ENVIRONMENTAL AND ENGINEERING GEOLOGY OF NORTHEASTERN NEW JERSEY

CONFERENCE PROCEEDINGS

EDITED BY
MATTHEW L. GORRING
MONTCLAIR STATE UNIVERSITY

GEOLOGICAL ASSOCIATION OF NEW JERSEY

XXIV ANNUAL CONFERENCE AND FIELD TRIP
OCTOBER 17-18, 2008
MONTCLAIR STATE UNIVERSITY,
MONTCLAIR, NEW JERSEY

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TWENTY-FIFTH ANNUAL CONFERENCE AND FIELD TRIP

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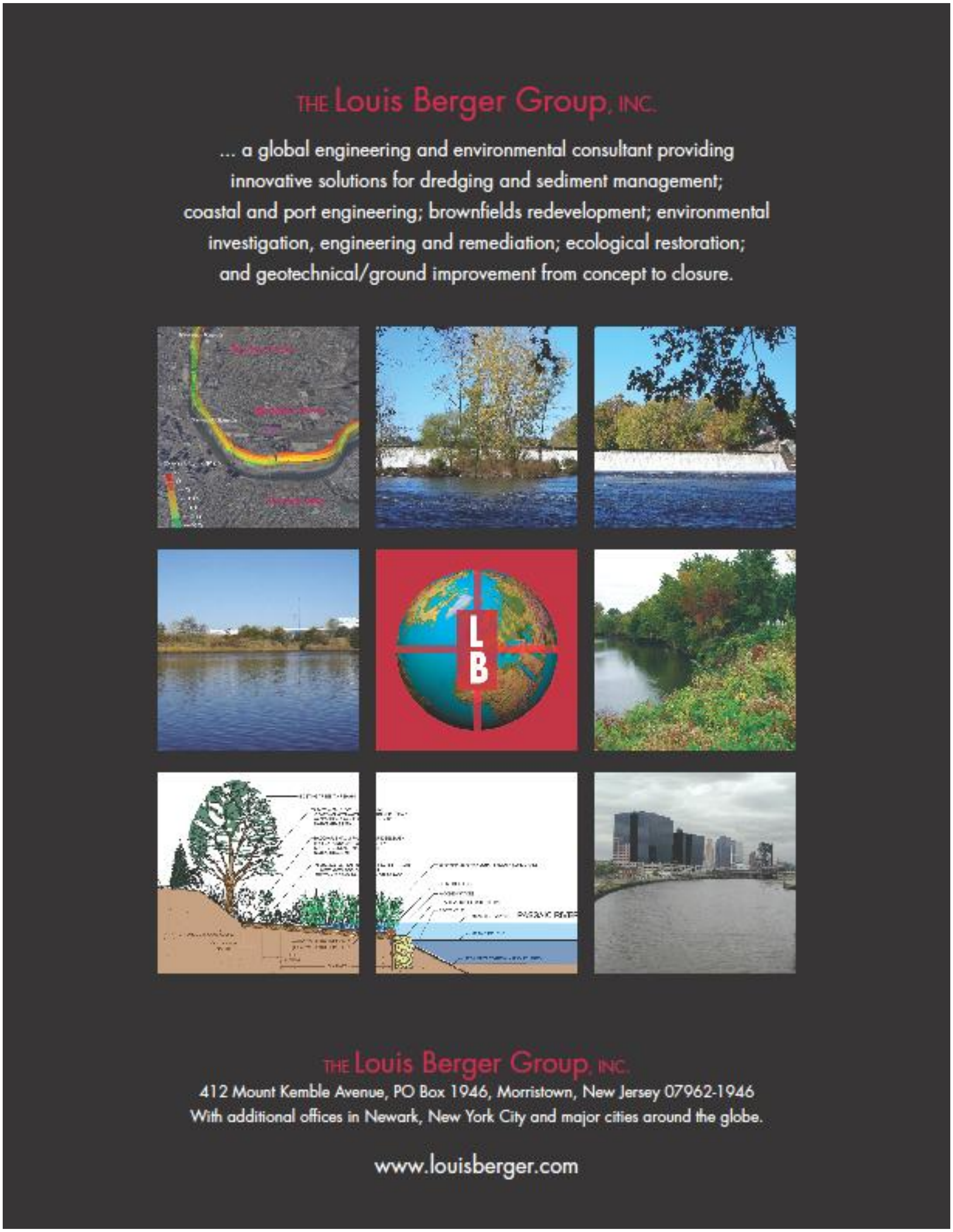

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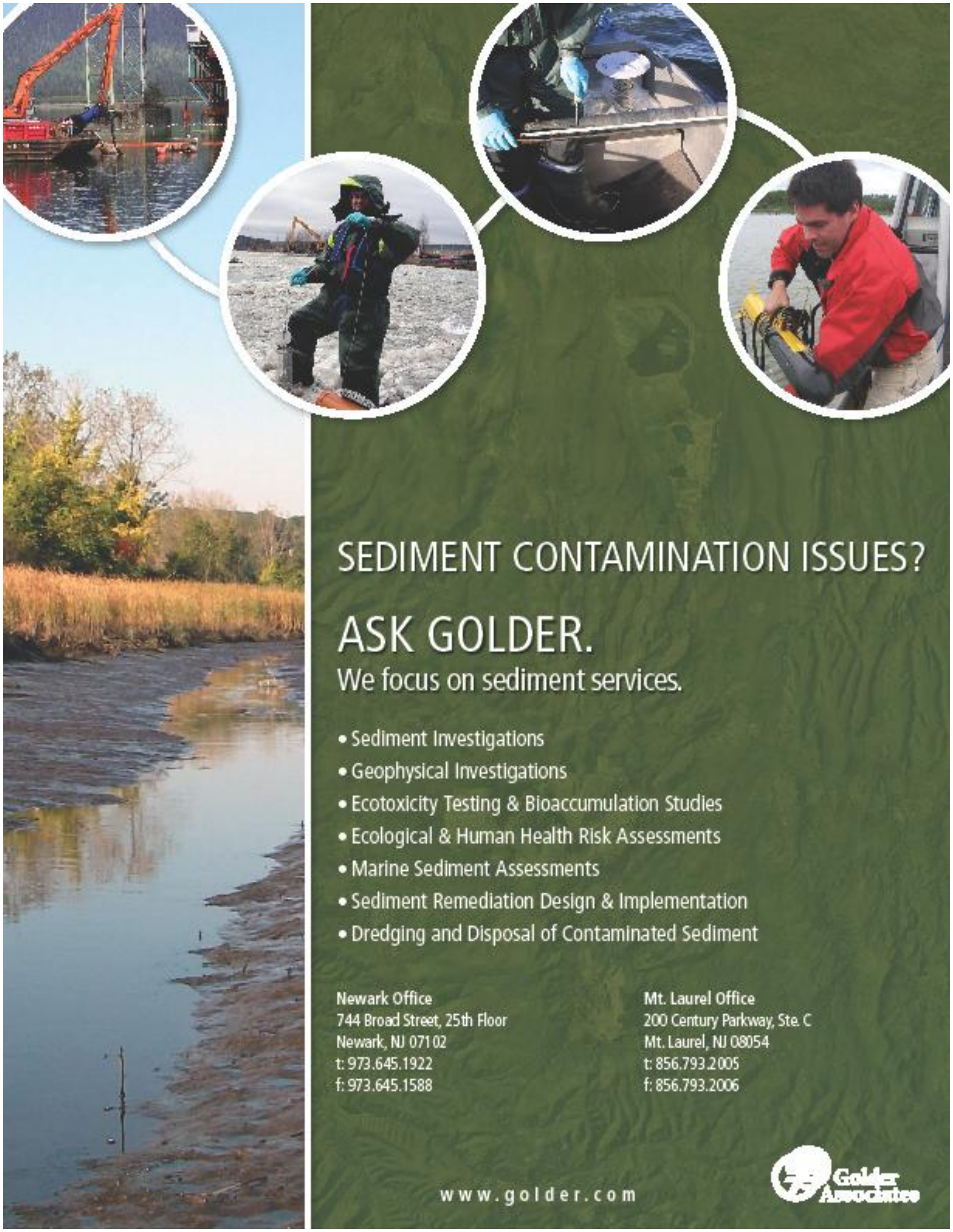

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Front Cover: The Great Falls of the Passaic River at Paterson, New Jersey. The 280-foot wide, 77-foot high Great Falls is one of the largest in terms of average discharge in the eastern United States. The falls are held up by the resistant Orange Mountain Basalt, an early Jurassic (~190 Ma) mafic volcanic unit. The brick building on the left is the turbine housing for the active hydroelectric facility. This photo was taken on April 18, 2007 by Den Spiess after 8 inches of rain the previous day. The resulting flood (15,500 ft^3) was the 5^{th} largest discharge ever recorded at the Little Falls, NJ gaging station since 1898.

FIELD GUIDES & PROCEEDINGS OF PRIOR ANNUAL MEETINGS

First Annual Meeting – 1984; Puffer, John H., ed., 1984, *Igneous Rocks of the Newark Basin: Petrology, Mineralogy, and Ore Deposits, and Guide to Field Trip.*

Second Annual Meeting – 1985; Talkington, Raymond W., and Epstein, Claude M., eds., 1985, *Geological Investigations of the Coastal Plain of Southern New Jersey: Part 1 - Field Guide; Part 2A - Hydrology and Coastal Plain; Part 2B - Paleontologic Investigations (The set, Parts 1, 2A, 2B, priced as one volume).*

Third Annual Meeting – 1986; Husch, Jonathan, M., and Goldstein, Fredric R., eds., 1986, *Geology of the New Jersey Highlands and Radon in New Jersey.*

Fourth Annual Meeting – 1987; Gallagher, William B., ed., 1987, *Paleontology and Stratigraphy of the Lower Paleozoic Deposits of the Delaware Water Gap Area.*

Fifth Annual Meeting – 1988; Husch, Jonathan, M., and Hozik, Michael J., eds., 1988, *Geology of the Central Newark Basin.*

Sixth Annual Meeting – 1989; Grossman, I. G., ed., 1989, *Paleozoic Geology of the Kittatinny Valley and Southwest Highlands N. J.*

Seventh Annual Meeting – 1990; Brown, James O., and Kroll, Richard L., eds., 1990, *Aspects of Groundwater in New Jersey.*

Eighth Annual Meeting – 1991; Crawford, Maria L., and Crawford, William A., eds., 1991, *Evolution and Assembly of the Pennsylvania - Delaware Piedmont.*

Ninth Annual Meeting – 1992; Ashley, Gail M., and Halsey, Susan D., eds., 1992, *Environmental Geology of the Raritan River Basin.*

Tenth Annual Meeting – 1993; Puffer, John H., ed., 1993, *Geologic Traverse Across the Precambrian Rocks of the New Jersey Highlands.*

Eleventh Annual Meeting – 1994; Benimoff, Alan I., ed., 1994, *Geology of Staten Island*, *New York*.

Twelfth Annual Meeting – 1995; Baker, John E. B., ed., 1995, *Contributions of the Paleontology of New Jersey.*

Thirteenth Annual Meeting – 1996; Dalton, Richard F., and Brown, James O., eds., 1996, *Karst Geology of New Jersey and Vicinity.*

Fourteenth Annual Meeting – 1997; Benimoff, Alan I., and Puffer, John H., 1997, *The Economic Geology of Northern New Jersey.*

Fifteenth Annual Meeting – 1998; Puffer, John H., ed., 1998, *The Economic Geology of Central New Jersey.*

Sixteenth Annual Meeting – 1999; Puffer, John H., ed., 1999, *New Jersey Beaches and Coastal Processes from a Geologic and Environmental Perspective.*

Seventeenth Annual Meeting – 2000; Harper, David P. and, Goldstein, Fredric L., eds., 2000, *Glacial Geology of New Jersey.*

Eighteenth Annual Meeting – 2001; Lacombe, Pierre, and Herman, Gregory, eds., 2001, *Geology in Service to Public Health.*

Nineteenth Annual Meeting – 2002; D'Amato, Dana, ed., 2002, *Geology of the Delaware Water Gap Area.*

Twentieth Annual Meeting – 2003; Hozik, Michael J., and Mihalasky, Mark J., eds., 2003, *Periglacial Features of Southern New Jersey.*

Twenty-first Annual Meeting – 2004; Puffer, John H., and Volkert, Richard A, eds., 2004, *Neoproterozoic, Paleozoic, and Mesozoic Intrusive Rocks of Northern New Jersey and Southeastern New York.*

Twenty-second Annual Meeting – 2005; Gates, Alexander E., ed., 2005, *Geology of the Central Newark Basin - The View From the 21st Century.*

Twenty-third Annual Meeting – 2006; Macaoay, Suzanne, and Montgomery, William, eds., *Environmental Geology of the Highlands.*

Twenty-fourth Annual Meeting - 2007 ; Rainforth, Emma C., ed., 2007, *Contributions to the Paleontology of New Jersey (II).*

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CONFERENCE SCHEDULE

FRIDAY, OCTOBER 17, 2008

Student Center Ballroom A

8:30-12:00 Check-In and/or Registration for Conference and Field Trip; Continental Breakfast

9:00-10:20 Teachers' Workshop – Watershed Awareness: Teaching geography, geology, public policy, and chemistry through monitoring water quality in local streams – *Marian Glenn, Seton Hall University*

10:30-10:40 Welcoming Remarks – *GANJ President Matthew L Gorring, Montclair State University*

10:40-11:00 Geologic Observations during Rock Excavation and Tunneling for the Croton Water Treatment Plant Construction, Bronx, New York – *Daniel Vellone, Malcom Pirnie, Inc. and Douglas Isler, Haley & Aldrich.*

11:00-11:20 Erosion and Weathering Processes in the Delaware River Basin – *Hongbing Sun, Carol Natter, Rider University and Pierre Lacombe, USGS.*

11:20-11:40 Chlorinated Solvent Contaminants in Soil and Ground Water at a Near-Shore Industrial Facility and Their Impact on Passaic River Water and Sediment Quality – *Janet Frey and Robert P. Blauvelt, Environmental Waste Management Associates, LLC.*

11:40-12:00 Identifying the Source of Fine-grained River Sediment Using Radionuclides – *Josh Galster, Montclair State University.*

Student Center Ballroom B

12:00-1:30 Lunch and Business Meeting

Student Center Ballroom A

1:30-1:50 The Environmental Geology of the Balbach Smelting and Refining Company Sites, Newark, NJ – *Mark Zdepski, JMZ Geology.*

1:50-2:10 An Analysis of Natural Attenuation at a Contaminated Site, Bloomfield, NJ – *Duke Ophori, Montclair State University.*

2:10-2:30 Trends in Baseflow in New Jersey Streams and Correlation with Imperviousness – *Kirk Barrett, Passaic River Institute, Montclair State University.*

2:30-2:50 A Spatial Analysis of Lead Concentration in the Soils of Parks in Jersey City, NJ – *Deborah Freile and Angela Rosiello, New Jersey City University.*

2:50-3:10 Environmental Geology of the New Jersey Meadowlands District – *Edward Konsevick, Meadowlands Environmental Research Institute.*

3:15-4:15 Keynote Speaker – *Charles Merguerian, Hofstra University* – Geological Controls on the Means and Methods of Hard Excavation, New York City, NY.

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TECHNICAL PAPERS

TEACHERS WORKSHOP

GEOLOGIC OBSERVATIONS DURING ROCK EXCAVATION AND TUNNELING FOR THE CROTON WATER TREATMENT PLANT CONSTRUCTION, BRONX, NY

Daniel Vellone[1] and Douglas E. Isler[2]
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New York City's water supply and distribution system has long been considered an engineering marvel. The system is comprised of a complex network of reservoirs, controlled lakes and more than 6,000 miles of water pipes, tunnels and aqueducts that provide over 1.1 billion gallons of safe drinking water daily to more than 9 million people. This high quality water comes from three water supply systems in a nearly 2,000 square-mile watershed that extends more than 125 miles north and west of New York City. Croton system water provides roughly ten percent of the total system demand to the City and is an important resource for the City during drought and in ensuring redundancy and dependability of the overall water supply.

The New York City Department of Environmental Protection (NYCDEP) is proceeding with the construction of the Croton Water Treatment Plant (CWTP) and associated works in the Borough of the Bronx, New York. The CWTP is part of the NYCDEP's Bureau of Engineering, Design & Construction project to upgrade the water supply system, improve water quality and ensure compliance with stricter water quality standards. The CWTP will be constructed in Van Cortlandt Park below the driving range of the Mosholu Golf Course and will have an estimated design capacity of 290 million gallons per day (MGD), providing filtration and disinfection for Croton system water conveyed to New York City through the New Croton Aqueduct (NCA). Upon completion of construction, the site will be returned to park use as a public golf course with driving ranges, golf clubhouse and parking facilities. While the majority of the CWTP filtration system will be underground and not visible to the public, they will derive the benefit of improved water quality long into the future.

Construction of the CWTP facility requires two major underground construction phases: site preparation and tunneling. Three tunnels are presently under construction, with mining and excavation being accomplished using drill-and-blast and Tunnel Boring Machine (TBM) operations. Of particular concern during construction is a segment where the new tunnel advancement will cross through the Mosholu Fault underlying the Mosholu Parkway. Additional tunnel segments will be constructed in low rock cover zones of approximately 30 feet of rock overlying TBM mining operations. The tunnel alignment is predominantly through the Fordham Gneiss complex, which constitutes the oldest underpinning of rock formations in the New York City area and consists of a complex assemblage of Proterozoic Z ortho- and paragneiss, granitoid rocks, metavolcanic- and metasedimentary rocks (Merguerian, 2005a). Ductile deformations associated with several orogenic events have produced a widespread mylonitic fabric on the rock that can be seen following tunnel excavation. Metamorphosed and tectonically sutured mafic intrusives and several granitic intrusive events, all of uncertain ages, are quite numerous. Multiple sets of less deformed pegmatite dikes further cross-cut localized banded, leucocratic, granitic and migmatitic gneisses. Along the tunnel alignment, two of the major joint sets strike NW-SE, while the third occurs along foliation. Foliation strikes on average N10°E; however these readings can vary due to the localized effects of faulting. Several NNW-SSE joints have created blocky conditions, while several vertically dipping N-S striking joints were easily crossed. Through the NW-trending Mosholu fault zone, mylonitic foliations display pervasive chlorite alteration and strong cleavage defined by preferred orientation of micas. Most of the joint surfaces are mineralized, many contain slickensides, and most are continuous. Pyrite-rich zones are observed suggesting hydrothermal alteration due to subsequent mineral-rich fluid flow.

Two walls of the main excavation pit were geologically mapped and photographed to document the cross-cutting relationship of structural controls. A well-planned geological mapping program consisting of full-periphery circumferential mapping at the scale of 1:120 (1" = 10') is presently underway for the first of two 13.5-foot diameter TBM bored tunnels, allowing for enough detail to categorize the lithologic and structural conditions of the rock mass during the as-built stage of construction for project documentation and recordkeeping.

EROSION AND WEATHERING PROCESSES IN THE DELAWARE RIVER BASIN

Hongbing Sun[1], Carol Natter[1] and Pierre Lacombe[2]
[1]Department of Geological, Environmental, and Marine Sciences, Rider University, Lawrenceville, NJ 08648. [2]USGS Water Resources Division, 810 Bear Tavern Rd., Suite 206 West Trenton, NJ 08628

Total suspended sediments and the total dissolved solids (TDS) from three river gaging stations, near Delaware Water Gap, Riegelsville and Trenton on the Delaware River measured by the USGS were used to estimate the physical erosion, chemical weathering and total denudation rates of the Delaware River Basin. The denudation rates are 28 and 128 tons/km^2/yr for the upper stream and downstream stretches. Overall, the chemical weathering is more prominent in the basin than the physical weathering due to the low gradient of the region and sufficient moisture levels in the regional soil. The total suspended sediments are high during March and April when snow melting and ground thawing occur, and low during the summer when the river discharge is low. The response of TDS to the river discharge is more complicated. Overall, higher temperatures increases the chemical weathering, and low discharge increases the ion concentration in the water. The saturation indices calculated using the WATEQ4F program indicate that calcite and dolomite are more saturated in the summer, while silica and halite show opposite patterns. While the saturation index of silica may be explained by its thermodynamic property, the saturation index of the halite that deviates from the normal pattern is thought to be related with the application of winter deicing salt in the region. Soil cores were also collected from four sites in the basin. Data from a 15-foot soil core indicates that weight percentage of quartz decreases with depth, while the weight percentage of feldspar increases. Various mineral types and abundance were also recognized from other shallow soil cores. These diverse mineral patterns reflect the diverse ion species in the river basin.

CHLORINATED SOLVENT CONTAMINANTS IN SOIL AND GROUND WATER AT A NEAR-SHORE INDUSTRIAL FACILITY AND THEIR IMPACT ON PASSAIC RIVER WATER AND SEDIMENT QUALITY

Janet Frey and Robert P. Blauvelt
Environmental Waste Management Associates, LLC, 100 Misty Lane, P.O. Box 5430, Parsippany, NJ 07054

Recent regulatory emphasis on Passaic River water and sediment quality has been focused primarily on those industrial facilities that have directly discharged pollutants into this important commercial and recreational waterway. However, New Jersey's long history of industrial development, and the strong interconnection that many of its waterways have with their surrounding geology, clearly demonstrates that other, less obvious contaminant pathways need to be considered in assessing potential sources and eco-system impacts. Chlorinated solvents present in soil and ground water at one industrial facility some 100 feet from the Passaic River and with no direct (end of pipe) discharges to the River provides an example of how ground water migration may contribute to water quality and sediment degradation. Flow net and seepage analysis predict that up to 4,800 gallons per day of ground water contaminated with up to 5,000 mg/L of chlorinated solvents may be entering the River. Although this represents a small contaminant mass that is quickly diluted, multiplied by the operational life of the facility and if considered representative of the hundreds of other such industrial sites that border the Passaic River, contaminant mass loading values quickly rise to significant levels. Further compounding the effects of these impacts is the potential for retention of chlorinated solvents on pelagic sediments and their eventual incorporation and bioaccumulation into local food webs. From an environmental policy perspective, these findings support the need to look beyond direct dischargers as the only class of potentially responsible parties worthy of inclusion in enforcement and remedial actions. Distant, yet hydraulically connected industrial facilities where releases to ground water have occurred can play an important role as contaminant contributors to the Passaic River. Although more difficult to administratively identify, regulatory agencies need to consider technically reasonable and reliable assessment methodologies that allow for a fair and equitable distribution of cleanup responsibility among all responsible parties.

