - 591	598, 596-591
OCIJ70	J7 on survey grid	604.7 - 589	596.5 - 591
OCIJ80	J8 on survey grid	602.3 - 590	595 - 591
OCIMW2	Near chemical bldg #2, and MW-2	610.3 - 599	none
OCIMW3	West of warehouse, and MW-3	606 - 584	none
OCIMW4	Between H3 and H4 on survey grid	604.3 - 590	600, 595.5-591.5
OCIMW5	Between I5 and I6 on survey grid	599.1 - 590	596 - 592
OCIMW7	Near G1 on survey grid, and MW-7	606.6 - 585	none
OCIMW8	Between E3 and F3 on survey grid	608.1 - 603.5	none
OCIMW16	G11 on survey grid	600 - 580	600 - 585
OCIMW22	Between I3 and J3 on survey grid	614.2 - 592	606-603, 597-593
OCIMW23	Near boiler house, and MW-23	611.2 - 589	593 - 589
OCIPB16	Between H11 and H12 on survey grid	600.8 - 588	600 - 592
OCI196	Near G12 on survey grid	605.5 - 578	none

34. The volumetric representation of the data has been rotated upward to present top views as shown in Figure 17 - 20. Figure 17 is the data having a concentration of 100 ppm and greater, Figure 18 is a view of concentrations 400 ppm and greater, Figure 19 is a view of concentrations 1000 ppm and greater, Figure 20 is a view of concentrations 5000 ppm and greater. In the left top corner of Figure 17 is a small diagram indicating the volume of the contaminant

Organic Chemicals Inc.
TRPH, ppm



Volume
6,553,734.5

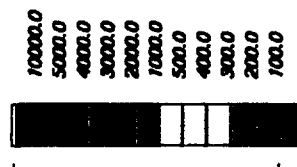


Figure 17. Volumetric representation of data, top view, showing all concentrations of 100 ppm and greater.

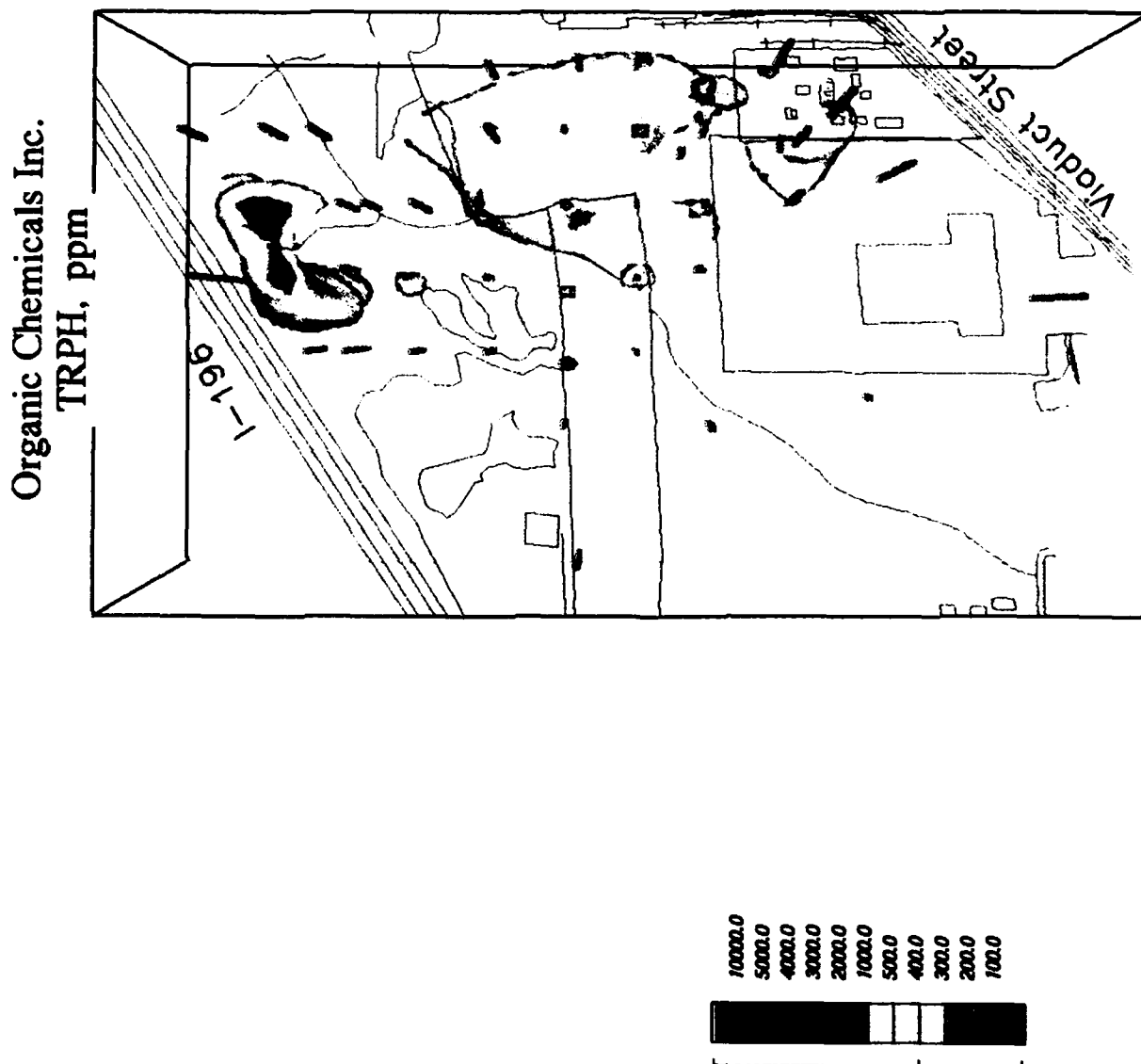


Figure 18. Volumetric representation of data, top view, concentrations of 400 ppm and greater.

Organic Chemicals Inc.
TRPH, ppm



Figure 19. Volumetric representation of data, top view, concentrations of 1000 ppm and greater.

Organic Chemicals Inc.
TRPH, ppm

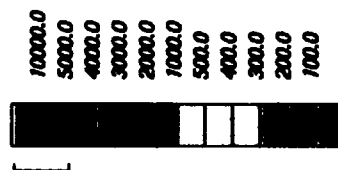


Figure 20. Volumetric representation of data, top view, concentrations of 5000 ppm and greater.

plume. The volume is 6,352,734.5 cubic feet of material for concentrations of 100 ppm and greater.

35. Figures 21 and 22 are views of the data looking east to west. Both figures show concentrations of 100 ppm and greater. Figure 22 is a view of the data where a cut has been made into the center of the data to reveal the higher concentrations.

36. Appendix B contains two top views of the contaminant plume that has been superimposed on top of the aerial photograph of the site. Figure B1 contains the data with concentrations of 100 ppm and greater, Figure B2 the concentrations with 5000 ppm and greater. This presentation gives an excellent view of where the contaminant plume has spread over the site.

37. A final attempt has been made to correlate the findings from the cone penetrometer with actual laboratory data. The soil samples collected prior to arrival of the cone truck, that were used to produce the data in Table 1 and Figure 10, were collected very close to the location between I5 and J5 on the survey grid. A push was made in this area, shown in Appendix A as Figure A28, therefore the data from the penetrometer and the laboratory analysis can be compared. Two samples were taken and analyzed, one at a depth of 1 ft and a second at a depth of 6 feet. From the laboratory analysis, Table 1 (the 1 ft sample is labeled clean, the 6 ft sample is labeled dirty), the concentrations are 3900 ppm TRPH at 6 ft and 45 ppm TRPH at 1 ft. The O&G concentrations are 4500 ppm at 6 ft and 230 ppm at 1 ft. From Figure A28, at a depth of 1 ft the concentration is less than 100 ppm (does not plot), and at a depth of 6 ft the concentration is approximately 4500 ppm.

Organic Chemicals Inc.
TRPH, ppm

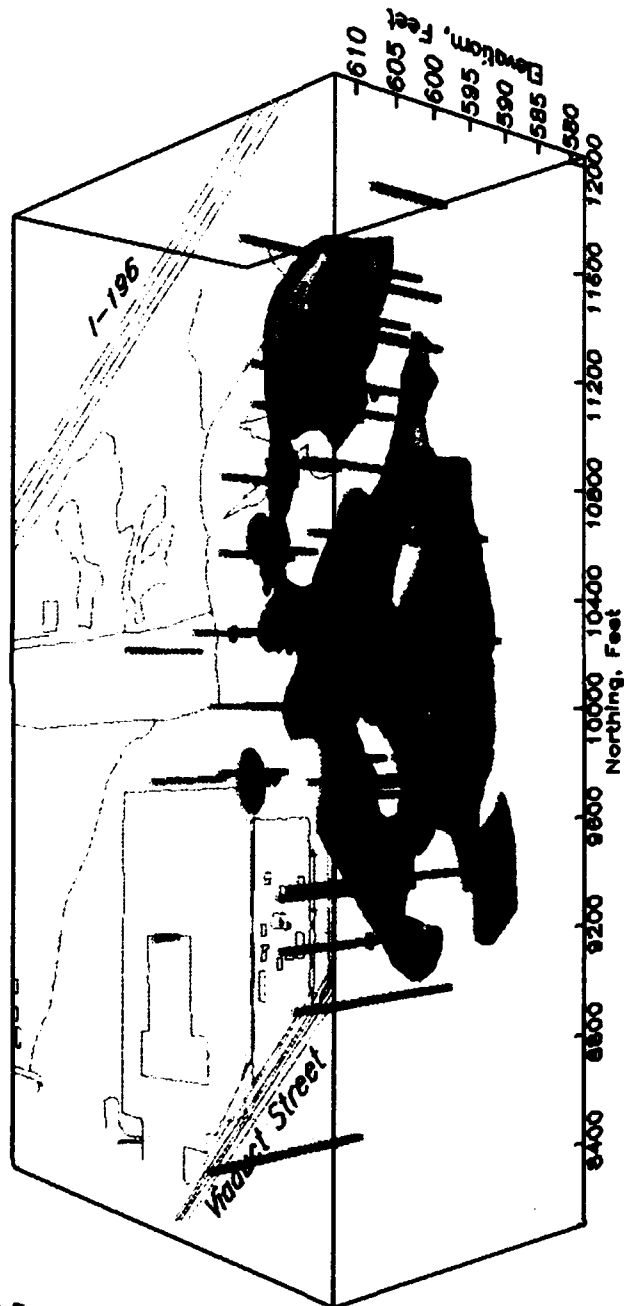
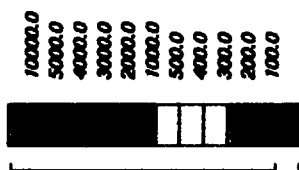


Figure 21. Volumetric representation of data looking east to west showing all concentrations of 100 ppm and greater.

Organic Chemicals Inc.
TRPH, ppm

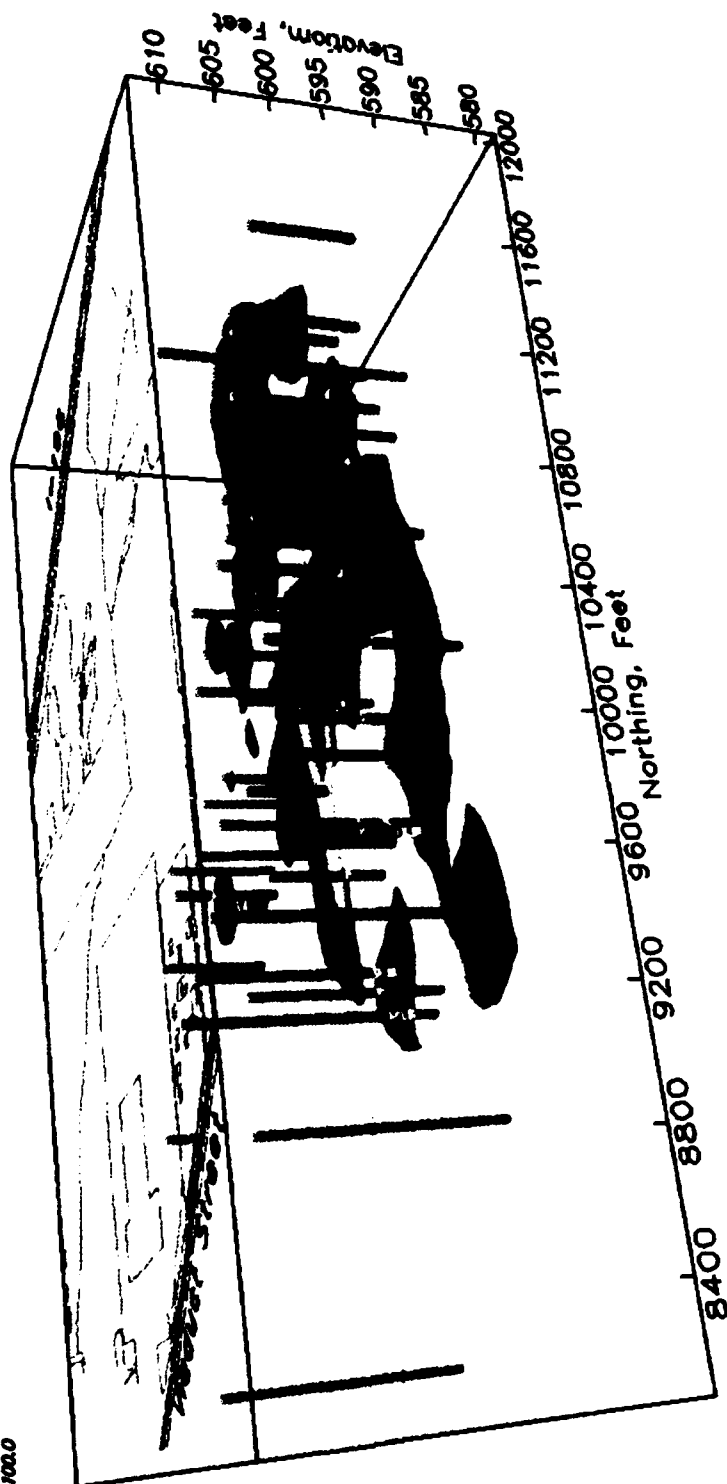
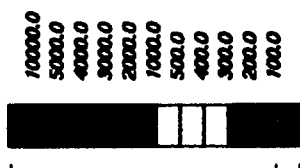


Figure 22 Volumetric representation of data looking east to west showing all concentrations of 100 ppm and greater, with a section sliced away to reveal higher concentrations inside the plume.

PART V: CONCLUSIONS

38. Summarizing the results of the probes conducted at the OCI site, several things are apparent. First, the plume was successfully mapped and delineated on all sides except for the east side. Property access did not allow pushing any further east, however the plume does appear to extend farther in that direction than was mapped. The plume boundaries were successfully delineated on the north, south, and west sides. The plume does not appear to have spread north of the interstate, but rather is located to the area south of that location. Second, it is entirely possible that there are two separate rather than one long continuous plume. This fact is clearly seen in Figure 17. One plume appears to be associated with the contaminants from the OCI site, extending from that location north for approximately 1600 ft. The second plume appears to be associated with a sludge pond located at approximate location G11 on the grid (very near MW-16). This pond was approximately 35 to 40 feet in diameter and contained a very thick, black tar like substance. Third, the contaminants are caught up in and travelling through the thick gravel layers located at varying depths around the site. Although the soil classification data was not collected, the locations of contaminants correlated extremely well with the sounds that could be heard as the cone was "crunching" through the gravel layers. Fourth, the direction the plume has travelled from the OCI facility is in the same direction as the groundwater gradient.

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Appendix A. Two dimensional plots of fluorescence data

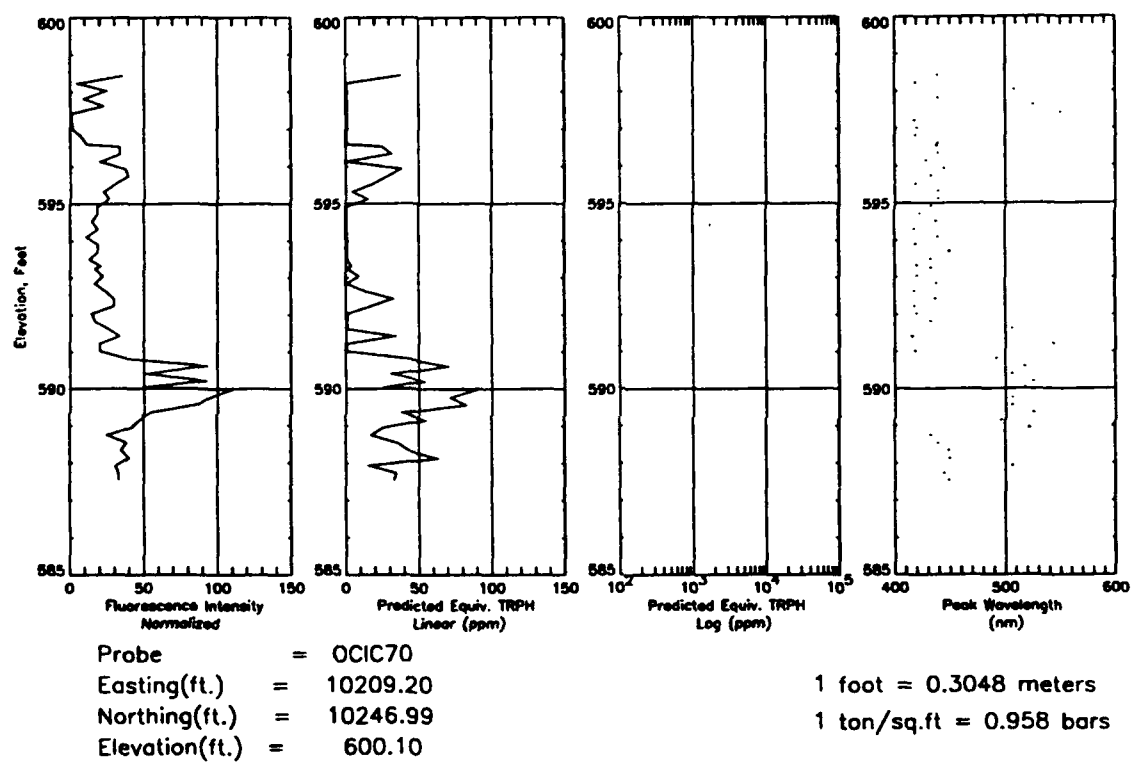


Figure A1. Results of fluorescence probe conducted at location C7 on the survey grid.

