GRANT ACTIVITY REPORT

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Dr. Kirk Barrett

# ASSESSING AND MONITORING GROUNDWATER CONTAMINATION FROM LANDFILL LEACHATE IN KEARNY MARSH USING HIGH-RESOLUTION GEOPHYSICS.

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## Introduction

The growing interest in wetland preservation and restoration highlights a need for effective subsurface characterization strategies in these shallow water environments. Conventional direct surface water and sediment sampling undertaken by geochemists, ecologists and hydrologist of wetland sediments typically provides a very sparsely sampled dataset, with high uncertainty regarding the temporal and spatial distribution of the physical characteristics of subsurface sediments. In contaminated wetlands, such as those in the New Jersey Meadowlands, there is a need for rapid wetland characterization to identify geochemical boundaries including: (1) the freshwater-saltwater interface in semi-freshwater wetlands; (2) the extent of contaminant plumes invading wetlands; (3) leakage from contaminant structures and industrial facilities fringing on wetlands.

Geophysical methods provide non-invasive, spatially extensive measurements of earth properties that are closely related to surface and subsurface water, as well as sediment, contamination (Reynolds 1997; Sharma 1997). Excellent examples of the successful delineation of groundwater contaminants using geophysics are available in the geophysical literature (Benson 1992; Greenhouse and Harris 1983; Kobr and Linhart 1994; Woldt, Hagemeister, and Jones 1998). However, application of geophysics in wetlands studies appears to have been overlooked. In this study, we have devised a new approach to wetlands investigations that incorporates high-resolution, non-invasive, spatially extensive geophysical survey within a GIS-based decision support system to investigate wetland environments (Fig. 1).

Work funded under this Meadowlands Environmental Research Institute (MERI) award permitted the development, testing and first application of this geophysical approach to wetlands characterization. An important part of this work is the incorporation of high-resolution geophysical technologies with GIS applications to facilitate interpretation of the geophysical data with respect to water quality/meteorological data, topographic information, satellite acquired data, aerial photography and land use characteristics (Figure 1). <u>An objective here is to couple the expertise of geophysics faculty and students at Department of Earth/Environmental Sciences, Rutgers Newark, with expertise of GIS-trained scientists at MERI.</u>

Work conducted under this MERI award primarily focused on determining techniques to rapidly map the spatial extent of water and sediment contamination in wetlands and identify likely sources of contamination. However, we envisage numerous applications of these geophysical technologies including (a) long term monitoring of contaminant plumes e.g. from landfills (b) characterization of extent of heavy metal contamination in wetland sediments (c) quantification of the amount of metallic debris in wetlands (d) evaluation of wetland stratigraphy. Integration of GIS technologies with the geophysical measurements will enhance the processing and display of these large geophysical datasets in a way that will facilitate incorporation of new datasets that may demand a revised interpretation of these dynamic systems.

## Method of Investigation

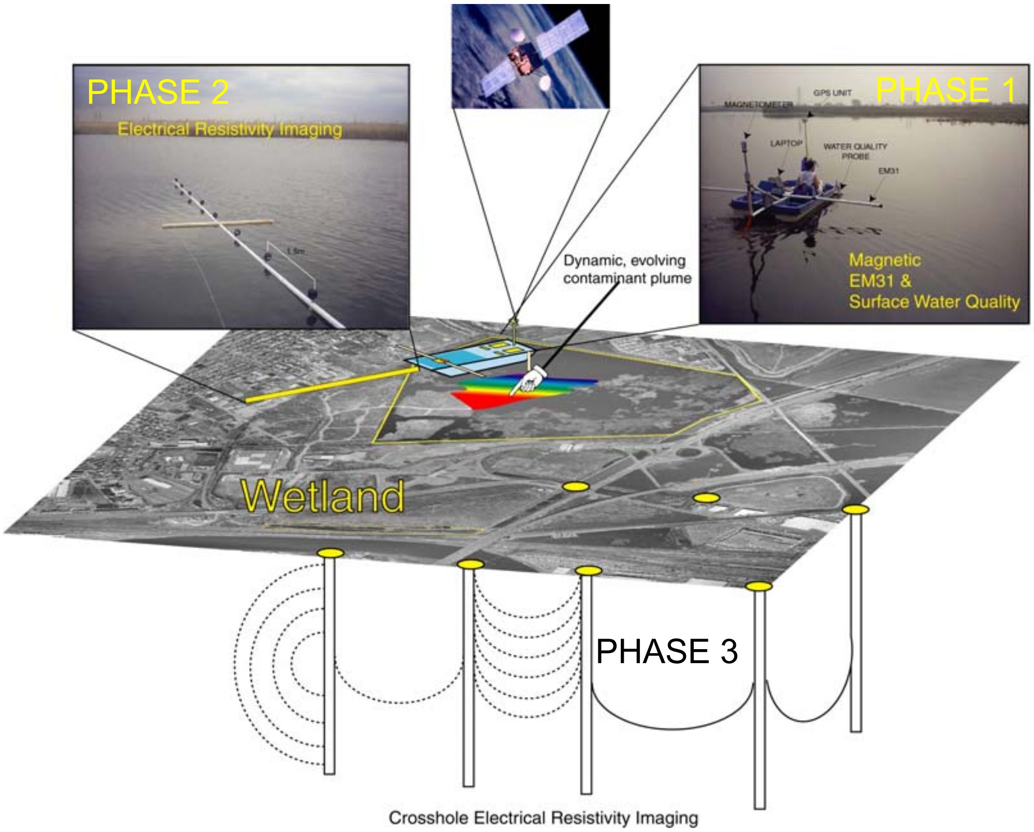


**Figure 1: Overview of the technological concept incorporated into a study of a wetland system, the concept includes three main phases: (a): rapid reconnaissance geophysical surveys from shallow-water boats including magnetic, EM31 and surface water quality survey; (b) electrical resistivity imaging (ERI) monitoring; (c) cross hole ERI monitoring.**

In this report we present in detail the methodology for applying and testing our approach of studying wetlands, discuss our initial results obtained for Kearny Marsh and outline our contribution in seminars and conferences. We also describe in progress and planned future work that is currently funded by a grant from New Jersey Water Resources Research Center (NJWRRC).

## Kearny Marsh

### *Background*

Implementation and testing of our approach was performed on Kearny freshwater marsh, an approximately 1.5 $km^2$ wetland within the Meadowlands complex of predominantly saline tidal wetlands (Fig.2). The marsh and wetlands immediately adjacent to landfills include a state-listed habitat for pied-billed grebe and a coastal heron rookery. Multiple point and non-point sources of pollution potentially impact Kearny Marsh. The primary recognized probable pollutant source is the approximately 110-acre Keegan landfill abutting the SW corner of Kearny Marsh. Other potential sources of contamination include the 1-E landfill to the north, a metal junkyard and aggregates processing facility to the west, as well as the NJ Turnpike and other highways (Fig. 2). The Hackensack Meadowlands District Commission (HMDC) plan to convert the Keegan landfill into a recreational park encourages efforts towards contaminant characterization and source evaluation.

The Keegan landfill was operated as an unlined landfill between the mid-1960s and 1970’s and landfill discharge to both groundwater and surface water is assumed to have occurred. Unauthorized and documented on-site dumping includes construction household waste, tires, appliances, automobiles, plating wastes, pigment wastes and organic wastes (Fig. 3a and b). Surface water and sediment sampling indicates that the marsh is heavily contaminated with heavy metals and other inorganic contaminants ((LEES) 1999). Metallic contaminants include As, Cd, Cr, Cu, Pb, Hg, and Zn. These contaminants have been detected in the marsh sediments as much as 30 ppm Cd, 5900 ppm Cr, 570 ppm Cu, 2000 ppm Pb, and 3600 ppm Zn ((LEES) 1999). Figure 4 presents the measured surface water specific conductance at 22 locations while figure 5 shows the measured salinity at the same locations after((LEES) 1999). Lead concentration measured within the sediments at 21 locations within the marsh is presented in figure 6 ((LEES)

1999). ((LEES) 1999) concluded that the Keegan landfill is a significant source of contamination and is releasing contaminants to the groundwater and into the marsh.

Topography and survey of groundwater levels indicate that the general direction of groundwater flow is from the Keegan landfill into the marsh (Kocis 1982) as presented in figure 4. Previous subsurface investigation conducted to investigate the land use feasibility of the Keegan landfill and inspection prioritization (Site inspection prioritization report, Keegan landfill, Kearny, Hudson County, New Jersey 1997; Land use feasibility study, Keegan Landfill, Kearny, New Jersey. 1998) gives some information on the marsh lithology. Peat and organic-rich silt (approx. 2 m thick) underlies the fill and overlies a relatively thick glacial till varying in thickness from 2 to 10 m. A gray to reddish brown varved clay deposit with silt exists beneath this sequence varying in thickness from 10 to 30m. Figure 7 is a composite showing the thickness range of the subsurface stratigraphy.