IDENTIFYING THE SOURCE OF EXCESS FINE-GRAINED SEDIMENTS IN NEW JERSEY RIVERS USING RADIONUCLIDES

Joshua C. Galster, Huan Feng, Kirk Barrett, Nicole Bujalski, and Jared Lopes
Department of Earth and Environmental Studies and Passaic River Institute, Montclair State University, 1 Normal Ave, Montclair, NJ 07043, 973-655-4123, galsterj@mail.montclair.edu

Fine-grained sediment is currently a major pollutant in New Jersey Rivers as well as other states. Excess sediment affects biologic systems, river aesthetics, recreation and water supply. However, one barrier to controlling sediment supply is that it is often difficult to determine the source of this sediment. The sediment may originate from widespread but shallow surficial erosion from overland flow occurring in the watershed or from the lateral erosion of vertical channel bank material. The goal of this study was to distinguish between these two sources using their different radionuclide signatures, including ^{210}Pb, and ^{137}Cs. Sediment generated from surficial erosion should have higher activity levels of these atmospherically-deposited radionuclides with short half lives than the sediment produced from vertical channel banks. We sampled channel bank material, watershed soils, in-stream fine sediment, and suspended sediment and analyzed them for their radionuclide signature to identify the relative contributions of sediments from the watershed and channel banks. The sampling was done for two small watersheds in New Jersey, each of which has sediment predominantly supplied by either overland flow or channel bank erosion. This knowledge will allow for improved stream and watershed management and the possible initiation of sediment-reduction programs.

THE ENVIRONMENTAL GEOLOGY OF BALBACH SMELTING AND REFINING COMPANY'S SITES IN NEWARK, NEW JERSEY

J. Mark Zdepski,
JMZ Geology, 43 Emery Avenue, Flemington, NJ 08822

Balbach Smelting and Refining Company operated at two locations in Newark between 1851 and 1927. Both of their two sites, the River and Bay Plants, have been redeveloped. The River Plant was developed into the County-owned Riverbank Park, the Bay Plant, continued industrial uses under multiple owners. Both sites have evidence of metal-processing slag in the subsurface. The County Park has not investigated groundwater quality. Most of the multiple businesses owning parts of the former Bay Plant have not been required to investigate the metal-processing residue, nor the groundwater conditions that result from the Balbach processes. The Bay Plant has been listed in USEPA documents while the River Plant has not.

AN ANALYSIS OF NATURAL ATTENUATION AT A CONTAMINATED SITE, BLOOMFIELD, NEW JERSEY

Duke Ophori and Deborah Katchen
Department of Earth and Environmental Studies, Montclair State University, Montclair, NJ 07043; Phone: 973-655-7558; ophorid@mail.montclair.edu

Hydrochemical data that were previously collected at a contaminated site in Bloomfield, New Jersey have been analyzed to determine whether 1) the contaminants are still at detectable concentration levels, 2) natural attenuation of contaminants is occurring, and 3) natural attenuation will remove the contaminants in a reasonable period of time. Plots of the distribution of Trichloroethene (TCE), and its daughter products, Dichloroethene (*Cis*-1,2 DCE) and Vinyl Chloride (VC) show that these contaminants are still present at the site. An initial decrease in TCE, *Cis*-1,2 DCE and VC suggests that natural attenuation was initially occurring at the site. However, optimal degradation of TCE is known to occur in a low oxygen environment (below 1 mg/L), but the current hydrochemical data portray a high oxygen environment. Numerical modeling of groundwater flow and contaminant transport was done at the site, using the MODFLOW and RT3D codes. The model suggests that reductive dechlorination, the optimal degradation process for TCE, should completely remediate the site within a period of eight years. The continued presence of TCE and the aerobic conditions at the site indicate that natural attenuation has not remediated the site as predicted by the models.

INVESTIGATION OF TRENDS IN BASEFLOW IN NEW JERSEY STREAMS AND THEIR CORRELATION WITH IMPERVIOUSNESS

Kirk R. Barrett, Joshua C. Galster, and Seth Xeflide
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Annual baseflow at 53 stream gages across New Jersey was analyzed to identify possible trends and if trends were correlated with extent of tributary impervious land cover in a gage's watershed. Different timeframes and baseflow metrics were assessed for their utility in identifying trends. We analyzed three measures of annual baseflow (baseflow per unit drainage area, BF), ratio of BF to precipitation; BF fraction of total flow and the minimum annual daily average flow per unit drainage area, included as a potential surrogate of baseflow. Blocks of years analyzed ranged from the most recent 10 years (ie, 1996 to 2005) to the last 60 years (1946 to 2005). Trends were assessed using the non-parametric Mann Kendal statistical test. Consistency of the results for the four metrics was investigated by calculating the rate of "disagreement", i. e., trend at a specific gage in one metric but not in another. A correlation was determined between current population density and current imperviousness for each gage's watershed. Historical imperviousness was then estimated using historical population density in each watershed. Trends in stable watersheds (little to no increases in imperviousness) were compared to trends in urbanizing watersheds (large increases in imperviousness). Also, for each gage, annual baseflow metrics were plotted against concurrent imperviousness to assess correlation between the two variables.

This project was supported by the National Research Initiative of the USDA Cooperative State Research, Education, and Extension Service, grant number 2005-35102-16372

A SPATIAL ANALYSIS OF LEAD CONCENTRATION IN THE SOILS OF PARKS IN JERSEY CITY, NJ

Deborah Freile and Angela Rosiello
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Old industrial cities on the East coast have a legacy of heavy metal accumulation within their highly disturbed urban soils. Jersey City, NJ is an excellent case study of some of the urban environmental issues facing many of these older cities. Jersey City was the end of the tracks for numerous railroads due to its proximity to the port cities of Newark, NJ and New York. Industry was central in Jersey City for centuries; this left a legacy of contaminants, particularly heavy metals including lead and chromium. For decades Jersey City has been economically depressed. Low-income housing is co-mingled with working class and working poor, multi-family dwellings; recently, however, a resurgence has taken hold of Jersey City, with new construction and luxury office and residential buildings. Many of these building are built atop fill that was used to create new land or to raise the topographic elevation. The exact chemical and mineralogical composition of the fill is generally unknown, but regionally it is known to contain chemical waste, as well as ore processing waste.

In the spirit of community relations, a pilot project began in the spring of 2007 to test soil samples collected from several public parks, playgrounds, and ball fields in Jersey City. The aim of this project is to analyze the soils for lead, as well as to conduct a sedimentological and mineralogical assay. Hamilton Park and Van Vorst Park in historic downtown Jersey City, were founded in the early 19th century. Hamilton Park was surrounded by foundries in the late 19th and early 20th century. It also lies close to the NJ Turnpike and Holland Tunnel. Several GIS maps were prepared as part of the spatial analysis. They show historic fills, known contaminated sites, sample locations, and other locations of interest. Of the 29 samples collected in 2007, 12 exhibited values above the residential limit of 400ppm lead and all 7 2008 Van Vorst Park samples are above this level. One site, Hamilton Park, has lead levels at 550ppm, while another park, Ennis Jones Park has lead levels over 800ppm. To determine the source of the Pb, the < 63μm fraction will be digested and analyzed using an ICPMS and the Pb isotope ratios will be determined. The ratios of the Pb isotopes 206Pb/207Pb, will allow us to discern the source of the lead. Lead from smelters has higher ratios of 206Pb/207Pb, while lead from leaded gasoline has lower ratios (1).

ENVIRONMENTAL GEOLOGY OF THE NEW JERSEY MEADOWLANDS DISTRICT

Edward Konsevick
Senior Environmental Scientist, Meadowlands Environmental Research Institute, One DeKorte Park Plaza, Lyndhurst, New Jersey 07071

In 1980, Sam L. Agron of Rutgers University, led a field trip to the Hackensack Meadowlands "to observe the natural environment, to see how incompatible land uses can be carried out harmoniously," and "to inspect several of the major projects that have been erected in the Meadowlands." He credited "the pioneering work done by the Hackensack Meadowlands Development Commission (HMDC) in planning and overseeing the harmonious growth of the District." Forty years after its establishment, the HMDC has changed its name but maintained its mandate. It operates a Solid Waste, Parks and Wetlands Division; a Planning group that focuses on sustainable development; and it has added a Research Institute to monitor the environment and disseminate information. The Hackensack Meadowlands has always attracted those with a penchant for transforming the marshes, and major projects continue to abound. As a former student and long-time employee of the Commission, it is my pleasure to revisit this fine work and compare the present to the future as envisioned by Dr. Agron.

GEOLOGICAL CONTROLS ON MEANS AND METHODS OF HARD ROCK EXCAVATION, NEW YORK CITY, NY

Charles Merguerian
Geology Department, Hofstra University, Hempstead, NY 11549;;Duke Geological Laboratory, 36 Fawn Lane, Westbury, NY 11590

A number of geological properties of coalescing importance dictate the destiny of hard rock excavation in the city of New York. Critical to both surface and subsurface geotechnical design engineering, a thorough investigation of such properties can provide important clues concerning performance and productivity during the bid and as-built stages of major construction efforts and help to avoid the expense and inefficiency of changed condition claims. Investigations over the past century have shown that the geology of NYC is complex with over a billion years of geological history emblazoned in the rock mass. NYC's former position at the core zone of convergent mountain building during Proterozoic and Paleozoic times has created a unique set of geological formations and variable rock mass properties that, when ignored (i.e. – "Rock" is "Rock" mentality), have proven to be an impediment to efficient mining and excavation and has resulted in claim hardships for owners and contractors. In addition to normal core data analysis and standard geotechnical testing for establishing rock mass properties, prudent contractors and design engineers must factor in intrinsic geological properties. Often overlooked, targeted petrographic microscopic analysis of mineralogy, texture, lithology, structure, and metamorphic fabrics are critical rock mass properties to establish. Megascopic study of stratigraphy, rock mass density, fabric orientation, ductile and brittle fault analysis and joint analysis are also paramount. Such allied studies hold the clues toward fully understanding the excavation behavior of the rock mass and will establish the proper means and methods for safe and efficient rock removal (roadheader, hydraulic ram, drill and blast, mini-mole, TBM, or a medley of methods).

BULKING AND TIERING WETLAND SYSTEMS

Paul Lerin
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The innovation of constructing multiple bulkheads in a tiered fashion can help recreate the unique ecosystem of a troubled waterway; especially, estuarine tidal banks that have been heavily encroached upon and dredged for commerce. The installation would be surveyed according to the fluctuation of the inter tidal zone which is termed ”a green belt in the littoral.” Bulking & Tiering Systems provide the ideal grade that is necessary in establishing saltmarsh foundation species. In addition, the aforementioned technology provides a platform for phytoremediation, which uses nature’s aquatic filters for Combine Sewer Overflow abatement. The method of installing a Bulking & Tiering Wetland System would be constructed of interlocking sheet pilings that are impervious to the harsh marine environment. These sheet pilings are specially formulated of post- industrial recycled vinyl. They are attractive in appearance, durable, and more affordable that conventional retaining walls. Unaffected by sunlight, salt water, or marine borers, this sustainable design material has been specified for its ability to contain toxins. The System would be particularly appropriate for sediments that are considerably contaminated and which may be a source of contaminants to other water ways in the area. Establishing a bulkhead and capping the existing sediments would specify significant amounts of beneficial uses material to achieve the proper elevation. A layer of sand must be applied to establish a root zone where seeding takes place and any modifications for proper drainage can be adjusted. Throughout much of our history salt marshes have been little regarded and often destroyed. They have been filled in as dumps and valued only when drained and developed. In the last several decades, we have only begun to unde4rstand that wetlands are a fertile and precious nursery. Besides nurturing millions of species -many endangered- wetlands replenish the Earth’s water supply, blunt the ravages of nature and provide sanctuary and serenity for humans.

MONITORING AN URBAN STREAM: STRATEGIES AND RESULTS FOR NON-POINT POLLUTION – MOLLY ANN BROOK, PASSAIC COUNTY, NEW JERSEY

Richard R. Pardi and Michael Sebetich
Department of Environmental Science and Department of Biology, William Paterson University, 300 Pompton Road, Wayne, New Jersey 07470; pardir@wpunj.edu

Molly Ann Brook is an urban stream that is a tributary to the Lower Passaic River. The stream is located in Passaic County, northern New Jersey with most of its watershed is located within the Boroughs of Franklin Lakes, North Haledon, Haledon, Prospect Park and the city of Paterson. The stream has been identified by New Jersey Department of Environmental Protection as being impaired along portions of its length for fecal coliform bacteria and ecosystem degradation as indicated by macroinvertebrate surveys. The results shown in this poster reflect an intensive water-quality survey of 6 sampling sites within the watershed. Fecal coliform and E. coli bacteria, nutrients, major elements and field variables (pH, dissolved oxygen, conductivity, temperature, and turbidity) were measured along with discharge beginning in August, 2006. Some of the results are shown on this poster. High levels of bacteria were measured along the entire length of the stream and nearly always exceeded the surface water standard for both fecal coliform and E. coli during both the 2006 and 2007 sampling seasons. Nutrient levels were low to moderate but showed some consistent variations along the length of the main channel and between low-water and storm events. Dissolved oxygen was close to saturation at the ambient water temperatures along the entire length of the stream during daylight hours when discrete sampling was conducted. However, continuous sampling over week-long periods indicated low oxygen levels at night and during periods of low flow. Other data presented within this poster provide insight into the water quality dynamics of this urban stream and contribute to a foundation of understanding that will aid in the planning of a restoration and protection plan for this water body.

GEOTECHNICAL AND EVNIRONMENTAL ENGINEERING AT MEADOWLANDS XANADU

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Meadowlands Xanadu is a large-scale entertainment complex located in the Hackensack Meadowlands that, upon completion, will feature five distinct sections: food and home, sports, fashion, youth, and entertainment. The centerpiece of the 4.8 millions square foot complex will be the United States' first indoor ski dome. The construction of Meadowlands Xanadu (MX) presented many complex geotechnical and environmental challenges. Both geological processes and human activity have shaped this section of the Hackensack Meadowlands. After the most recent glaciers retreated, Glacial Lake Hackensack formed, depositing varved clay and silty sand over glacial till throughout the area. The lake eventually drained, forming a vast, low-lying area known as the Meadowlands. At the location where MX is being built, uncontrolled filling and the remains of former industrial properties can be seen in the impacted soil and groundwater below grade. Due to the compressible nature of the peat and varved clay, a shallow foundation was immediately ruled out for the proposed MX. Instead, concrete-filled, steel pipe piles were chosen to support the building load. These piles were driven to solid bedrock until meeting a resistance of 20 blows per inch. 150-ton capacity piles were used for building columns and 60-ton capacity pipe piles were used to support on-grade building slabs. During pile-driving activities, filling of remnant wetlands on the east side of the site were taking place. Geotextile membranes and prudent filling practices were used in an attempt to avoid creating mud waves. Once the wetlands were filled, wick drains were installed into the varved clay stratum to expedite consolidation of this clay layer. In addition to wick drains, several 10 ft high surcharge piles were placed to allow additional rapid settlement of the compressible peat later. Prior to construction, several permits were necessary for the project to begin. MX required a Waterfront Development Permit, a Water Allocation Permit, a Construction Dewatering Permit, a Stream Encroachment Permit, and Gas Venting System Permit. During construction, many complex environmental conditions arose. During excavation activities, underground storage tanks, buried drums, and buried asbestos containing materials (ACM) were encountered. In addition, product and creosote were observed on groundwater during construction activities. These conditions had to be remediated on an expedited basis to avoid impacting the construction schedule. Remedial actions included soil excavation and disposal, removal of hazardous materials, and groundwater sampling. The MX project presented many difficult challenges due to the natural and anthropogenic processes in the past. Each challenge is being successfully addressed through proper design and construction. Construction is expected to be completed in June 2009. Environmental monitoring will continue into the foreseeable future.

GEOLOGIC OBSERVATIONS DURING ROCK EXCAVATION AND TUNNELING FOR THE CROTON WATER TREATMENT PLANT CONSTRUCTION, BRONX, NY

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ABSTRACT

New York City's water supply and distribution system has long been considered an engineering marvel. The system is comprised of a complex network of reservoirs, controlled lakes and more than 6,000 miles of water pipes, tunnels and aqueducts that provide over 1.1 billion gallons of safe drinking water daily to more than 9 million people. This high quality water comes from three water supply systems in a nearly 2,000 square-mile watershed that extends more than 125 miles north and west of New York City. Croton system water provides roughly ten percent of the total system demand to the City and is an important resource for the City during drought and in ensuring redundancy and dependability of the overall water supply.

The New York City Department of Environmental Protection (NYCDEP) is proceeding with the construction of the Croton Water Treatment Plant (CWTP) and associated works in the Borough of the Bronx, New York. The CWTP is part of the NYCDEP's Bureau of Engineering, Design & Construction project to upgrade the water supply system, improve water quality and ensure compliance with stricter water quality standards. The CWTP will be constructed in Van Cortlandt Park below the driving range of the Mosholu Golf Course and will have an estimated design capacity of 290 million gallons per day (MGD), providing filtration and disinfection for Croton system water conveyed to New York City through the New Croton Aqueduct (NCA). Upon completion of construction, the site will be returned to park use as a public golf course with driving ranges, golf clubhouse and parking facilities. While the majority of the CWTP filtration system will be underground and not visible to the public, they will derive the benefit of improved water quality long into the future.

Construction of the CWTP facility requires two major underground construction phases: site preparation and tunneling. Three tunnels are presently under construction, with mining and excavation being accomplished using drill-and-blast and Tunnel Boring Machine (TBM) operations. Of particular concern during construction is a segment where the new tunnel advancement will cross through the Mosholu Fault underlying the Mosholu Parkway. Additional tunnel segments will be constructed in low rock cover zones of approximately 30 feet of rock overlying TBM mining operations.

The tunnel alignment is predominantly through the Fordham Gneiss complex, which constitutes the oldest underpinning of rock formations in the New York City area and consists of a complex assemblage of Proterozoic Z ortho- and paragneiss, granitoid rocks, metavolcanic- and metasedimentary rocks (Merguerian, 2005a). Ductile deformations associated with several orogenic events have produced a widespread mylonitic fabric on the rock that can be seen following tunnel excavation. Metamorphosed and tectonically sutured mafic intrusives and several granitic intrusive events, all of uncertain ages, are quite numerous. Multiple sets of less deformed pegmatite dikes further cross-cut localized banded, leucocratic, granitic and migmatitic gneisses. Along the tunnel alignment, two of the major joint sets strike NW-SE, while the third occurs along foliation. Foliation strikes on average N10°E; however these readings can vary due to the localized effects of faulting. Several NNW-SSE joints have created blocky conditions, while several vertically dipping N-S striking joints were easily crossed. Through the NW-trending Mosholu fault zone, mylonitic foliations display pervasive chlorite alteration and strong cleavage defined by preferred orientation of micas. Most of the joint surfaces are mineralized, many contain slickensides, and most are continuous. Pyrite-rich zones are observed suggesting hydrothermal alteration due to subsequent mineral-rich fluid flow.

Two walls of the main excavation pit were geologically mapped and photographed to document the cross-cutting relationship of structural controls. A well-planned geological mapping program consisting of full-periphery circumferential mapping at the scale of 1:120 (1" = 10') is presently underway for the first of two 13.5-foot diameter TBM bored tunnels, allowing for enough detail to categorize the lithologic and structural conditions of the rock mass during the as-built stage of construction for project documentation and recordkeeping.

INTRODUCTION

The New York City Department of Environmental Protection (NYCDEP) is proceeding with the construction of the Croton Water Treatment Plant (CWTP) at the Mosholu Golf Course Site in Van Cortlandt Park in the Borough of the Bronx, New York. The CWTP is part of the NYCDEP's Bureau of Engineering, Design & Construction project to upgrade the New York City water supply system and ensure compliance with stricter water quality standards. The CWTP requires construction of tunnels and shafts for raw and treated water conveyance. Figure 1 illustrates the general project location on the USGS Yonkers Quadrangle.