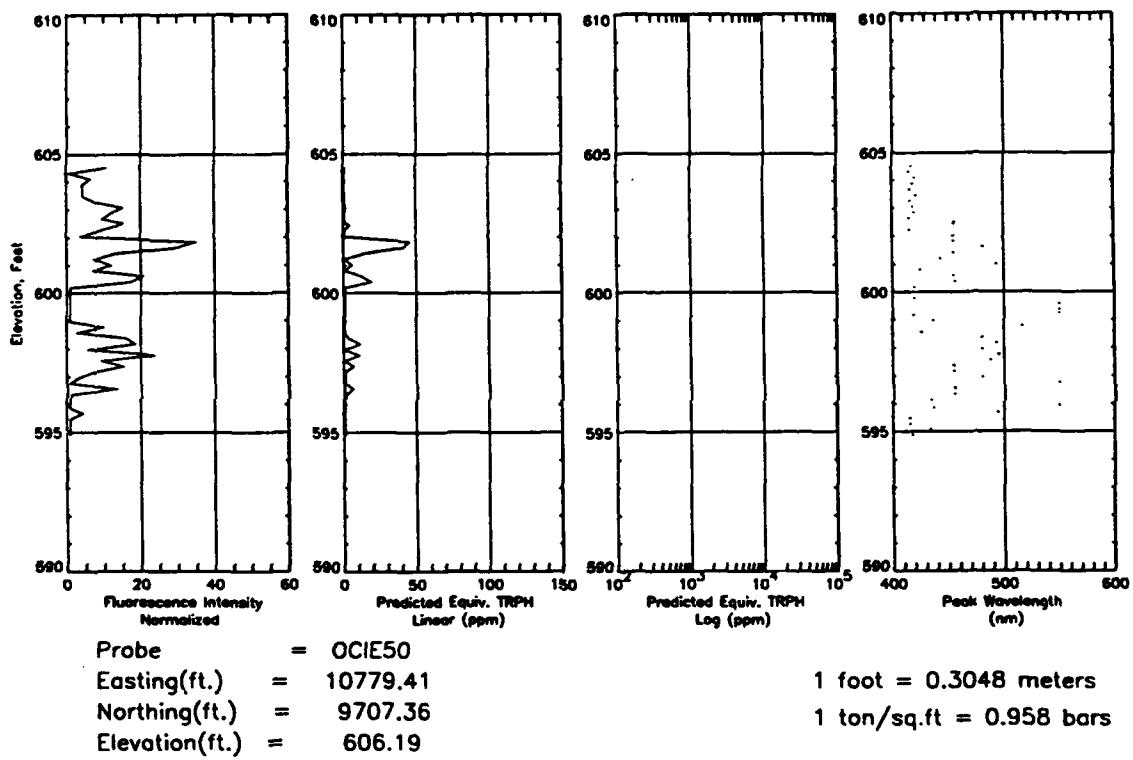


Figure A2. Results of fluorescence probe conducted at location E5 on the survey grid.

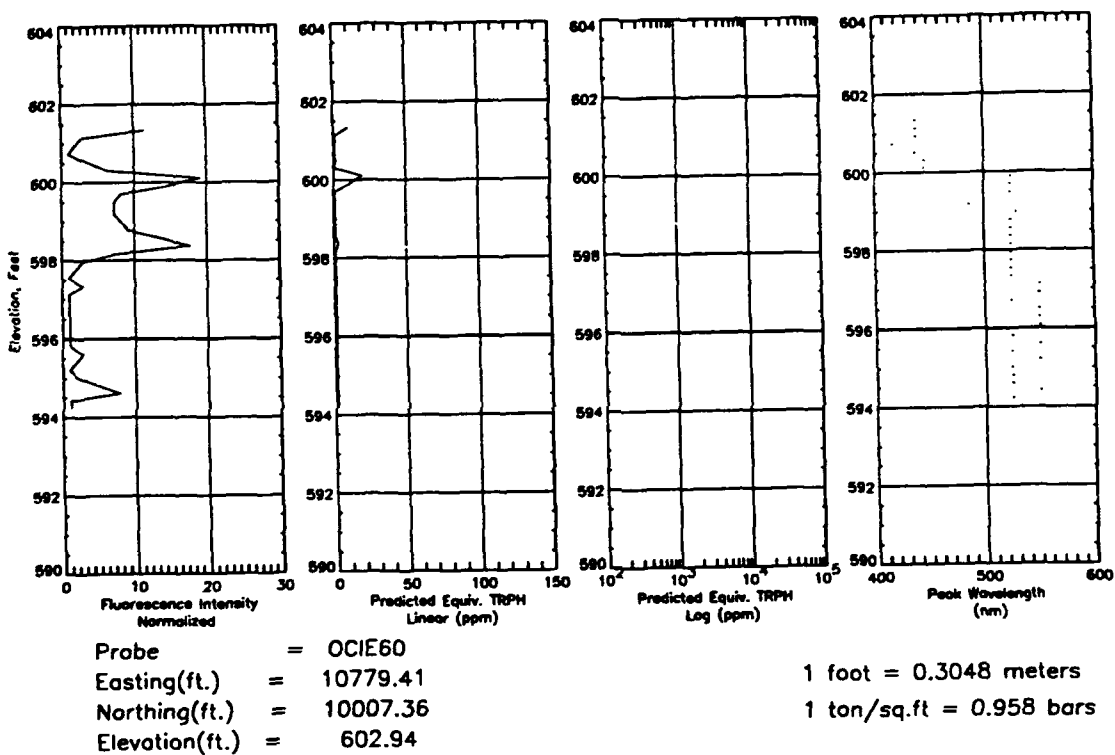


Figure A3. Results of fluorescence probe conducted at location E6 on the survey grid.

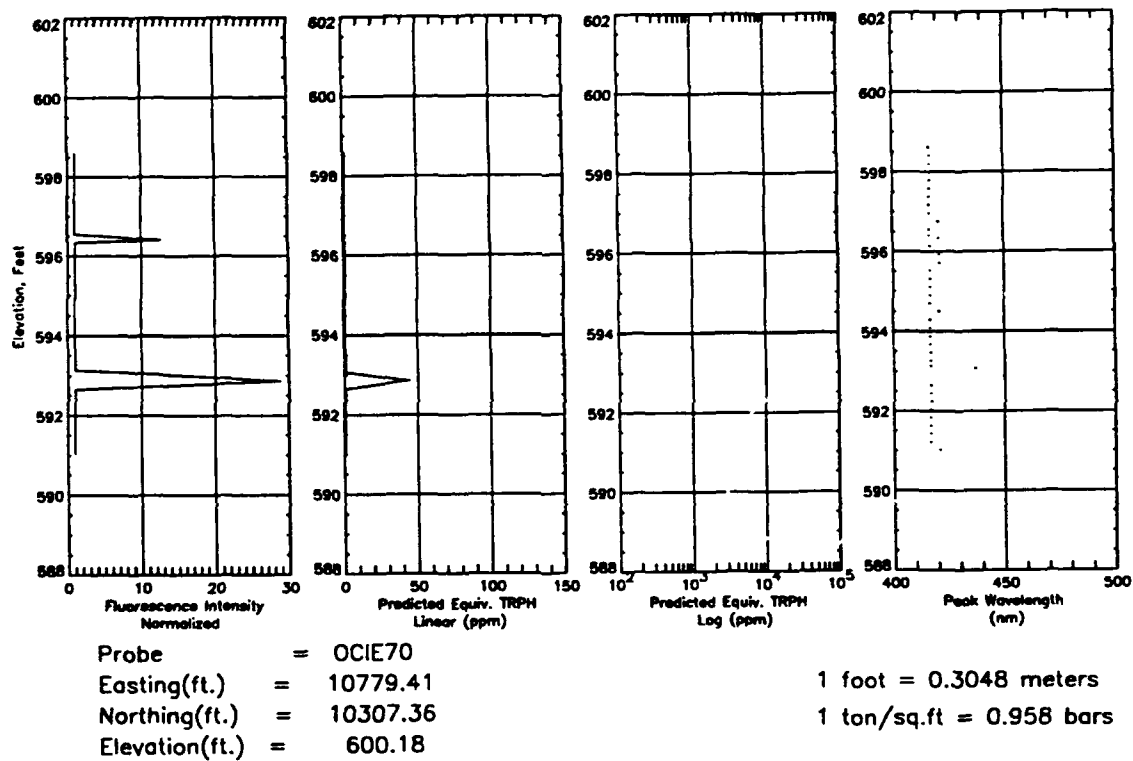


Figure A4. Results of fluorescence probe conducted at location E7 on the survey grid.

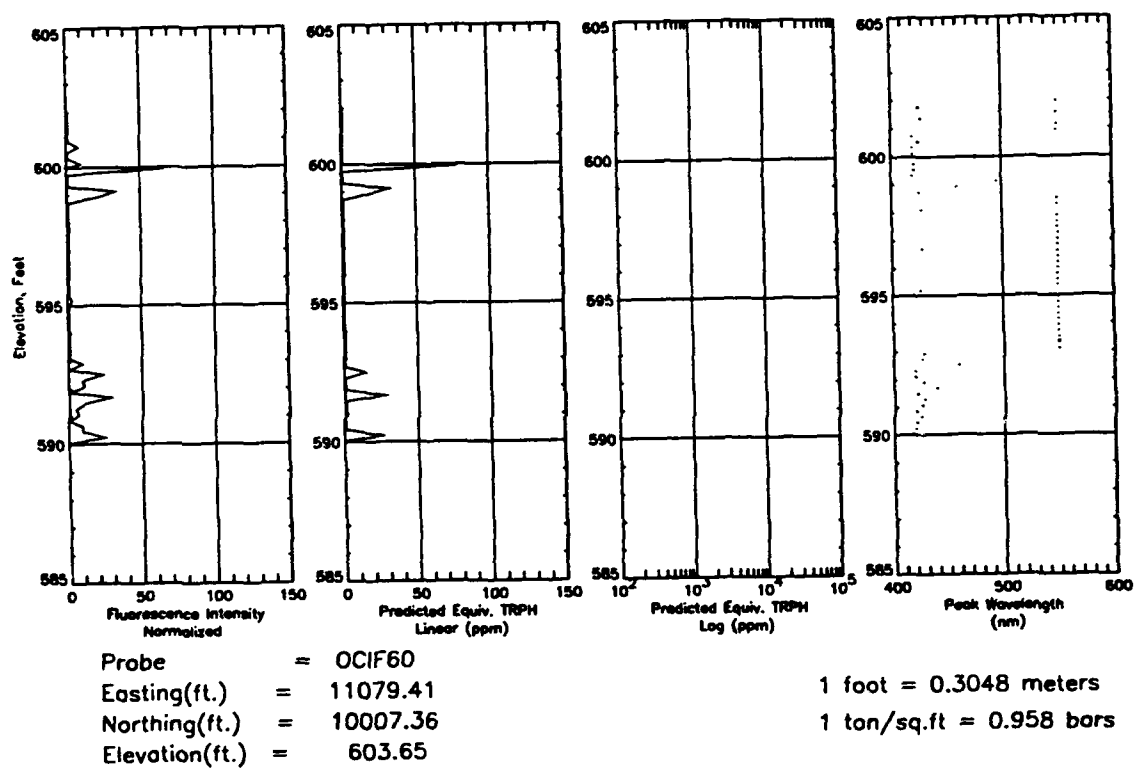


Figure A5. Results of fluorescence probe conducted at location F6 on the survey grid.

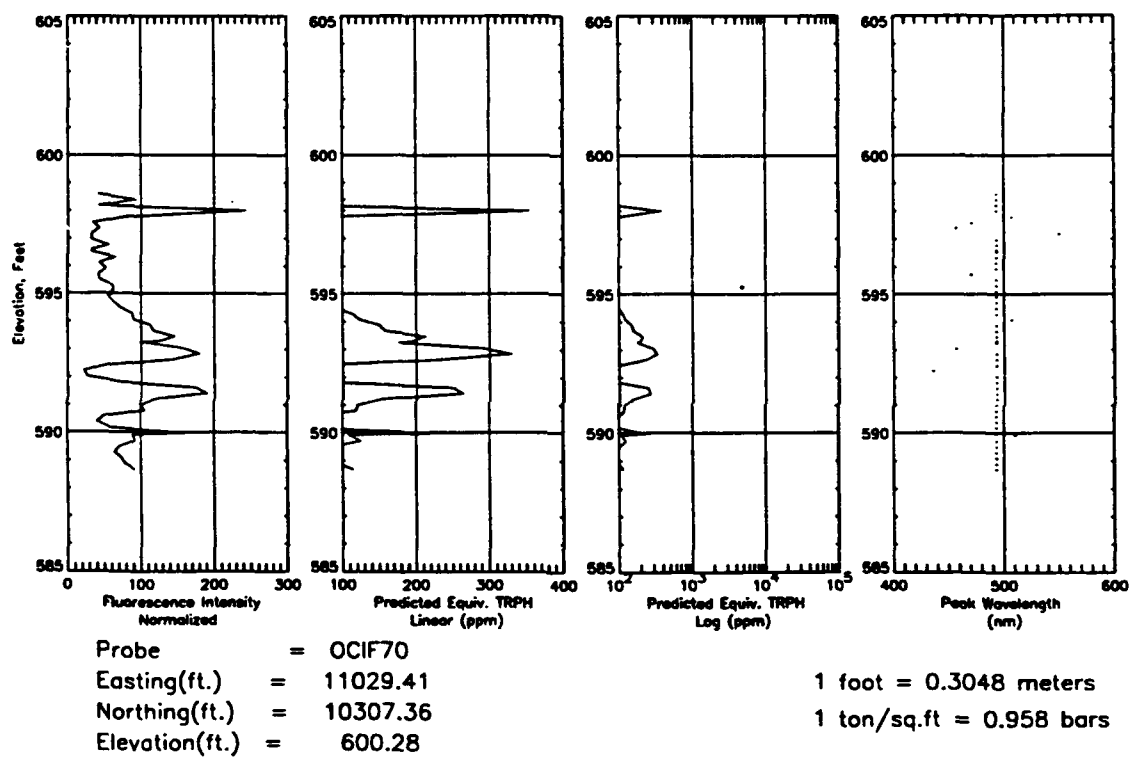


Figure A6. Results of fluorescence probe conducted at location F7 on the survey grid.

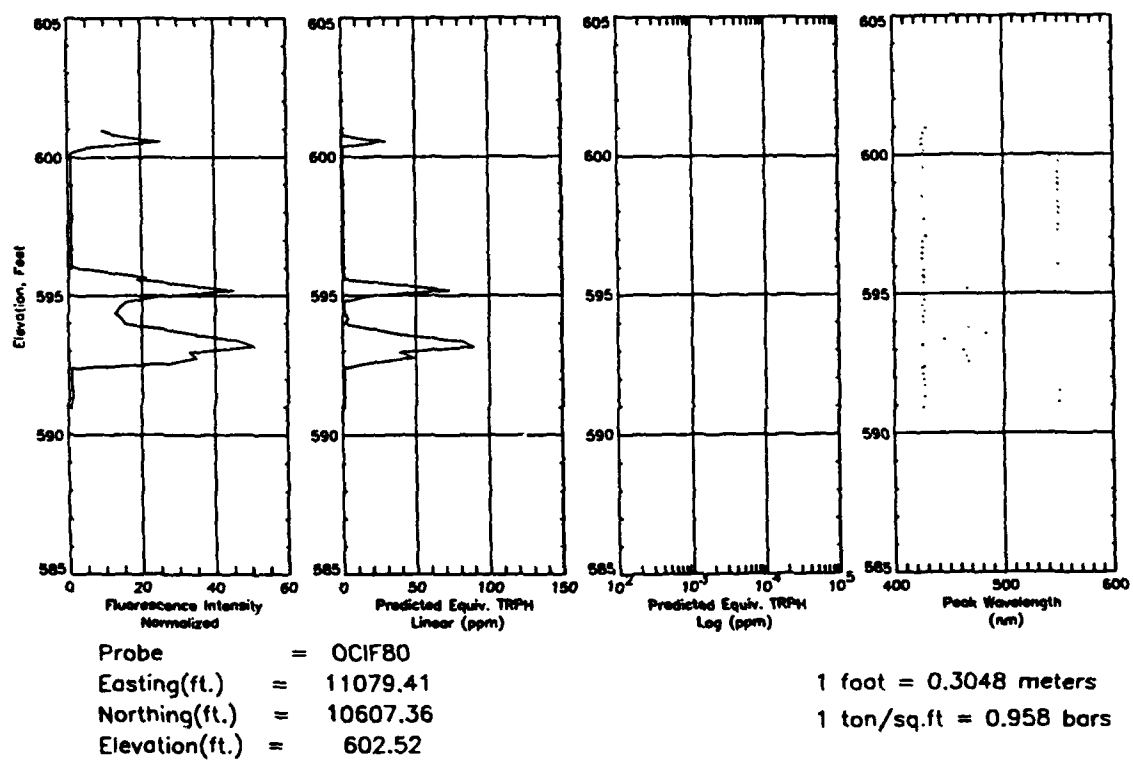


Figure A7. Results of fluorescence probe conducted at location F8 on the survey grid.

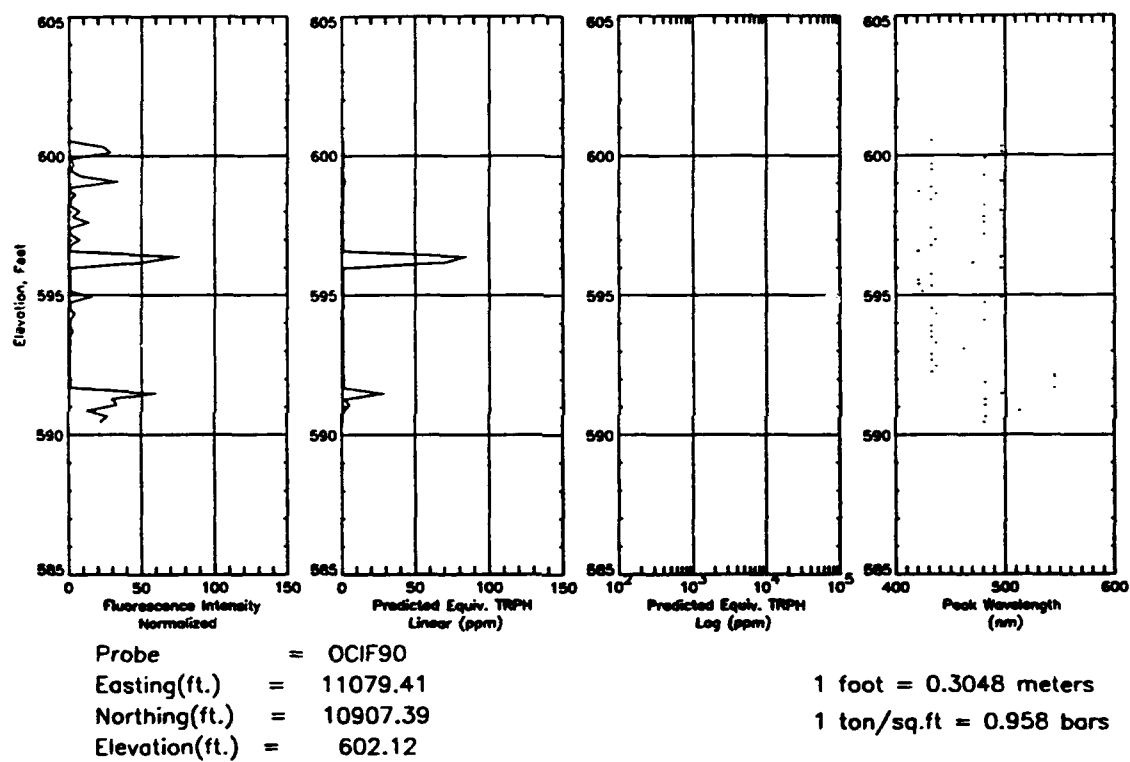


Figure A8. Results of fluorescence probe conducted at location F9 on the survey grid.