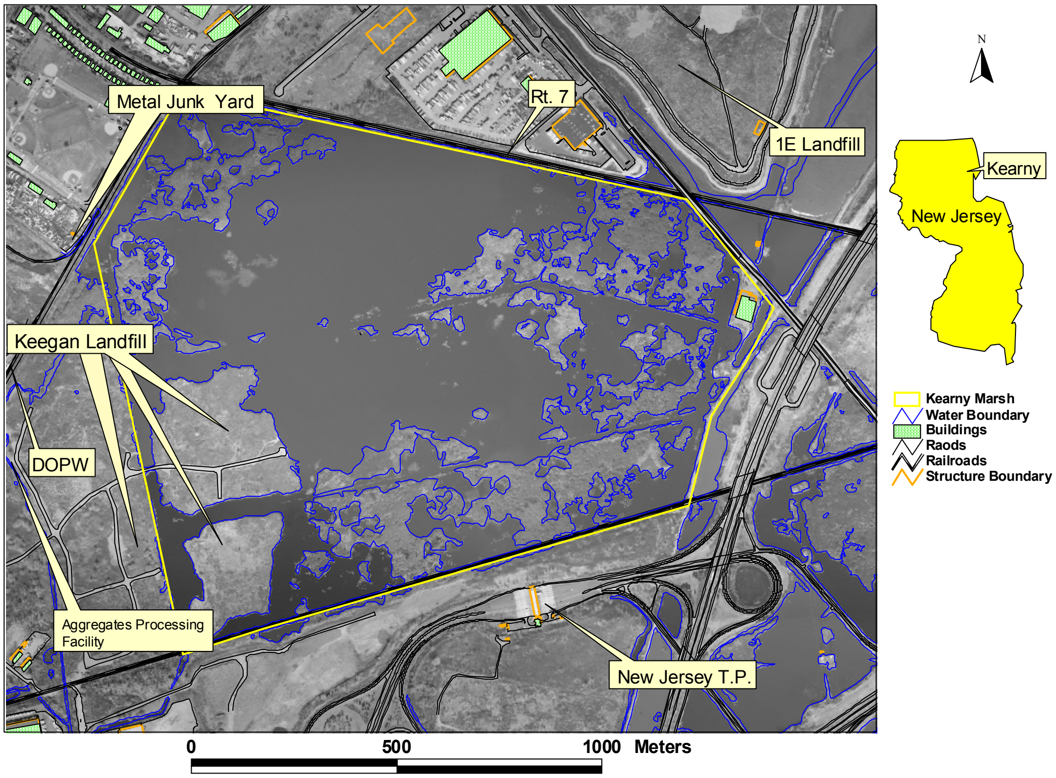


**Figure 2: Site map delineating Kearny marsh and showing identified potential contaminant source zones fringing on the marsh.**

Figure 3: Examples of unauthorized dumping of (a) automobiles and (b) tires at the Kearny marsh.

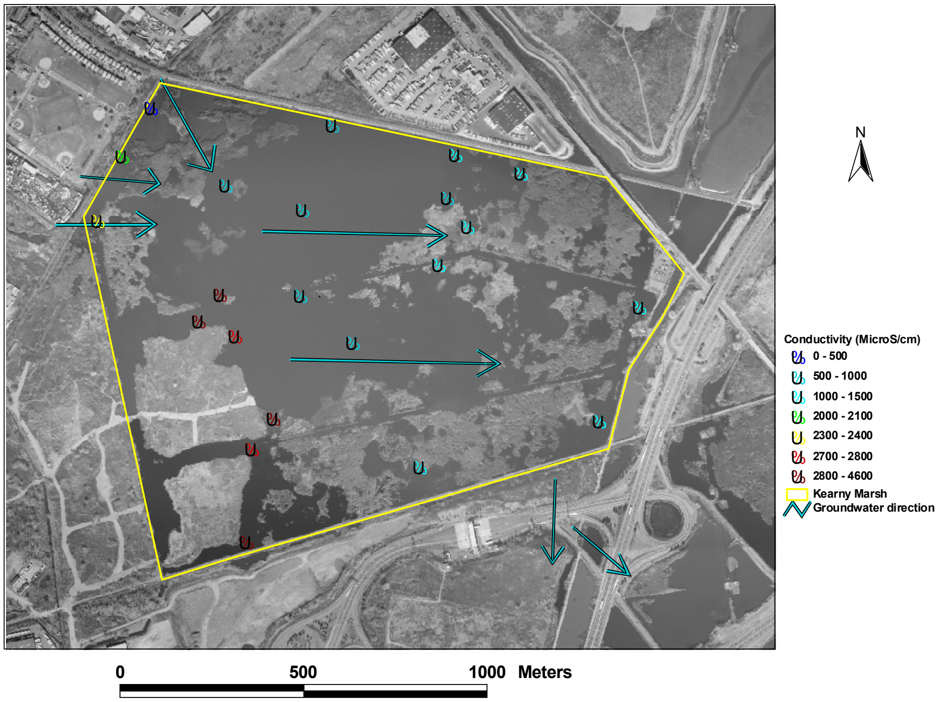


Figure 4: Surface water specific conductance measured at 22 locations within the Kearny marsh showing high values around the Keegan landfill ((LEES) 1999). Arrows show direction of groundwater flow based on topography (Kocis 1982).

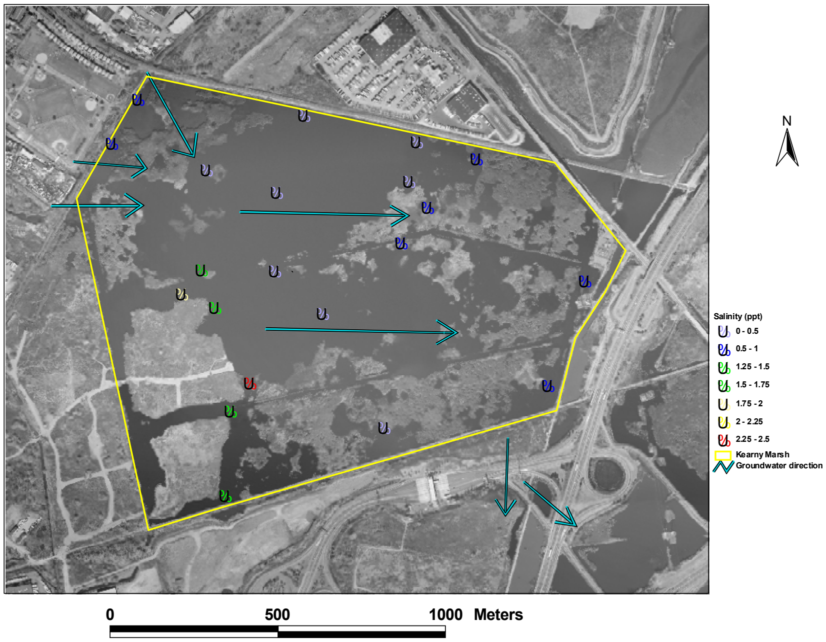


**Figure 5: Surface water salinity measured at 22 locations within the Kearny marsh showing high values around the Keegan landfill ((LEES) 1999). Arrows show direction of groundwater flow based on topography (Kocis 1982).**

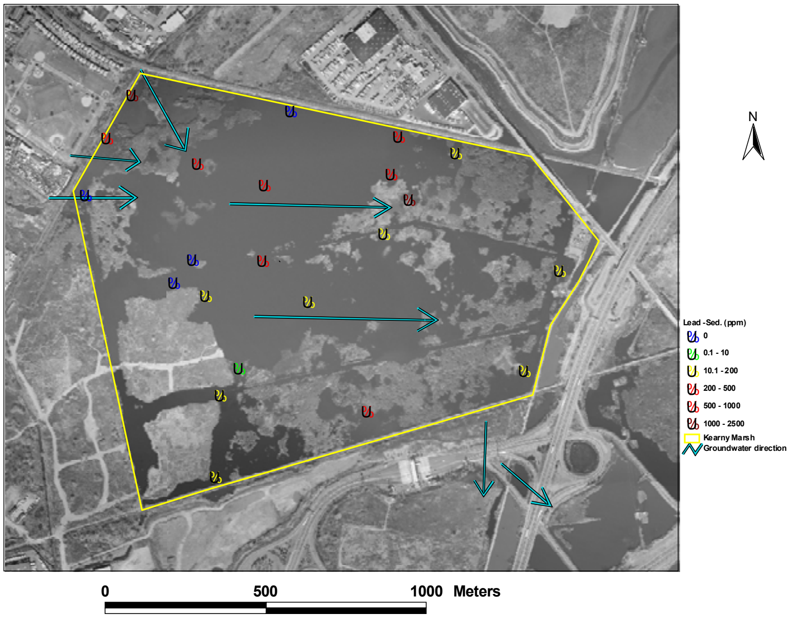


**Figure 6: Lead concentrations in the sediments measured at 21 locations within the Kearny marsh ((LEES) 1999). Arrows show direction of groundwater flow based on topography (Kocis 1982).**

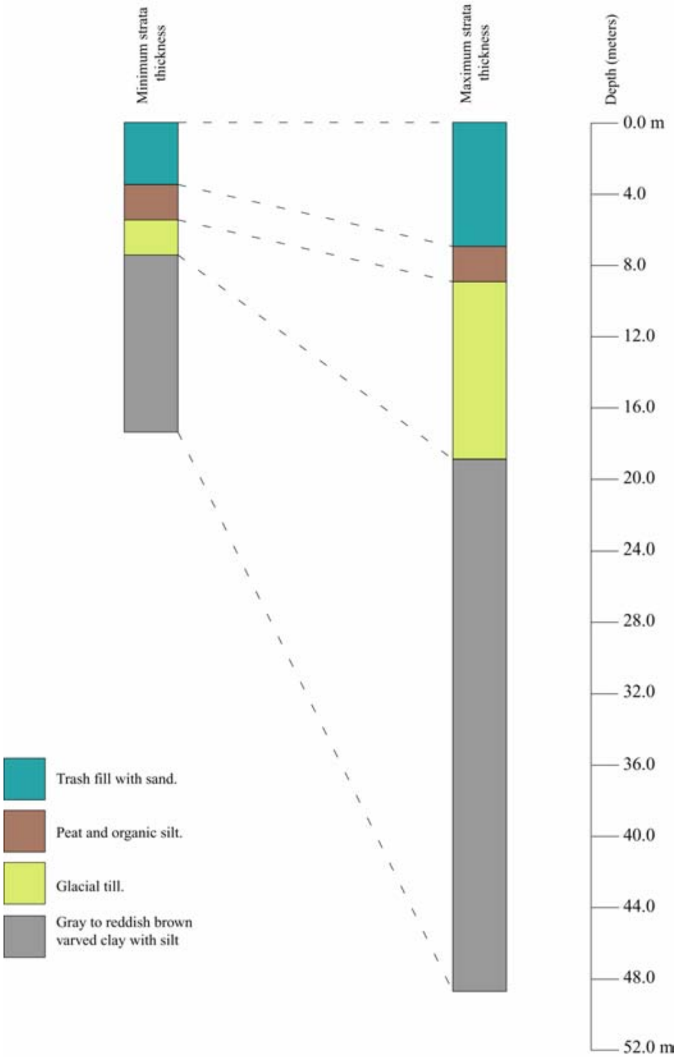


**Figure 7: Composite columnar section of the minimum and maximum thickness of the subsurface stratigraphy measured within the Keegan landfill. Exact location is unknown**

## Objectives

The main objectives of this study can be summarized as follows:

- Advancement of the implementation of geophysical technologies in wetland environments from shallow-water boats.
- Development of a protocol for the integration of geophysical datasets within a 3D and 4D spatial GIS framework.