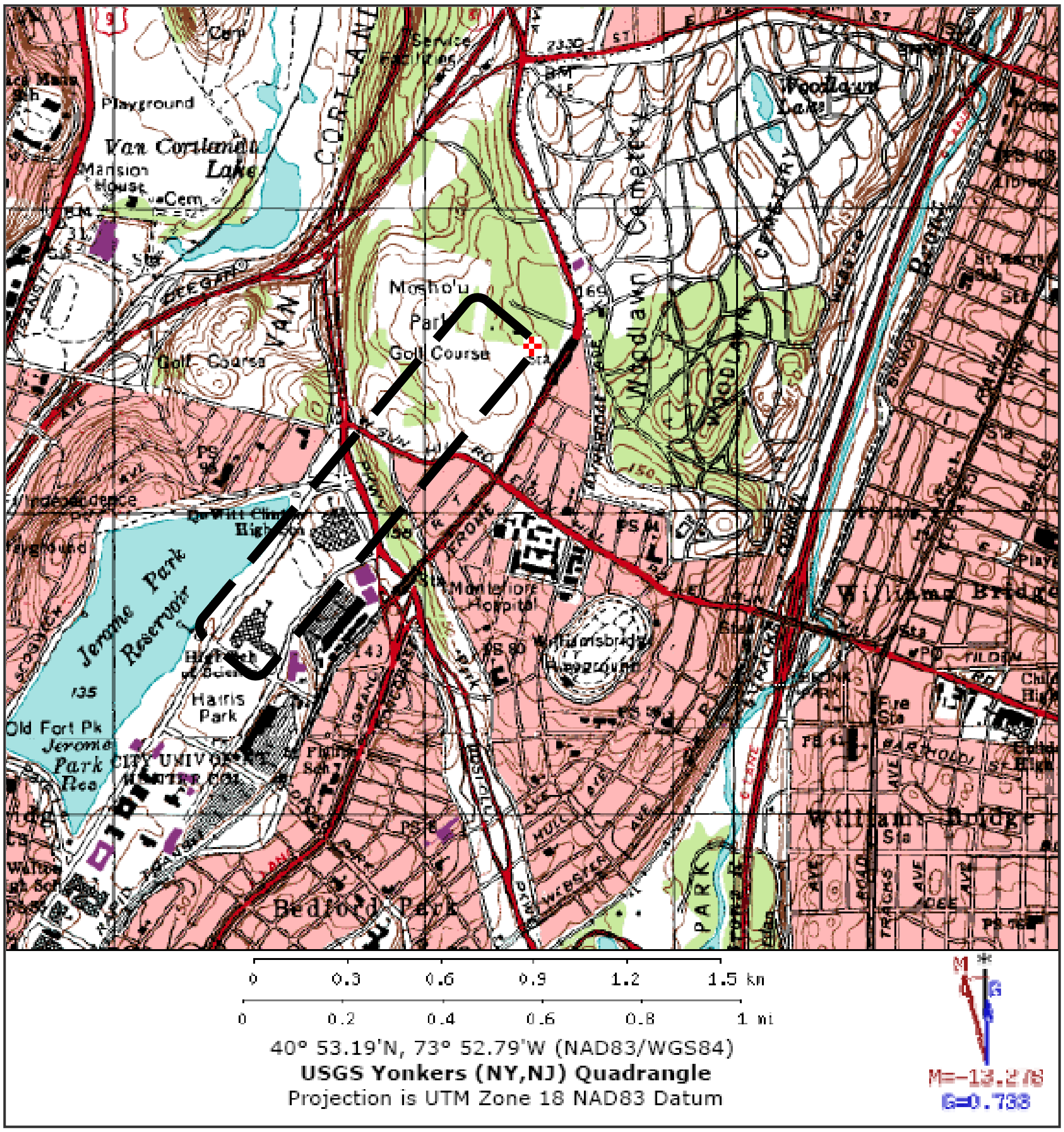

Figure 1: Site Vicinity Map (USGS Yonkers Quadrangle). The general tunnel alignment is in a northeast to southwest orientation, beginning at the Mosholu Golf Course and terminating at the Jerome Park Reservoir.

The Croton water supply system provides roughly ten percent of the total system demand of more than 1.1 billion gallons per day of safe drinking water delivered to the taps of more than 9 million people throughout New York State. Water conveyed through the New Croton Aqueduct (NCA) will be filtered and disinfected at the CWTP prior to distribution throughout the New York City system. Operating conditions will result in the filtration of a maximum of 290 MGD to a minimum of 90 MGD. On average, the nominal flow is anticipated to be approximately 150 MGD.

The CWTP will be constructed in Van Cortlandt Park, within the boundaries of the Mosholu Golf Course, below the driving range. Construction of the facility requires two major underground construction phases: site preparation (which has been completed) and tunneling (which is underway). During the site preparation stage, a massive rock excavation was conducted to a depth of approximately 100 feet below ground surface, requiring drill-and-blast excavation methods and removal by heavy equipment (Figure 2). Approximately 300,000 cubic yards of soil and 800,000 cubic yards of rock were removed in the site preparation contract. The CWTP building will be approximately 900 feet by 470 feet, with its roof slab at an elevation of 195 feet.

Figure 2: Pit Excavation for CWTP Foundation Construction and Tunnel Tie-In. Left panel - Aerial view of the CWTP Main Excavation Pit (MEP). North is oriented to the lower right of the photograph. Right Panel - Close-up of MEP wall in bedrock. Note pre-split lines for drill-and-blast excavation and soldier pile and lagging wall at the top of the excavation.

Three tunnels and multiple shafts will be constructed as an additional phase of this project. Tunnel mining and excavation will be accomplished using drill-and-blast and Tunnel Boring Machine (TBM) operations, with ancillary procedures associated with tunneling. After completion of construction, the site will be returned to park use as a public golf course, driving ranges, golf clubhouse and vehicle parking, as illustrated on Figure 3.

The principal items of the tunnel and shaft work consist of the excavation and support of two Treated Water (TW) tunnels, between the CWTP and the Jerome Park Reservoir (JPR) shaft chamber, each approximately 3,650-feet long and 13.5-feet in diameter TBM cylindrical bore, and each finished with 9-foot diameter conduits. Tunneling will also be comprised of the excavation and support of a Raw Water (RW) tunnel, approximately 865 feet long and horseshoe-shaped, 14.5 feet by 14.5 feet, between the CWTP and the New Croton Aqueduct (NCA), having a finished inside diameter of 12 feet. Several shafts will also be constructed utilizing top-down and raise bore excavation methods.

Raw water will flow from the Croton Reservoir in Westchester County within the unpressurized NCA to the new RW tunnel and into the CWTP. Following treatment, High Level (HL) and Low Level (LL) treated water will be pumped to a new TW shaft chamber at JPR in the Bronx. TW/HL will then be

Figure 3: Rendering of the Completed Croton Water Treatment Plant Project Site Upon completion of the project, the site will be restored to a public golf course and driving ranges for community use, making the majority of the CWTP visibly hidden from sight underground.

directed to City Tunnel No.1 and the Stage 1 section of City Tunnel No.3. TW/LL will be conveyed to Manhattan, via the NCA, and to the Bronx, via new and existing water mains.

GENERALIZED GEOLOGY OF THE NEW YORK CITY REGION

The New York City Metropolitan region is characterized by complex bedrock geology and structure overlying three physiographic units: the New England Upland on the northeast, the Triassic Lowland on the southwest, and the Atlantic Coastal Plain to the southeast. New York City is situated at the extreme southern end of the Manhattan Prong, a northeast-trending, deeply eroded sequence of metamorphosed Proterozoic to Lower Paleozoic rocks that widen northeastward into the crystalline terrains of New England.

The Manhattan Prong is a landscape of rolling hills and valleys whose configurations are closely controlled by the structure and lithology of the underlying bedrock. The bedrock of the Manhattan Prong is composed of metamorphic rocks, ranging from Proterozoic to Ordovician in age. The hilly terrains are underlain by rocks that are resistant to erosion (Fordham Gneiss, Yonkers Gneiss, and various schists and gneisses of the Manhattan, Walloomsac, and Hartland formations). Generally, the valleys are underlain by brittle faults or the Inwood Marble because of carbonate weathering susceptibility (Vellone and Merguerian, 2007; Merguerian and Ozdemir, 2003).

About 450 million years ago, during the Taconic orogeny, the rocks of the Manhattan Prong were tightly folded and metamorphosed. Consequently, complex fold and fracture patterns have resulted from many stages of polydeformation. The geologic structure of metamorphic bedrock is typically dominated by surfaces of foliation and gneissic layering formed by the preferential alignment of platy minerals within the rock (Vellone and Merguerian, 2007). Figure 4 illustrates the generalized geology encountered along the tunnel alignment.

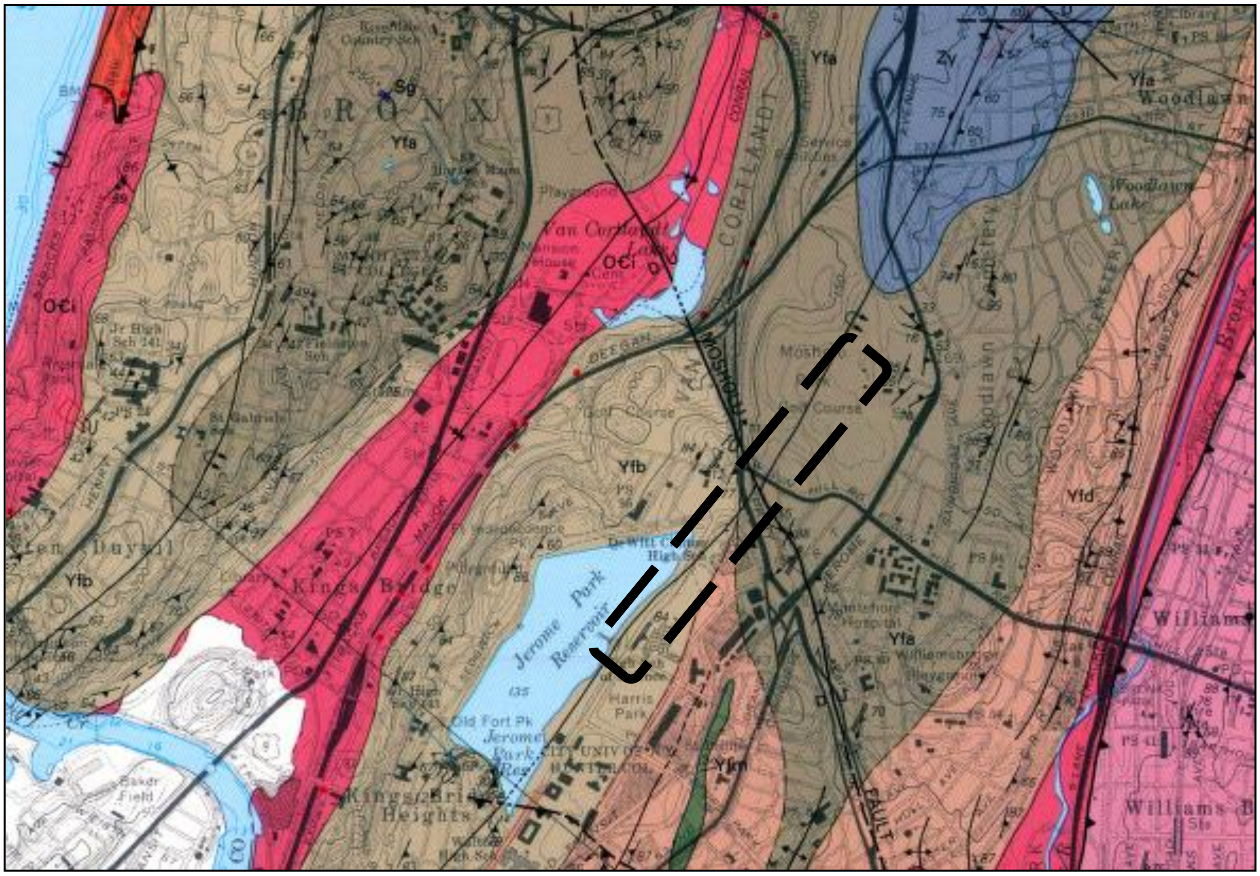

Figure 4: Bedrock and Engineering Geologic Map of the Tunnel Alignment (Baskerville, 1992). Construction of the Main Excavation Pit was exclusively in the Fordham Gneiss Member A unit, while the tunnel alignment was constructed in both the Fordham Gneiss Member A and Member B units.

GEOLOGICAL MAPPING

Geological mapping at the scale of 1:120 (1" = 10') was conducted for the Main Excavation Pit (MEP). Two walls of the MEP were geologically mapped and photographed to document the cross-cutting relationship of structural controls for archival purposes. Figure 5 illustrates the geologic map compiled for the west wall of the excavation pit at the Treated Water and Raw Water tunnel portals. Additionally, a well-planned geological mapping program, consisting of full-periphery circumferential mapping at the scale of 1:120 (1" = 10') is presently underway for the first of two 13.5-foot diameter TBM bored tunnels. The purpose of the mapping program is to develop an appropriate visual and quantitative representation of the rock mass that characterizes and documents tunnel lithological and structural conditions during the as-built stage of TBM excavation activities for archival purposes.

Tunnel mapping is being performed in general accordance with industry convention, as outlined in the reference document ASTM D4879 “Standard Guide for Geotechnical Mapping of Large Underground Openings in Rock,” with the noted variation that the reference orients the crown of the tunnel through the center of the map section, with the invert drawn at the map’s edges; a technique that permits an “outside looking in” view of the structural and lithological relationships. Instead, it was considered desirable for this application to represent the tunnel crown at the map’s edges and the invert through the center of the map to account for the partial visual obstruction of the crown during mapping due to the presence of the 42-inch diameter ventilation duct suspended from the crown. This visual imparity was overcome by initial observations made during tunnel excavation advancement, prior to the placement of the ventilation line. This technique permits an “inside looking out” view of the bored tunnel excavation, consistent with prior New York City tunnel mapping performed by Dr. Charles Merguerian of Hofstra University (Merguerian, 1999; 2000; 2002; 2003; 2005a).

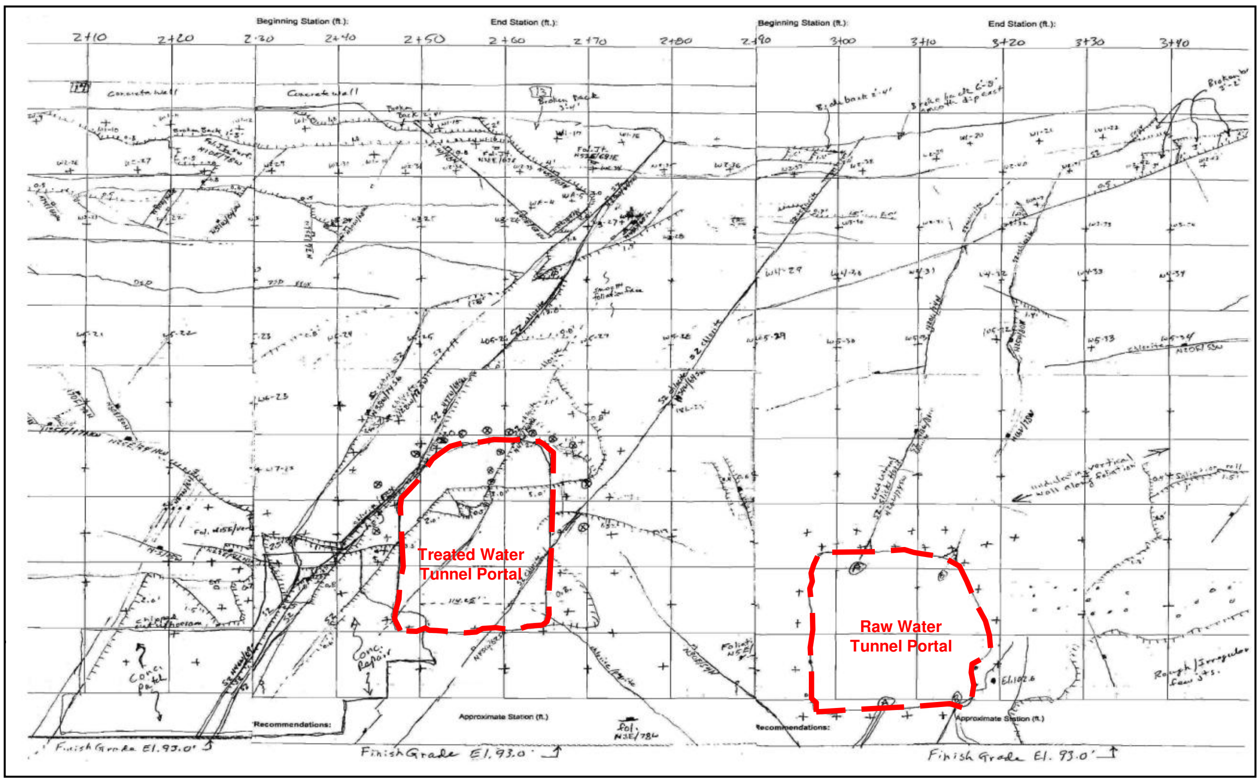

Figure 5: Geologic Map of West Wall Pit Excavation at Treated and Raw Water Tunnel Portals. The Main Excavation Pit contained a number of through-going shear joints having a trend parallel to the Mosholu Fault trace.

Excavation Pit Initial Ground Support and Structural Controls

The bedrock was supported as a phased excavation that proceeded in lifts of approximately 15- to 30-feet in depth. The primary rock support was achieved through use of Dywidag Threadbars®, anchored with an end wedge, tensioned at 45-to-68 kips lock-off load, and subsequently cement-grouted. The rock bolts were placed on a standard 10-foot-by-10-foot pattern, at an inclination of 5- to 15-degrees downward from the horizontal. Rock bolts were 23-feet long in the uppermost two or three rows, followed by 15-feet long bolts in the remaining rows on each of the four walls of the MEP and in sump adits, where walls exceeded 10-feet in height. All bolts were witnessed for tension loading with an electric hydraulic center hole jack. Data on drill date/depth, bar/wedge installation, jacking load/lock-off load/date/depth and grouting for each rock bolt installed was recorded for acceptance, and proof testing was performed in accordance with the design specification requirements. Where additional rock bolts were required, the contractor and geotechnical engineers would agree on each additional bar for record and payment prior to drilling installation.

In addition to the primary rock bolt pattern, untensioned #8 rebar dowels were installed on the perimeter of the entire rock cut and on several benches within the excavation, four feet off the design line, with six feet center-to-center spacing and at an eight foot embedment depth. These bars provided a pinned perimeter beyond the line-drilled blasting limit. Within the base elevation of the MEP, narrow linear rock trenches were presupported using design rock bolts that were placed, prior to blasting, on a 45 degree batter away from the trench. After tensioning and grouting, these rock bolts provided a compressed wedge of rock beyond the theoretical excavation line, prior to excavation by blasting and backhoe/hoeram removal. Shotcrete was used in combination with double-twist Maccaferri wire mesh, where chloritized amphibolitic rock walls, susceptible to weathering and spalling upon exposure to the air, were encountered with good results.

GEOLOGY OF THE TUNNELS

Presently, the TW/LL tunnel has been excavated by TBM. The general lithology along the tunnels and shafts consists of Fordham Gneiss Members A and B, and Yonkers Gneiss intrusions in Fordham Gneiss Member A. The Fordham Gneiss (Yf on engineering geologic map, Figure 4) constitutes the oldest underpinning of rock formations in the New York City area and consists of a complex assemblage of Proterozoic Z ortho- and paragneiss, granitoid rocks, metavolcanic- and metasedimentary rocks (Merguerian, 2005a). In New York City, only a few attempts have been made to decipher the internal stratigraphic relationships; hence, the three-dimensional structural relationships remain obscure. Based upon earlier detailed studies in the Queens and Brooklyn water tunnels by Merguerian 2000; Merguerian, Brock, and Brock 2001; Brock, Brock, and Merguerian 2001, the Fordham consists of predominantly massive mesocratic, leucocratic, and melanocratic orthogneiss, with subordinate schistose rocks. These rocks have been metamorphosed to the high pressure granulite facies, which has produced a tough, anhydrous interlocking mineral texture (Merguerian, 2005b).

The tectonic/stratigraphic units of the region have been displaced along isoclinally folded and imbricated ductile thrust faults (Merguerian, 1996). Ductile deformations associated with several orogenic events have produced a widespread mylonitic fabric on the rock that can be seen following tunnel excavation. The ductile thrust faults now appear as steep, complexly folded and migmatized zones of commingled mylonitic rocks. Banded gneisses display well-developed compositional layering and strong foliation, defined by preferred orientations of quartzofeldspathic aggregates. The banded gneiss grades into more homogeneous and less strongly foliated granitic gneiss, which has a lower content of mafic minerals compared to the banded gneiss. Metamorphosed and tectonically sutured mafic intrusives and several granitic intrusive events, all of uncertain ages, are quite numerous. Multiple sets of less deformed pegmatite dikes and veins further cross-cut localized banded, leucocratic, granitic and migmatitic gneisses. Along the tunnel alignment, two of the major joint sets strike NW-SE, while the third occurs along foliation. Foliation strikes on average N10°E; however, these readings can vary due to the localized effects of faulting. Several NNW-SSE joints have created blocky conditions, while several vertically dipping N-S striking joints were easily crossed. Figure 6 illustrates a map section of the TW/LL tunnel, depicting the cross-cutting relationship of the younger pegmatitic and amphibolitic intrusions through the Fordham Gneiss Member A. Tunnel stationing decreases from the shaft at the CWTP (left) to the NCA (TW/LL tunnel bearing is N41°E).

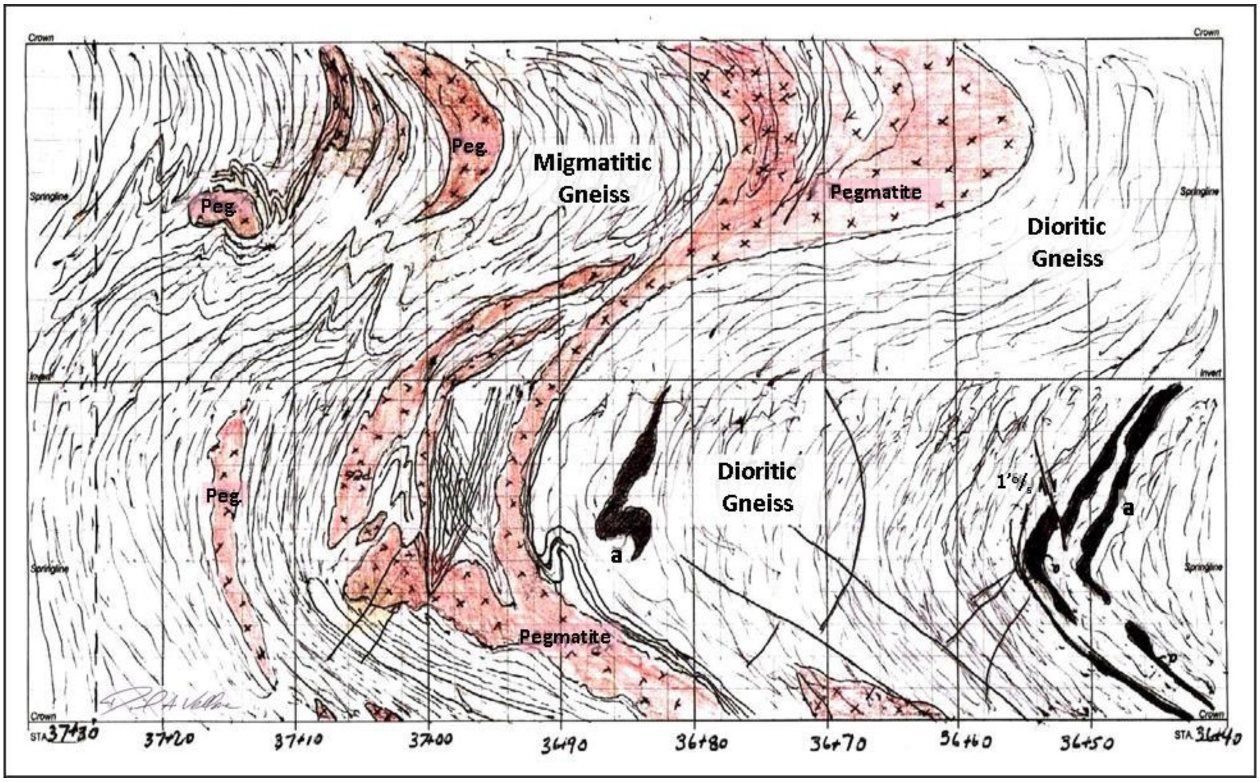

Figure 6: Full-Periphery Geologic Map of the TW/LL (Station 37+30 to 36+40). Geological map of the TW/LL shows pegmatite injections and locally sheared inclusions of granulite-facies amphibolite gneiss.