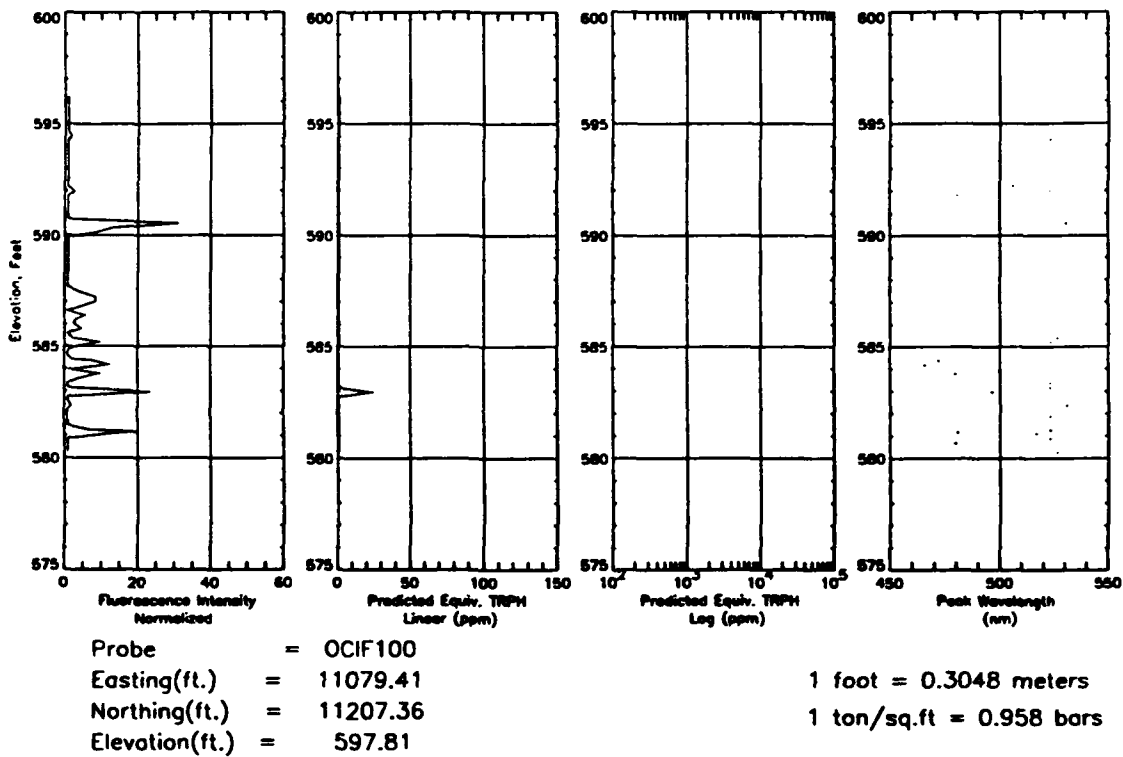


Figure A9. Results of fluorescence probe conducted at location F10 on the survey grid.

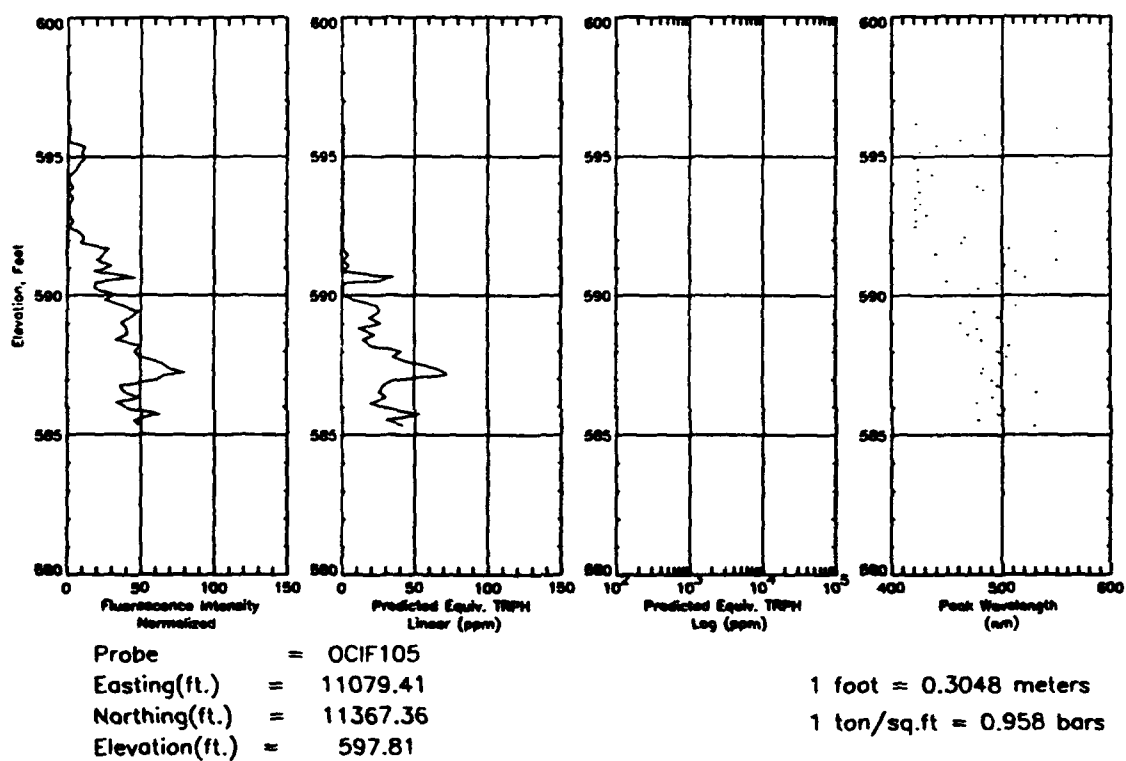


Figure A10. Results of fluorescence probe conducted between F10 and F11 on the survey grid.

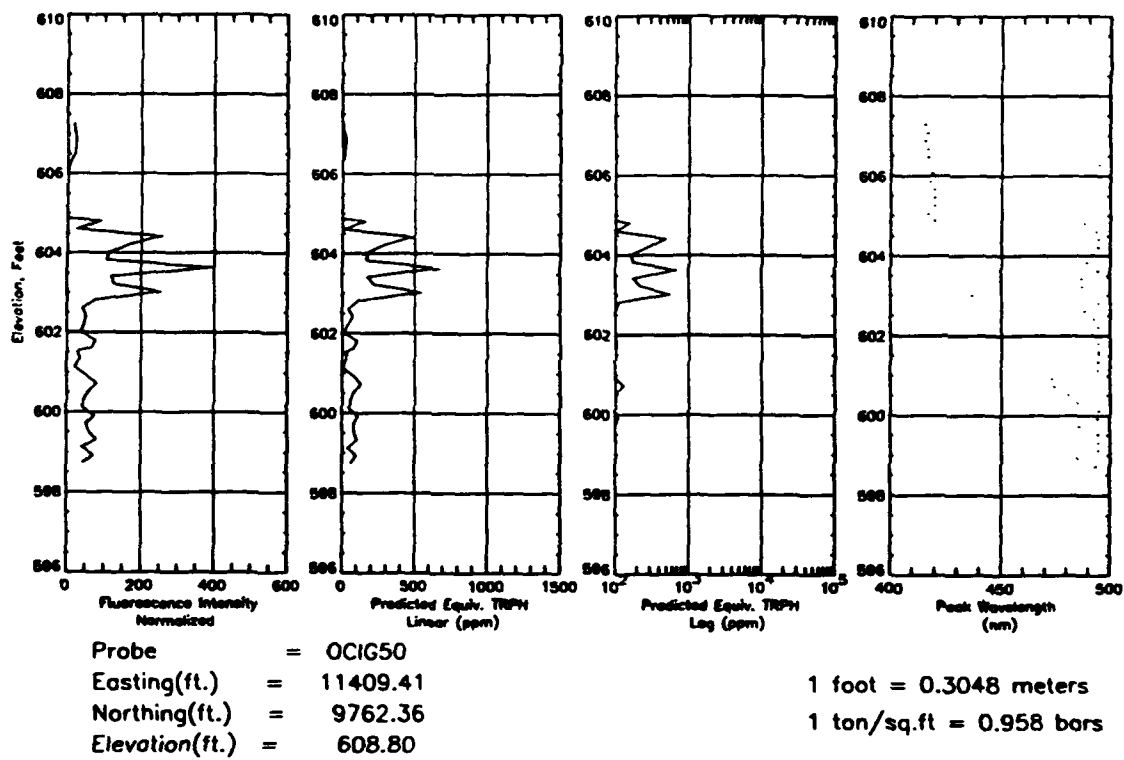


Figure A11. Results of fluorescence probe conducted at location G5 on the survey grid.

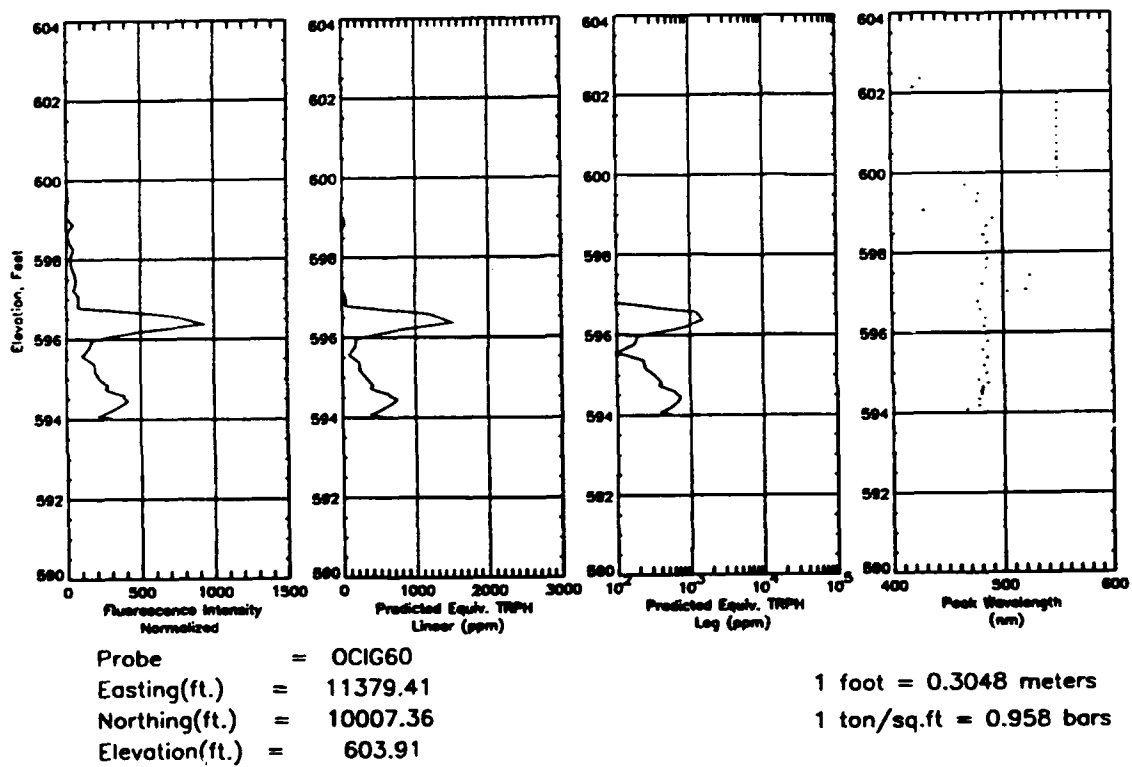


Figure A12. Results of fluorescence probe conducted at location G6 on the survey grid.

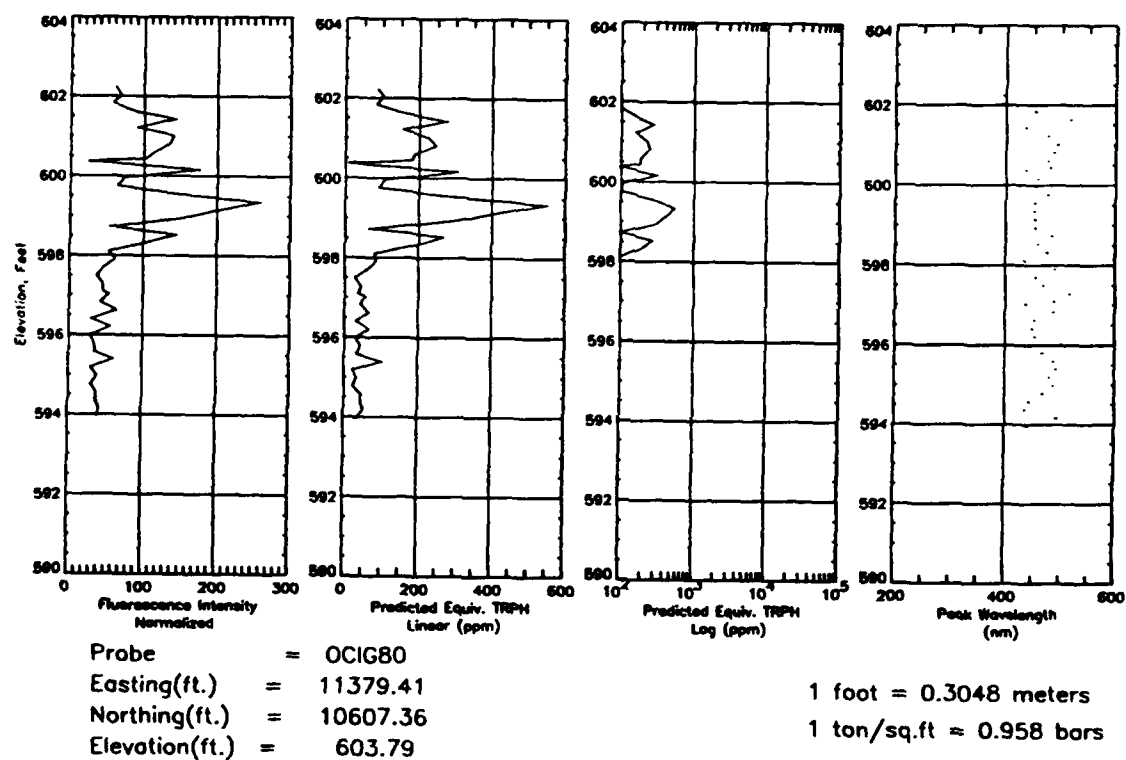


Figure A13. Results of fluorescence probe conducted at location G8 on the survey grid.

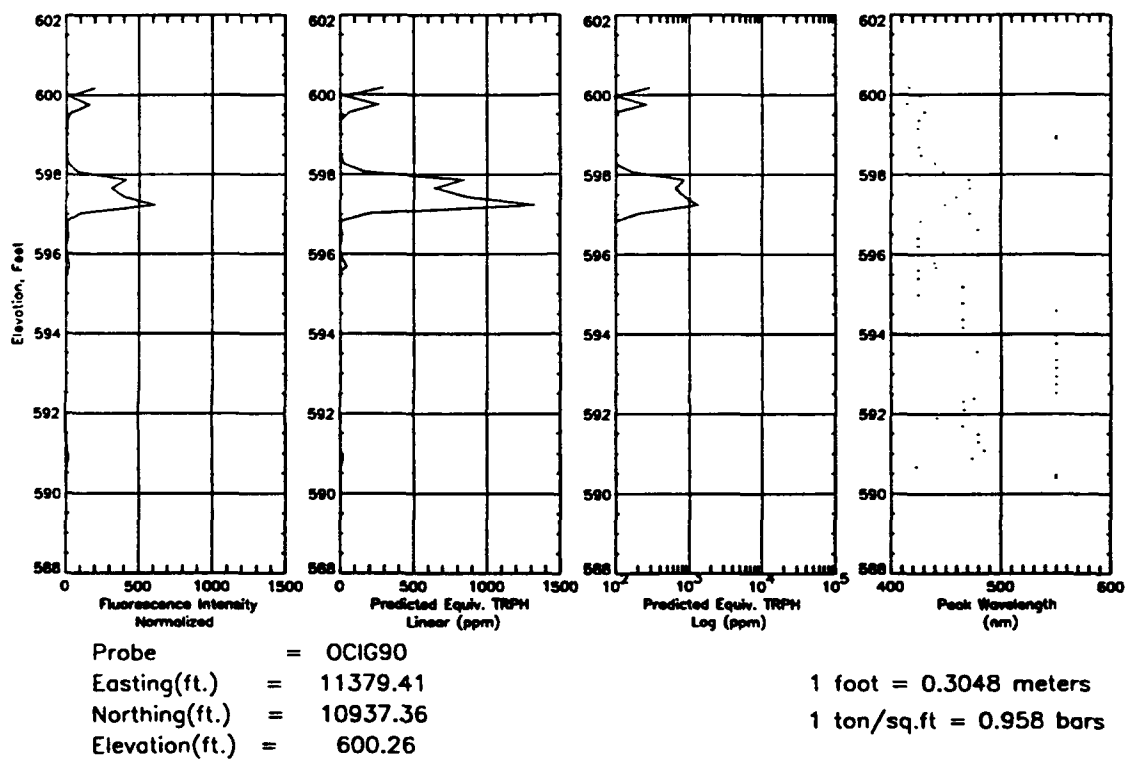


Figure A14. Results of fluorescence probe conducted at location G9 on the survey grid.

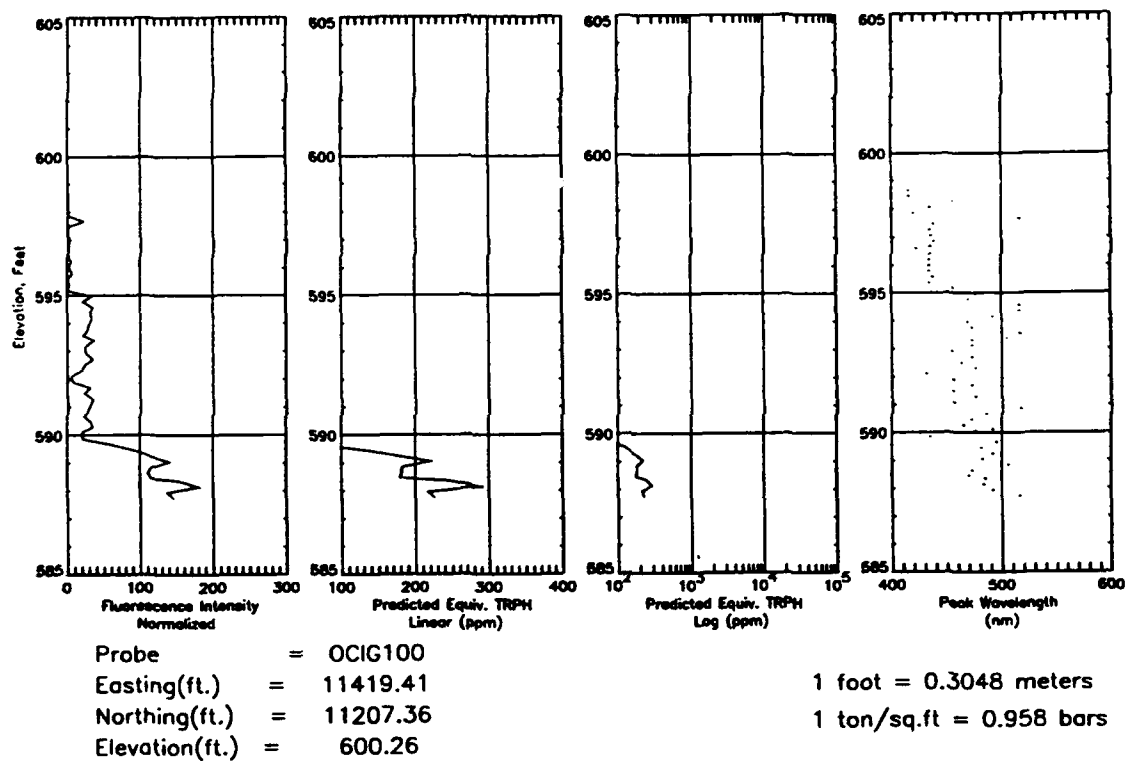


Figure A15. Results of fluorescence probe conducted at location G10 on the survey grid.