- Implementation of high-resolution geophysical imaging for monitoring solute release from landfills fringing on wetlands and to delineate and temporally monitor contaminant plumes entering wetlands.
- Adopting the integrated geophysical/GIS approach in Kearny Marsh, Hackensack Meadowlands, New Jersey to: (a) evaluate the primary sources contributing to pollution of Kearny Marsh; (b) determine the distribution of these pollutants within the marsh;

## Concept implementation

### *Geophysical technologies from shallow-water boats*

Our method incorporates high-resolution, accurate, and continuous acquisition of EM31 terrain conductivity (TC) meter, magnetic gradiometer, electrical resistivity imaging (ERI) and water quality data. A four-person paddleboat used for recreation on small lakes/ponds was modified as a "research vessel" (R.V. Pride of Rutgers) for geophysical studies in wetlands. The paddleboat incorporates the following instrumentation: a high precision differential GPS, surface water quality probe, magnetometer, EM31 and a laptop (Fig. 8).

Advantages of these boats include: (a) very shallow draft permitting operation in less than 1 ft standing water (b) adequate space for two persons plus high accuracy GPS unit, geophysical instrumentation, surface water quality probes, and laptop (c) all plastic construction minimizing interference of boat with geophysical measurements (d) hands-free control permitting operation of geophysical instruments whilst surveying. The boat also allows towing of an electrical imaging (ERI) array to be used repeatedly for contaminants characterization (Fig. 9).

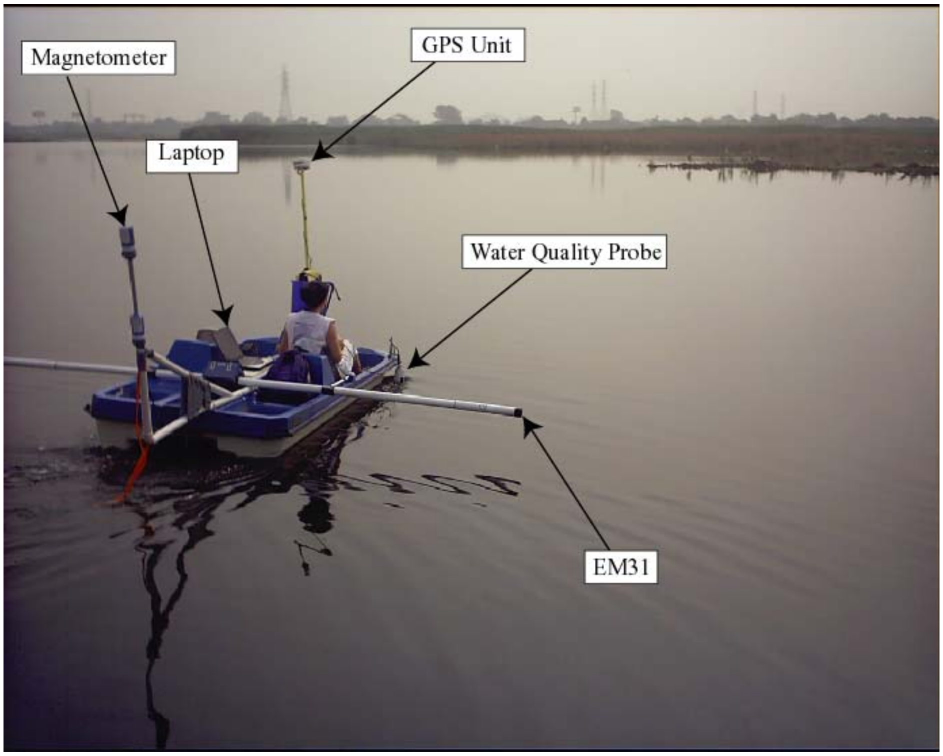


**Figure 8: Paddleboat in operation on Kearny marsh showing on-board instrumentation (note: magnetometer and EM31 both shown for illustration purposes only – datasets are collected independently to avoid interference).**

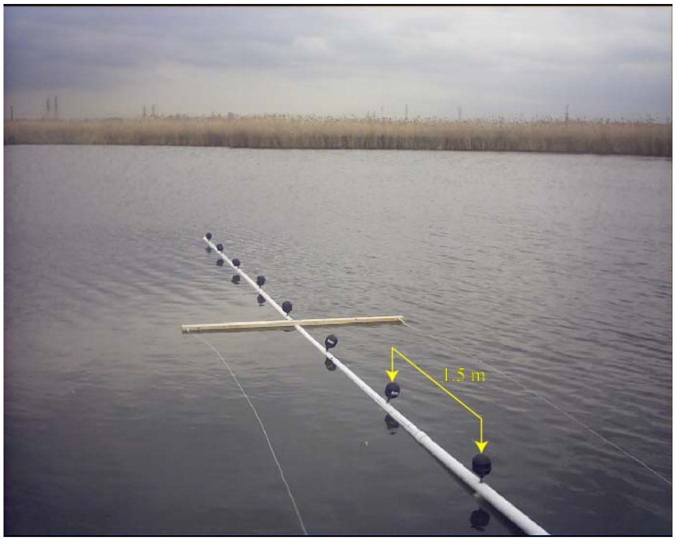


**Figure 9: Floating electrode array fabricated specifically for this study for electrical resistivity imaging (ERI) surveys**

### Magnetic gradiometry

The magnetic geophysical method measures small perturbations in the earth's magnetic field caused by localized accumulations of magnetic material (particularly buried metal). The method is also sensitive to leachate plumes with significant metal content (Roberts et al., 1990). For near surface, high-resolution studies the magnetic gradient (gradiometer) offers a better means of survey since it is much less affected by diurnal changes in the magnetic field. Gradiometer measures the difference in the total magnetic field strength between two identical magnetometers separated by a fixed small distance. Because gradiometers take differential measurements, no correction for diurnal variation is necessary, as both sensors will be equally affected.

Data collection was conducted using SCINTREX ENVI portable magnetometer system. Backpack mounted vertical gradiometer configuration was carried out in which both sensors are read simultaneously by the ENVI console to provide a true gradient measurement. The magnetometer was tested extensively to remove the DC offset that generated by the metal steering mechanism of the paddleboat. After testing and furnishing certain modification, the instrument sensors were mounted in a PVC attachment tied to the end of the boat at about 1.5 m and connected to the ENVI console, which is placed at the rear of the paddleboat.

The system was operated in the automatic acquisition mode (every 2 seconds) and data stored in the ENVI console memory. An average of 6000 points was surveyed each working day. Data from each survey period then were downloaded and merged with the GPS spatial coordinates for each measurement using the time stamp from each instrument. Output files were then saved in a database (dBase IV) format (Figure 10) and imported into our digital GIS framework for further processing and results display.

**Table 1: Example of dBase table showing the different parameters measured for the gradiometry within Kearny Marsh and input into the GIS framework.**

| East | North | Noise | Gradient (nT/m) | Total Field (nT) |
|---|---|---|---|---|
| 593498.055 | 703494.867 | 0.08 | -5.9 | 53326.3 |
| 593500.642 | 703496.562 | 0.09 | -5.2 | 53327.8 |
| 593503.101 | 703498.046 | 0.08 | -2.4 | 53330.2 |
| 593508.226 | 703500.507 | 0.10 | -1.9 | 53334.6 |
| 593511.516 | 703501.610 | 0.11 | -2.1 | 53336.1 |
| 593514.549 | 703502.245 | 0.10 | -4.2 | 53336.1 |
| 593515.945 | 703502.547 | 0.09 | -3.7 | 53337.4 |
| 593516.649 | 703503.171 | 0.09 | -2.7 | 53336.5 |
| 593515.262 | 703505.253 | 0.08 | -3.8 | 53333.3 |
| 593512.561 | 703509.160 | 0.10 | -6.0 | 53329.3 |
| 593509.373 | 703515.188 | 0.10 | -6.4 | 53322.2 |
| 593504.700 | 703524.195 | 0.09 | -6.3 | 53324.0 |
| 593510.621 | 703518.296 | 0.09 | -7.6 | 53323.6 |
| 593509.722 | 703528.878 | 0.09 | -7.5 | 53330.9 |
| 593511.791 | 703532.639 | 0.09 | -7.5 | 53340.9 |
| 593512.565 | 703537.689 | 0.10 | -9.1 | 53356.0 |
| 593517.834 | 703534.125 | 0.10 | 38.3 | 53444.0 |
| 593522.351 | 703543.264 | 0.14 | 107.1 | 53557.1 |
| 593524.393 | 703548.169 | 0.17 | -70.9 | 53297.8 |
| 593526.032 | 703553.179 | 0.14 | -18.9 | 53295.0 |
| 593527.144 | 703556.568 | 0.13 | -48.4 | 53272.4 |
| 593528.564 | 703560.842 | 0.16 | -0.7 | 53342.4 |
| 593531.141 | 703568.658 | 0.18 | 47.9 | 53399.1 |
| 593532.428 | 703573.919 | 0.14 | -19.0 | 53318.5 |
| 593532.709 | 703577.443 | 0.16 | -64.5 | 53290.0 |
| 593532.308 | 703584.253 | 0.14 | -3.7 | 53403.7 |
| 593530.930 | 703588.846 | 0.12 | 124.6 | 53593.0 |
| 593526.839 | 703594.142 | 0.27 | 198.1 | 53656.5 |
| 593524.101 | 703596.397 | 0.22 | -63.8 | 53341.1 |
| 593521.782 | 703598.110 | 0.38 | -171.7 | 53207.5 |
| 593518.802 | 703600.899 | 0.35 | -297.6 | 53107.6 |
| 593516.100 | 703603.981 | 0.30 | -125.7 | 53240.9 |
| 593511.114 | 703611.957 | 0.28 | -133.5 | 53229.7 |
| 593508.210 | 703616.990 | 0.27 | -138.6 | 53224.1 |
| 593510.742 | 703612.310 | 0.28 | -138.7 | 53219.5 |
| 593510.192 | 703612.233 | 0.25 | -134.8 | 53221.2 |
| 593514.471 | 703611.631 | 0.25 | -132.1 | 53220.7 |
| 593514.445 | 703611.584 | 0.25 | -131.6 | 53218.8 |
| 593514.421 | 703611.610 | 0.23 | -128.4 | 53219.6 |
| 593514.382 | 703611.691 | 0.25 | -130.0 | 53219.1 |
| 593513.644 | 703609.411 | 0.29 | -135.2 | 53214.7 |
| 593510.793 | 703610.670 | 0.24 | -140.2 | 53204.9 |

### Electromagnetic terrain conductivity

The terrain conductivity meter (EM31) is a popular tool for preliminary site characterization on land especially for groundwater surveys, mapping contaminant plumes and landfill surveys as well as other applications. It measures the average electrical conductivity of the upper few meters of the subsurface. The EM31 instrument was mounted firmly on the back seats of the boat. Due to the shallow water depth the EM31 measurement is primarily sensing the electrical conductivity of the sediments. Surface water chemistry measurements were measured simultaneously and continuously to constrain the EM31 data as mentioned previously to quantify the effect of changing surface water chemistry on terrain conductivity data. The EM31 was used in the automatic mode to record every two seconds while paddling the boat. Data from each survey period then were downloaded, merged with the GPS spatial coordinates for each measurement using the time stamp from each instrument and saved as a dBase IV file.