Through the northwest-trending Mosholu Fault zone, bearing approximately N42°W, 88°SW and occurring approximately at TW/LL tunnel Station 26+55, mylonitic foliations display pervasive chlorite alteration and strong cleavage defined by preferred orientation of micas. The Mosholu Fault zone was anticipated to span an approximately 1,000 foot section along the TW tunnel alignments based upon observations of the fault during construction of both City Water Tunnel Nos. 1 and 3; however, it was encountered as a significantly more discrete occurrence than anticipated. The Mosholu Fault, as observed following the TW/LL tunnel excavation, consists of an abrupt zone of retrograde metamorphic alteration, approximately 24 inches thick, of chloritic clayey gouge which bisects the tunnel alignment orthogonally as can be seen in Figure 7. This chloritic zone is flanked on either side by brecciation and aligned biotite, and is permeated by pyrite mineralization. Most of the joint surfaces are mineralized, many contain slickensides, and most are continuous. In places pyrite-rich zones are observed, suggesting hydrothermal alteration due to subsequent mineral-rich fluid flow. No offset displacement was noted along this brittle strike-slip fault. However, movement on the Mosholu Fault is believed to have been dominantly right lateral, although a complex movement history is indicated by offsets and superimposed slickensides along variously oriented steeply dipping surfaces (Merguerian, 1996).

Further, it is also worthy to note that Baskerville (1992) references the occurrence of a coarse-grained siliceous dolomite found to be interlayered within the Fordham Gneiss in the Jerome Park Reservoir excavation (1895 to 1906); however, no occurrence of dolomite was observed throughout the CWTP TW/LL tunnel excavation. As the excavation of the TW/HL tunnel progresses, further lithological and structural observations will be made.

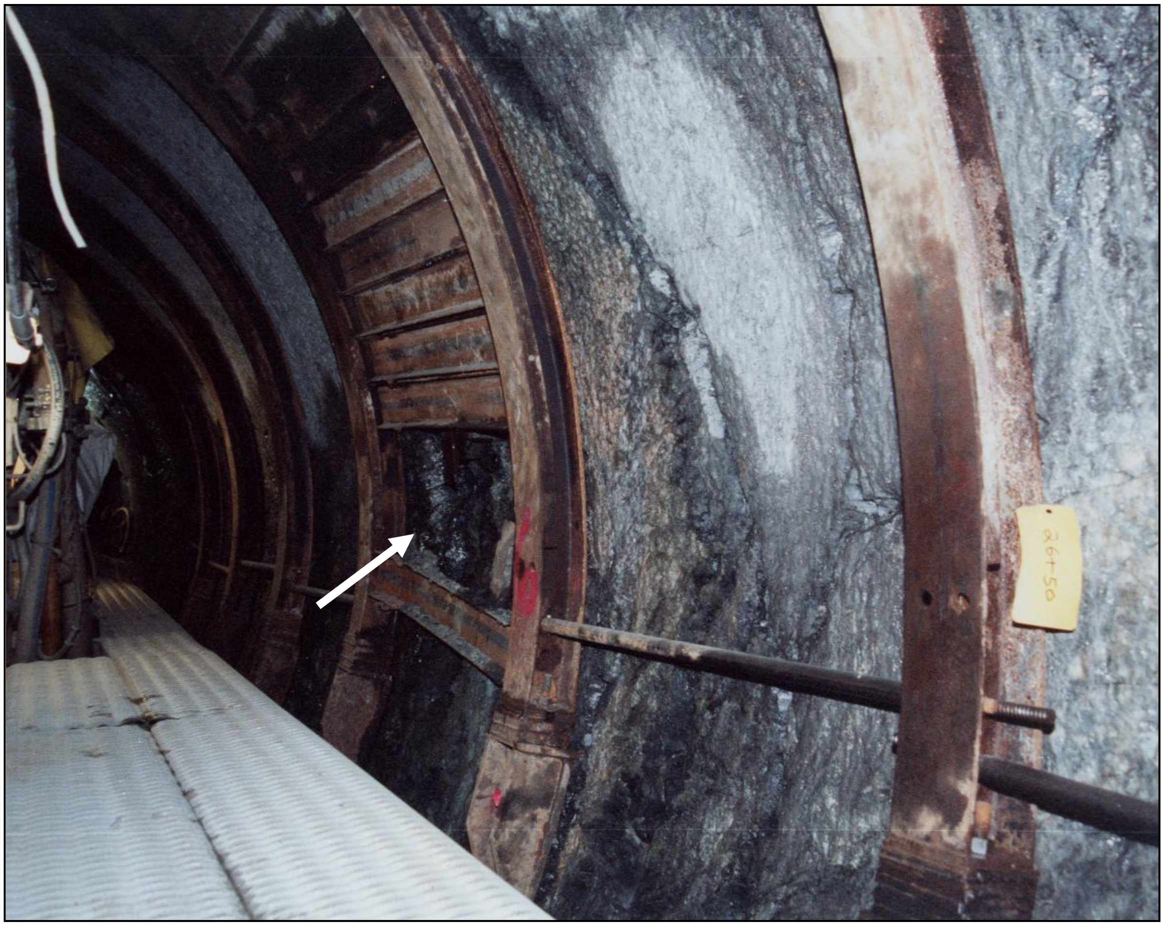

Figure 7: Mosholu Fault Zone at Approximate TW/LL Tunnel Station 26+55 The white arrow in the photograph points to the fresh chloritic clayey gouge infilling of the Mosholu Fault. Steel channel lagging, in combination with successive sets of full circumferential ring beams secured with 4-foot collar ties, were required for initial ground support.

Tunnel Initial Ground Support and Structural Controls

Throughout the tunnel alignment during excavation, initial ground support was achieved using pattern bolting of Swellex® Pm24 untensioned dowels of varying lengths, ranging from 5-feet to 7-feet, and varying spacings installed through the crown, arch and at springline. Through localized shear zones, initial ground support was achieved using full circumferential ring beams and incorporated steel channel lagging. Figure 8 illustrates the full circumferential ring beams used to stabilize the tunnel excavation through a NNW trending shear zone roughly parallel to the Mosholu Fault trace between approximate TW/LL tunnel Stations 35+30 to 35+05. It is observable in the left photograph that the steel channel lagging is installed with a more-or-less partial (staggered) pattern, with numerous lagging sections through the crown and down through the right springline in the foreground of the photograph, while the lagging transitions from the crown down through the left springline in the background of the photograph. This is to account for the brittle shear zone bisecting the tunnel alignment with a trend of approximately N30°W, 81°SW. Unlike the Mosholu Fault, this shear zone did not exhibit any pervasive chloritic clayey gouge, but rather contained non-cohesive, angular broken rock as infilling. Further, this shear zone exhibited a high degree of weathering, requiring timber cribbing behind the lagging, as well as moderate water inflow and excavation instability, which can be seen in the right photograph.

Figure 8: Full Circumferential Ring Steel Required for Initial Tunnel Support through Shear Zone Successive sets of full circumferential ring beams and steel channel lagging were required intermittently throughout the TW/LL tunnel alignment at shear zones having the greatest potential for instability.

CONCLUSIONS

While this project is ongoing at this time, some general conclusions can be drawn with respect to the lithological and structural conditions encountered in the CWTP TW/LL tunnel during mining operations. The pre-bid geotechnical reports provided adequate documentation of the conditions anticipated in the TW/LL tunnel. Rock conditions encountered during tunnel excavation within the Fordham Gneiss Member A unit was chiefly dominated by lithological controls through the intensely folded migmatitic, leucocratic and mylonitic gneissic fabric, while excavation within the Fordham Gneiss Member B unit was dominated by structural controls attributed to intersecting discontinuities and orthogonal conjugate joints. While the Mosholu Fault zone was anticipated to span an approximately 1,000-foot section along the TW tunnel alignments based upon observations during construction of both City Water Tunnel Nos. 1 and 3; it was encountered as a significantly more discrete occurrence than anticipated. However, the Mosholu Fault was reported in the design documents to bisect the TW/LL tunnel at Station 26+50, which was within approximately 5-feet from its occurrence within the TW/LL excavation. Further, an extensive surface pre-grouting program through the anticipated fault zone, using pattern borehole spacing, contributed to a significant reduction of water inflow and improved the structural competence of the rock mass.

ACKNOWLEDGMENTS

The authors wish to gratefully acknowledge the New York City Department of Environmental Protection, specifically Bernard Daly, Executive Construction Manager, for permitting this manuscript to be shared with the regional geological community and copy editing by Rose Marabetti. Support provided by the joint venture of URS/Malcolm Pirnie is also appreciated. In particular, the peer-review by James Macdonell, P.G., was greatly appreciated. Additionally, the authors enjoyed regular discussions with Dr. Scott Chesman regarding the tunnel geology.

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EROSION AND WEATHERING PROCESSES IN THE DELAWARE RIVER BASIN

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ABSTRACT

Total suspended sediments and the total dissolved solids (TDS) from three river gaging stations, near Delaware Water Gap, Riegelsville and Trenton on the Delaware River measured by the USGS were used to estimate the physical erosion, chemical weathering and total denudation rates of the Delaware River Basin. The denudation rates are 28 and 128 tons/km^2/yr for the upper stream and downstream stretches. Overall, the chemical weathering is more prominent in the basin than the physical weathering due to the low gradient of the region and sufficient moisture levels in the regional soil. The total suspended sediments are high during March and April when snow melting and ground thawing occur, and low during the summer when the river discharge is low. The response of TDS to the river discharge is more complicated. Overall, higher temperatures increases the chemical weathering, and low discharge increases the ion concentration in the water. The saturation indices calculated using the WATEQ4F program indicate that calcite and dolomite are more saturated in the summer, while silica and halite show opposite patterns. While the saturation index of silica may be explained by its thermodynamic property, the saturation index of the halite that deviates from the normal pattern is thought to be related with the application of winter deicing salt in the region.

Soil cores were also collected from four sites in the basin. Data from a 15-foot soil core indicates that weight percentage of quartz decreases with depth, while the weight percentage of feldspar increases. Various mineral types and abundance were also recognized from other shallow soil cores. These diverse mineral patterns reflect the diverse ion species in the river basin.

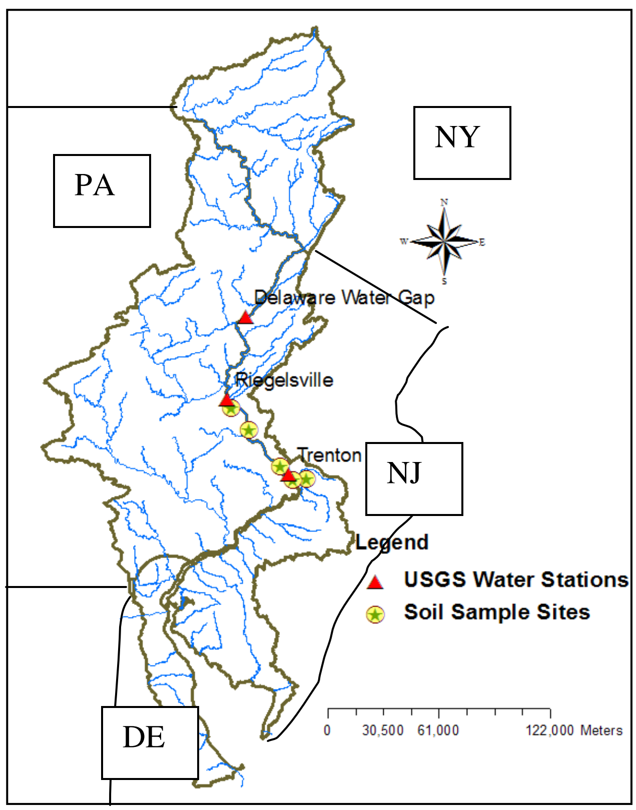

Figure 1. Locations of soil sample sites and three USGS water stations in the Delaware River Basin, including State lines of NJ, NY, PA,

INTRODUCTION

Because of the effect of weathering on water quality and landscape in a basin, there are always interests in better understanding the weathering processes (Blum et al., 1998, Braun et al., 2005, Grosbois et al., 2000, White and Blum, 1995, White and Brantley, 2003). Various methods, from mass balance, isotope analysis, lab experiment to computer modeling, have been used in the erosion and weathering studies (Roy et al., 1999, Moon et al., 2007, Yuan et al., 2007). During recent years, because of the detrimental effect of sulfate, nitrate and road salts on the ecosystem, the buffering capacities of various weathering processes have become the focuses of some of the studies as well (Douglas et al., 2002, Witfield et al., 2006, Lerman and Wu 2006, Moncoulon et al., 2004, da Gonceicao and Bonotto, 2004). Progress has been made on understanding how the chemical weathering of soils and bedrock respond to different environmental factors such as temperature, pH, and landscape (Riebe et al., 2004, White and Fernando, 1995, White and Brandtley, 2003). However, because of the climatic, geographic and geologic variations of regions, weathering can be significantly different from region to region. The relationship developed for the chemical ions also can be different (Braun et al., 2005, Millot et al., 2003). In addition, there has not been a thorough study of the weathering processes and the effect of anthropogenic loadings in the Delaware River Basin (DRB). Therefore, this project intends to provide an initial investigation on the weathering processes in the DRB (Fig. 1).

RESEARCH METHODS

Total Denudation Rate

Total denudation rate of the DRB is the sum of its physical erosion and chemical weathering rates. Physical erosion is calculated as the average of the total suspended sediments normalized by the catchment area of the basin up to that particular outlet station. The suspended sediments are the sediment particles that were removed by the river water from the basin.

Chemical weathering rate is calculated as the product of total dissolved solids (TDS) and the discharge of the river water, with this product being normalized by the catchment area (Yuan et al., 2007, Douglas, 2006). The TDS is approximated by the sum of the concentrations of major cations, including the Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, SO_4^{2-}, Cl^{-} and silica in the system, mainly the first seven ions. This approach has been practiced in many previous studies (Riebe et al., 2004, Ryu et al., 2008, Roy et al., 1999, Yuan et al., 2007, Karim and Veizer, 2000).

Seasonal Variations of Erosion Rate

Because discharge and precipitation change seasonally, the physical removal of sediments and chemical dissolution of the ions, which are related to discharge and precipitation, will change seasonally. The total loadings of suspended sediments reflect the amount of physical erosion, and the total dissolved major ions reflect the chemical weathering of the rocks and soil in the basin. The monthly averages were calculated by adding all the sample data collected in a particular month for all the years that data are available. Also, in order to examine the relationship between the water temperature and dissolved silica concentration, a simple linear correlation was calculated.

Saturation Indices of Mineral Species

Saturation index is a term that is used to describe the dissolution state of a mineral in water. It is calculated as the log ion activity product of the dissolution reaction divided by the equilibrium constant of a reaction (Drever, 1997). For example, for the dissolution of gypsum, the saturation indices equation is given as,

$$Saturation\ Index = \log \frac{IAP}{K_{sp}} = \log \frac{\left(a_{ca^{2+}} a_{so_4^{2-}}\right)_{solution}}{K_{sp(gypsum)}}$$

where IAP is Ion Activity Product and K_{sp} is equilibrium constant of the reaction equation. The ratio of IAP and K_{sp} can also be normalized by the number of ions to obtain the saturation ratio (Zhang and Nacollas, 1990).

The WATEQ4F (Ball and Nodstrom, 1991) which evaluates the distribution and the saturation level of each species for each element was used to calculate the saturation index of each species. The program uses the measured ion concentrations of a water system as input.

Soil Mineral Patterns of the Area

Soil cores were collected from five sites in the basin (Fig. 1). A 15-foot core collected at the Naval Air Warfare Center (NAWC), West Trenton site was obtained from the USGS Trenton office. Two-foot shallow soil cores were collected from four sites along Route 29 near the Delaware River. The soil sample's X-ray powder diffraction spectra were collected. RockJock6 (Eberl, 2003) was used to quantify weight percentage of the soil minerals based on the X-ray spectra of the soil and rock minerals. Mertens et al. (2006) recommended the RockJock program to be the "method of choice" for the soil clay mineral analysis based on the X-ray spectra. Weight abundances of soil minerals are the bases for mass balance analyses of the chemical weathering.

RESULTS

Denudation Rate of the DRB

The Delaware Water Gap is the most upstream station, Riegelsville is the middle station, and Trenton is the most downstream station. The Delaware River becomes tidal in less than a mile below the Trenton station (Fig. 1). Total suspended sediments generally increase with river discharge. During 1945-82, the mean annual suspended sediments at the Trenton station ranged from 50 to 6500 tons per day (Fig. 2).

Concentrations of the major ions, calcium, magnesium, potassium, and silica, which resulted from the chemical weathering, fluctuated annually in response to river discharge. However, they did not show a significantly trend from 1945 to 2008 (Figure 3). Concentrations of sodium and chloride increased by 2 to 4 times as a result of increased application of the winter deicing salt (Sun et al., 2006, Lucarino and Sun, 2007). Also, the molar concentration of chloride has risen above the sodium concentration in the last 20 years. This reversal of concentrations may indicate that sodium derived from weathering of albite to kaolinite, which was considered the sole source of sodium (Blum et al., 1998), has become less significant in relation to the artificial input of sodium from the deicing salt. Sulfate concentration shows a low and decreasing trend since the 1970s. This decline may be related to the clean-air act passed by Congress in 1970's which

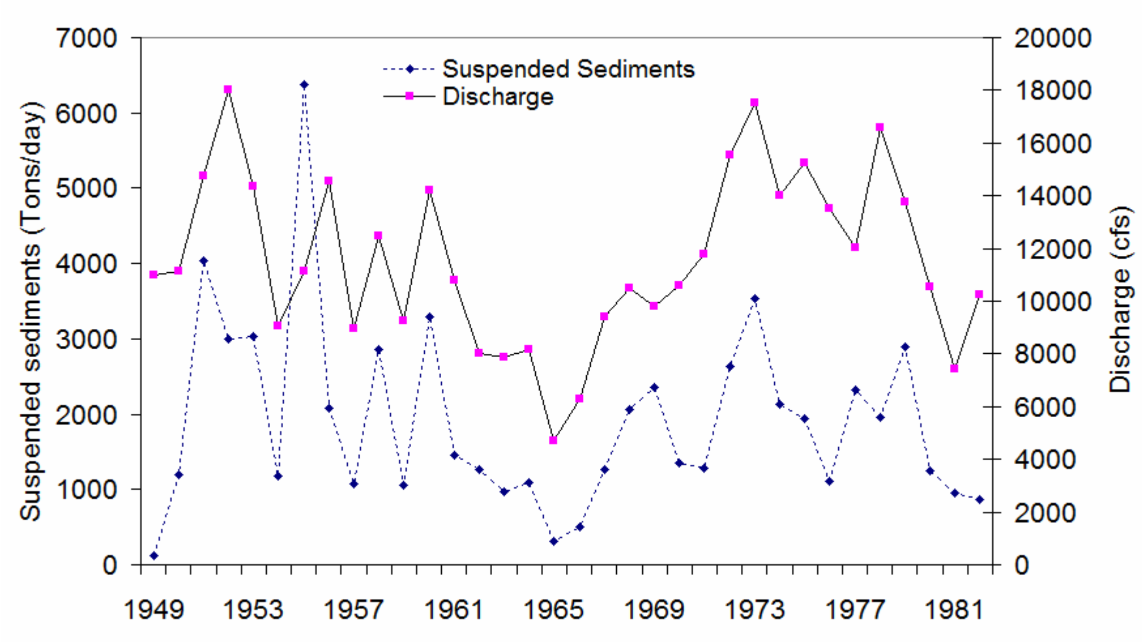

Figure 2. Annual average suspended sediments and discharge of the Delaware River at Trenton station.

resulted in the reduction of the dry wet depositions of sulfate in the basin. However, this decline also may be related to the change of equilibrium balance brought by the increased use of NaCl in the basin (Lucarino and Sun, 2007). Bicarbonate data at the three stations were recorded for less than10 years by USGS. Because of the positive linear relationship between the concentration of bicarbonate and the concentrations of calcium and magnesium (with R^2 from 0.5 to 0.96), one can deduce that the concentration of bicarbonate probably did not have a significant trend based on the concentrations of calcium and magnesium (Fig. 3). The high concentration of silica during the mid 1950's, may be caused by floods that exposed unweathered bedrock with the removal of thick sediment deposits (Fig. 3). However, there is the possibility of an imbalance brought about by increased NaCl concentrations that cause a change in the weathering rates of orthoclase, plagioclase and other silicates. Data from the two precipitation stations in the basin collected between 1981 and 2006 by National Atmospheric Depositional Program, show the atmospheric depositions of ions, compared with the ion concentrations in the river, are insignificant. Therefore, the main sources of ions in the river are the chemical weathering of rocks and the deicing salt applied in the basin.