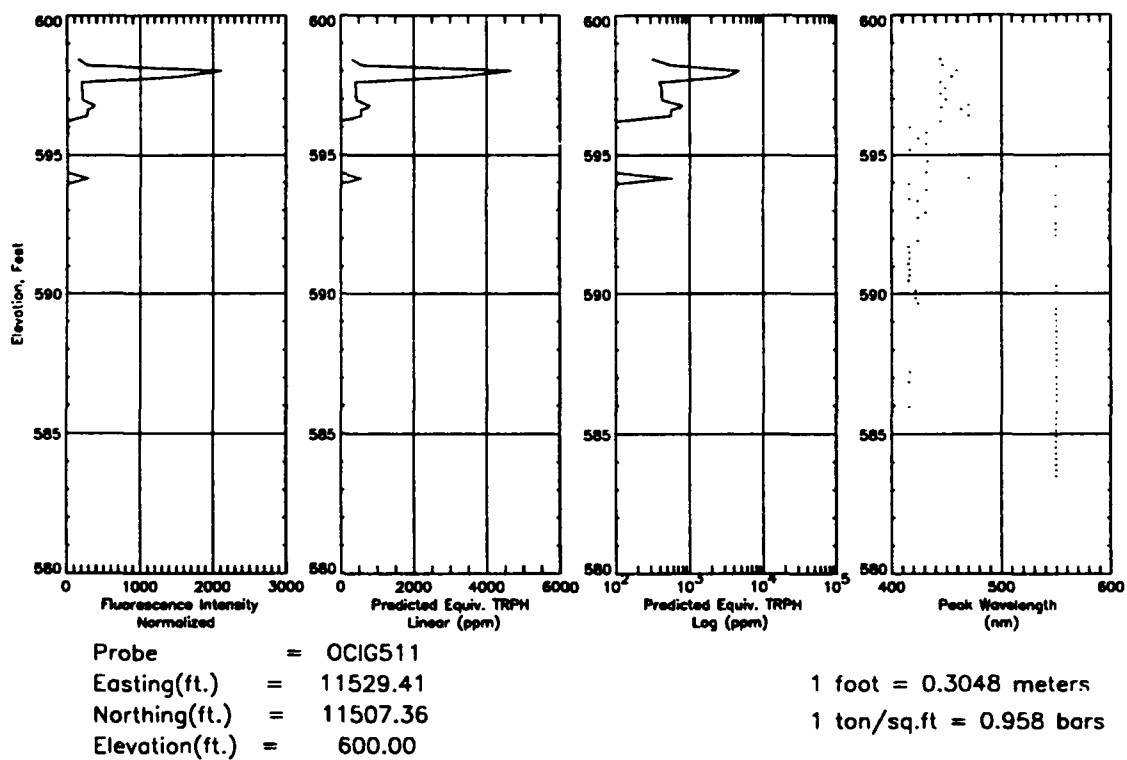


Figure A16. Results of fluorescence probe conducted between G11 and H11 on the survey grid.

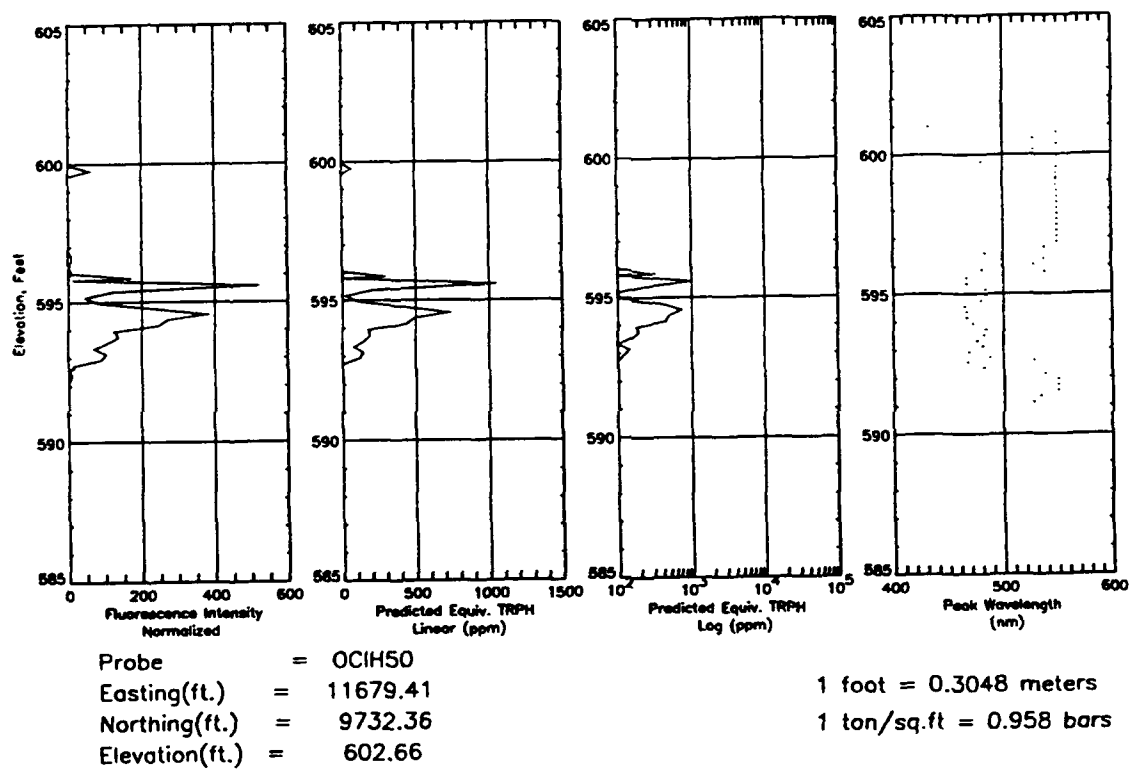


Figure A17. Results of fluorescence probe conducted at location H5 on the survey grid.

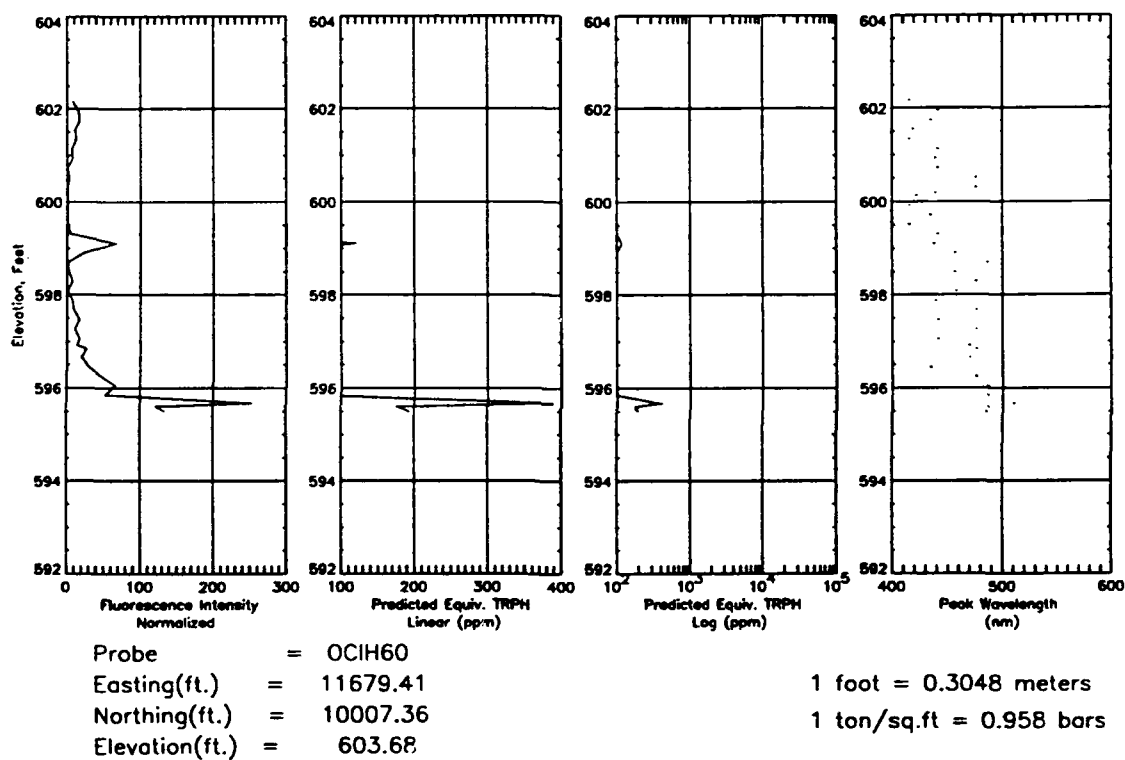


Figure A18. Results of fluorescence probe conducted at location H6 on the survey grid.

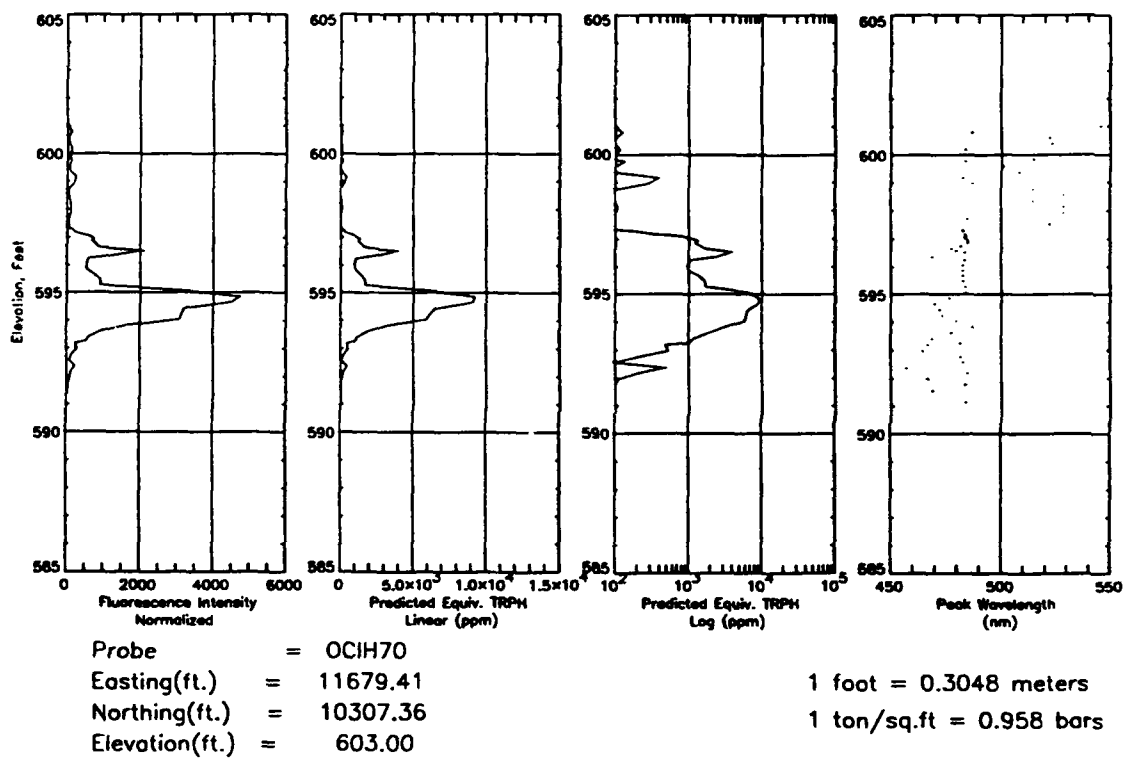


Figure A19. Results of fluorescence probe conducted at location H7 on the survey grid.

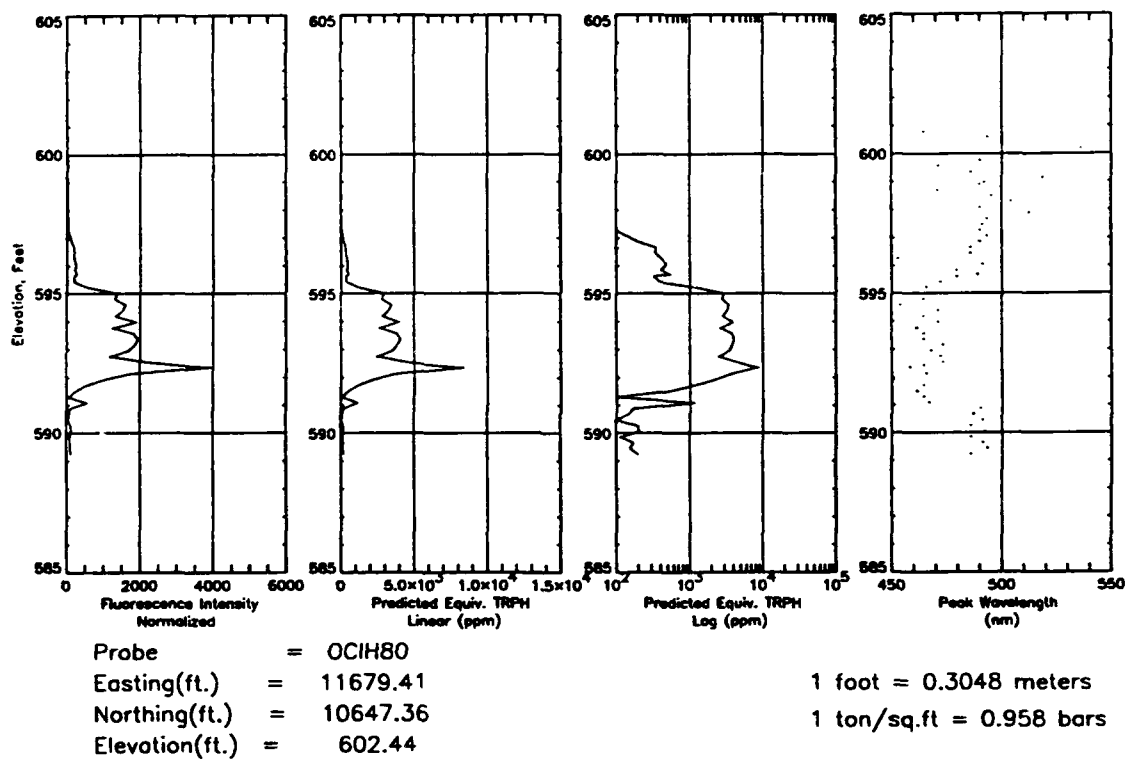


Figure A20. Results of fluorescence probe conducted at location H8 on the survey grid.

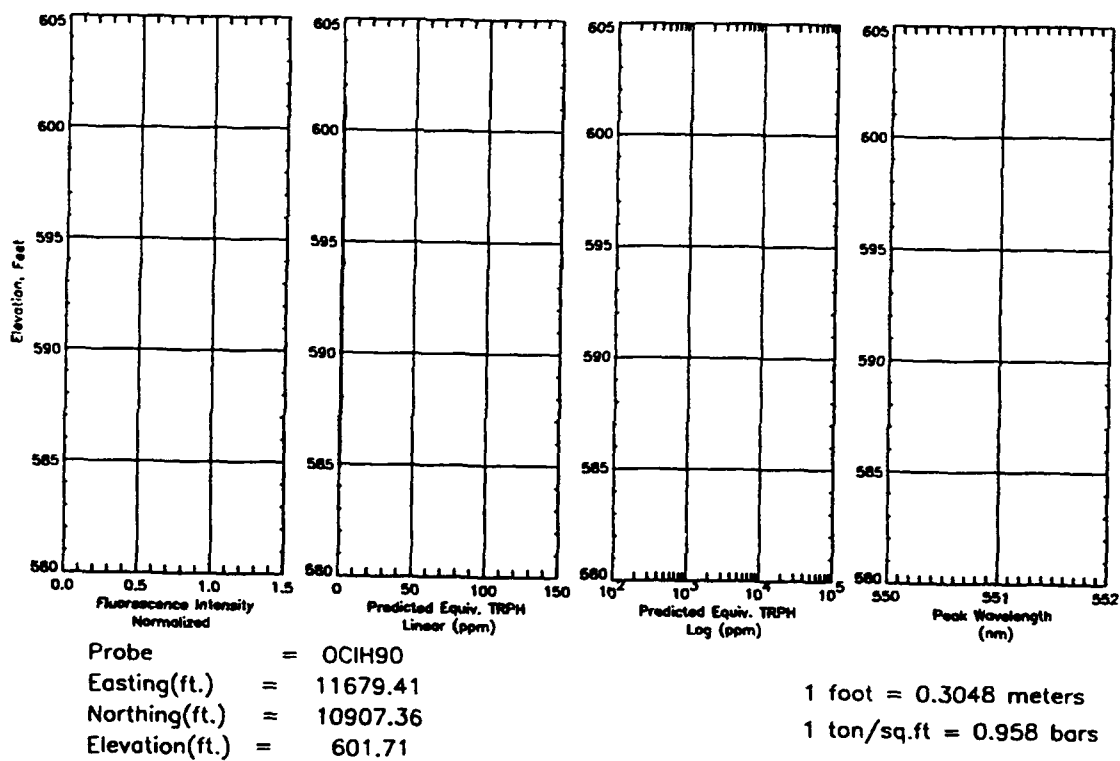


Figure A21. Results of fluorescence probe conducted at location H9 on the survey grid.

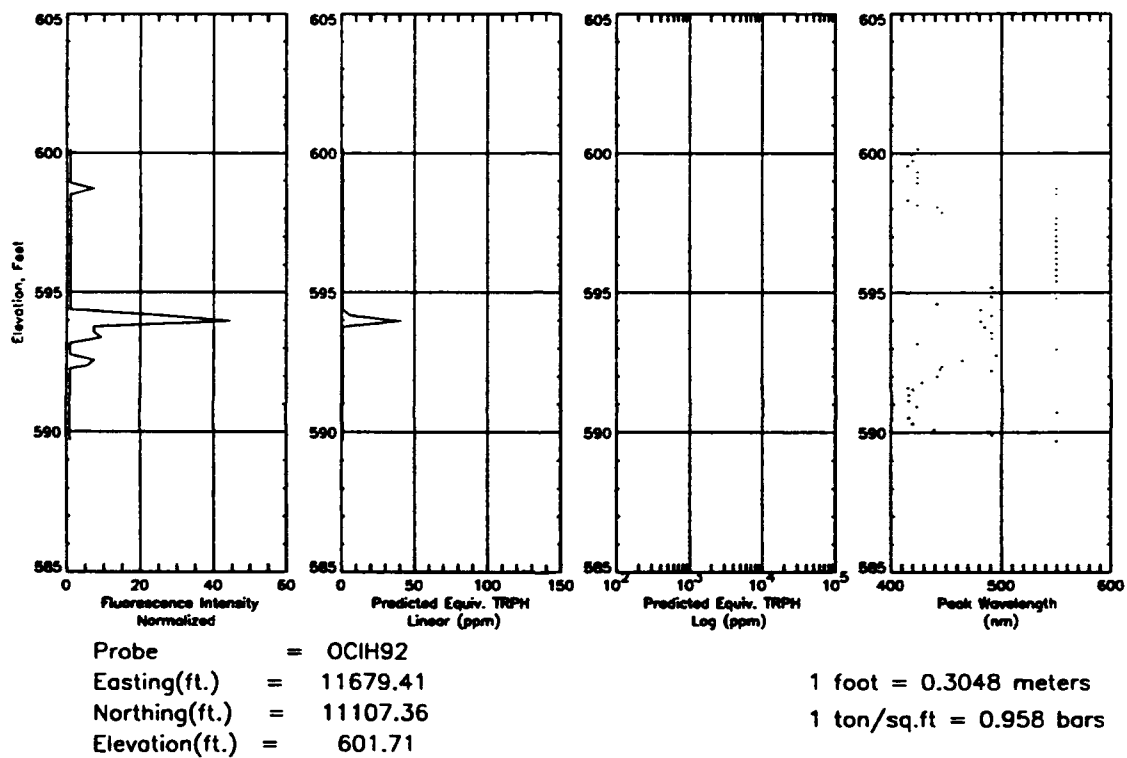


Figure A22. Results of fluorescence probe conducted between H9 and H10 on the survey grid.