**Table 2: Example of dBase table showing the terrain conductivity measurements taken within Kearny Marsh and imported into the GIS framework.**

| East | North | I | Q (µS/cm) |
|---|---|---|---|
| 594612.838 | 701583.697 | -0.68 | 1210.0 |
| 594610.757 | 701581.416 | -0.67 | 1210.0 |
| 594608.177 | 701578.639 | -0.65 | 1210.0 |
| 594603.463 | 701573.770 | -0.65 | 1210.0 |
| 594600.117 | 701570.552 | -0.64 | 1210.0 |
| 594595.974 | 701567.798 | -0.63 | 1215.0 |
| 594592.746 | 701566.622 | -0.62 | 1218.0 |
| 594588.597 | 701565.683 | -0.57 | 1210.0 |
| 594580.857 | 701565.433 | -0.57 | 1200.0 |
| 594575.588 | 701566.333 | -0.66 | 1213.0 |
| 594572.193 | 701567.366 | -0.62 | 1228.0 |
| 594567.964 | 701569.000 | -0.63 | 1220.0 |
| 594562.901 | 701571.392 | -0.62 | 1220.0 |
| 594555.445 | 701575.732 | -0.61 | 1220.0 |
| 594550.736 | 701579.261 | -0.60 | 1220.0 |
| 594547.727 | 701581.816 | -0.59 | 1220.0 |
| 594543.986 | 701585.117 | -0.60 | 1220.0 |
| 594539.639 | 701589.323 | -0.60 | 1230.0 |
| 594533.824 | 701596.484 | -0.61 | 1223.0 |
| 594530.844 | 701601.914 | -0.65 | 1228.0 |
| 594529.428 | 701605.723 | -0.65 | 1223.0 |
| 594528.111 | 701610.646 | -0.65 | 1210.0 |
| 594527.270 | 701616.684 | -0.66 | 1220.0 |
| 594527.006 | 701625.650 | -0.73 | 1220.0 |
| 594527.339 | 701631.582 | -0.72 | 1220.0 |
| 594527.938 | 701635.477 | -0.65 | 1200.0 |
| 594528.687 | 701640.293 | -0.56 | 1200.0 |
| 594529.592 | 701645.961 | -0.48 | 1200.0 |
| 594531.217 | 701654.426 | -0.43 | 1200.0 |
| 594531.990 | 701659.935 | -0.47 | 1190.0 |
| 594532.711 | 701663.609 | -0.43 | 1190.0 |
| 594533.514 | 701668.214 | -0.43 | 1190.0 |
| 594534.395 | 701673.831 | -0.42 | 1190.0 |
| 594537.614 | 701682.819 | -0.40 | 1190.0 |
| 594538.394 | 701688.707 | -0.43 | 1193.0 |
| 594538.742 | 701692.659 | -0.42 | 1193.0 |
| 594539.213 | 701697.640 | -0.42 | 1200.0 |
| 594539.768 | 701703.643 | -0.35 | 1200.0 |
| 594540.616 | 701712.589 | -0.39 | 1200.0 |
| 594541.310 | 701718.479 | -0.41 | 1200.0 |
| 594541.502 | 701722.331 | -0.41 | 1210.0 |
| 594541.606 | 701727.199 | -0.43 | 1213.0 |
| 594541.611 | 701733.229 | -0.40 | 1220.0 |

### Electrical resistivity imaging

Electrical imaging provides a visual representation of the subsurface electrical structure. Recent studies illustrate the application of the method to characterization of old landfills (Bernstone and Dahlin 1997; Carlson, Hare, and Zonge 2001; Ogilvy et al.

2002). A buoyant 13 electrodes array was constructed specifically for ERI surveys using Pb-$PbCl_2$ junctions. Previous studies show that the best stability of the potential and the minimum noise are obtained for a solution saturated in salts of $PbCl_2$ and KCl (Petiau 2002). The electrodes were mounted on 20 m long, 2” diameter PVC pipes. The PVC pipes are designed to be towed using the paddleboat with swinger mounted in the middle to maintain the direction of the surveyed line (Fig 9). The array consists of two current electrodes and eleven potential electrodes. The electrodes were placed at 1.5 meter spacing with the current electrodes located between the potential electrodes 4-5 and 7-8. Trial and error forward modeling, based on average water depth and average water conductivity, was conducted to determine a set of ten potential measurements that giving good penetration of electric current into the sediments beneath the 1-2 ft water layer.

Each electrode was constructed and fabricated using a lead metal plate immersed into a lead chloride paste placed in a PVC cup capped with a porous wood and connected to the main wiring by sealed galvanized steel bolts. Each electrode was mounted with a floating ball on top to help keep the array buoyant at the water surface during the survey. The paste was made by mixing 1.65 kg of Kaolin, 40 g of $PbCl_2$, 680 g of KCl, 3.7 $cm^3$ of HCl (33% Conc.) in a liter of water (Petiau 2002). The salt and kaolin used in the fabrication process were powder with a purity of 99% for salts since lead electrodes are very weakly sensitive to impurities. The electrodes were then fitted on the PVC tube and sealed to avoid leakage. Each of the electrodes was wired internally using a solid copper wire, which runs to the ERI instrument. Figure 10 presents a schematic diagram of the electrode array and cross sectional view of one of the potential electrodes. Electrodes were tested in the field using a single channel Geopulse resistivity meter. The fabricated array and a set of comparison steel electrodes were placed at the edge of Kearny Marsh (Fig. 11). Measurements were taken from both the lead chloride electrodes and the steel electrodes. Near-identical resistivities were recorded using these electrode types with an error margin of 0.1 ohm m.

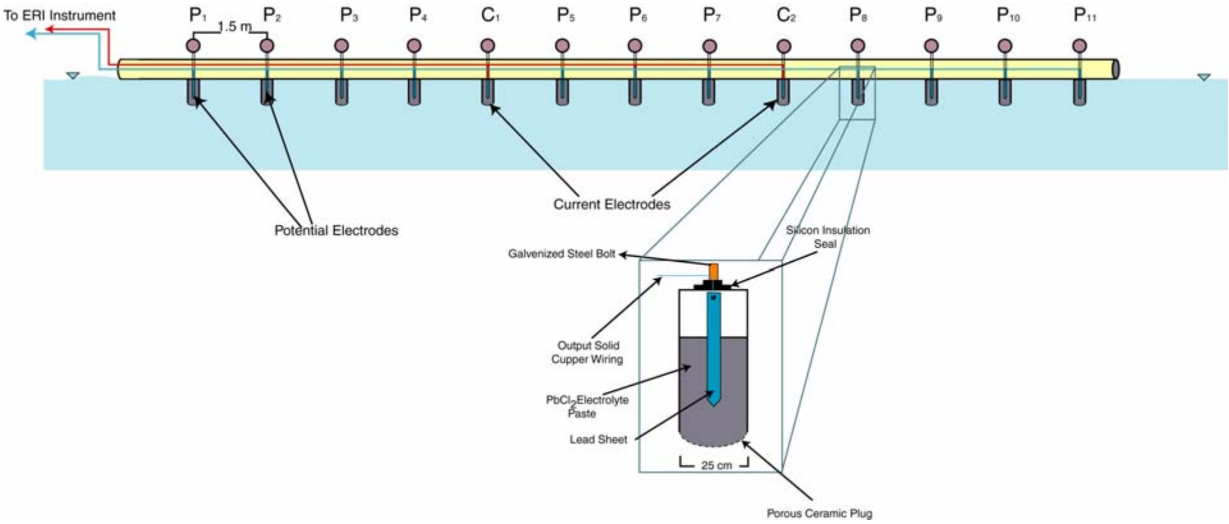


**Figure 10: Schematic diagram of the fabricated lead chloride electrode arrays made for this research showing in detail components of the main structure.**

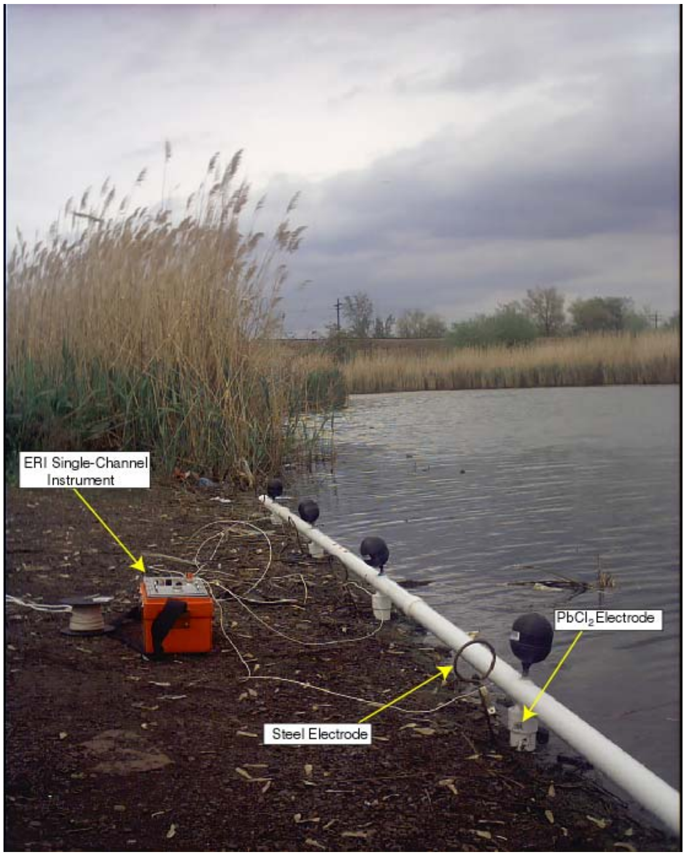


**Figure 11: ERI single channel instrument connected to the lead chloride electrode and then to regular steel electrodes used for testing purposes at the edge of the Kearny marsh.**