Comparing the denudation rate at Trenton, Water Gap and Riegelsville (Table 1), it is apparent that the chemical weathering increases downstream. This change might reflect the changing underlying geology and the slopes of drained area from upstream to downstream regions. The denudation rates of 28 and 128 tons/km^2/year are comparable with the data from studies in other regions by Riebe at al. (2004). Because Trenton station is located downstream and it drains nearly the whole basin, its denudation rate is more representative of the whole Delaware River basin.

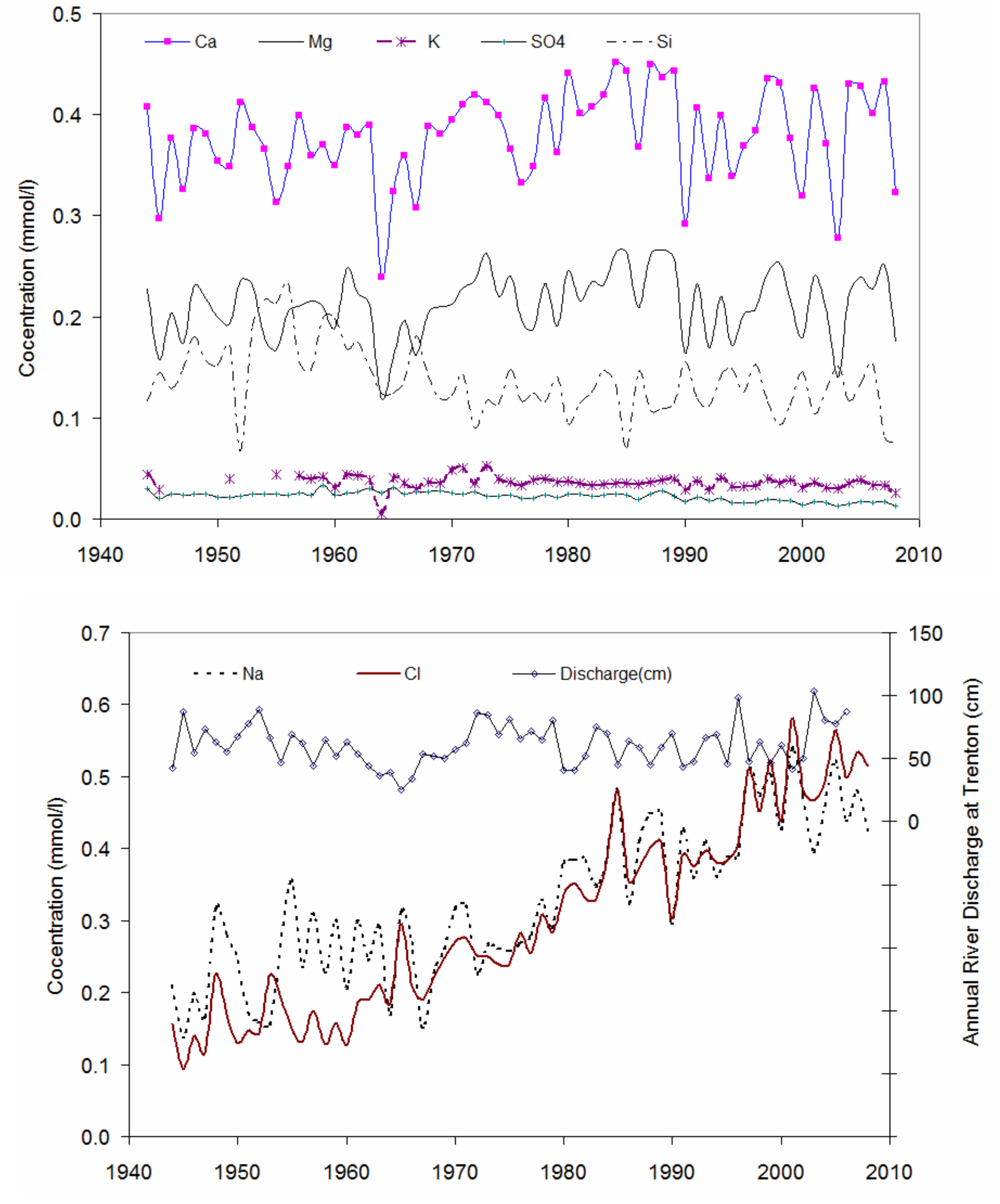

Figure 3. Average monthly concentration trends of major ions and discharge of the Delaware River at Trenton station. Upper panel, Ca, Mg, K, SO_4 and Si; lower panel, Na, Cl and the normalized discharge.

Table 1. Denudation rates calculated from the suspended sediments and total dissolved solid at three gage stations of the Delaware River: near Delaware Water Gap, Riegelsville and Trenton stations.

Stations	Physical Erosion Tons/km^2/yr	Chemical Weathering Tons/km^2/yr	Total Denudation Tons/km^2/yr	Data Period /Source
Water Gap	11.47	16.94	28.41	Physcial:1964-65, 1971-72; Chemical: 1965-68
Riegelsville	---	77.79	---	Chemical: 1960-78; 1991-2008
Trenton	41.71	86.34	128.04	Physical: 1950-82; Chemical: 1944-2008
Panola Min. GA	14±2	---	23±3	Source: Riebe et al., (2004).
Nicols Peak, S. Sierra Nevada	127±12	---	111±13	Source: Riebe et al., (2004).

Seasonal Variation of Erosion Rate

Changes of suspended sediment rates in the Delaware River corresponded mainly to the increase and decrease of river discharge. This implies that suspended sediment loading is larger during March and April when the snow-melting and ground thawing occur (Fig. 4). However, because of the large amount of precipitation in August, the total sediment loading can increase significantly in August in response to the flash flooding, such as the spike of total suspended sediments observed in 1955 (see Fig. 2). The average suspended sediments of August from 1950 to 1982 for Trenton station is 2830 tons/km^2/year (Fig. 4). However, excluding the sediment loading spike of August 1955, the average sediment loading of August during this same period from 1950 to 1982 will be only 707 tons/km^2/year at Trenton station, which is similar to the average sediment loadings for July and September. The concentrations of the seven major ions except silica correlate inversely with the discharge of the river (Fig. 5). They are low when the discharges are high in March and April, and high in the summer when the river discharges are low. The monthly concentrations of silica are high in the winter period and low in the summer and fall periods, and have a negative correlation with temperature. This might indicate that the solubility of silica may be responding to the temperature differently from the other ions (Moon et al., 2007). However, the silica concentration generally increases with temperature from most of the previous studies (White and Blum, 1995). The total TDS loading (TDS x discharge), which is the total weight of the major ions including silica, shows a similar changing pattern as the total suspended sediment (Fig. 4), with a small loading in the summer months and a relative large loading in the spring months.

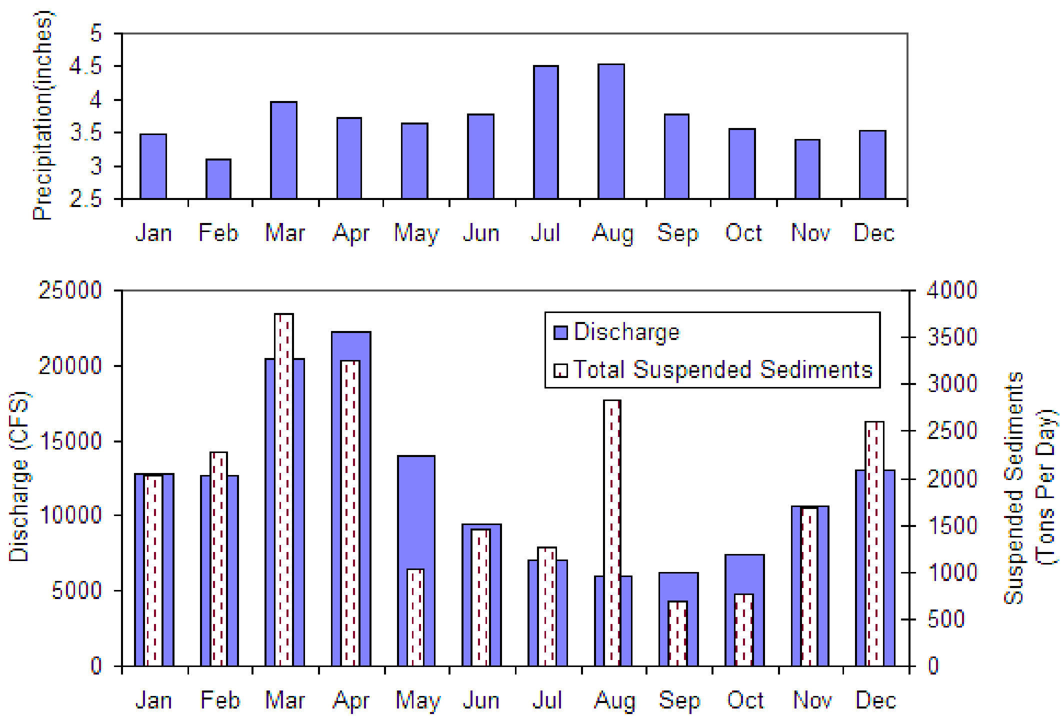

Figure 4. Average monthly suspended sediment loads vs. average NJ precipitation and discharge of the Delaware River at Trenton station.

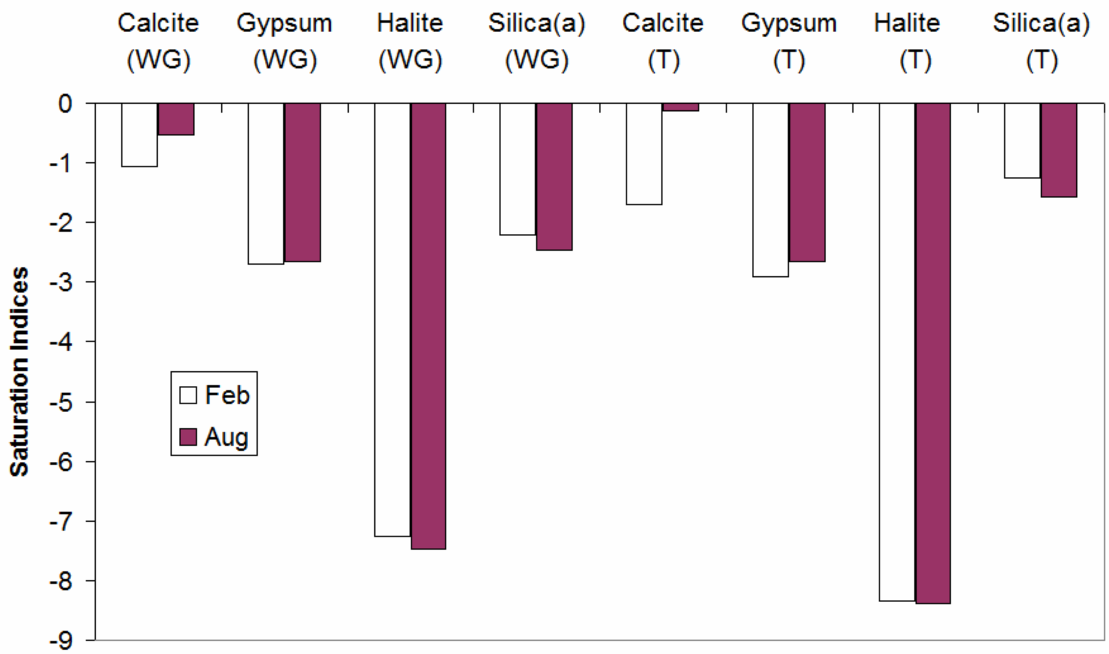

Figure 5. Seasonal variation of ion concentrations vs. discharge of the Delaware River at Trenton station.

Saturation Indices of Minerals in Water

The saturation index (SI) was calculated for the period between 1970 and 2008 for each station when the data are available, with the river chemistry as the input for the WATEQ4F program. Saturation indices of 50 mineral species were given by the program output. Only the average SI of a few minerals that are related with the road salt, sulfate atmospheric loading and two other common weathering products, calcite and amorphous silica are identified here (Fig. 6). For calcite, it is near saturation in August, which corresponds to its higher molar concentration in the summer (Fig. 5). Halite (NaCl) shows a slightly higher SI in February than in August. This seasonal change of halite might be related to the deicing salt application in the winter as discussed in the previous section. But overall, the halite saturation in the water is still very low as indicated by their large negative SI (Fig. 6). The SI of amorphous silica shows a trend that is opposite of calcite. It is more saturated in February than in August. The seasonal trend of gypsum's SI is similar to that of the calcite, with a high SI in August. However, there are obvious differences between the SI of the data at the Delaware Water Gap and Trenton stations. Their differences might reflect the differences in their underlying geology and the atmospheric deposition.

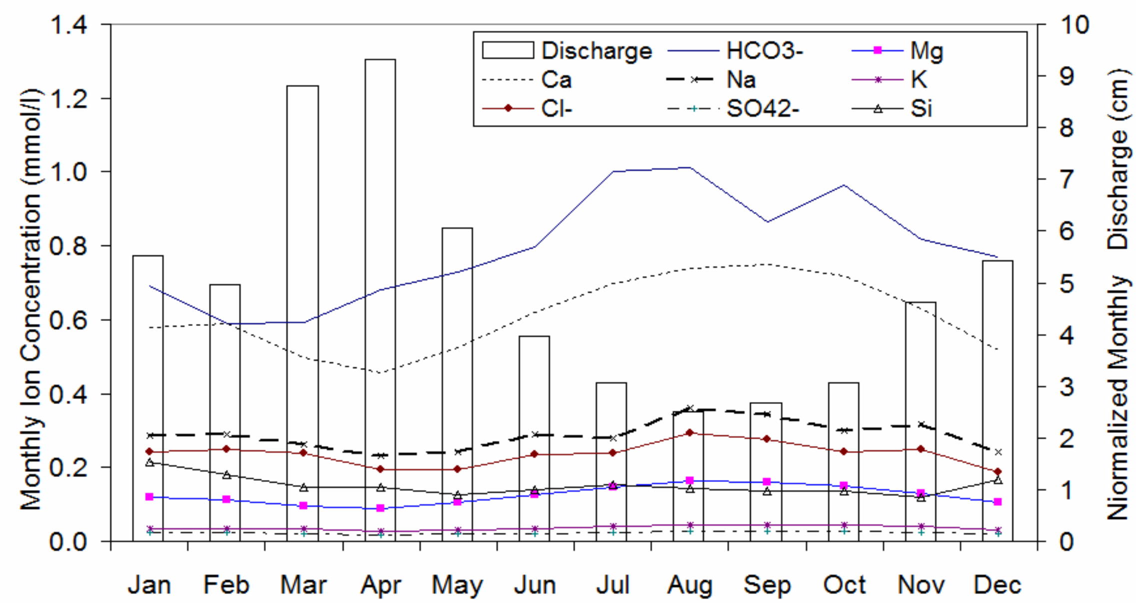

Figure 6. Saturation indices of calcite, gypsum, amorphous silica and halite from Delaware Water Gap (**WG**) and Trenton (**T**) stations in February and August.

MINERAL WEATHERING IN THE AREA

The mineral weight percent of soils samples for four soil cores are given in Table 2. The mineral weight abundance of the NAWC core shows that the weight abundance of quartz decreases with depth, while weight abundance of feldspar increases with depth. Relatively, there is more plagioclase feldspar in the samples. The change of weight abundance of clay minerals with depth depends on the specific type of mineral dominant and varied weight abundances for clay minerals. This diverse mineral weight abundance from various soil sites including some of our earlier studies (Sun et al., 2008) reflects the diverse ion concentrations in the DRB.

Even though the weight abundance of carbonate minerals, calcite and dolomite are only a small portion of the soil mineral mass, because of the relative large amount of calcium, and magnesium in the river water, they still might play a large role in the mass balance calculation of calcium and magnesium in the Delaware River based on similar studies conducted by other researchers (Blum et al, 1998, Grosbois et al, 2000).

Table 2. Mineral weight percent abundance of the study sites

	NAWC West Trenton Site, Depths below Land surface in Feet							Other Sites		
Depth →	0	2	3.8	7.9	10	11.8	15.8	Stock	PARK	Diosite
Quartz	45.16	46.32	42.40	7.08	0.00	1.96	14.07	35.08	0.00	8.56
K-feldspar	10.56	3.02	7.51	21.81	25.29	16.11	3.42	12.87	2.48	8.35
Na,Ca feldspar	3.06	7.28	14.78	7.27	23.76	42.51	48.94	15.49	23.04	35.69
Calcite	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11
Dolomite	0.54	0.00	0.17	0.07	0.13	0.00	0.00	0.25	0.90	0.29
Pyrite	0.00	0.03	0.09	0.13	0.00	0.40	0.17	0.02	0.97	0.43
Gypsum	1.33	0.58	0.00	0.49	0.34	0.00	0.88	0.67	0.00	1.01
Magnetite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.73	0.01
Hematite	0.00	0.07	0.34	0.10	0.00	3.76	5.03	0.58	2.16	0.10
Goethite	1.72	1.75	1.66	0.89	0.80	0.00	0.26	1.21	0.00	1.27
Kaolinite	6.29	4.88	5.00	11.59	6.51	0.09	0.60	1.96	0.00	7.59
Smectite	20.56	18.40	19.04	28.43	22.37	18.20	11.86	9.98	20.28	16.17
Illite	2.16	5.08	1.24	4.63	19.28	12.58	0.00	5.03	5.09	2.01
Biotite	1.91	1.69	1.35	2.68	0.00	0.00	0.14	6.35	8.78	4.31
Chlorite	3.32	3.34	0.80	5.83	1.51	1.66	0.20	9.88	33.03	11.80
Muscovite	3.36	7.56	5.61	8.99	0.00	2.71	14.42	0.40	2.54	2.31

NAWC = Naval Air Warfare Center, West Trenton; Stock = Stockton Elementary School ground; Park = Washington Crossing Park; Diosite = diorite road cut on Route 29.

SUMMARY AND CONCLUSIONS

Denudation rates in the Delaware River Basin vary from upper stream to downstream. Overall, the chemical weathering is prominent due to the high moisture level and longer soil water residence time in the DRB. The total denudation rates of 28 and 128 tons/km^2/yr are comparable to the rates obtained from other regions of the country. The major ion concentrations are usually high in the summer with a sequence of Ca>Mg>Na>K. Concentration of silica shows a slightly different trend. Because of the anthropogenic contribution of the winter deicing salt, the concentrations of Na and Cl have nearly quadrupled during 1945-2007. The weight abundance of soil minerals changes with soil depth. Overall, there is more quartz near the surface and more feldspar at depth, which could reflect the decreasing level of mineral weathering with depth.

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CHLORINATED SOLVENT CONTAMINANTS IN SOIL AND GROUND WATER AT A NEAR-SHORE INDUSTRIAL FACILITY AND THEIR IMPACT ON PASSAIC RIVER WATER AND SEDIMENT QUALITY

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ABSTRACT

Recent regulatory emphasis on Passaic River water and sediment quality has been focused primarily on those industrial facilities that have directly discharged pollutants into this important commercial and recreational waterway. However, New Jersey's long history of industrial development, and the strong interconnection that many of its waterways have with their surrounding geology, clearly demonstrates that other, less obvious contaminant pathways need to be considered in assessing potential sources and eco-system impacts. Chlorinated solvents present in soil and ground water at one industrial facility some 100 feet from the Passaic River and with no direct (end of pipe) discharges to the River provides an example of how ground water migration may contribute to water quality and sediment degradation. Flow net and seepage analysis predict that up to 4,800 gallons per day of ground water contaminated with up to 5,000 mg/L of chlorinated solvents may be entering the River. Although this represents a small contaminant mass that is quickly diluted, multiplied by the operational life of the facility and if considered representative of the hundreds of other such industrial sites that border the Passaic River, contaminant mass loading values quickly rise to significant levels. Further compounding the effects of these impacts is the potential for retention of chlorinated solvents on pelagic sediments and their eventual incorporation and bioaccumulation into local food webs. From an environmental policy perspective, these findings support the need to look beyond direct dischargers as the only class of potentially responsible parties worthy of inclusion in enforcement and remedial actions. Distant, yet hydraulically connected industrial facilities where releases to ground water have occurred can play an important role as contaminant contributors to the Passaic River. Although more difficult to administratively identify, regulatory agencies need to consider technically reasonable and reliable assessment methodologies that allow for a fair and equitable distribution of cleanup responsibility among all responsible parties.

INTRODUCTION

The Lower Passaic River Pilot Project (LPRPP) addresses the cumulative contamination and degradation that is the result of nearly two hundred years of industrial activities that have taken place since the early 19th century. The goods responsible for the economic growth, prosperity and modernization enjoyed by most Americans were generated by chemical, paint, and pigment manufacturing plants, petroleum refineries, and myriad other industrial facilities along an 8.25 mile reach of the Passaic River from the Dundee Dam to the confluence at Newark Bay. The contribution of industrial effluents are recorded in river sediments as high concentrations of mercury, lead, dioxins, polychlorinated biphenyls, polycyclic aromatic hydrocarbons, and chlorinated volatile organic compounds. As a result, wildlife habitats have degraded extensively; floatable debris and pathogenic microbial contamination abounds, and recreational resources are diminished or non-existent, while the economically disadvantaged are inequitably exposed to contaminants and heath risks that remain where economic boon once flourished (Deason, 2008).

Estimates of time required to remove sediment acting as contaminant sources reach into the centuries, assuming all contaminant discharge has ceased. But the fact remains that at least a dozen petroleum refineries and six chemical plants are still operating within the approximately 400 square mile watershed (Deason, 2008), and the effective control of municipal waste discharges, urban runoff, and non-point source contributions remain problematic under current regulatory frameworks. The LPRPP has underscored the premier perpetrators and depository of a pollution-prolific industrial revolution. It appears that extensive dredging and removal is the required primary solution; no long term alternatives can be realized, however, without reversing the input/output equation. While some discharges to the lower Passaic River are monitored, regulated and tallied, upstream sources, and more elusive, non-point sources have not been weighed in, remaining unmeasured and unknown.