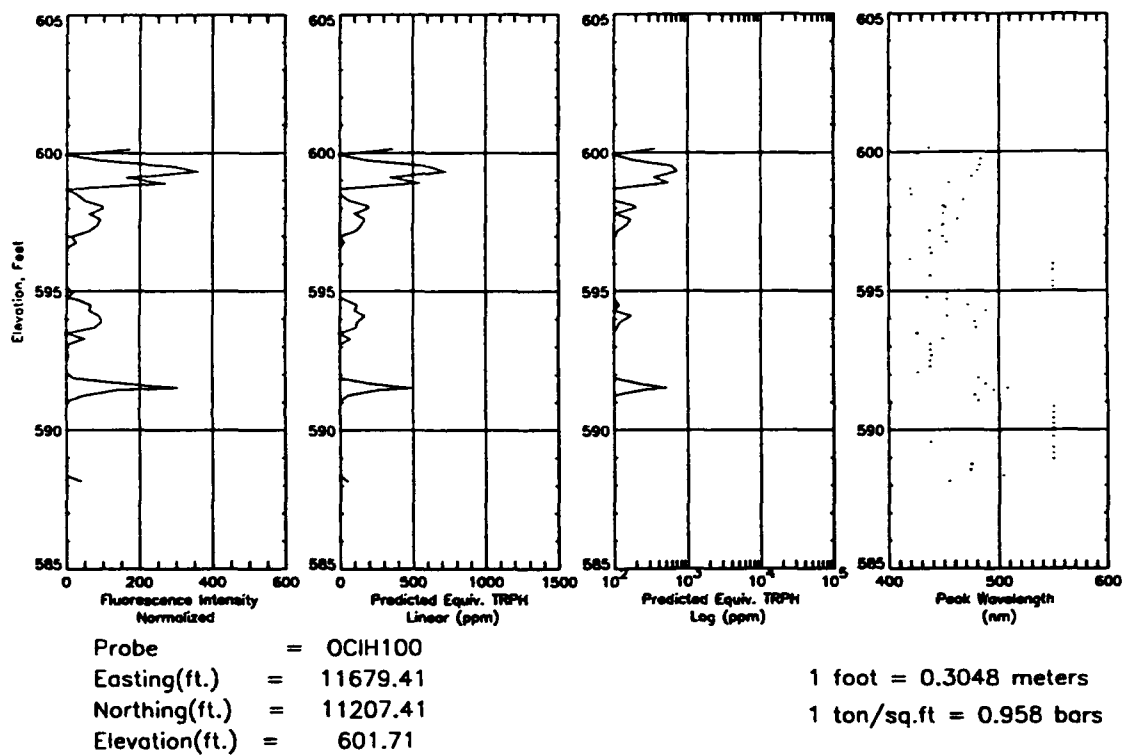


Figure A23. Results of fluorescence probe conducted at location H10 on the survey grid.

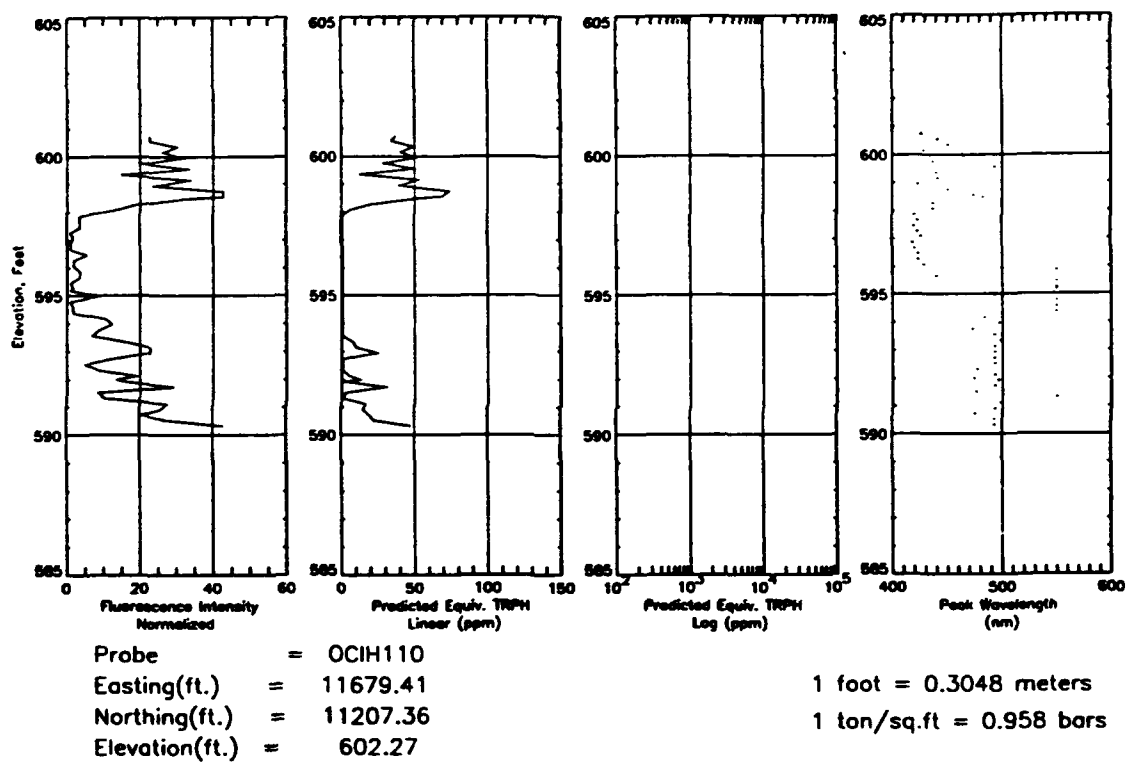


Figure A24. Results of fluorescence probe conducted at location H11 on the survey grid.

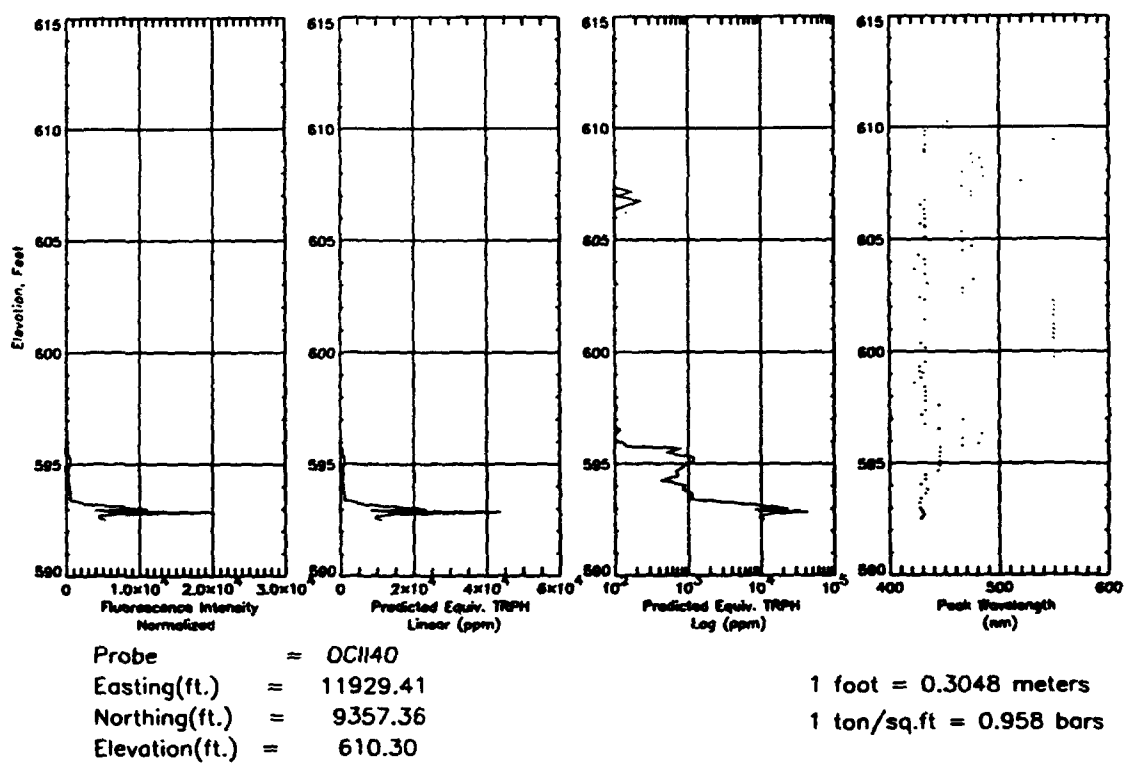


Figure A26. Results of fluorescence probe conducted at location I4 on the survey grid.

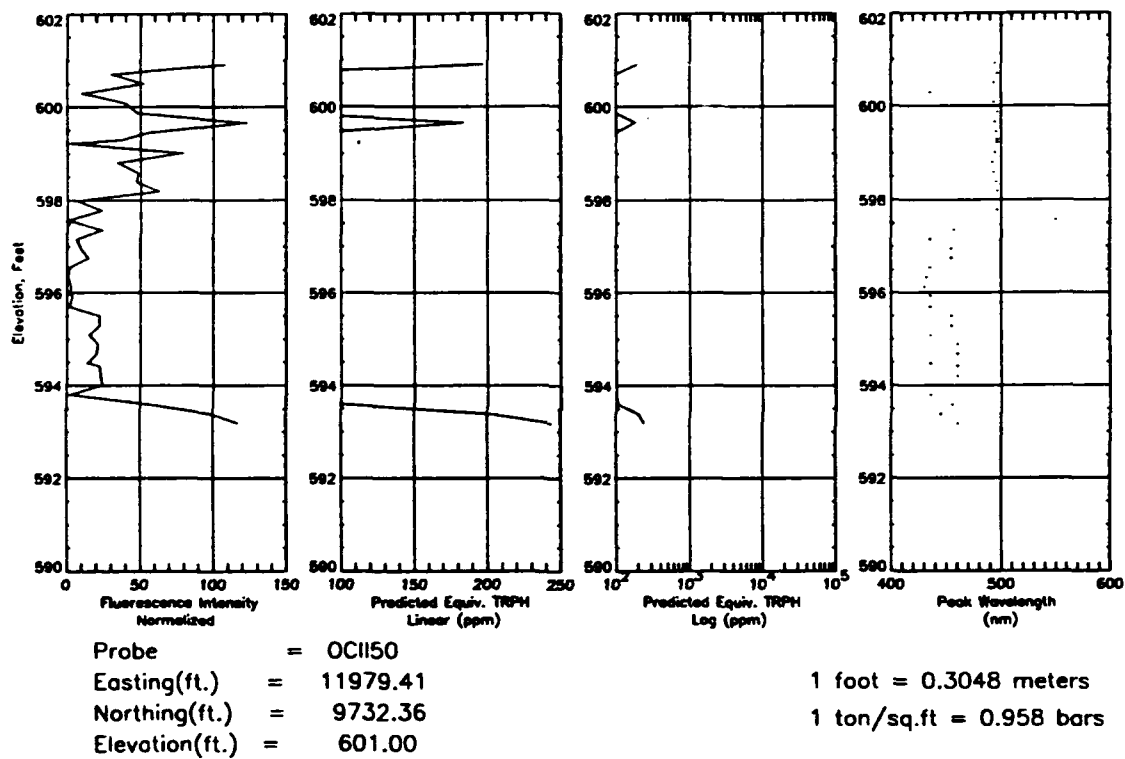


Figure A27. Results of fluorescence probe conducted at location I5 on the survey grid.

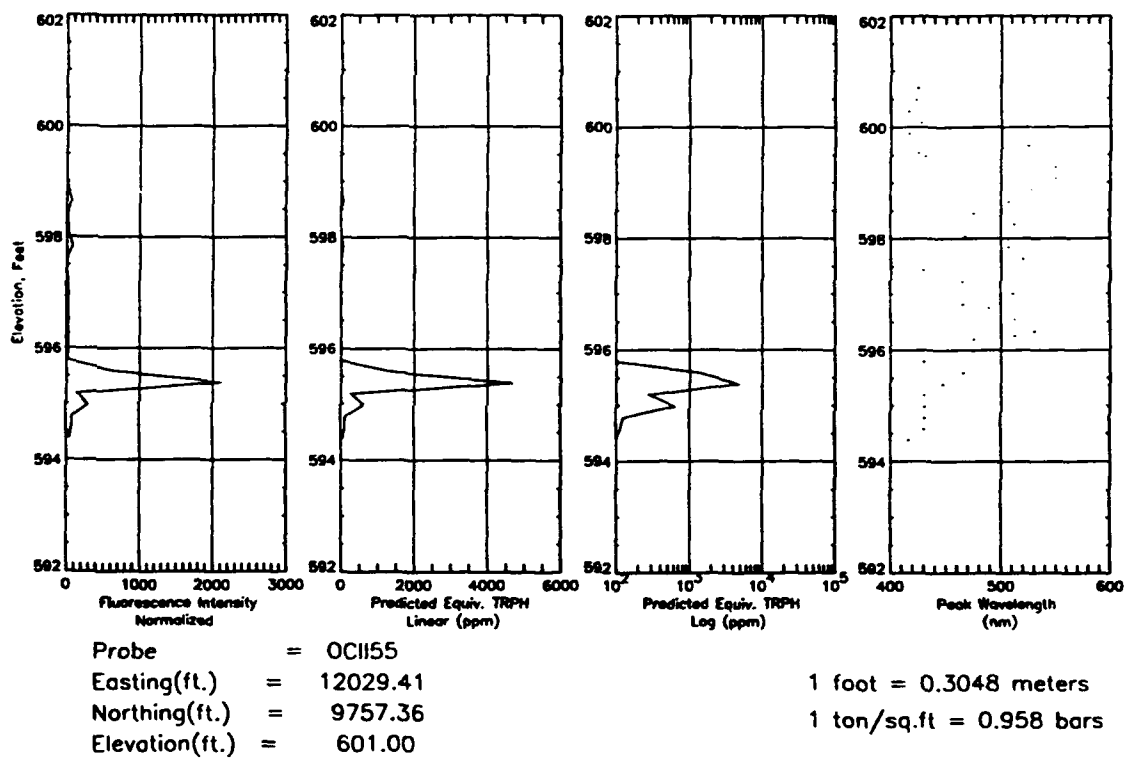


Figure A28. Results of fluorescence probe conducted between I5 and J5 on the survey grid.

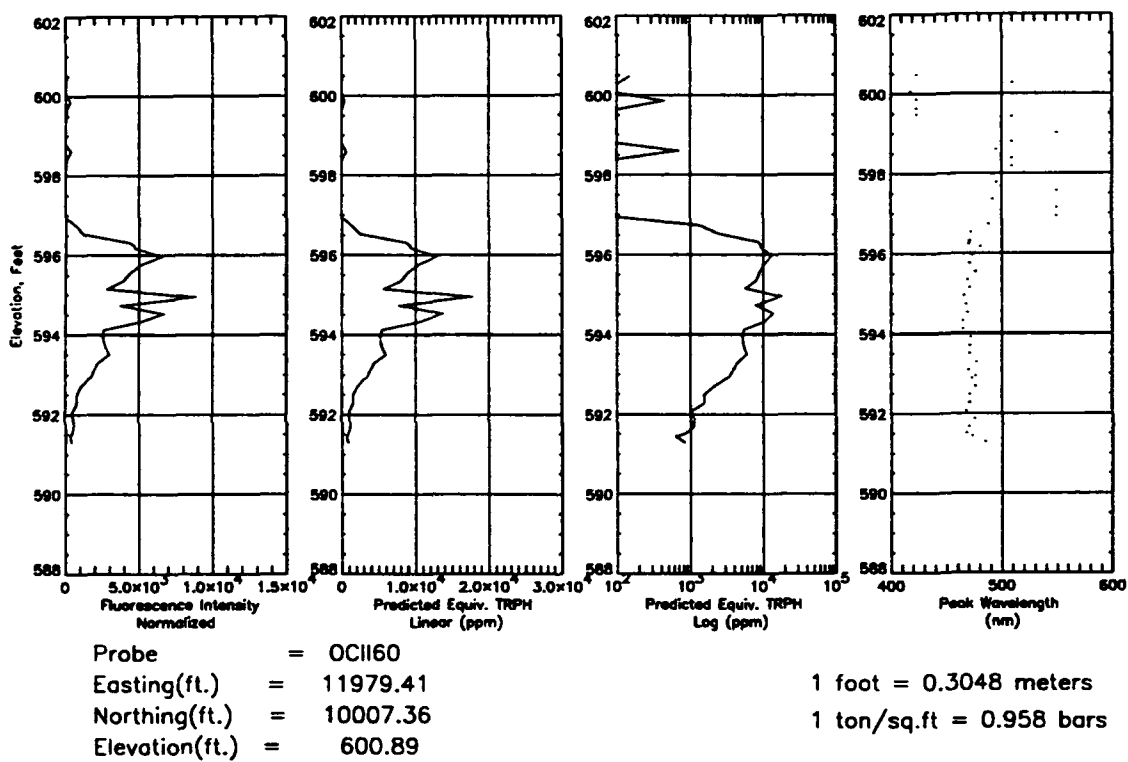


Figure A29. Results of fluorescence probe conducted at location I6 on the survey grid.

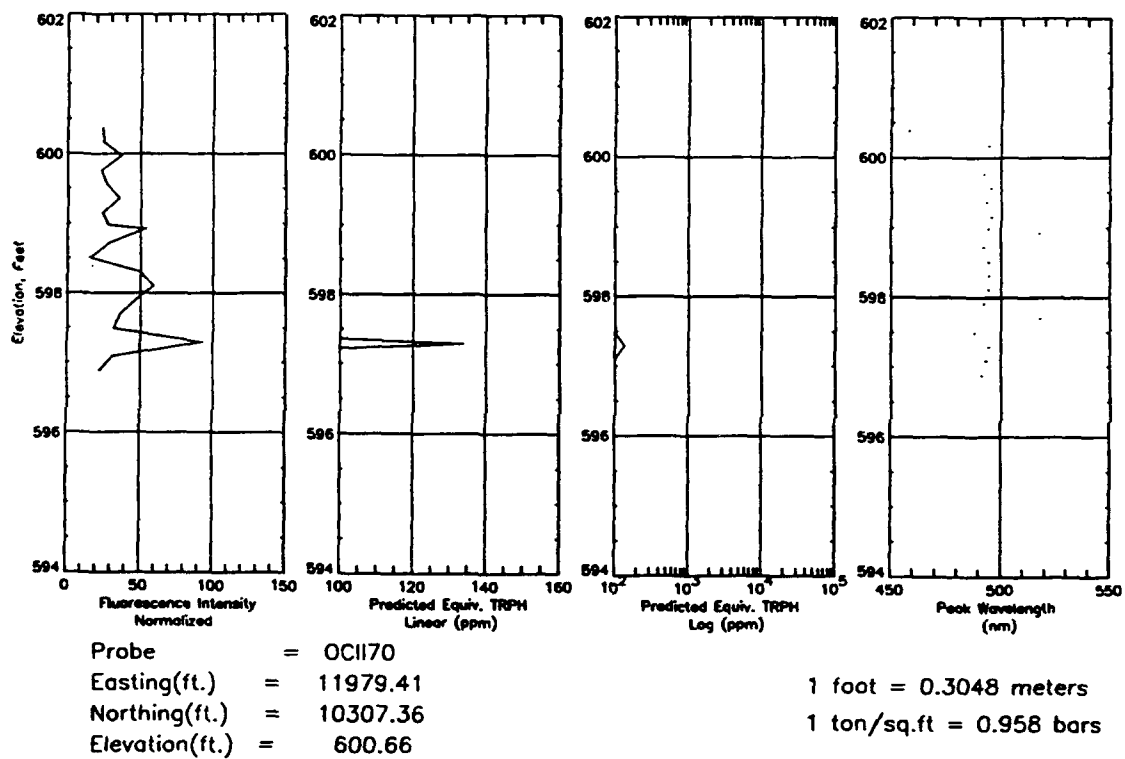


Figure A30. Results of fluorescence probe conducted at location I7 on the survey grid.