Surface water quality

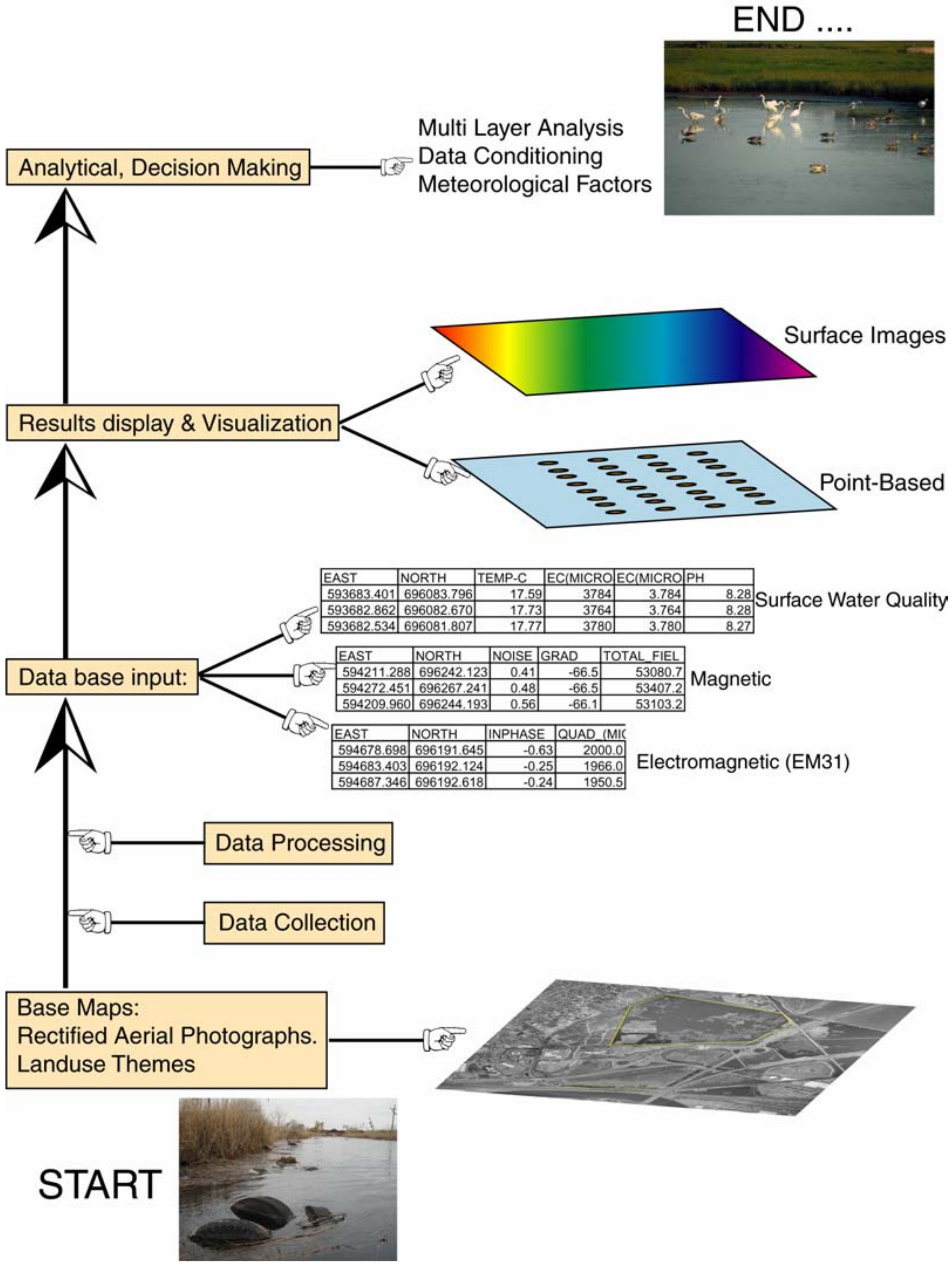
Surface water quality parameters were measured using *HYDROLAB probes* provided by the Meadowlands Environmental Research Institute (MERI) simultaneously with geophysical surveys. The measured parameters include surface water temperature, surface water electrical conductivity, salinity, pH, turbidity, dissolved oxygen, saturation percent, and depth of water. The surface water quality probe was mounted at the front right edge of the paddleboat and readings were taken every two seconds whilst surveying (Fig. 8). Two different quality probes were used in our survey. Both configured for similar purposes. One requires a connection to a laptop to which the measured parameters are streamed. The other has and internal memory card in which the data were stored and thereafter downloaded to the laptop. Both of these probes were calibrated and tested at the same time in the field to make sure that there is no variation in the measured parameters using either instrument. All the data were processed and georeferenced to their exact location and then saved as a dBase IV file (Fig. 12) to be downloaded and displayed in the GIS framework set for this research.

### *Concept implementation: integration of GIS and geophysical data*

A geographical information system (GIS) database was used for managing and visualizing multiple types of data, including the high-resolution geophysical data. This fundamental data integration aspect of our work is summarized in Figure 12. Spatial and temporal geophysical data were organized within a wetland GIS to integrate information into a coherent georeferenced framework suitable for analyses and decision-making. The GIS database incorporates previous data, maps, aerial photographs and digital geophysical data into an analytical environment, permitting easy modification and updating with the acquisition of additional data. It can incorporate data from different layers or different datasets, consolidating them into one comprehensive image for decision-making. GIS also permits the setting of boundaries and interpolation limits, giving a high level of control over the spatial interpolation of the geophysical datasets generated in this study. Query of data points or sampling sites based on spatial coordinates, date frame, contaminant concentration and any other measured property within its database facilitates generation of accurate maps, charts and reports for decision making.

**Table 3: Example of dBase table showing the water quality measurements taken within Kearny Marsh and imported as an input into the GIS framework.**

| East | North | T (ºC) | Depth (in) | pH | EC (µS/cm) | Sal (ppt) | DO% | DO (mg/L) | Turb (NTU) |
|---|---|---|---|---|---|---|---|---|---|
| 594584.175 | 701160.170 | 23.49 | 10.21 | 8.67 | 2472 | 1.27 | 52.3 | 4.42 | 15.9 |
| 594583.255 | 701159.638 | 23.51 | 10.21 | 8.67 | 2469 | 1.27 | 53.9 | 4.55 | 16.0 |
| 594581.401 | 701158.475 | 23.52 | 10.21 | 8.67 | 2472 | 1.27 | 53.9 | 4.55 | 16.0 |
| 594580.353 | 701157.630 | 23.52 | 10.21 | 8.67 | 2469 | 1.27 | 55.3 | 4.66 | 16.1 |
| 594533.580 | 701199.042 | 23.58 | 10.21 | 8.67 | 2462 | 1.27 | 70.1 | 5.90 | 15.9 |
| 594531.232 | 701205.423 | 23.58 | 10.21 | 8.67 | 2459 | 1.27 | 74.6 | 6.28 | 15.9 |
| 594529.721 | 701208.507 | 23.59 | 10.21 | 8.67 | 2462 | 1.27 | 74.6 | 6.28 | 15.9 |
| 594528.380 | 701210.796 | 23.59 | 10.21 | 8.67 | 2460 | 1.27 | 68.4 | 5.76 | 15.9 |
| 594526.649 | 701214.287 | 23.59 | 10.21 | 8.67 | 2463 | 1.27 | 68.4 | 5.76 | 15.9 |
| 594524.623 | 701217.579 | 23.59 | 10.21 | 8.67 | 2460 | 1.27 | 68.8 | 5.80 | 15.9 |
| 594521.603 | 701223.213 | 23.59 | 10.21 | 8.67 | 2463 | 1.27 | 68.8 | 5.80 | 15.9 |
| 594519.951 | 701226.491 | 23.60 | 10.21 | 8.67 | 2460 | 1.27 | 72.0 | 6.06 | 15.9 |
| 594485.563 | 701317.265 | 23.60 | 10.21 | 8.64 | 2459 | 1.27 | 71.7 | 6.03 | 16.1 |
| 594482.300 | 701323.773 | 23.62 | 10.21 | 8.65 | 2456 | 1.26 | 72.5 | 6.10 | 16.1 |
| 594481.177 | 701327.528 | 23.63 | 10.21 | 8.65 | 2457 | 1.26 | 72.5 | 6.10 | 16.0 |
| 594480.640 | 701330.498 | 23.64 | 10.21 | 8.66 | 2454 | 1.26 | 70.1 | 5.90 | 15.9 |
| 594479.985 | 701334.783 | 23.68 | 10.15 | 8.68 | 2430 | 1.25 | 70.1 | 5.89 | 15.8 |
| 594479.270 | 701339.017 | 23.76 | 10.22 | 8.68 | 2421 | 1.24 | 74.1 | 6.22 | 15.6 |
| 594478.112 | 701345.724 | 23.01 | 10.23 | 8.69 | 2535 | 1.31 | 74.7 | 6.36 | 15.6 |
| 594477.341 | 701349.540 | 23.45 | 10.21 | 8.75 | 2490 | 1.28 | 72.3 | 6.10 | 15.9 |
| 594422.176 | 701428.137 | 23.51 | 10.20 | 8.77 | 2483 | 1.28 | 73.7 | 6.22 | 15.5 |
| 594417.630 | 701430.429 | 23.61 | 10.20 | 8.73 | 2468 | 1.27 | 68.6 | 5.77 | 15.6 |
| 594413.944 | 701432.524 | 23.63 | 10.22 | 8.70 | 2483 | 1.28 | 68.6 | 5.77 | 15.8 |
| 594411.096 | 701434.425 | 23.54 | 10.18 | 8.65 | 2487 | 1.28 | 66.7 | 5.62 | 15.9 |
| 594407.144 | 701437.455 | 23.65 | 10.15 | 8.68 | 2462 | 1.27 | 66.6 | 5.60 | 16.0 |
| 594401.340 | 701440.885 | 23.68 | 10.20 | 8.66 | 2458 | 1.27 | 69.9 | 5.88 | 16.0 |
| 594397.382 | 701442.094 | 23.71 | 10.20 | 8.65 | 2477 | 1.28 | 69.9 | 5.87 | 16.1 |
| 594394.017 | 701442.334 | 23.66 | 10.21 | 8.66 | 2476 | 1.28 | 68.1 | 5.73 | 16.2 |
| 594584.175 | 701160.170 | 23.49 | 10.21 | 8.67 | 2472 | 1.27 | 52.3 | 4.42 | 15.9 |
| 594583.255 | 701159.638 | 23.51 | 10.21 | 8.67 | 2469 | 1.27 | 53.9 | 4.55 | 16.0 |
| 594581.401 | 701158.475 | 23.52 | 10.21 | 8.67 | 2472 | 1.27 | 53.9 | 4.55 | 16.0 |
| 594580.353 | 701157.630 | 23.52 | 10.21 | 8.67 | 2469 | 1.27 | 55.3 | 4.66 | 16.1 |
| 594533.580 | 701199.042 | 23.58 | 10.21 | 8.67 | 2462 | 1.27 | 70.1 | 5.90 | 15.9 |
| 594531.232 | 701205.423 | 23.58 | 10.21 | 8.67 | 2459 | 1.27 | 74.6 | 6.28 | 15.9 |
| 594529.721 | 701208.507 | 23.59 | 10.21 | 8.67 | 2462 | 1.27 | 74.6 | 6.28 | 15.9 |
| 594528.380 | 701210.796 | 23.59 | 10.21 | 8.67 | 2460 | 1.27 | 68.4 | 5.76 | 15.9 |
| 594526.649 | 701214.287 | 23.59 | 10.21 | 8.67 | 2463 | 1.27 | 68.4 | 5.76 | 15.9 |
| 594524.623 | 701217.579 | 23.59 | 10.21 | 8.67 | 2460 | 1.27 | 68.8 | 5.80 | 15.9 |
| 594521.603 | 701223.213 | 23.59 | 10.21 | 8.67 | 2463 | 1.27 | 68.8 | 5.80 | 15.9 |
| 594519.951 | 701226.491 | 23.60 | 10.21 | 8.67 | 2460 | 1.27 | 72.0 | 6.06 | 15.9 |
| 594485.563 | 701317.265 | 23.60 | 10.21 | 8.64 | 2459 | 1.27 | 71.7 | 6.03 | 16.1 |
| 594481.177 | 701327.528 | 23.63 | 10.21 | 8.65 | 2457 | 1.26 | 72.5 | 6.10 | 16.0 |