NON-QUANTIFIED CONTAMINANT SOURCES

One contaminant source that certainly reaches the river but is rarely included in discharge mitigation planning is ground water. An industrial facility that has no end of pipe discharge, but contains contaminated soil through which ground water passes, often goes unnoticed for years. Given the close interconnection between the Passaic River and its surrounding geology, those constituents the soil readily desorb to ground water, which eventually flows to the river.

Geology determines the life span and transport of ground water constituents, and the Passaic Formation can provide a benevolent host for natural attenuation; but more often, the heterogeneous deposits of silts and clays sequester even low concentrations of volatile organic compounds, rendering them unresponsive to air sparging, vapor extraction, and other physiochemical (remedial) processes, and instead, generate contaminated ground water plumes that impact the river waters and sediments. A case study of an industrial facility situated in the upper reaches of the Passaic, approximately five miles north of Dundee Dam, and approximately 100 feet east of the River, is presented as one example of an unmeasured contaminant threat. This site, when combined with the many other similar sites along the upper Passaic River, represents a significant contribution to both existing and ongoing contaminant pathways degrading this important waterway.

MANUFACTURING COMPANY CASE STUDY

The BETA Manufacturing Company[1] was developed in 1929 as a fabric finishing business engaged in textile dying and processing. These activities took place on the property until 1960, when the building was sold, and subsequently leased to BETA Manufacturing. BETA Manufacturing distributed and assembled electrical parts for the automobile industry. An

[1] This site currently is within the regulatory review process so a fictitious name has been used to protect the privacy of the owners.

aerial photograph of the property as it looks today is provided as Figure 1. In December 1997, as part of refinancing for the property, a Phase I Environmental Site Assessment (ESA) was performed. In August 1999, an additional Phase I ESA was conducted as part of another real estate transaction. Both Phase I ESAs concluded that, because of the site's long industrial history and the nature of manufacturing operations, a soil and ground water investigation was necessary.

Figure 1. The site of BETA Manufacturing Inc.

In March 2000, ten monitoring wells were installed on the property. Subsequent laboratory analysis of ground water samples found that chlorinated solvent concentrations were present above the New Jersey Department of Environmental Protection (NJDEP) Ground Water Quality Standards (GWQS). Analysis of soil gas indicated that 1,1,1-trichloroethane (TCA), tetrachloroethene (PCE), and trichloroethylene (TCE) were detected in several locations throughout the property. The NJDEP was notified of a release, and a spill number assigned. BETA agreed to conduct further remedial activities under a Memorandum of Agreement (MOA) as part of the NJDEP's Voluntary Cleanup Program. A Preliminary Assessment was submitted in July 2000, which identified 20 areas of concern. Areas of Concern or AOC are places where releases of hazardous constituents to the environment may have occurred). The most important AOCs are shown on Figure 2 and included:

- Three concrete vaults, ranging in capacity from 10,000 to 65,000 gallons, which may have been used in the dying/textile finishing process,
- One 1,000 gallon chlorinated solvent above ground storage tank (AST),
- Numerous above ground piping and vats associated with a parts degreasing process, and
- An aboveground storage tank (AST) used for TCA and TCE.

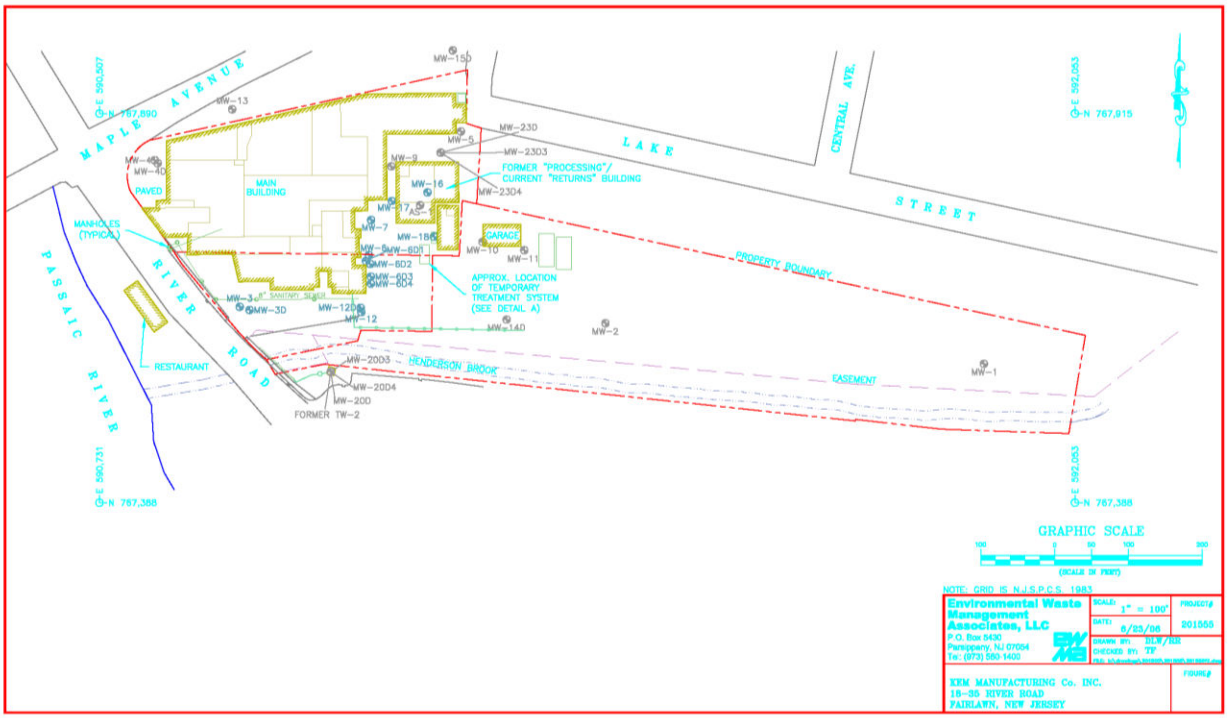

Figure 2. Site plan

A remedial investigation (RI) was done in August 2000; soil borings were advanced within targeted areas that contained elevated concentrations of PCE, TCE and TCA in ground water and soil-gas. Soil borings were initially advanced to an obvious confining layer, bedrock, or the water table, whichever was encountered first. Soils were field screened with a photo-ionization detector (PID); and positively biased samples were collected and analyzed where the readings were highest. Of the forty samples collected, eight contained volatile organic compounds (VOCs) above NJDEP soil cleanup criteria. Soil sampling data are summarized in the following table:

Soil Exceeding NJDEP IGWSCC
(Impact to Ground water Soil Cleanup Criteria)[2]

Soil Sample ID	Depth of Sample (feet)	NJDEP IGWSCC (mg/kg)	TCE (mg/kg)	PCE (mg/kg)
B4-8/00	4.25-4.75	1	**2.06**	Not Detected (ND)
B9-8/00	3.25-3.75	1	**13.0**	ND
B13-8/00	5.0-5.5	1	**14.4**	0.720
B3-042001	1.5-2.0	1	**4.76**	0.261 J
B6-042001	1.5-2.0	1	**2.89**	0.304 J
B6-042001	11.5-12.0	1	**3.03**	0.304 J
B8-042001	7.5-8.0	1	**9.2**	**1.34**
B21-062005	5-5.5	1	**9.43**	0.58
B23-062005	4.25-4.75	1	**4.32**	ND

Laboratory analysis of ground water samples collected from monitoring wells in April 2000 reported concentrations of TCE, PCE, TCA and Vinyl Chloride in six of ten samples at concentrations wells above the respective NJDEP GWQS. An additional eighteen monitoring wells then were installed to delineate the horizontal and vertical extent of ground water impacts. These delineation wells were installed in the saturated overburden, to approximately 25 feet below ground surface (bgs), and at several intervals within the underlying bedrock to depths of up to 160 feet below ground surface (bgs). Results from three subsequent sampling events confirmed that ground water was impacted in the saturated overburden and the underlying bedrock. Total VOC concentrations, consisting predominantly of PCE and TCE in shallow ground water ranged from 25 to 47,100 µg/L, with total VOC concentrations in bedrock ground water in the range of 3,000 µg/L. The NJDEP GWQS for PCE and TCE is 1 µg/L. Figures 3 and 4 illustrate the distribution of chlorinated solvents in both shallow and bedrock water-bearing zones.

GROUND WATER DISCHARGE TO THE RIVER

Currently, the extent of impacted ground water has not yet been fully delineated at the site and the vertical extent of the plume is not fully defined. Despite these, we are in the process of developing remedial strategies, including air sparging and soil vapor extraction in the overburden, while characterization of the plume continues with the installation of additional delineation wells. Down-hole geophysical surveys also are being conducted to identify pertinent fractures associated with pollution transport within the bedrock, and to allow for effective development of treatment options.

The process of contaminant delineation, evaluation, impact assessment and remedial design and implementation takes years, and even decades to complete under current (very prescriptive) regulatory guidelines and long review time periods. The cost of remediation of a single industrial site escalates into the millions of dollars, particularly when chlorinated solvents are discovered at depths of a hundred feet and more into bedrock, and laterally extend across the overburden onto neighboring properties and into adjoining waterways.

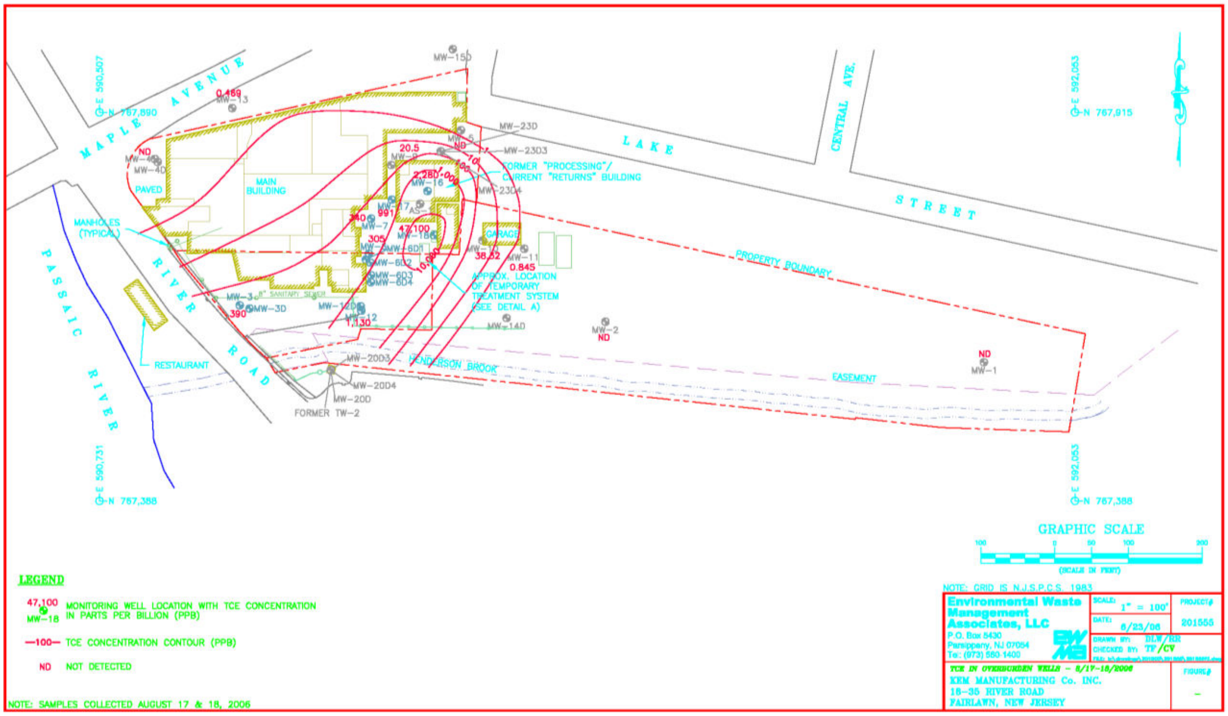

Figure 3. TCE Iso-concentration plan in saturated overburden

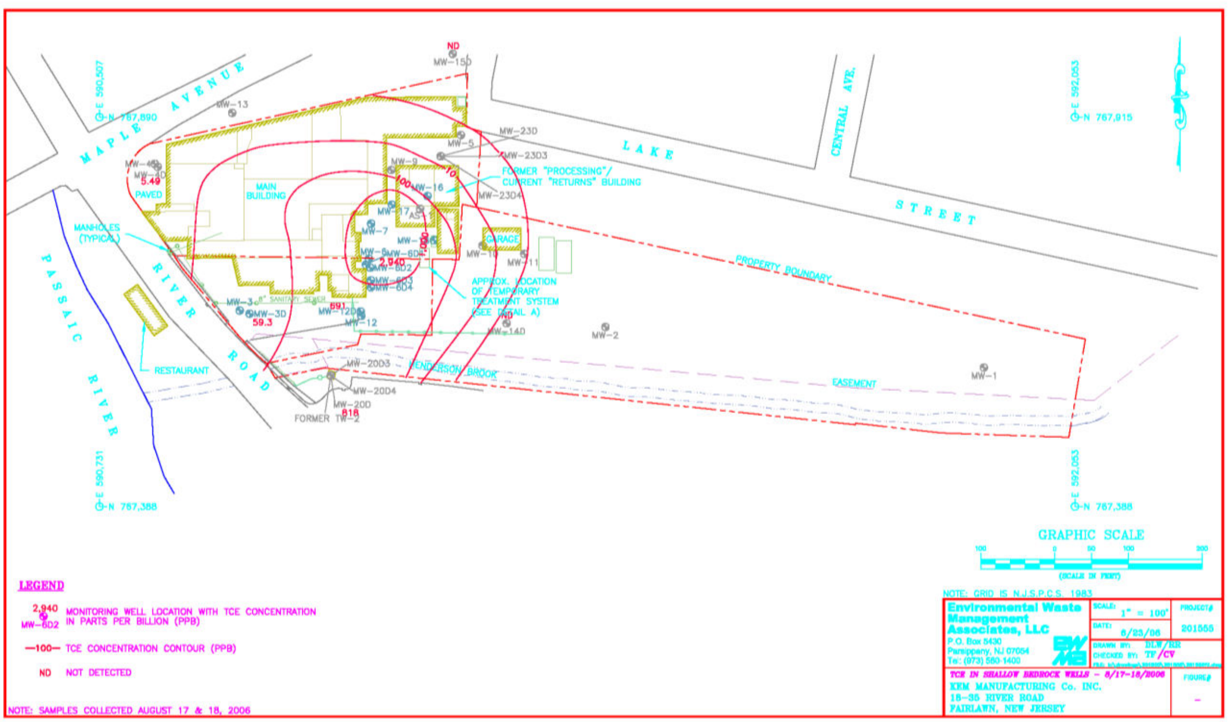

Figure 4. TCE Iso-concentrations in shallow bedrock

Using the information gathered through 2007, and some basic hydrogeologic calculations, we have calculated a conservative estimate of contaminant contribution to the Passaic River from this single site. We have assumed that all ground water within the plume area in the saturated overburden will enter the river and that ground water contribution from the sandstone bedrock beneath the overburden also will be discharged to the River. This is based on a flownet that indicates an upward gradient (flow) component exists between the underlying bedrock and the river (Figure 5).

Q = KAi, where

Q = Total discharge rate (gallons per day)
A = Cross-sectional area of the plume
K = Estimated hydraulic conductivity
i = Hydraulic gradient

where:

A = 6,300 ft^2 (width of the plume * the average thickness of the saturated overburden)
K = 2.83 ft/day (fine sand taken from Freeze and Cherry, 1979)
i = 0.036 (calculated from overburden ground water elevations)

Q = 641.84 ft^3/day or roughly 4,800 gallons per day

Similarly, an estimate of ground water discharge into the Passaic River through the underlying shallow bedrock can be calculated:

A = 32,500 ft^2 (width of the plume * and a (somewhat) arbitrary thickness of 50 feet in the shallow bedrock)
K = 0.028 ft/day (sandstone from Freeze and Cherry, 1979)
i = 0.012 (calculated from shallow bedrock ground water elevations measured on Nov 5, 2007)

Q = 10.92 ft^3/day or roughly 80 gallons per day.

A conservative (i.e., low) estimate of ground water entering the river from this BETA site can be expressed as 4,900 gallons per day. Combining representative total VOC concentrations in overburden and bedrock water bearing zones with these discharges rates yields the following contaminant loading rates:

Overburden: 4,800 gpd * 5,000 µg/L = 0.2 pounds per day (70 pounds or 32 kg per year) of total VOCs discharged.

Bedrock: 80 gpd * 300 µg/L = 0.0002 pounds per day (0.07 pounds or 30 grams per year) of total VOCs discharged

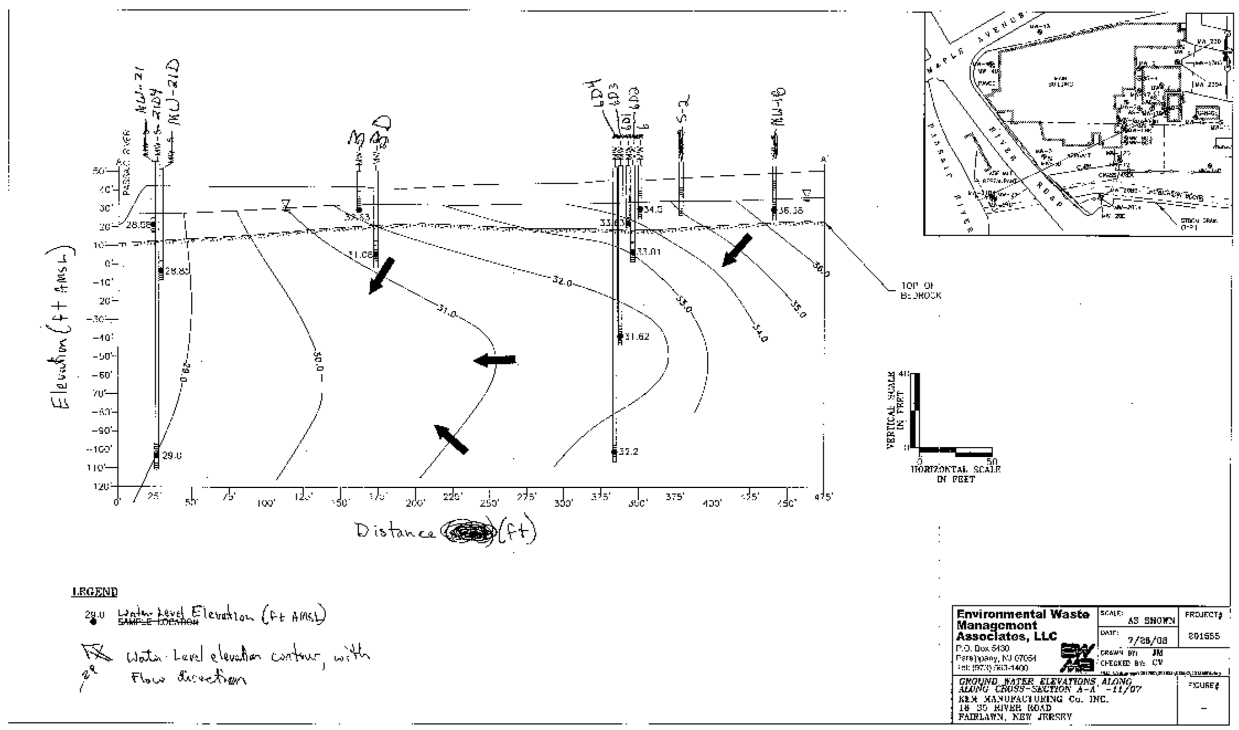

Figure 5. Groundwater elevations along the A-A` cross-section.

The daily mean discharge value for the Passaic River at the Little Falls gauging station, in cubic feet per second (cfs), as determined by the United States Geological Survey (U.S.G.S.) is about 780 cfs, which can be roughly expressed as 500 million gallons per day of discharge in the Passaic River. Therefore, ground water impacted with chlorinated solvents from the BETA site represents only a very small fraction of the total volume of water flowing to Newark Bay. And this, indeed, has been the argument that has been offered for decades to justify inaction. But the additive and, perhaps, synergistic effects of numerous industrial sites and other facilities reported with similar contaminant releases that have contributed pollutants over the course of a century are evidenced by the degraded state of the River, the disappearance of habitat and wildlife, and lackluster appeal of riverfront real estate.

One obvious cause of the current state of pollution is the shear number of known contaminated sites that have adversely impacted ground water and are on this upper reach of the Passaic River. Based on a review of the NJDEP I-map web-site, seventy five known contaminated sites are present along the upper reach of the Passaic River. These sites are likely current sources of ground water contamination in the Passaic River watershed. Figure 6 illustrates the NJDEP I-map of the River that runs from the falls at Paterson to the Dundee Dam and graphically illustrates the industrial and commercial activity present in this area. If our (very simplistic) model is expanded to include these seventy five sites, and using the same fairly conservative (low) flow rates and contaminant concentrations, annual discharges of VOCs into this part of the Passaic River increase to over 5,000 pounds per year.