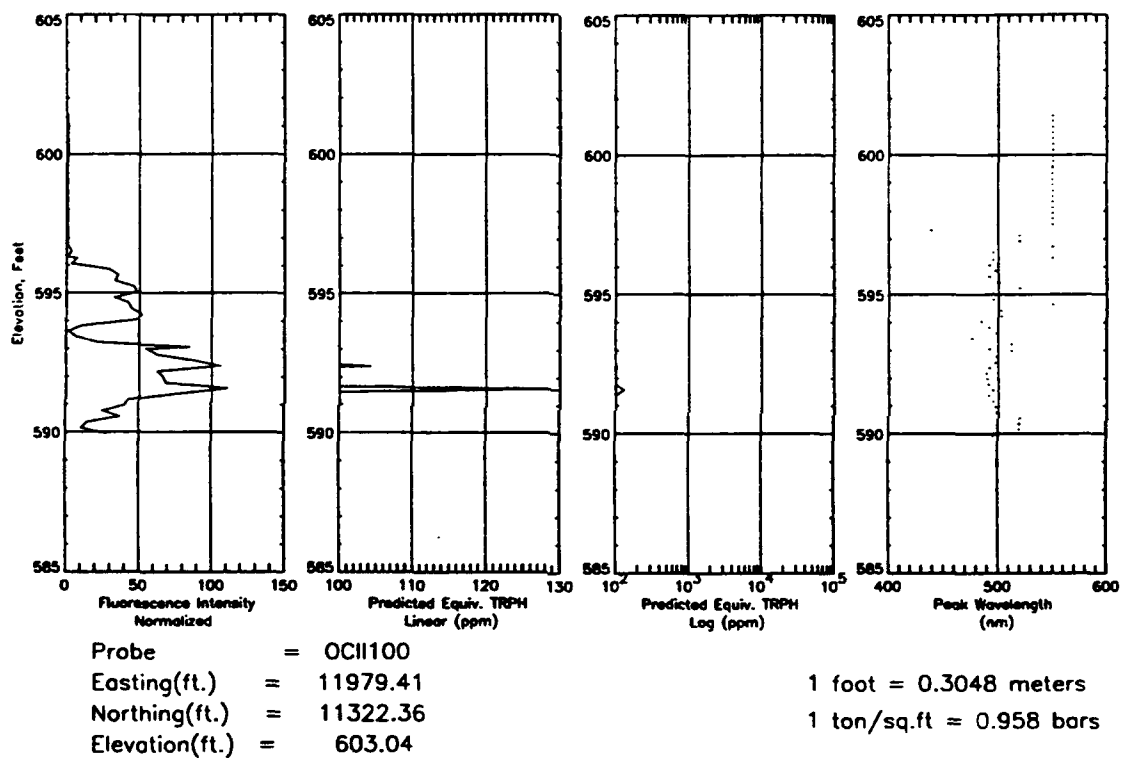


Figure A32. Results of fluorescence probe conducted at location I10 on the survey grid.

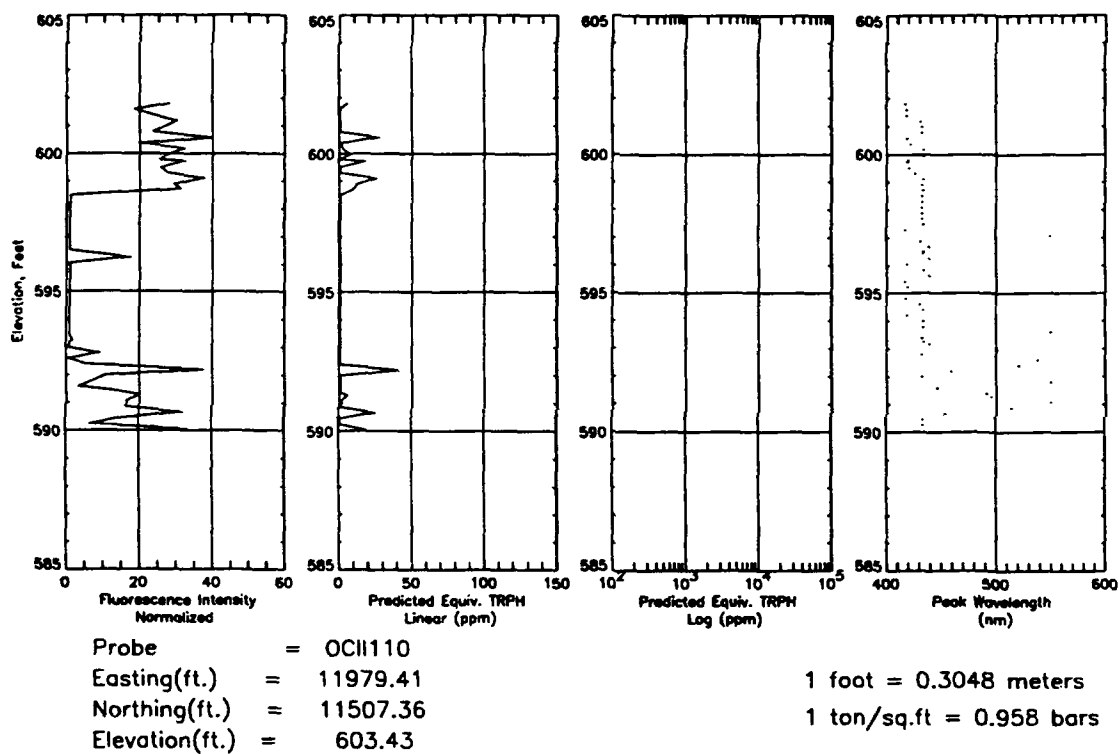


Figure A33. Results of fluorescence probe conducted at location 111 on the survey grid.

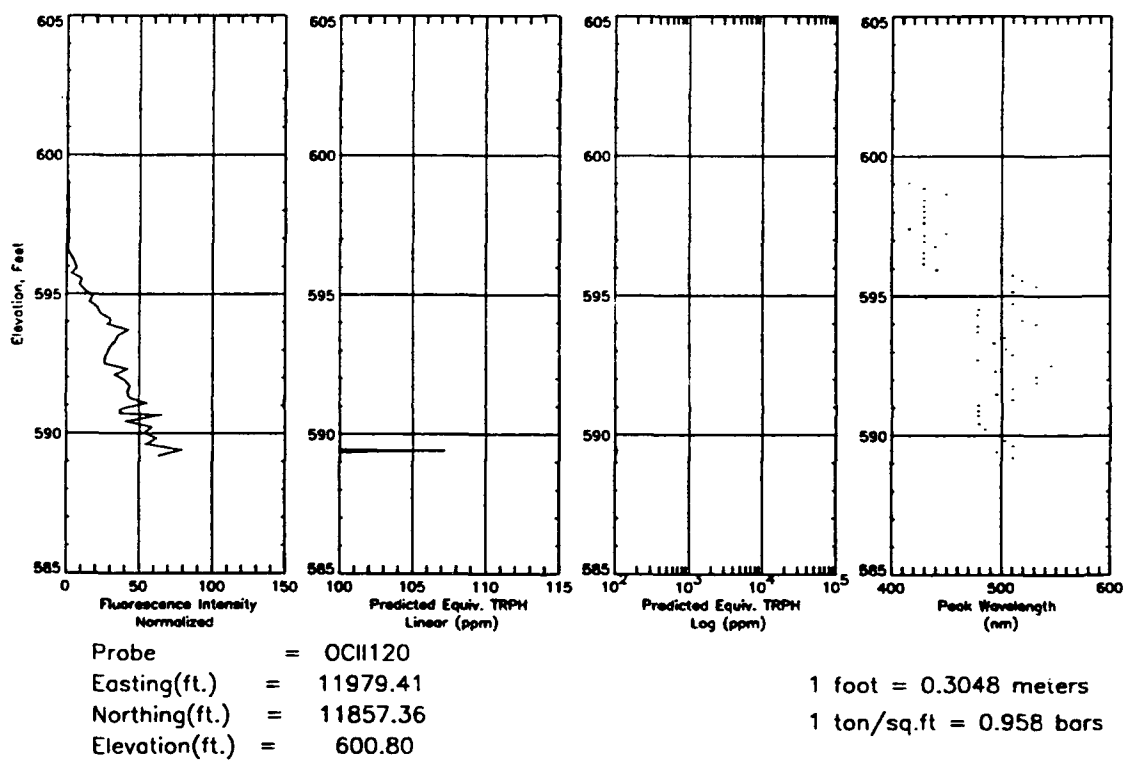


Figure A34. Results of fluorescence probe conducted at location I12 on the survey grid.

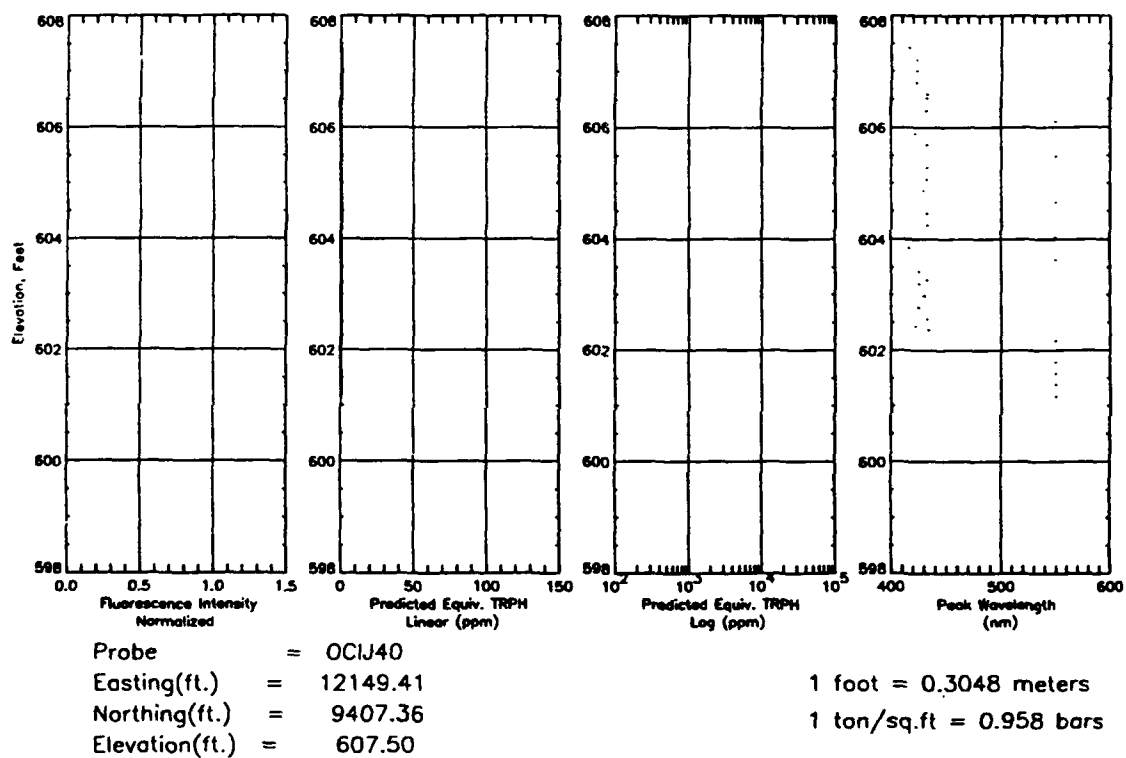


Figure A35. Results of fluorescence probe conducted at location J4 on the survey grid.

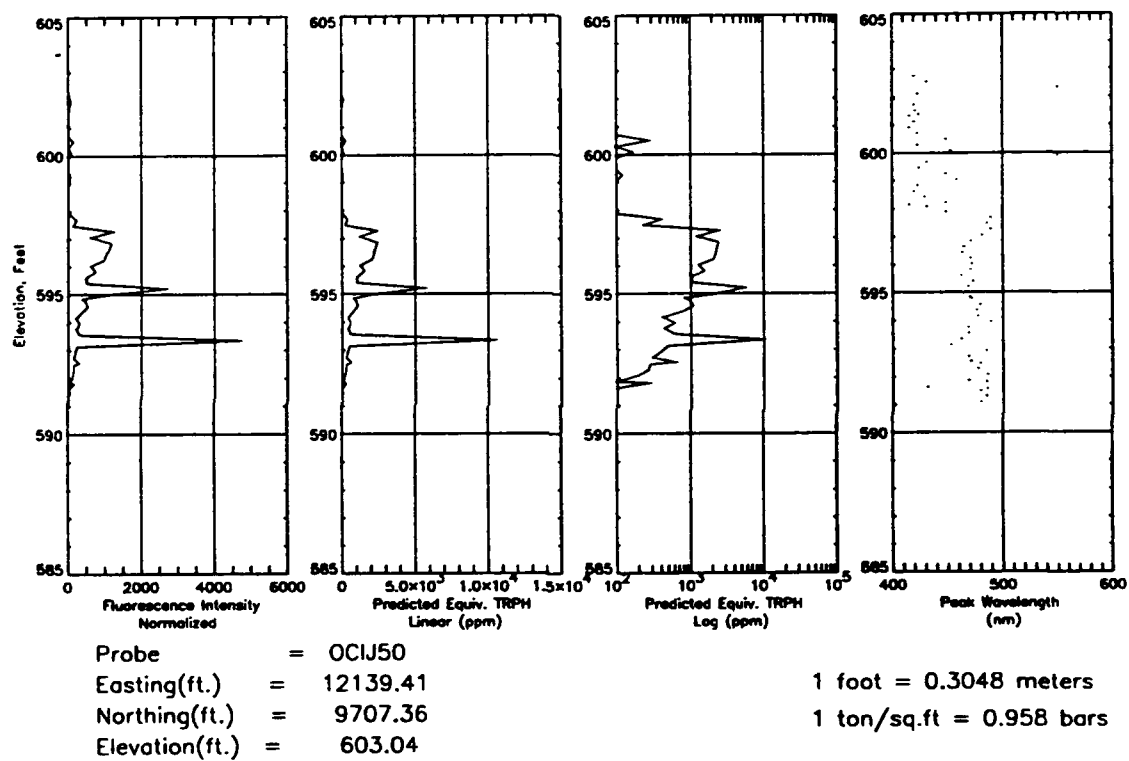


Figure A36. Results of fluorescence probe conducted at location J5 on the survey grid.

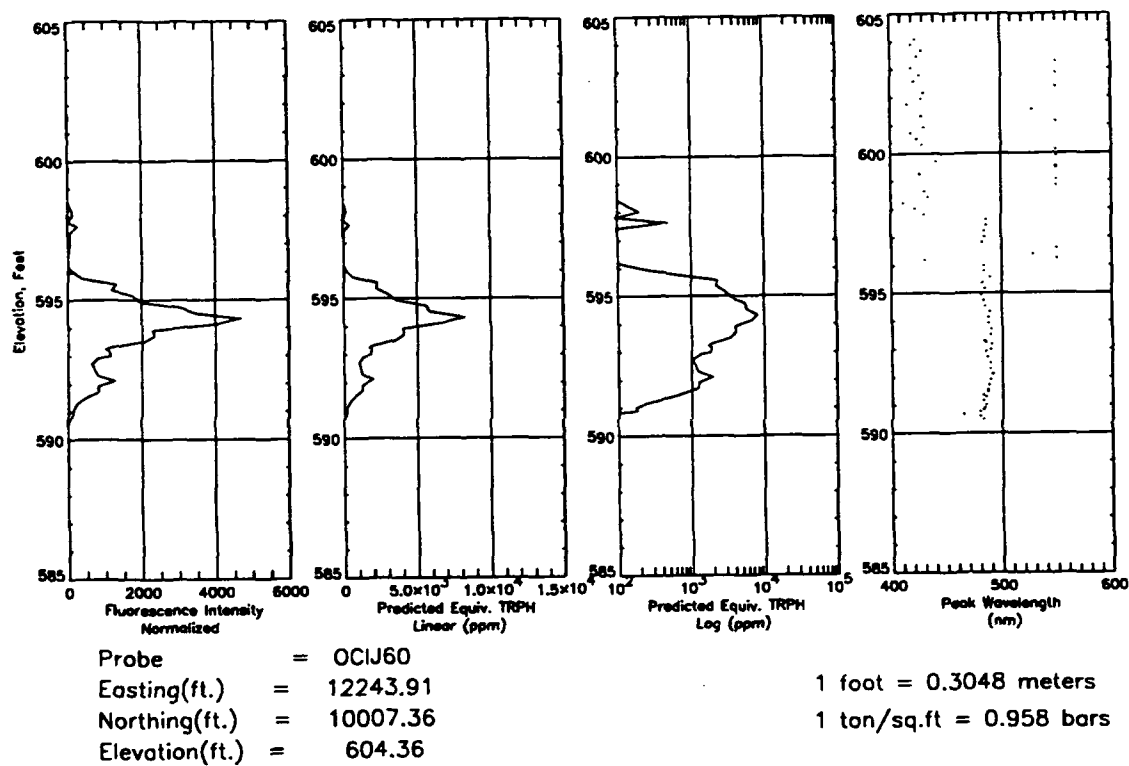


Figure A37. Results of fluorescence probe conducted at location J6 on the survey grid.

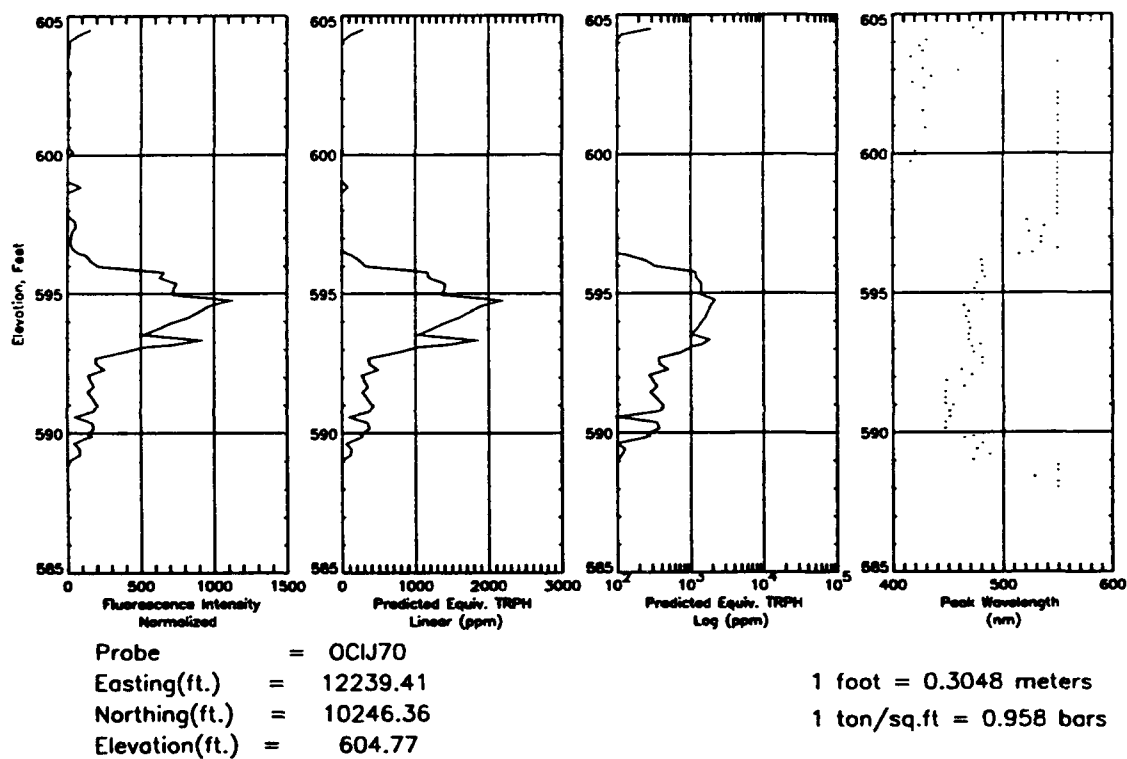


Figure A38. Results of fluorescence probe conducted at location J7 on the survey grid.