| EAST | NORTH | TEMP-C | EC(MICRO | EC(MICRO | PH |
|---|---|---|---|---|---|
| 593683.401 | 696083.796 | 17.59 | 3784 | 3.784 | 8.28 |
| 593682.862 | 696082.670 | 17.73 | 3764 | 3.764 | 8.28 |
| 593682.534 | 696081.807 | 17.77 | 3780 | 3.780 | 8.27 |

| EAST | NORTH | NOISE | GRAD | TOTAL_FIEL |
|---|---|---|---|---|
| 594211.288 | 696242.123 | 0.41 | -66.5 | 53080.7 |
| 594272.451 | 696267.241 | 0.48 | -66.5 | 53407.2 |
| 594209.960 | 696244.193 | 0.56 | -66.1 | 53103.2 |

| EAST | NORTH | INPHASE | QUAD_(MI |
|---|---|---|---|
| 594678.698 | 696191.645 | -0.63 | 2000.0 |
| 594683.403 | 696192.124 | -0.25 | 1966.0 |
| 594687.346 | 696192.618 | -0.24 | 1950.5 |

**Figure 12: Schematic diagram illustrating the technological concept of integration of geophysical and GIS data for wetlands characterization.**

## Kearny Marsh: Data acquisition and results

### *Data acquisition*

This integrated geophysical-GIS approach was applied to an investigation of Kearny Marsh. Geophysical data acquisition from the paddle boat resulted in approximately 8-km line (+ 6000 measurements) in one day. Figure 13 presents an example of the data sampling density around the Keegan Landfill. Data sampling density was increased around potential pollution sources such as the landfills, metal junkyard and within the northeast corner of the marsh where a tidal connection was expected.

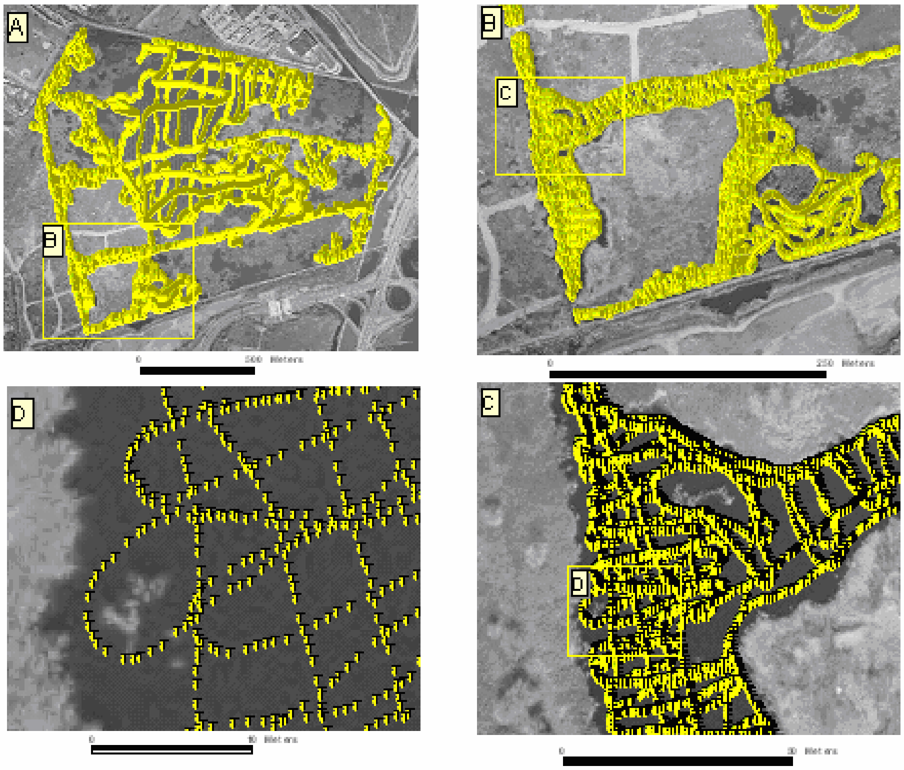


**Figure 13: Example of data sampling density of geophysical and surface water data within the vicinity of the Keegan Landfill in Kearny Marsh**

### *Surface water data*

The surface water electrical conductivity measured within Kearny Marsh ranges between 500 and 4,000 µS/cm (Fig. 14). Very low conductivity values, ranging between 500 and 1,500 µS/cm were measured in the west and northwest part of the marsh along the metal junkyard and the baseball field. The conductivity values around south portions of the Keegan landfill range between 2,000 and 3,000 µS/cm, while the north parts of the landfill have low to moderate values (1,500 to 2,000 µS/cm) along the west edge while the east edge has conductivity values as high as 4,000 µS/cm. The central and the north parts of the marsh are dominated by very high conductivities of values reaching up to 3,500 µS/cm, while the east side of the marsh shows variable values with a wide range from 1,500 to 3,000 µS/cm.

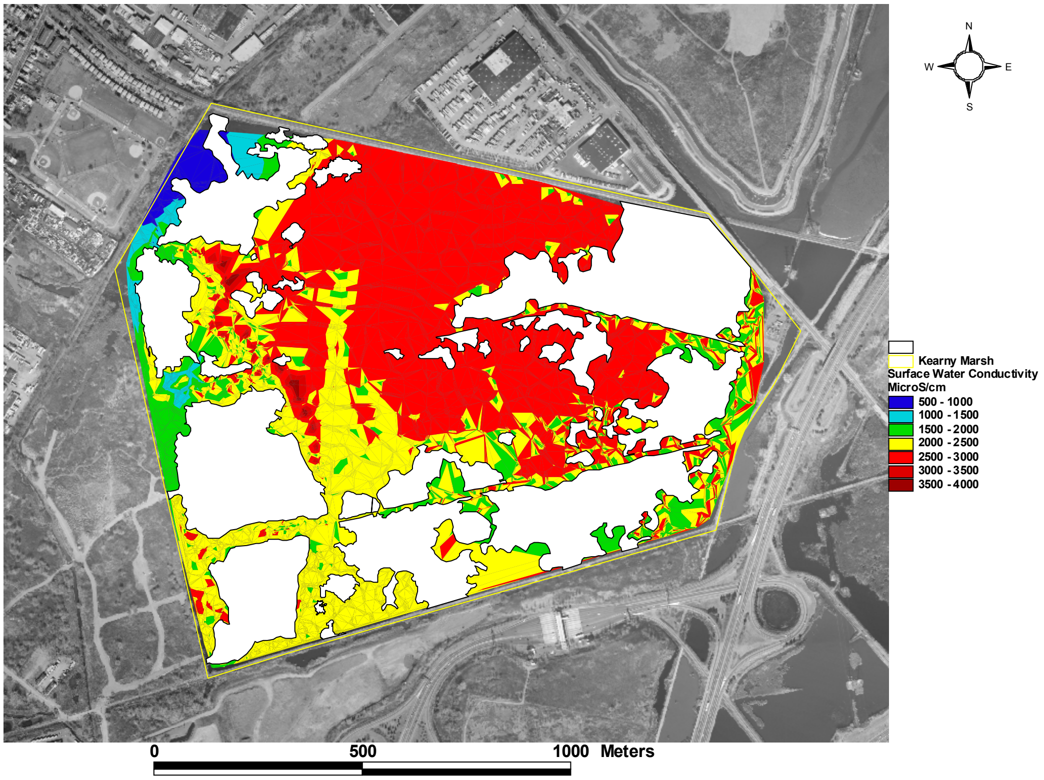


**Figure 14: Spatial image showing the surface water conductivity distribution measured within the Kearny Marsh.**

The surface water salinity measurements were found to have similar trend as the conductivity (Fig. 15). The salinity measurements range between 0.2 to 2.2 ppt with the highest values along the east edge of the northern part of the Keegan landfill and within the central and the northern portions of the marsh.