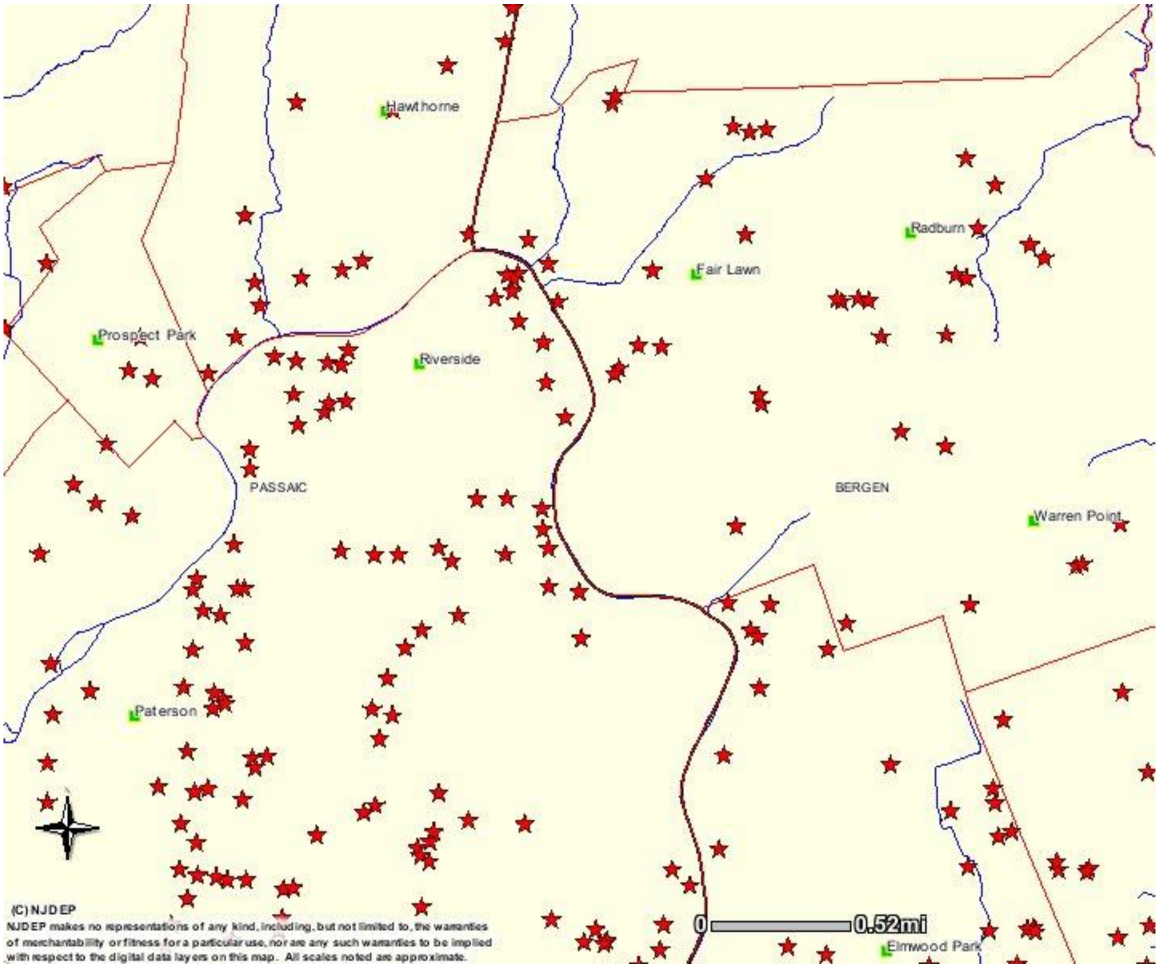

Figure 7. NJDEP I-map

REGULATORY CONTEXT

The full array of discharges to the River from facilities that operate on its Upper Reach cannot be fully characterized by the activities of the known contaminated sites operating in that area. Regulatory measures designed to protect human health and the environment by monitoring use of natural resources and managing wastes generated were not introduced until 1972, with the enactment of the Federal Clean Water Act (CWA). Among legislation to follow was the Resource Conservation and Recovery Act (RCRA), enacted in 1976, a Federal law that addressed:

- Conserving energy and natural resources.
- Reducing the amount of waste generated.
- Ensuring that wastes are managed in an environmentally-sound manner.

The Source Water Assessment Program (SWAP) was established in 1996 as a requirement of the Safe Water Drinking Act, under which the Federal government requires states to evaluate potential risk of contamination to public drinking water. As these were implemented by New Jersey, further State legislation provided additional protections including the classification of the surface waters, regulation of storm water, and finally, the legislation targeted at industrial discharges; the New Jersey Pollution Discharge Elimination System (NJPDES). Under NJPDES, industrial facilities, sewage treatment plants and storm sewers require a permit to discharge to the state's waterways. Discharge Monitoring Reports (DMRs) are required to evaluate compliance, and subjected to public scrutiny in a review process once every five years. But these measures came slowly, following decades of unmonitored activity, much of which is still unknown, and the process of cleanup is slow, expensive, and a process of environmental detective work.

The discovery of unknown soil sources, contributing contaminants to ground water and eventually to surface water is an ongoing task. Its main driver has been the establishment of the New Jersey Bureau of Underground Storage Tanks (BUST) in 1998, and another important vehicle targeting the real estate transaction and responsible parties: the Industrial Site Recovery Act (ISRA). With the Technical Requirements for Site Remediation (TRSR), specific guidelines and time frames for the operation, upgrade and closure of underground storage tanks was provided and helped address one of New Jersey's major threats to waters. In addition, the subsequent investigation and remedial action required for impacted soils and ground water are specifically outlined within the TRSR.

By targeting the storage of hazardous materials, gasoline, heating oil, waste oils, and other petroleum products, other contaminants were uncovered; thus, many site investigations were begun, revealing a century's worth of unchecked pollutant releases into ground water and soil. Under ISRA, the point of action comes with the transaction of real estate, as both parties are required to examine financially costly environmental liability as ownership changes hands, and lending facilities require transparency before approving mortgages. The BETA site is a case in point of this very process. A real estate transaction required investigation of underground storage tanks, so commonly used on industrial sites for storing gasoline, heating oil, and other materials pertinent to the manufacturing process. As is the case for many industrial facility transactions, the presence of industrial solvents was uncovered as a by-product of a ground water investigation required under BUST, as the gasoline USTs were removed and closure of the system was sought. It is clear that no one will ever know all that transpired from 1929, when this was the site of a textile dying and finishing plant, through 1997, when a real estate transaction illuminated part of the contaminant impact to soil and ground water; all due to such recent environmental legislation.

WATERSHED IMPLICATIONS

One way to gain an understanding of the environmental impact industry has brought to bear on the Passaic River is by examining river sediments. Although imperfect as a forensic tool, as sediments are washed to Newark Bay, and eventually to the sea, the study of sediments gives the primary starting point for large scale clean-up, and a laboratory for understanding the specific processes of waste breakdown, and impact on the health of a stream. The LPRPP provided funding for a detailed investigation of the Passaic River, and numerous papers have been published using the extensive data collected.

One recent U.S.G.S. publication (Wilson, Bonin; 2007), examines the contaminants contained in sediments that are transported by tributaries, including the Passaic River. Using storm flow events in each of the study areas, flow-weighted composite samples were collected from the Passaic River, from which both sediment particles and sequestered dissolved contaminants were analyzed for concentrations of organic compounds and trace elements. The annual load of suspended sediments transported by the Passaic River was an estimated 22,700,000 kg/yr. Sediment bound polychlorinated biphenyls (PCBs) chlorinated dibenzo-p-dioxins (CDDs), polycyclic aromatic hydrocarbons (PAHs), organo-pesticides and some trace elements including mercury and lead, were among the contaminants monitored. Estimated concentrations of these constituents transported ranged from grams per year to kilograms per year. Although this study did not analyze for chlorinated volatile organic compounds; those contributed by BETA Manufacturing and other similar sites on the Passaic Upper Reach, important information regarding contaminant transport is presented.

A database of samples obtained from sediments in the Upper Passaic Reach is available online at the site of the Lower Passaic River Restoration Project. Data obtained in September 1994, from sediments sampled 0.5 feet below the river bottom surface are reported for many compounds; data reported specifically for chlorinated volatile organic compounds (CVOCs) is examined as these are the constituents reported in ground water at the BETA site. Samples are reported with concentrations of total CVOCs ranging between 300 µg/kg to approximately 2,000 µg/kg, averaging about 750 µg/kg overall. Volatiles, by nature, are perhaps, an unlikely pollutant on which to focus when compared to the larger quantities of the heavier compounds discussed above, and because they are often contributed by ground water, a non-point source discharge, their importance as contributors to the degradation of rivers and streams can easily be overlooked. But there is evidence that ground water migration does effectively transport CVOCs, and their toxicity is a highly destructive force in the environment.

A study performed on the Savannah River Site in Aiken, South Carolina examines microbial degradation of TCE at seep zones into rivers, streams and wetlands. Conclusions made based on studies at this site were that common degreasing agents containing TCE, TCA and PCE, restricted in their use today because of associated health hazards, are contained in wastes from various industrial uses that have often been dumped or buried into unlined pits, or allowed to seep into soils from vats, tanks and piping. Further, these pollutants seep into subsurface ground water, which transports these constituents over large areas, and commonly through seep zones into streams, rivers and wetlands.

In some areas, microbial degradation of these products can occur where there are active communities of certain reduction capable micro-organisms thriving. But often, this degradation is only partial, where TCE is degraded to DCE or vinyl chloride, and then stops. Both of these daughter products are at least as toxic as the original product and as undesirable in water and soil. Other locations, where sediments are less nutrient rich, organic communities are unavailable to provide natural attenuation. Because of the quantity and variety of contaminants existing in the sediments of Passaic River, and downstream Newark Bay, it is reasonable to assume that healthy organic communities of microbes do not thrive. The degradation of the River and Bay, as evidenced by the loss of wildlife and habitat, is proof that we have overloaded the earth’s natural cleansing abilities.

CONCLUSION

The Lower Passaic River Pilot study has set the stage for what may be the most important cleanup challenge faced today with Northern New Jersey. An expensive, time-consuming, large scale absolution of the sins of the past is in the making. But to strike the balance required to re-establish a healthy, self maintaining ecosystem in the Passaic River, all contaminant pathways must be included in the equation. The contribution of ground water from soil source contamination that exists inland within the Passaic River watershed is a key component that must be addressed in order to decrease contaminant input to the Passaic River and truly manage its restoration to a vibrant and productive waterway.

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THE ENVIRONMENTAL GEOLOGY OF BALBACH SMELTING AND REFINING COMPANY'S SITES IN NEWARK, NEW JERSEY

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ABSTRACT

Balbach Smelting and Refining Company operated at two locations in Newark between 1851 and 1927. Both of their two sites, the River and Bay Plants, have been redeveloped. The River Plant was developed into the County-owned Riverbank Park, the Bay Plant, continued industrial uses under multiple owners. Both sites have evidence of metal-processing slag in the subsurface. The County Park has not investigated groundwater quality. Most of the multiple businesses owning parts of the former Bay Plant have not been required to investigate the metal-processing residue, nor the groundwater conditions that result from the Balbach processes. The Bay Plant has been listed in USEPA documents while the River Plant has not.

INTRODCUTION

Balbach Smelting and Refining Company operated at two sites in Newark (Figure 1) between 1851 (Ford, 1874) and 1927 (Newark Evening News, 1927). The business was said to start at the River Plant at the foot of Merchant Street, a small two block long street. Balbach first specialized in reclaiming precious metals from jewelry manufacturing "sweeps", a term for small-sized scrap metal. Balbach offices were located at 233 River Street (now Raymond Boulevard), advertisements for the business also listed it as Newark Refining and Smelting Works, Ed. Balbach & Son (Newark Daily Advertiser, 1873). As the business grew, they engaged in smelting of non-ferrous metal ores, lead refining, electrolytic copper refining, precious metals refining, as well as nickel and nickel sulfate production. Balbach operated the first electolytic tank-house operation in the United States (Kershaw, 1908), patented a revolutionary de-silverizing process, and was an innovator in the development of the water-jacketed metal reduction furnace. In 1874 the annual revenue of Balbach was $5MM (Atkinson, 1878); by 1913 it was up to $40MM (Lewis Publishers, 1913).

In 1874, the River Plant covered 2½ acres and employed 125 men (Ford, 1874). Balbach bought a 107 acre tract of marshland at the end of Wilson Avenue in the 1890's and by 1903 had started construction on a modern American Factory System plant that fronted on Newark Bay. The processes where gradually moved to the Bay Plant and by 1924, only small portions of the River Street property were in use. In contrast to the River Plant, the modern arrangement of the Bay Plant showed planning for fire protection, and organized movement of both fuel and product by rail. It had numerous parallel rail sidings stemming from the Bayshore Connecting RR that serviced both building loading docks and interiors. The Bay Plant covered over 49 acres that is now subdivided into at least five different industrial properties along Doremus and Wilson Avenues (Figure 2). One portion of the larger marshland property along Wilson Avenue was used by the City of Newark as a City dump during the 1940's and 1950's, it is now owned by NJ Transit. Likewise, a tract to the north shown on Figure 2 was also used as a dump.

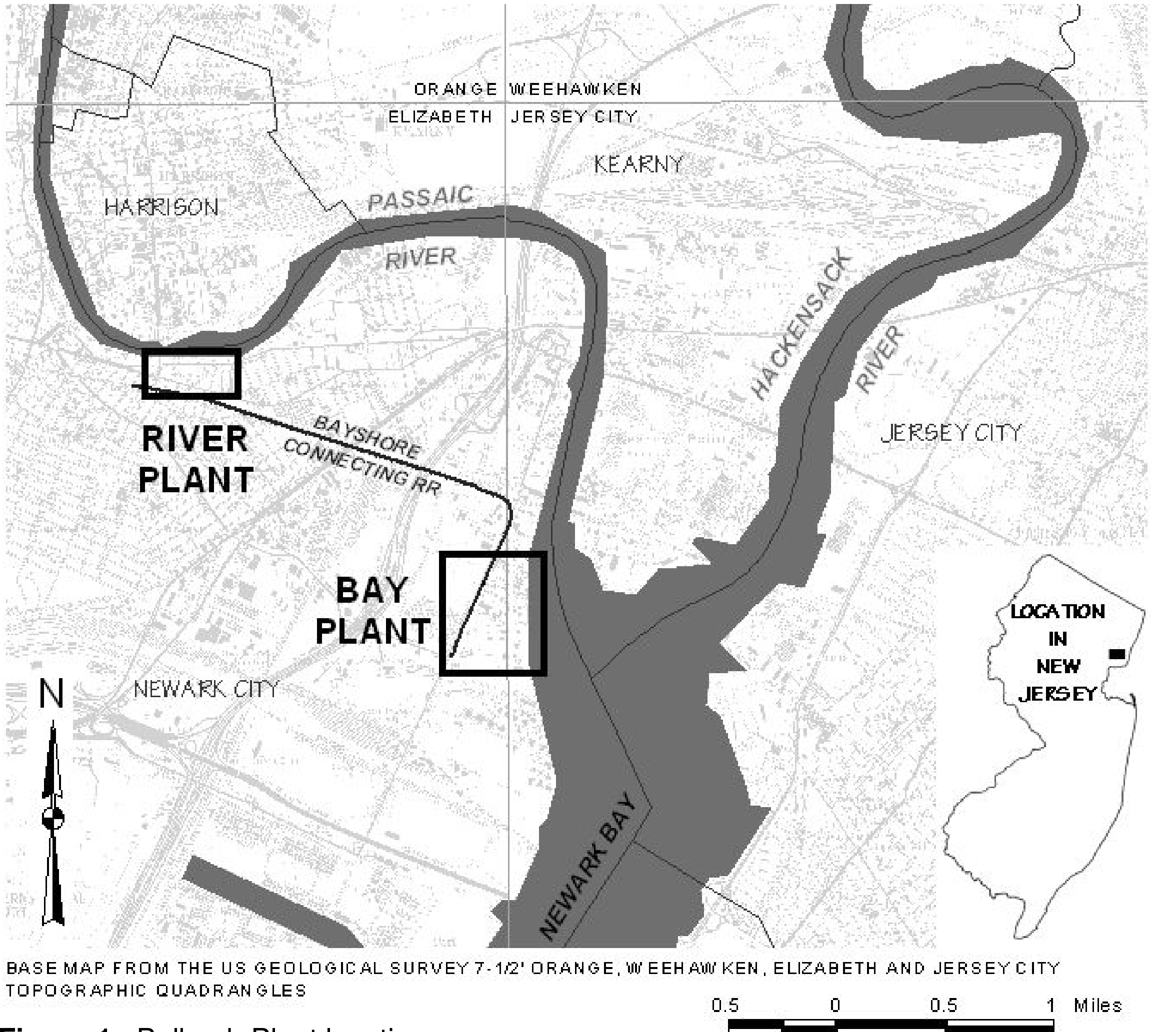

Figure 1. Balbach Plant locations.

The original Balbach mansion site was on 5.75 acres (Newark Board of Trade, 1912), consisting of one city block directly east of the River Plant. It was designated as a City Park in 1907 shortly before Edward Balbach, Jr. died in 1910 (Zakalak, 1997; Sanborn, 1909, notation). The park was enlarged to cover the River Plant site after the processes moved in the 1920's. With street closures it was made into the current 10.77 acre Riverbank Park during a 1930-1931 complete redesign by the Olmstead Brothers architectural firm (Zakalak, 1997). The Park was accepted to the National Register of Historic Places in 1998 after nomination by an organization of dedicated private citizens who stopped Essex County from turning it into a Minor League ballpark (Star-Leger, 1996-2001 series). The citizens had collected a soil sample that showed high levels of heavy metals that closed the Park before construction could begin. The political fight over Minor League redevelopment issue kept the Park closed for approximately five years. After it was reopened, problems with covering-soil quality then closed the park a second time during 2001 and 2002, while consultants and lawyers worked to sort facts and liabilities. The Restricted Use Deed Notice was approved by NJDEP on June 21, 2004, for the entire Park site. Riverbank Park is quite popular with the Ironbound residents, making it the most heavily used of the Essex County Park System.

Figure 2. Land holdings of the Balbach Co. in the 1890's shown with hachure.

RIVER PLANT

Geology, Natural Stratigraphy

Both plant sites of Balbach are located on a flat glacio-fluvial plain. The shallow unconsolidated sandy deposits at the River Plant result from a delta extending into Glacial Lake Hackensack (Stanford and others, 1995). The bedrock is present at depth of 60 to 100 feet and it consists of shales and sandstones of the Passaic Formation. Figure 3 illustrates the sequence beneath the River Plant. A 500 foot deep well drilled by Balbach in 1879 at the River Plant (State Geol., 1879) penetrated 100 feet of sand and encountered red sandstone for the remainder of the depth. A soil boring placed on the southern approach to the Jackson Street bridge penetrated sand and gravel terminating in red hard pan (either till or shallow rock) at a depth of just 22 feet below surface (HAER, 1985). Borings used by Parillo and Kasabach (1962) show a sequence of sand and gravel underlain by silts and clays with bedrock occurring at 98 feet.

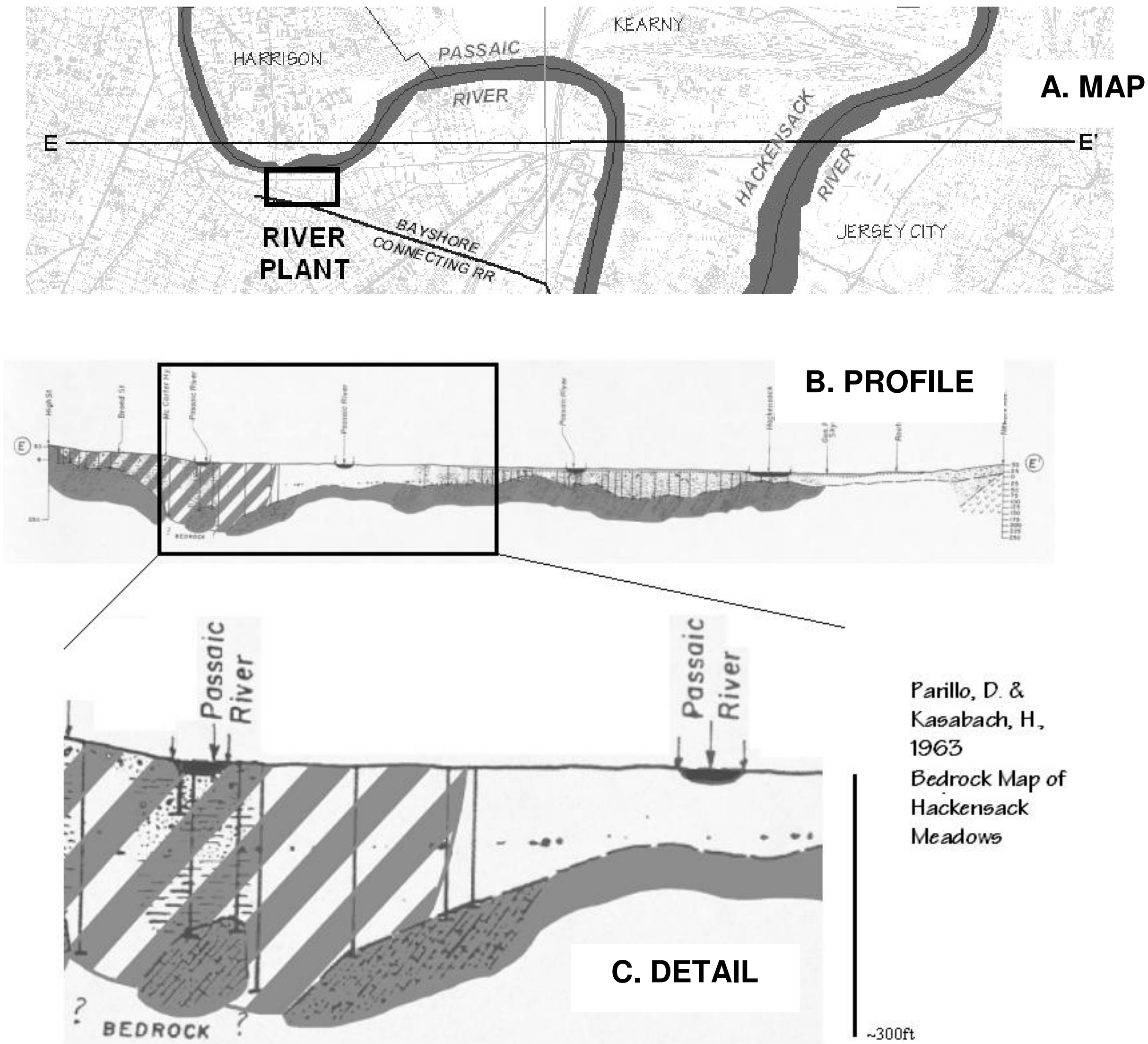

Figure 3. Parillo & Kasabach Section E-E', River Plant. 3A shows the map location. 3B shows the profile view. 3C shows a detail view of the central area.