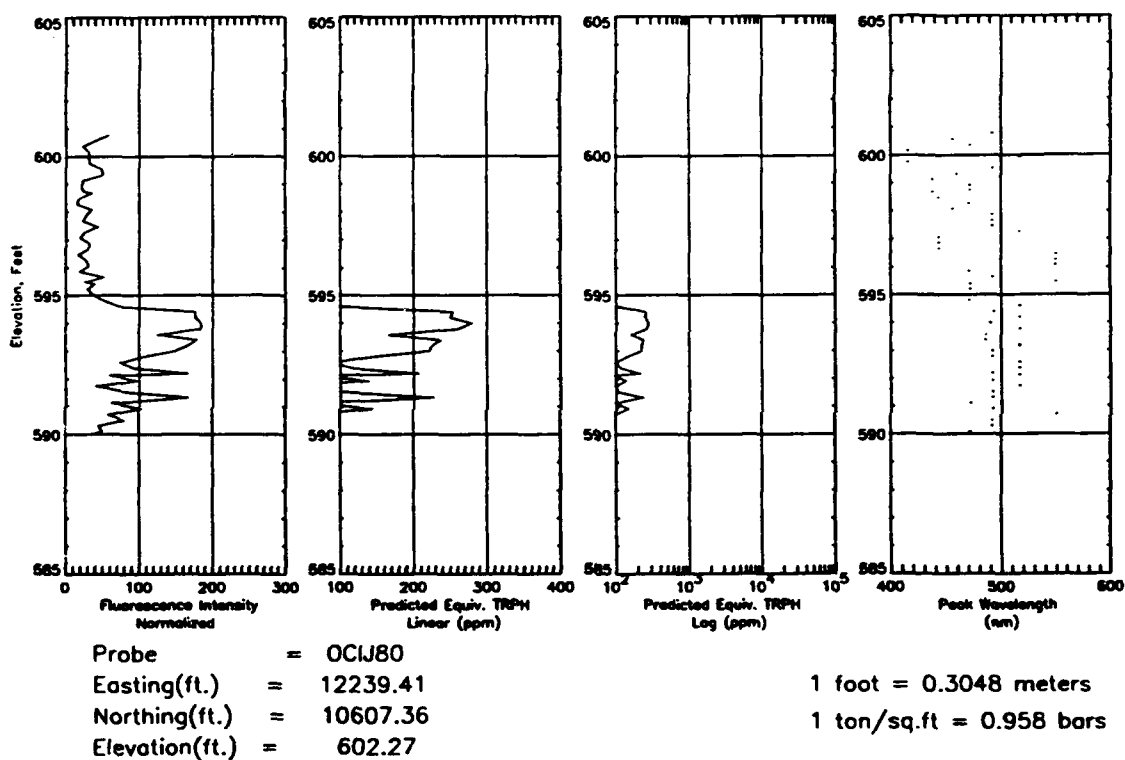


Figure A39. Results of fluorescence probe conducted at location J8 on the survey grid.

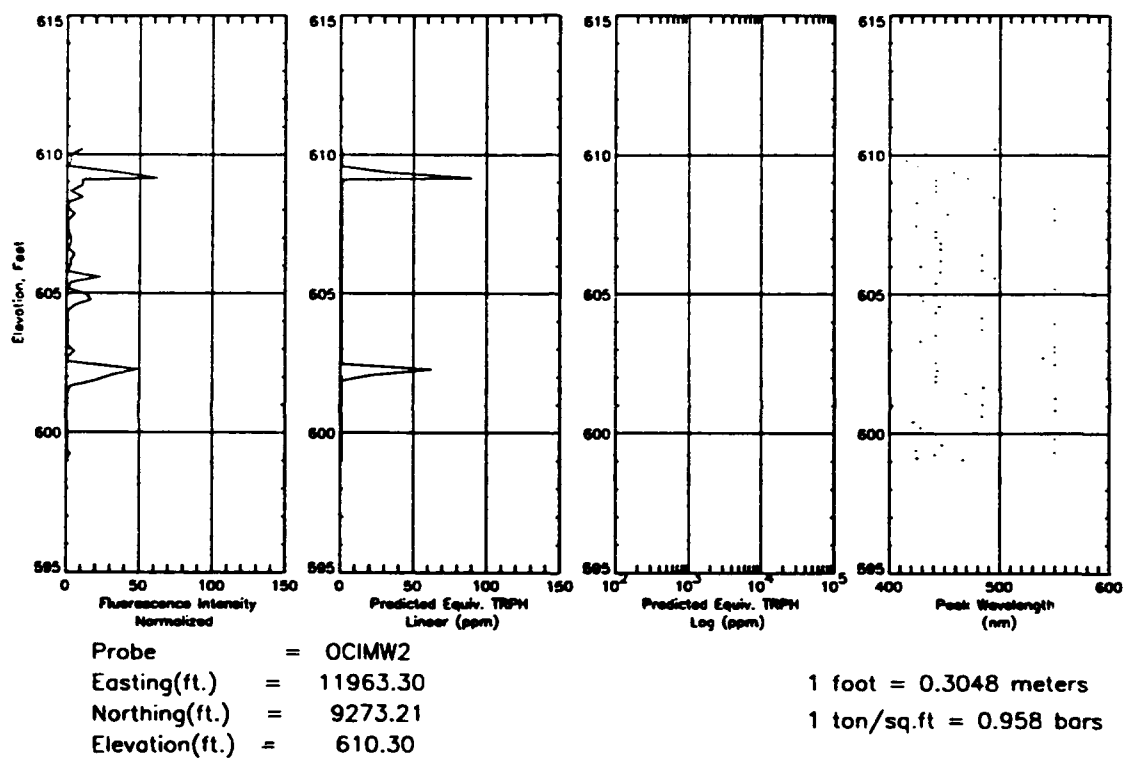


Figure A40. Results of fluorescence probe conducted near Chemical Building #2 (MW-2) on the survey grid.

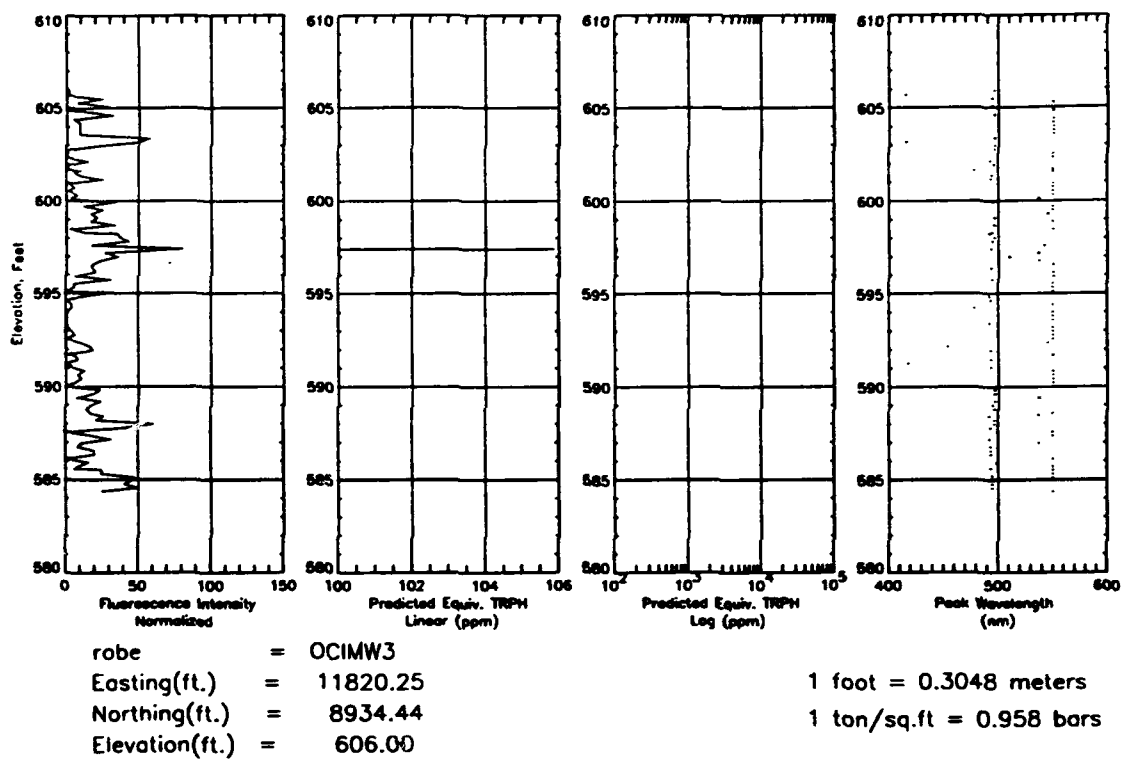


Figure A41. Results of fluorescence probe conducted west of Warehouse (MW-3) on the survey grid.

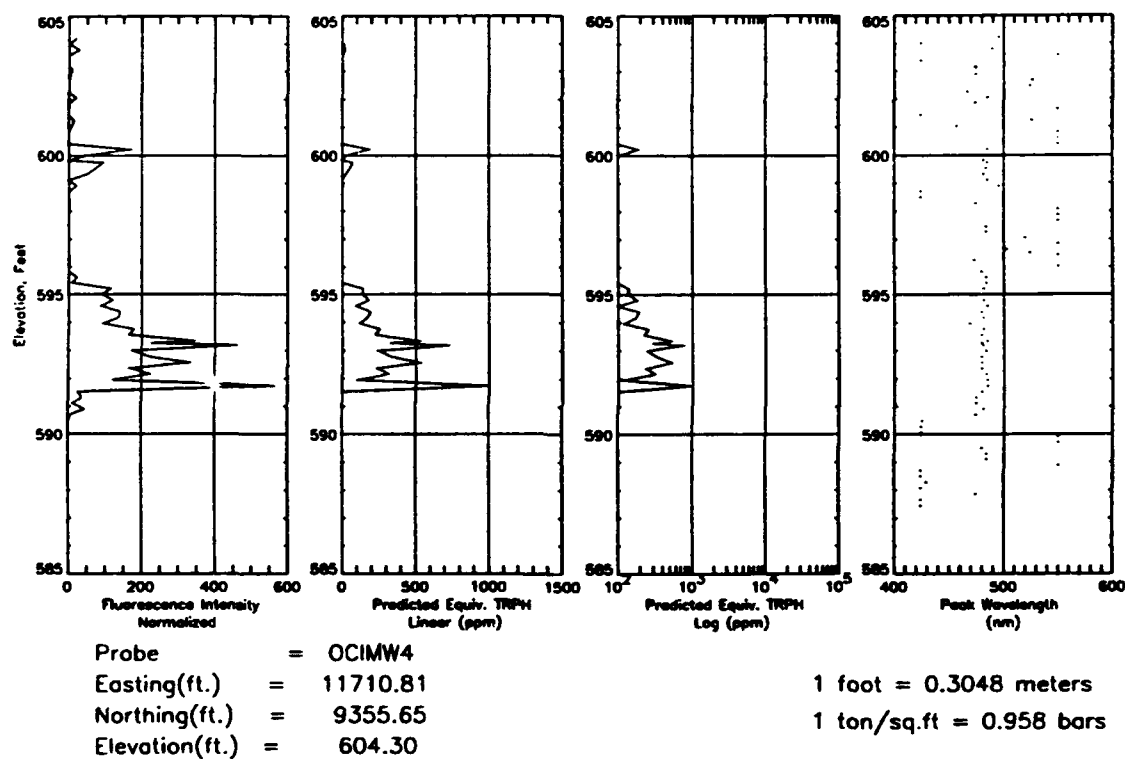


Figure A42. Results of fluorescence probe conducted between H3 and H4 (MW-4) on the survey grid.

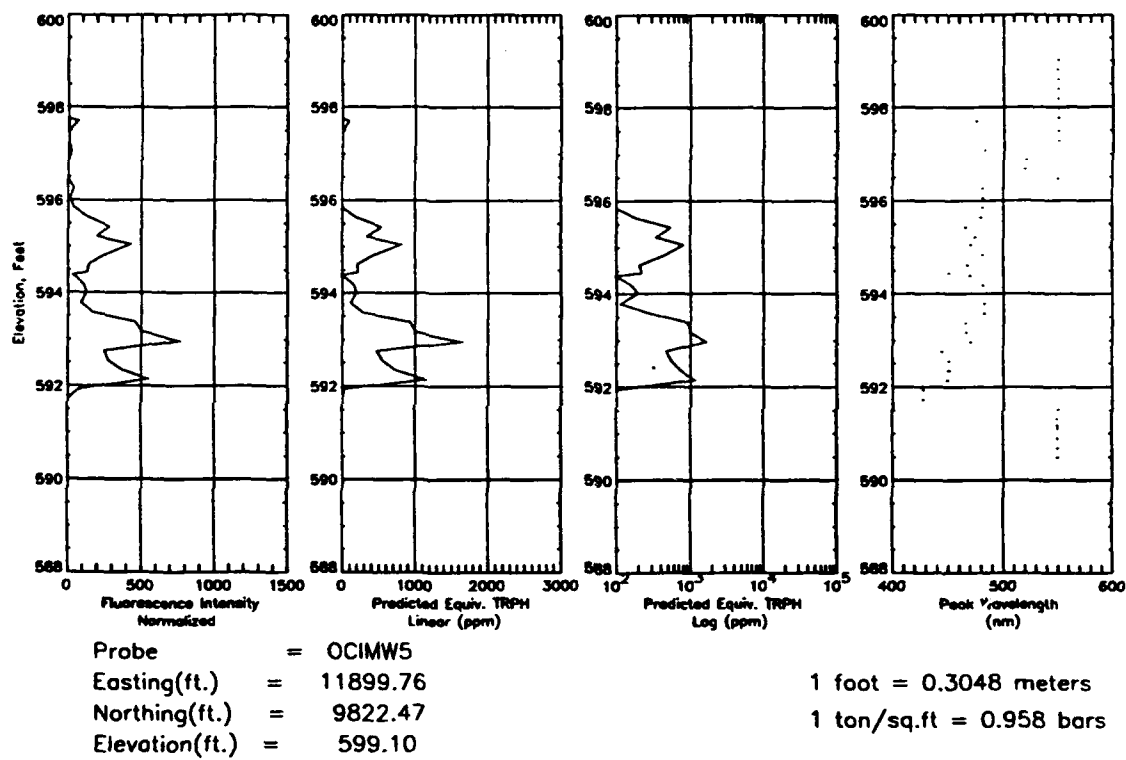


Figure A43. Results of fluorescence probe conducted between I5 and I6 (MW-5) on the survey grid.

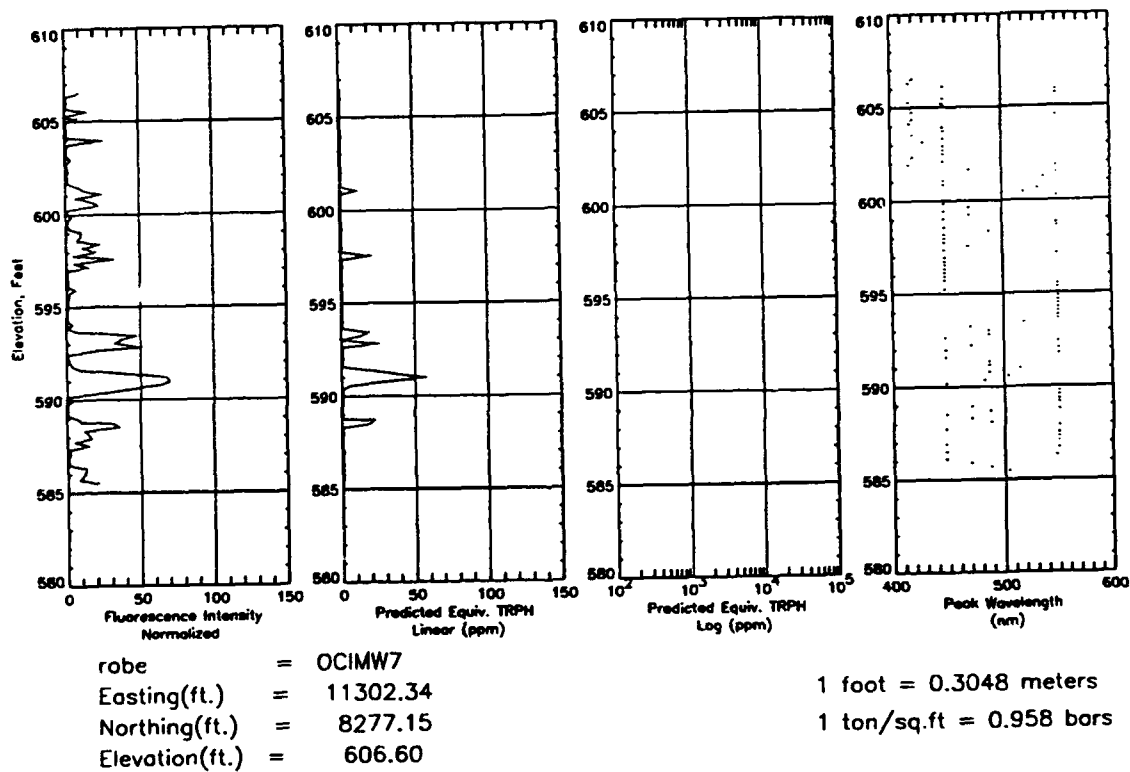


Figure A44. Results of fluorescence probe conducted near G1 (MW-7) on the survey grid.

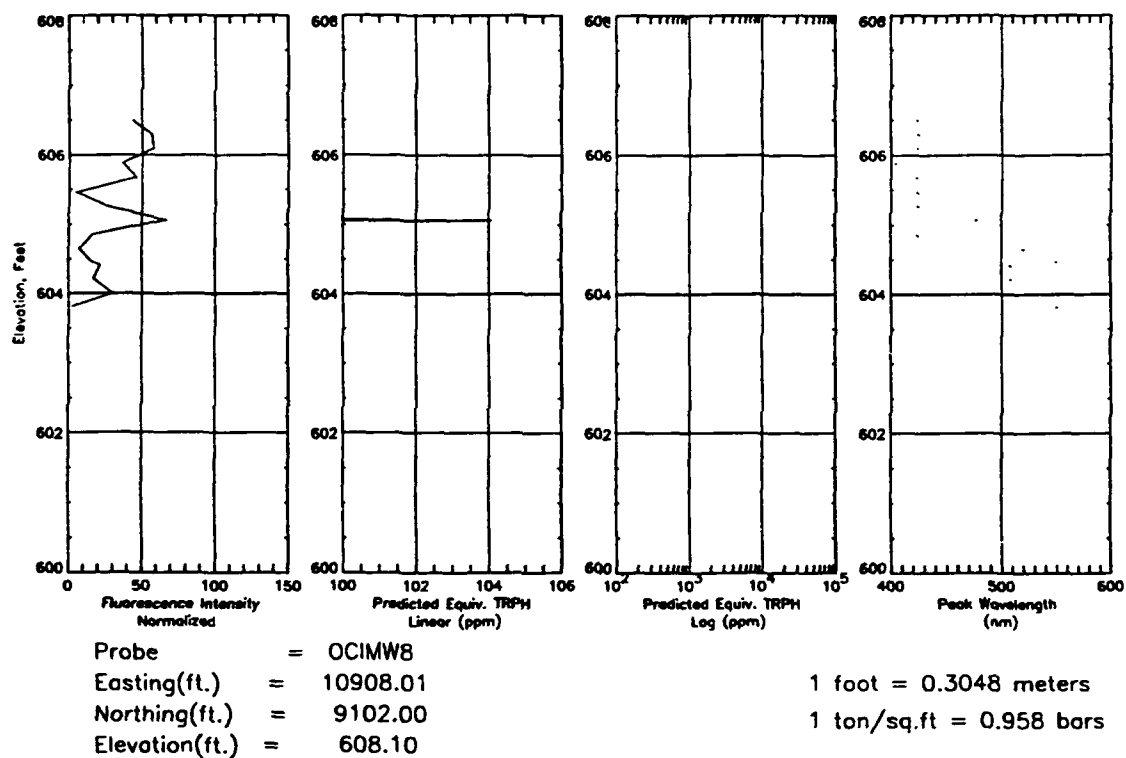


Figure A45. Results of fluorescence probe conducted between E3 and F3 (MW-8) on the survey grid.