The Kearny Marsh water was found to be slightly alkaline to highly alkaline as indicated by the pH measurements (Fig. 16). The areas around the Keegan landfill is dominated by values ranging from 8.25 to 9.0, while the east and the southeast parts of the marsh is characterized by values ranging from 7.5 to 8.25. The central and the northern parts of the marsh are dominated by pH values ranging from 8.25 to 8.5. The lowest pH values (as low as 7.0) were found within the northwest corner along the baseball field and the metal junkyard.

## Geophysical data

### Terrain conductivity

The terrain conductivity values obtained from surveying with the EM31 range from 500 to 3,000 µS/cm (Fig. 17). The lowest values ranging from 500 to 1,000 µS/cm were found within the west and northwest part of the marsh along the metal junkyard and the baseball field. The central and the northern parts of the marsh are dominated by moderate values ranging from 1,000 to 1,500 µS/cm, while the northeast corner of the marsh shows the highest values of terrain conductivity ranging from 1,500 to 3,000 µS/cm. The areas around the Keegan landfill show two different trends, low to moderate terrain conductivity values ranging from 750 to 1,500 µS/cm dominate the west parts, while the east parts of the Keegan landfill are dominated by significantly higher conductivity values reach as high as 2,000 µS/cm.

### Magnetic gradiometry

The magnetic gradiometer survey is still in progress. Most portions of the marsh were surveyed and the results of the covered areas are presented in a spatial image constructed in the GIS framework and presented in figure 18. The magnetic gradient measurement range from values of -600 to +600 nT/m. Gradiometer data indicate that buried metallic debris is scattered within the marsh especially around the western and southern areas of the Keegan landfill. It is also detected within a circular area adjacent to the baseball field suggesting dumping at this point.

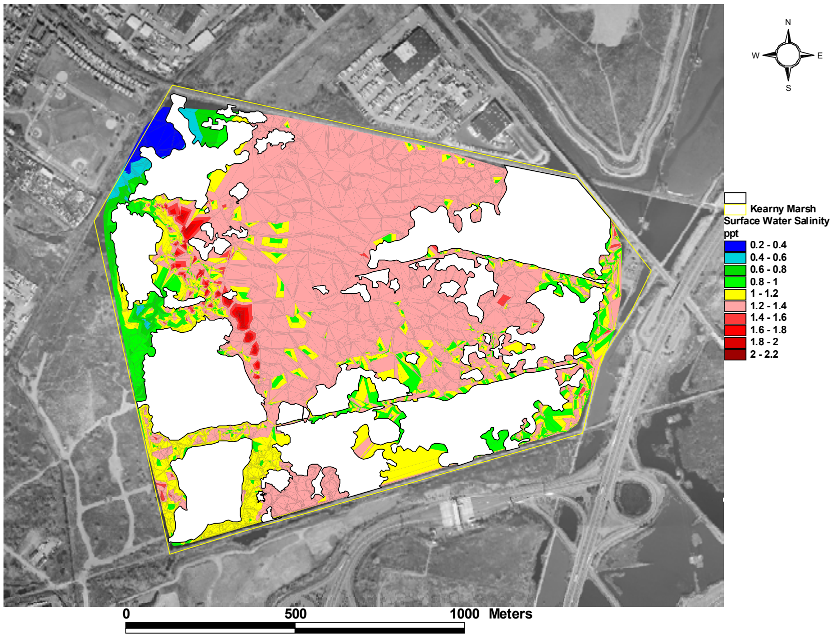


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Figure 15: Surface water salinity spatial image constructed from the point based measurements taken within the Kearny Marsh.

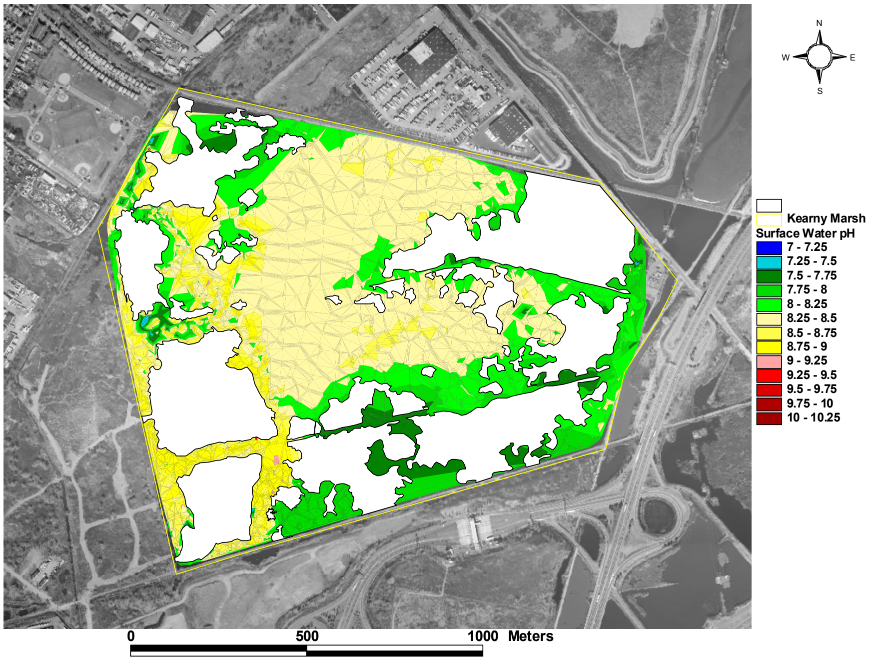

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Figure 16: Surface water pH spatial image constructed from the point based measurements taken within the Kearny Marsh.

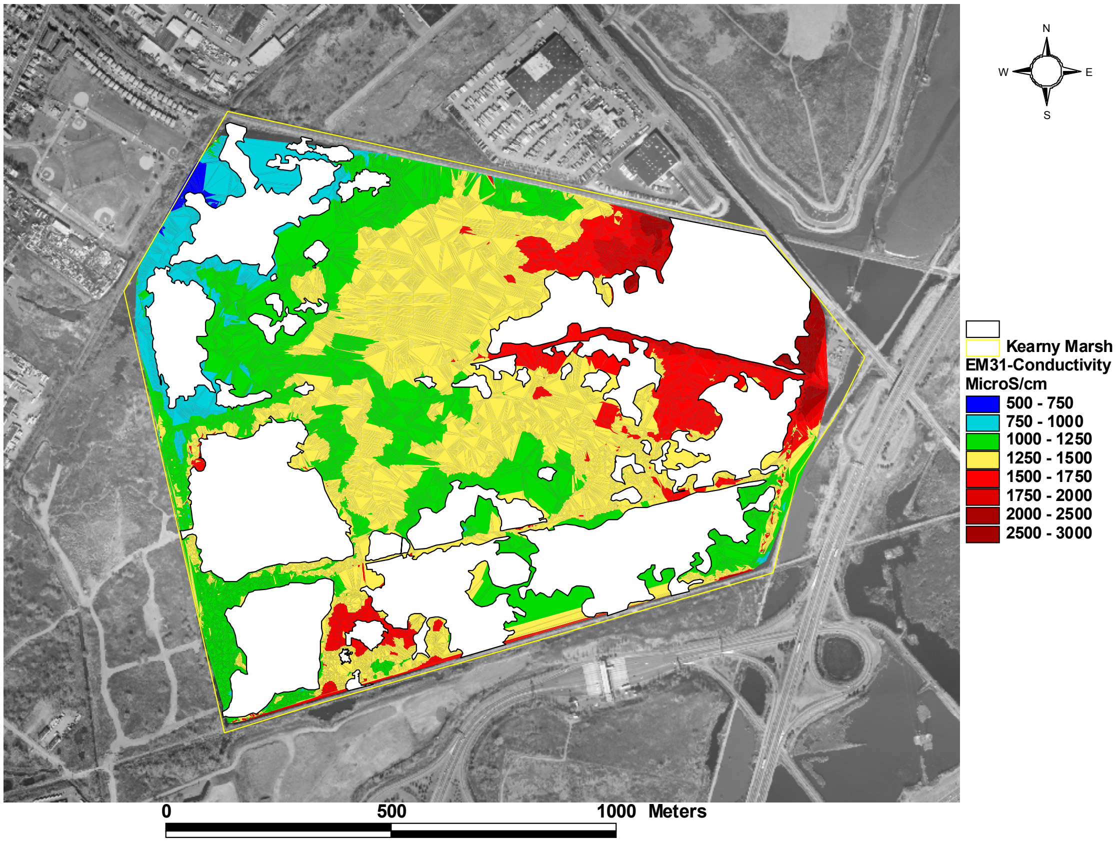

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**Figure 17: Terrain conductivity spatial image constructed from the point based measurements of the EM31 taken within Kearny marsh.**

### *Interpretation: Kearny Marsh data*

Previous studies based on limited number of water samples ((LEES) 1999) indicate that the water around the landfill especially east of the Keegan landfill is dominated by high conductivity values due to presence of a groundwater/surface water plume. Further, it was suspected that the northeast area of the marsh is affected by a tidal connection south of the 1E landfill (Kocis 1982). Geophysical surveys reveal a different pattern of surface water and sediment conductivity. Surface water conductivity and salinity show the highest values around the north parts of the Keegan landfill and in the central and northern parts of the marsh. No significant elevation in conductivity due to a tidal connection to the marsh is observed. The terrain conductivity image shows a different trend than that depicted from the surface water data in the northeast corner of the marsh where the tidal connection is suspected. Along the west and northwest areas of the marsh along the baseball field and the metal junkyard, both the surface water conductivity and the terrain conductivity suggest that contamination is absent or low. The most significant findings are (1) a possible groundwater plume from the Keegan Landfill has a very defined and restricted spatial extent (2) there is no surface water plume associated with the Keegan landfill (3) a zone of high terrain conductivity mapped to the north suggests either an extensive groundwater plume from the 1E landfill or the response to past dumping known to have occurred when this area not under water.

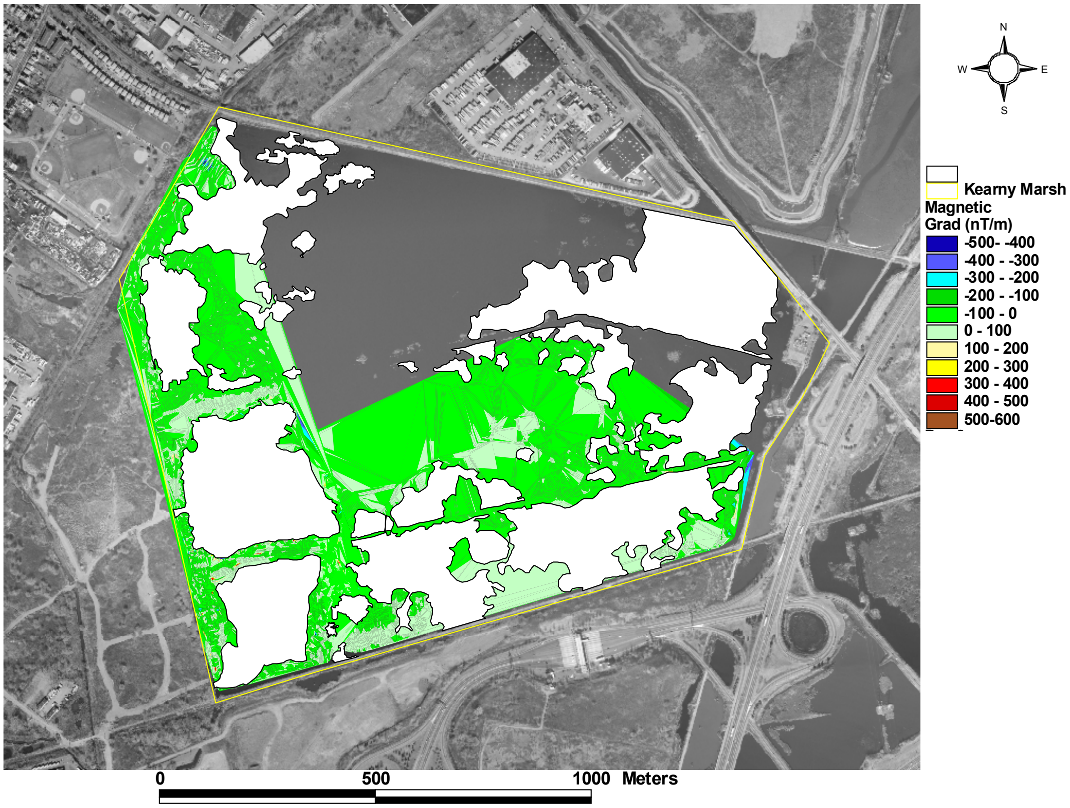

**Figure 18: Magnetic gradiometer spatial image constructed from the point based measurements taken within Kearny marsh, further survey is required.**

## Future work (now funded under NJWRRC grant)

Kearny Marsh contamination is a spatially and temporally complex environmental problem. In order to achieve the main objectives mentioned previously, we will continue the magnetic gradiometer within the marsh and the water chemistry survey in order to define the exact extent of pollution and relation to source zones. We will also extend the EM31, magnetic gradiometer and the water chemistry surveys along the south edge of the 1E landfill adjacent to the marsh from north. The magnetic gradiometer surveys will resolve the location of metallic debris and help assess the level of metallic debris pollution in Kearny Marsh and will be used to condition the EM31. We will conduct ERI in areas of interest, which will permit imaging beneath the wetland sediments and evaluation of the lateral and vertical extent of potential groundwater contaminant plumes not discernable from EM31 surveys. ERI on selected lines will be repeated at monthly or closer intervals throughout the year of 2004. Changes in subsurface electrical structure will be correlated with rainfall observed at a meteorological station located approximately 1 mile from Kearny Marsh. We will investigate the hydrologic forcing that likely determines leachate fluxes entering Kearny Marsh from Keegan landfill. The study will determine whether such subsurface fluxes, important in designing long-term remediation efforts, are resolvable with electrical imaging.

Geophysical methods only provide proxy measures of subsurface contamination and electrical measurements also respond to lithological variability. It is hence necessary to collect control data to constrain interpretation of geophysical images in terms of contaminant distribution and concentration. We will constrain the geophysical datasets in the following manner: 1) We will obtain fifteen sediment samples for pore fluid and sediment analysis using standard procedures available at the MERI analytical laboratory. The fifteen site locations will be conditioned on the geophysical results, with the intention to sample the full range of geophysical response (highest to lowest conductivity) in order to permit calibration of the subsurface conductivity in terms of contaminant concentration. 2) We will compile groundwater data from piezometers currently being installed in the vicinity of Kearny Marsh to ascertain whether general groundwater flow directions support a contaminant flux into the marsh 4) a limited number of sediment samples will be collected and analyzed with chemical and sequential analyses applied to quantify the toxic metal content including Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, and Zn. Finally, we will continue streaming all geophysical data into a GIS database and visualization environment maintained by the Meadowlands Environment

Research Institute (MERI). We will examine how integration of geophysical data with meteorological, chemical/ land-use and other archived data for Kearny Marsh can improve understanding of dynamic solute fluxes with the intent of conditioning decision making regarding restoration plans for Kearny Marsh on our geophysical studies.

## Dissemination of results

The results of this research to date have been presented in the following:

- Mansoor, N. and Slater, L.D., 2004, Integrating high-resolution geophysical technologies with a GIS-based decision support system into evaluation and management of wetlands, 2004 Joint Assembly, American Geophysical Union (AGU), Canadian Geophysical Union (CGU), Society of Exploration Geophysicists and Environmental and Engineering Geophysical Society, May 17-21, Montreal, Canada, Abstract NS13A-02
- Mansoor, N., Slater, L., Trubacco, T. and Baz, M., 2003, Assessing and monitoring groundwater contamination from landfill leachate in Kearny Marsh using high-resolution geophysics, The Meadowlands Symposium: A Scientific Symposium on the Hackensack Meadowlands, October 9-10, 2003. Lyndhurst, NJ, Abstract

A front page article focusing on the work was published in the state newspaper, the Star Ledger. The work was also discussed in article in the Bergen Record newspaper. Other items of note include:

- Continued funding: “High-resolution geophysical imaging as a novel method for non-invasive characterization of contaminated wetlands: application to Kearny Marsh”, United States Department of Interior – Geological Survey, New Jersey Water Resources Research Institute (NJWRRI), $29,678, project period 01/03/04-02/28/05
- Continued funding: "Assessing and monitoring groundwater contamination from landfill leachate in Kearny Marsh using high-resolution geophysics", Rutgers Undergraduate Research Fellows Program, $1,500, project period 07/01/03-06/30/04
- Collaborative arrangements: faculty and graduate students at the Department of Earth & Environmental Sciences – Rutgers Newark are collaborating with faculty

and graduate students in the Center for Information management, Integration, and Connectivity Rutgers Newark regarding database construction and management of geophysical data

- Ph.D. degree: Rutgers graduate student Nasser Mansoor will complete his Ph.D. research on this work

## References

Benson, A.K. 1992. Integrating ground penetrating radar and electrical resistivity data to delineate groundwater contamination. *Geological Survey of Finland Special Papers* 16:197-203.

Bernstone, C. , and T. Dahlin. 1997. DC resistivity mapping of old landfills: two case studies. *European Journal of Environmental and Engineering Geophysics* 2:121-136.

Carlson, N.L., J. Hare, and K Zonge. 2001. Buried landfill delineation with induced polarization: progress and problems. Paper read at Proceedings of the Symposium on the Application of Geophysics to Environmental & Engineering Problems (SAGEEP), March, 2001, at Denver, CO.

Greenhouse, J., and R. Harris. 1983. Migration of contaminants in groundwater at a landfill: a case study. 7. DC, VLF, and Inductive Resistivity Surveys. *Journal of Hydrology* 63:177-197.

Kobr, M., and L. Linhart. 1994. Geophysical survey as a basis for regeneration of waste dump Halde 10, Zwickau, Saxony. *Journal of Applied Geophysics* 31:107-116.

Kocis, J. M. 1982. The Kearny freshwater marsh: the dynamics of a young freshwater marsh. In *Hackensack Meadowlands Development Commission (HMDQ) Basin Management Plans*.

Land use feasibility study, Keegan Landfill, Kearny, New Jersey. 1998. Camp Dresser and McKee Inc.

(LEES), Langan Engineering and Environmental Services. 1999. Sediment and water sampling report, Kearny Marsh, Kearny, NJ: Langan Engineering and Environmental Services (LEES).

Ogilvy, R., P. Meldrum, J. Chambers, and G. Williams. 2002. The use of 3D electrical resistivity tomography to characterize waste and leachate distribution within a closed landfill, Thniplow, UK. *Journal of Environmental & Engineering Geophysics* 7:11-18.

Petiau, G. 2002. Second generation of lead-lead chloride electrodes for geophysical applications. *Pure Applied Geophysics* 157:357-382.

Reynolds, J. M. 1997. *An introduction to applied and environmental geophysics*: John Wiley & Sons.770

Sharma, P.V. 1997. *Environmental and engineering geophysics*: Cambridge University Press

Site inspection prioritization report, Keegan landfill, Kearny, Hudson County, New Jersey. 1997. In *Report number 1997-010*: Region II Superfund Technical Assessment and Response Team, Federal Program Division, Edison, NJ.

Woldt, W.E., M.E. Hagemeister, and D.D. Jones. 1998. Characterization of an unregulated landfill using surface-based geophysics and geostatistics. *Ground Water* 36:966-974.