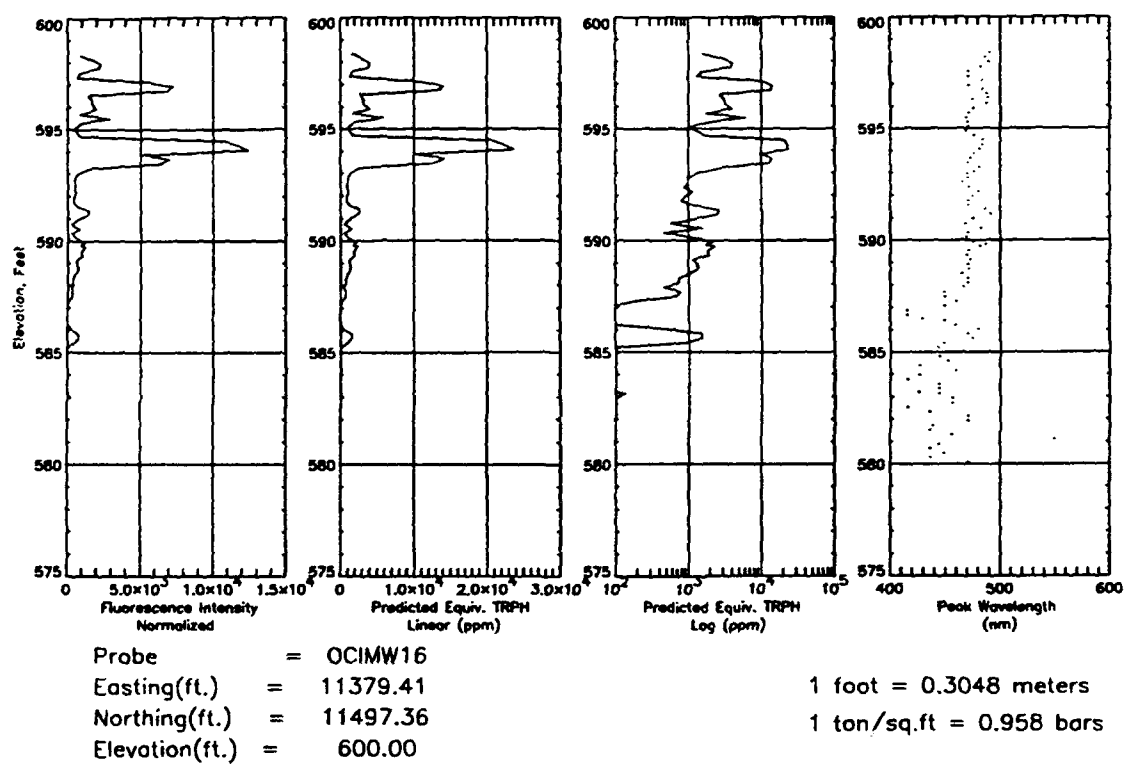


Figure A46. Results of fluorescence probe conducted at location G11 (MW-16) on the survey grid.

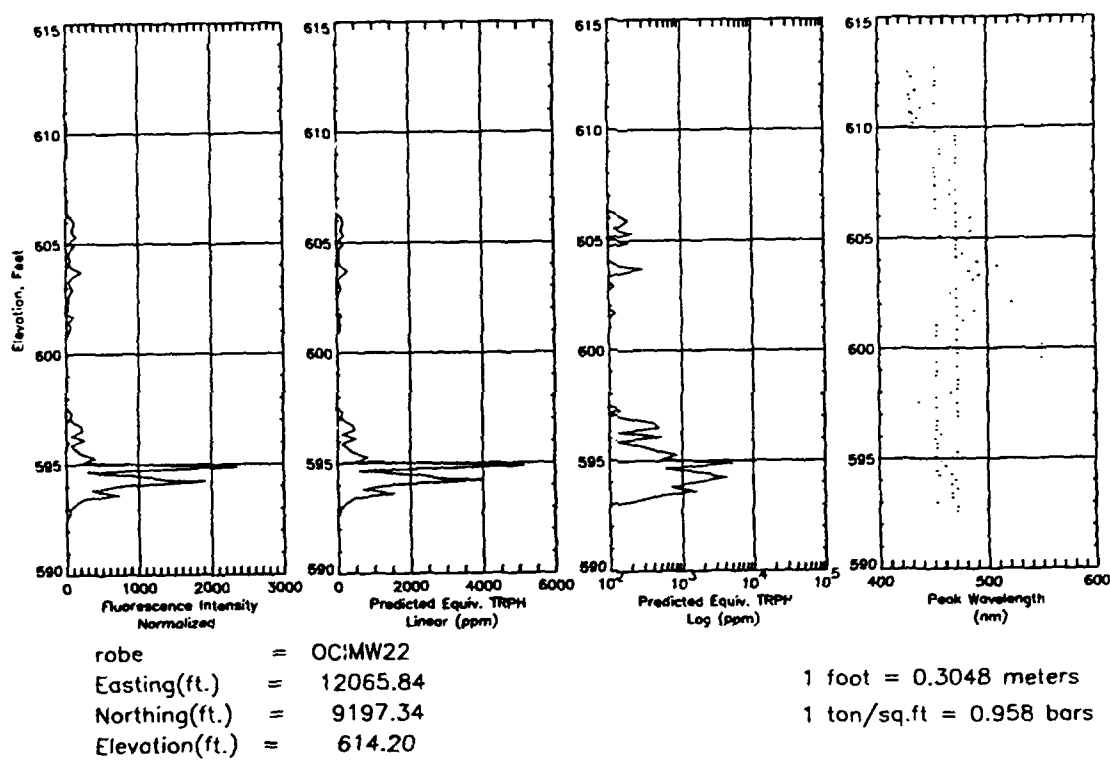


Figure A47. Results of fluorescence probe conducted between I3 and J3 (MW-22) on the survey grid.

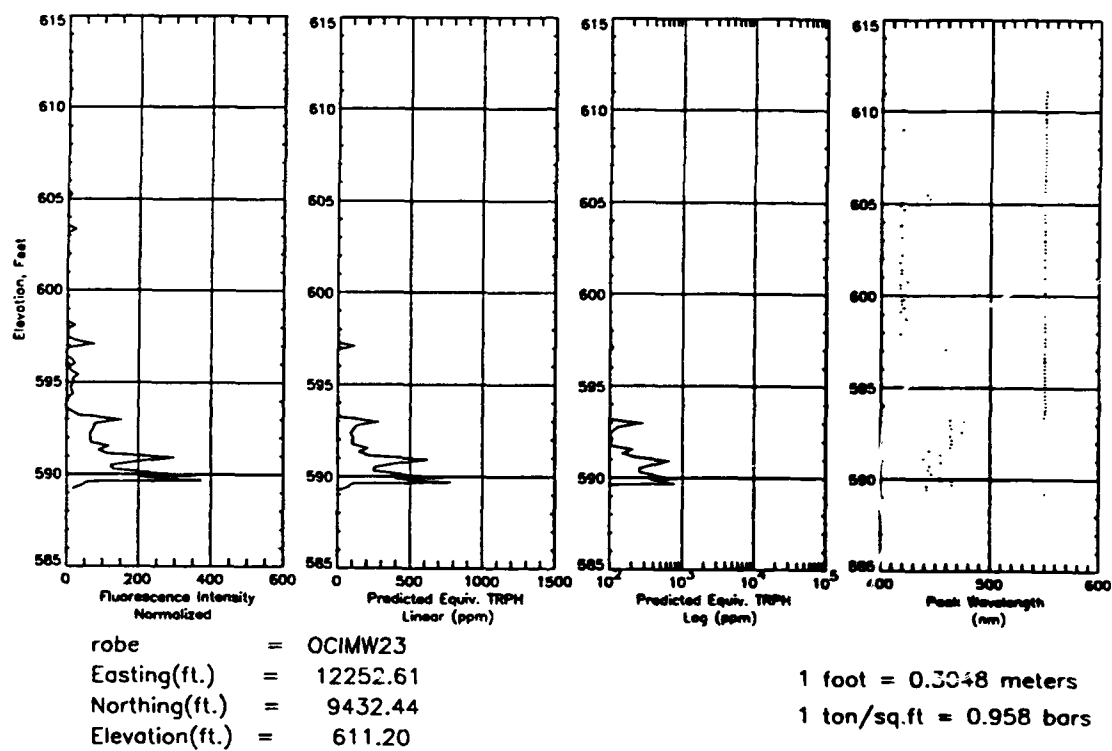


Figure A48. Results of fluorescence probe conducted near Boiler House (MW-23) on the survey grid.

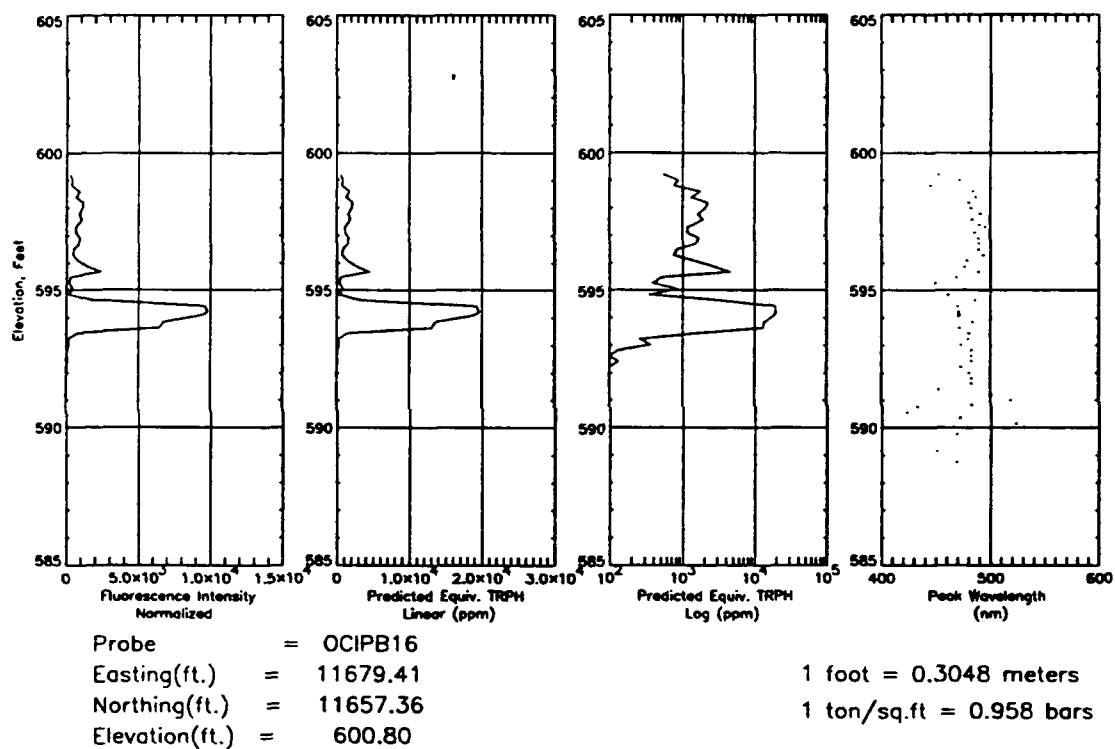


Figure A49. Results of fluorescence probe conducted between H11 and H12 (near Prein & Newhoff boring #16) on the survey grid.

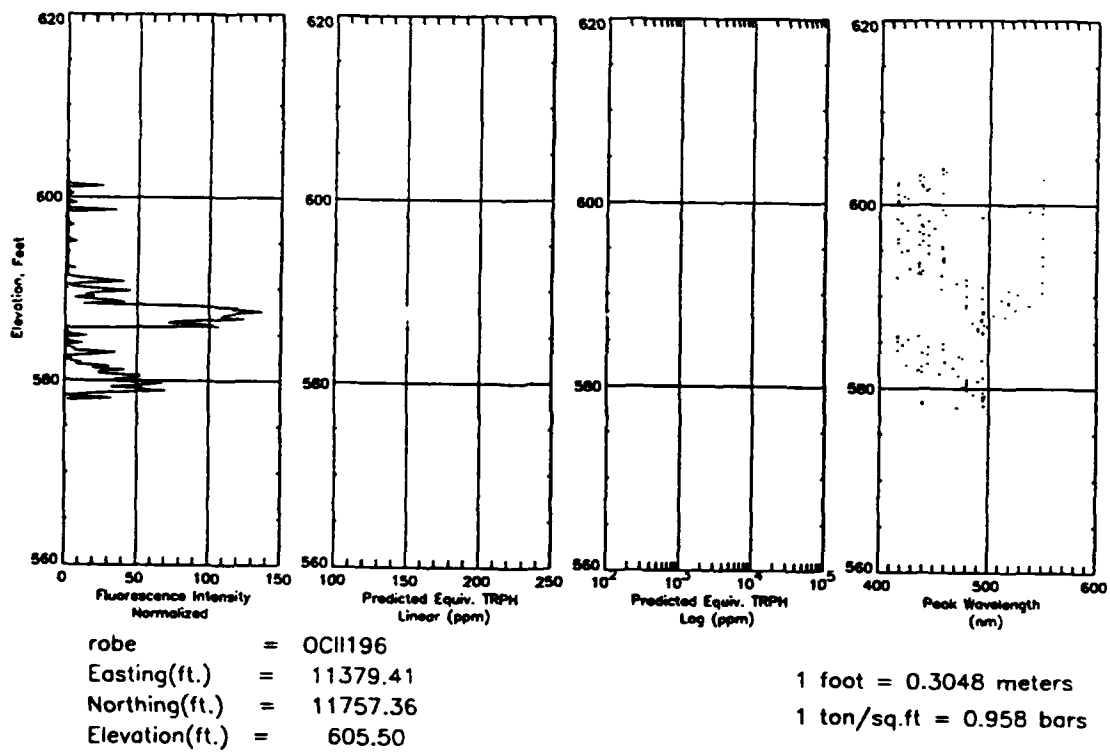
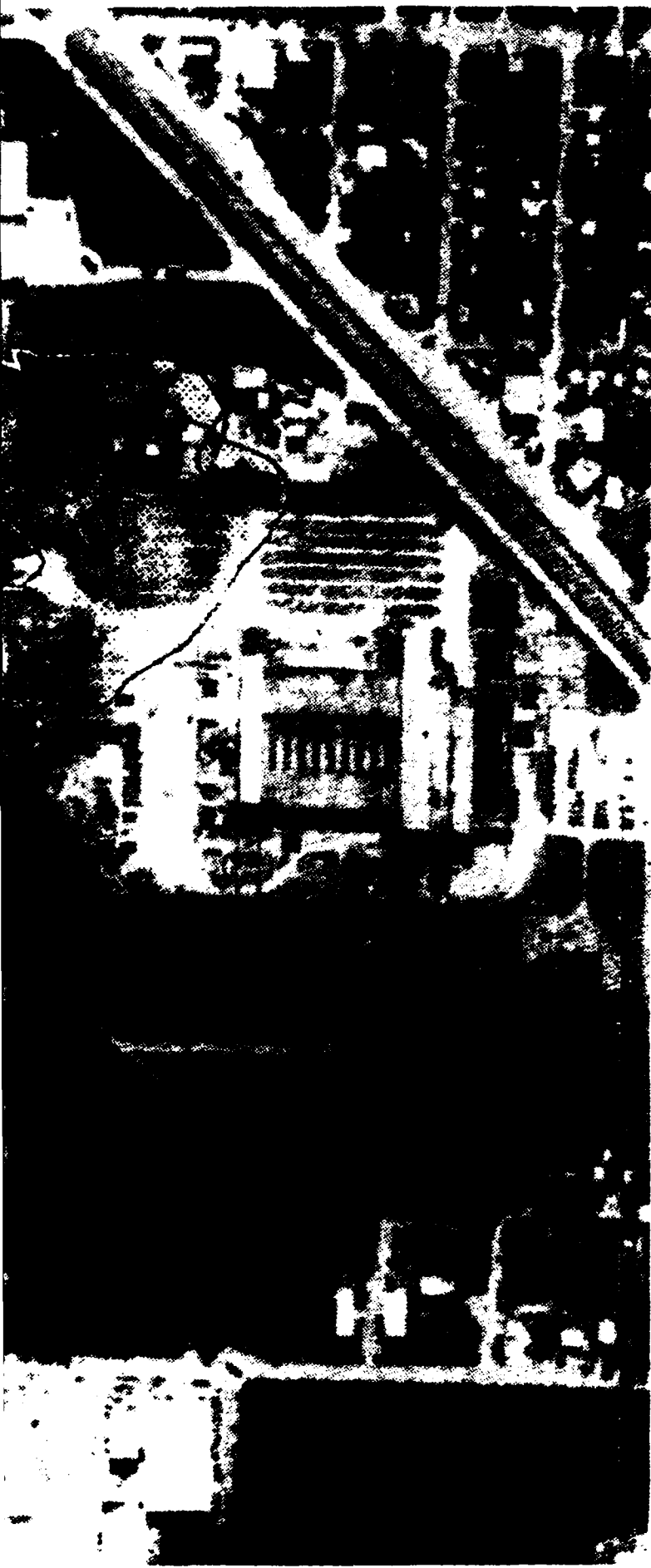


Figure A50. Results of fluorescence probe conducted across Interstate 196 (near G12).

Appendix B: Aerial photographs with plume superimposed.

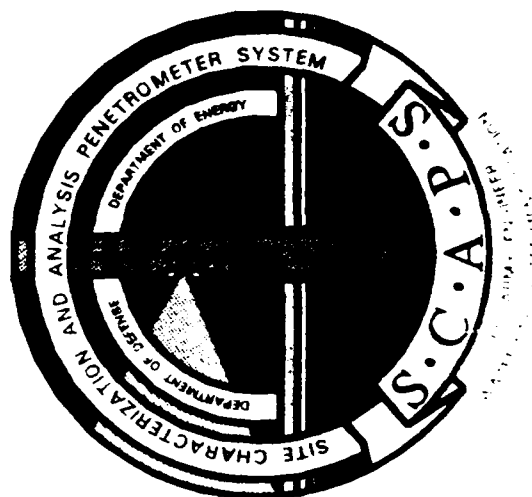
Organic Chemicals Inc. 100 TRPH and Above





Scale 1: .001

100–300 ppm	
Volume	5,990,157.40 ^b
Elevation range	587.4 ^c –602.6
300–1000 ppm	
Volume	362,577.04 ^b
Elevation range	587.4 ^c –601.5
1000–4000 ppm	
Volume	1,180,497.40 ^b
Elevation range	587.4 ^c –599.5



Organic Chemicals Inc. 4000 TRPH and Above





Scale 1" $\approx$ 400'

Above 4000 ppm
 Volume = 717,289.4 ft³
 Elevation range 588.9' - 596.8'

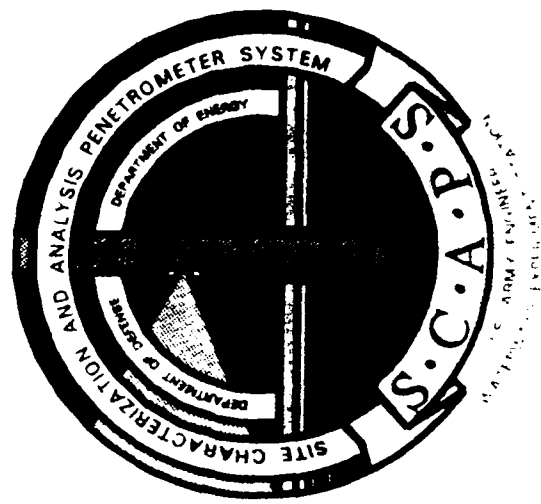


Figure 1. Aerial photograph of the site showing the location of the SCAAPS system and the location of the SCAAPS system.

Waterways Experiment Station Cataloging-In-Publication Data

Sharp, Michael K.

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