Geology, Man-made Stratigraphy

Holden (1880) mapped fill material within Newark in an effort to correlate human mortality with fill and the presence of sanitary sewers. As shown on Figure 4, a natural stream course was filled and the water course was transformed into a sewer. The former outfall of the stream now occurs at the boundary of the Jackson Street Bridge and a sliver of neglected Riverbank Park land (the site of Balbach's silver refinery); it was mapped as an historical Combined Sewer Outfall by USEPA (2008). The fill shown on Figure 4 was applied after the Morris Canal was constructed. The Morris Canal passed along the alignment of Raymond Boulevard between 1831 and 1835 (Kalata, 1983) and the Balbach plant was gradually enlarged, eventually with operations both north and south of it. The original contour of the land had to have been altered beginning in the 1830's with the construction of the canal, land to the south was brought to grade by filling as shown by Holden (1880) and two small ponds shown on Holden's map were also subsequently filled. Water level in the canal was eight feet above low tide (Kalata, 1983), the embankments therefore, were higher and filling must have met them. This filling depth-estimate dovetails with the map by Holden (1880).

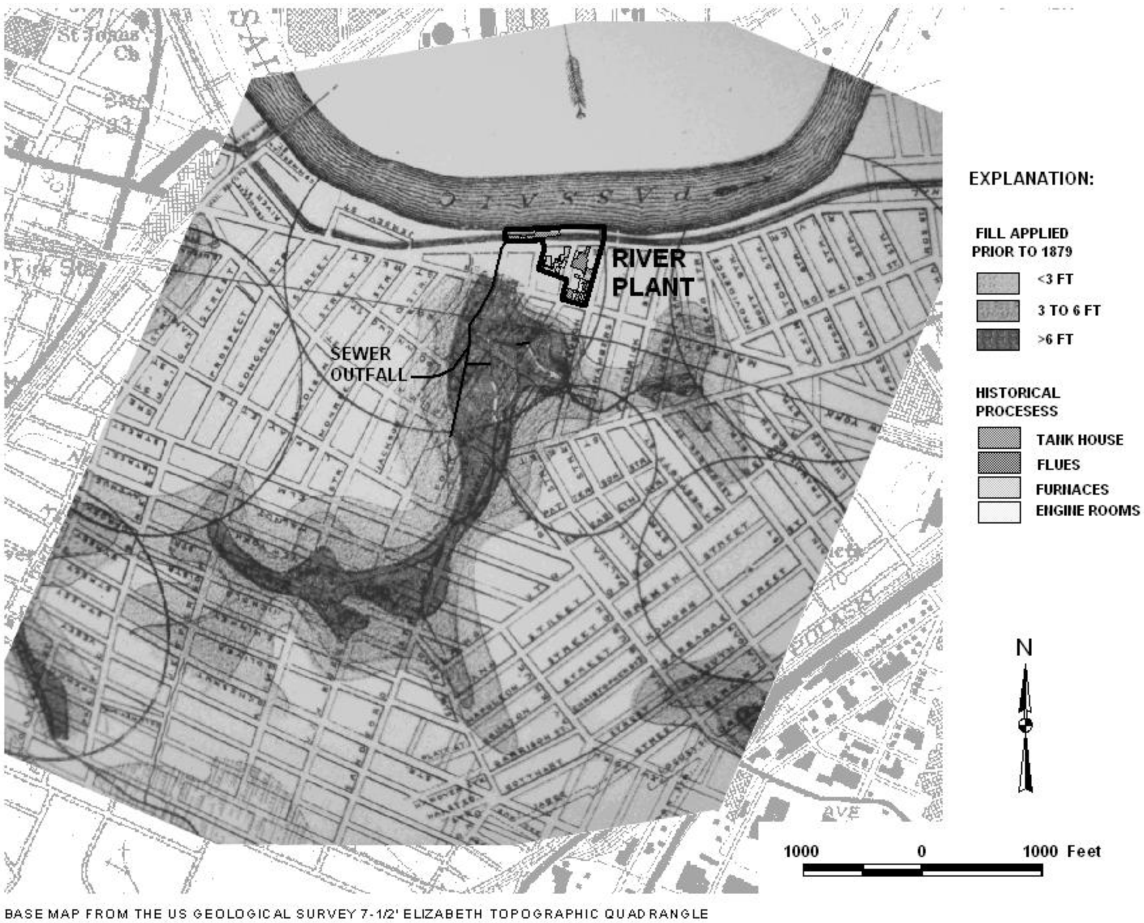

Figure 4. Holden 1880, Fill Material Thickness Map showing the River Plant from the 1884 Sanborn Map.

Balbach also owned property on both the east and west sides of the southern approach of the Jackson Street Bridge which was built through the site in 1897 and 1898 (HAER, 1985). Soil borings on the bridge approach have shown high concentrations of antimony, arsenic, copper and lead, as well as, Polynueclear Aromatic Hydrocarbons (PAHs) in soils, which were probably derived from Balbach (Dresdner Robin, 1994). The highest concentration of lead (32,300 mg/kg) is indicative of lead-processing slag (personal observation). The PAHs are most likely derived from coal combustion residues. The Plant site was found to have widely distributed lead, cadmium and arsenic during the early phases of the investigation (Figure 5).

Balbach used process-derived slag to fill timber-cribbed bulkheads along the Passaic River, and these can be seen today at low tide. Rectangular slag cakes can also be seen on the bank above the high-tide line. In addition, slag was used as an aggregate in substantial concrete piers that are also above the high-tide line. Consultants for the Army Corps of Engineers identified two locations with high metals concentrations adjacent to Riverbank Park, on the Jackson Street Bridge site. These were reported to be removed during the establishment of the Joseph G. Minish Passaic River Waterfront Park and Historic Area during 1996 (EcolSciences, 1997) Within the groomed parkland south of Raymond Boulevard, soil borings by consultants to Essex County found concentrations of arsenic, cadmium and lead with PAHs that they attributed to Balbach (EcolSciences, 1998).

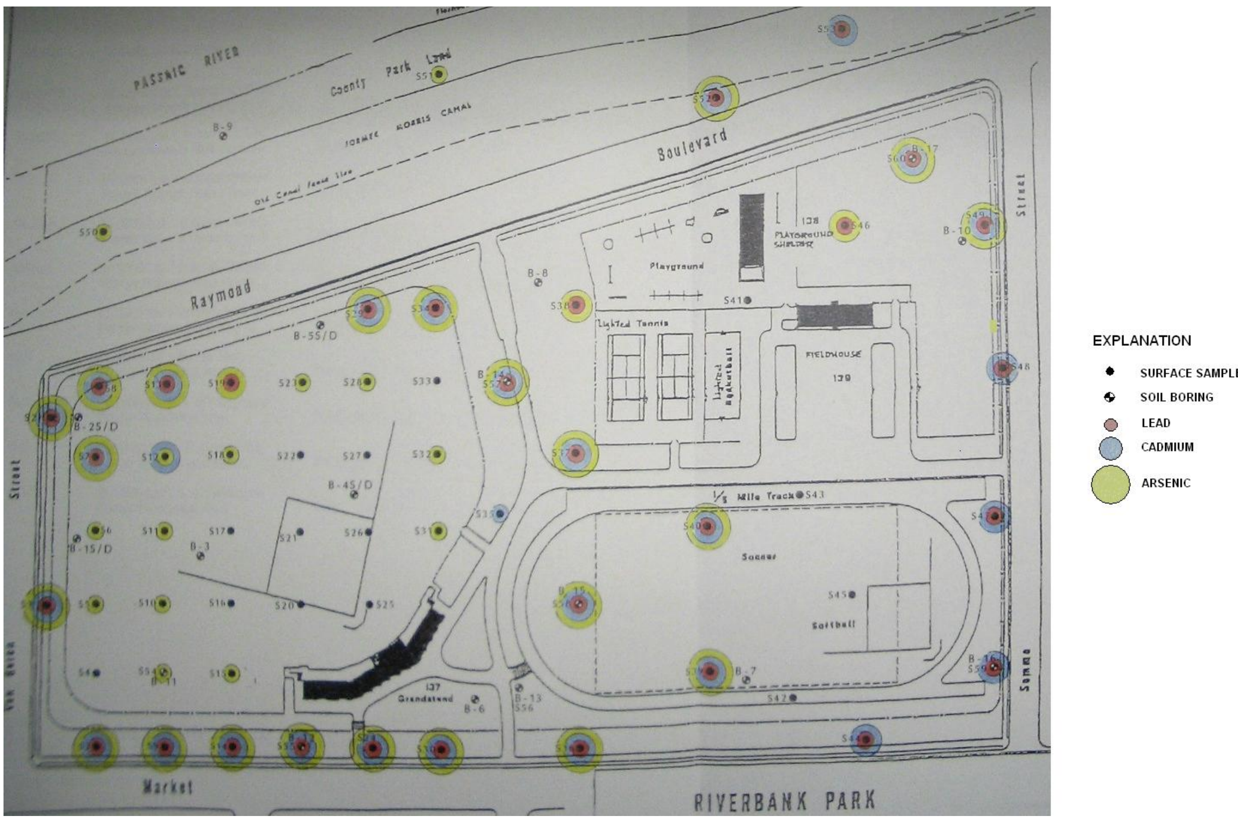

Figure 5. Riverbank Park Contamination Map, from EcolSciences, 1996, Fig. 3

The NJDEP declared urban soil beneath the Park to be Historic Fill as defined by statute on the basis of just 17 borings ranging from 6 to 12 feet deep, some of which stopped without fully penetrating fill; by NJDEP regulations at least 44 fully penetrating borings with an appropriate number of Priority Pollutant analyses and groundwater sampling should have been performed (NJAC 7:26E 4.6(B)). In addition there was no attempt to map out areas containing metal processing wastes. Many samples were collected by three consulting firms to sort-out and verify soil quality after it was discovered that "clean" fill brought to the site exceeded NJDEP's most stringent direct contact soil cleanup criteria. Numerous other soil samples in the top three feet of the groomed Park soil have been analyzed to demonstrate that the park is safe for direct human contact (TRC Raviv, 2003). The NJDEP approved no further action on the basis of the numerous surface samples and the use of artificial turf on the soccer field. The relationship of the Park to the River Plant is shown on Figure 6.

Figure 6. River Plant on 2002 orthophoto imagery

Groundwater

No groundwater quality investigation was conducted at the Riverbank Park site as part of the site remediation and repairs, although water was encountered at depths of 9 to 10 feet below grade (EcolSciences, 1998). The Balbach site had a groundwater production well that was 500 feet deep and capable of producing 500 gpm (State Geologist, 1879). The static water level rose to just above tide level. The location, construction details and disposition of this well are unknown. Groundwater degradation due to salt water intrusion was mapped by Herpers (1947) for the City of Newark. The River Plant location is in an area mapped as having high chloride concentrations (Figure 7). Herpers and Barksdale (1951) presented this earlier map and attributed the salt water intrusion to over-pumping by industrial wells coupled with dredging of the fine sediment barrier over bedrock beneath the river. Nichols (1968) concentrated on other portions of Essex County and does not discuss the Newark groundwater beyond what was previously published.

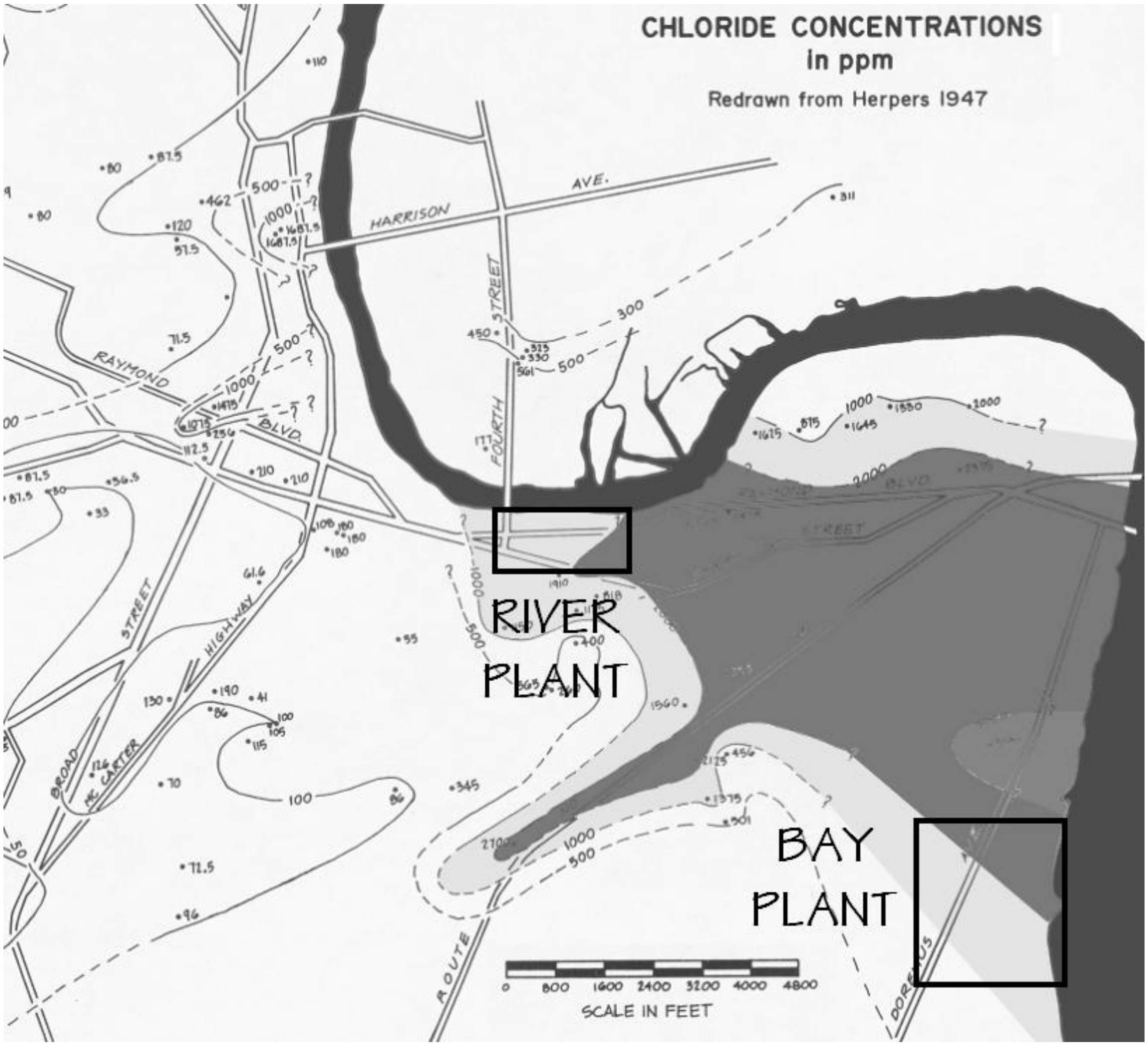

Figure 7. Chloride concentrations in groundwater, Herpers,1947

Sediment

A single sediment sample station (013A) is located just down stream from (east of) the former Balbach site. Although it showed elevated concentrations of arsenic, lead and chromium (USEPA, 1993), it is far enough removed that no direct link can be drawn to the River Plant Site. This area is slated for restoration by the Army Corps of Engineers (2008).

BAY PLANT

Geology, Natural Stratigraphy

The Bay Plant was constructed on a portion of the Newark Meadows that was originally a salt marsh (Vermule, 1868). The unconsolidated deposits consist of lake bottom deposits and in places glacial till (Stanford and others, 1995; Parillo and Kasabach, 1962). Stratified drift composed of silt, sand and clay overlies bedrock of the Passaic Formation at approximately 40 feet deep (Figure 8). Soil borings and monitoring well logs show 8 to 12 feet of fill have been placed on the former meadow mat which is underlain by silt and clay. The shallow groundwater is present in the fill material.

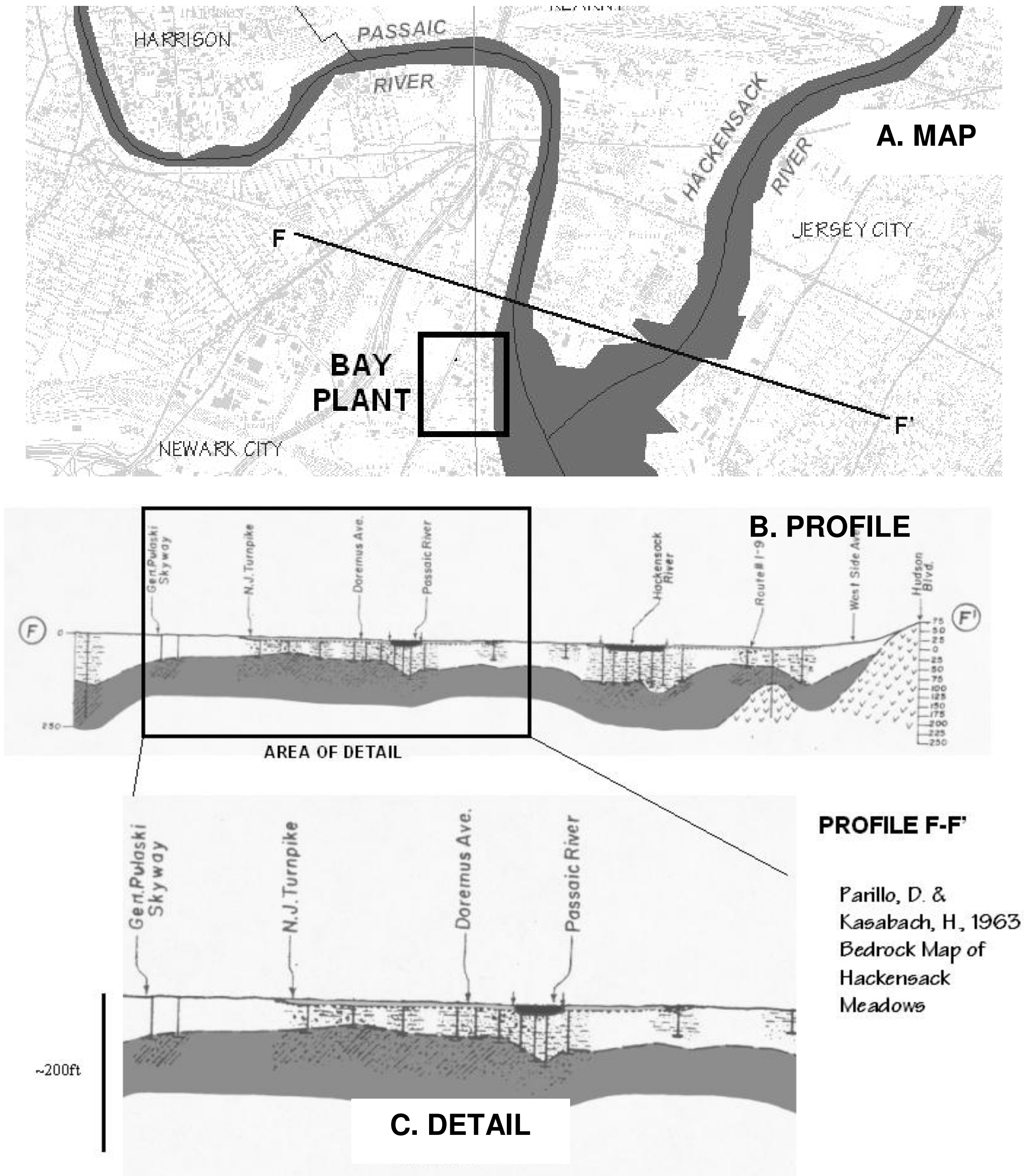

Figure 8: Cross-Section through the Bay Plant Area.

Geology, Man-made Stratigraphy

This site and many more nearby sites were systematically filled with man-made debris before building took place (Zdepski, 1992). It appears that Balbach used the Bay Plant site for disposal of River Plant slag before construction of the new complex, because slag underlies the grade of the smelting buildings and sidings (as shown by boring logs from Sun Terminal, Cardolite Corp., McKesson and Darling International files). The Bayshore Connecting Railroad was built along the alignment of Doremus Avenue during 1903 and it would have provided a convenient route for bulk haulage from the River Plant into the Bay Plant site (Figure 1).

The bulk of the fill was placed by Balbach, because the grade level established for the early plant buildings is still extant, with only recent shallow cover of gravel and in places thicker formal engineering control measures obscuring the earlier building outlines. Aerial photography from 1995 available on the NJDEP I-Map shows the former Balbach building outlines as bare slabs. In some cases the Balbach buildings are in-use. Therefore, no significant application of new fill has occurred in those areas.

The environmental evaluation has taken a fragmented path because the Bay Plant site was subdivided in the mid-1940s. Investigations for the NJDEP by Sun, concentrate on gasoline and light petroleum constituents, not Metals and PCBs. Cardolite investigated a full range of Priority Pollutants in soils under an MOA, finding Metals, PAHs, and PCBs were present above the constituent standards and most likely result from Balbach. McKesson also found PCBs and PAH's that could result from Balbach, or their process. McKesson is investigating PAH's and VO's that were handled in their solvent-reclaiming business. McKesson has investigated the Darling International site to the south, because the prevailing groundwater contours showed there was movement of their contaminants in that direction. The Doremus Avenue Recycling and Transfer (DART on Figure 2) site has not conducted any soil (or groundwater) investigations. Cardolite is the only business that has been required to investigate metals contamination in soil and groundwater.

Groundwater

Current groundwater conditions are shown on Figure 9. Sun has had numerous small spills reported and boring logs show petroleum is present in the subsurface in many places across the site. A large spill of gasoline shown on Figure 9 occurred at the center of a persistent groundwater mound. Sun is engaged in free-product and total phase extraction to address the petroleum spills. Cardolite consistently shows a large mound in the center of the property with flow traveling to the south and east. McKesson installed an HDPE cut-off wall that has changed the groundwater flow conditions slightly. The cut-off wall now forces water to split at the Cardolite site, with some travel south west, the remainder traveling east. The extension of the mound from the Sun site meeting the cut-off wall creates a divide. Water inside the McKesson barrier is one to two feet higher than the surrounding sites.

Sediment

Five sediment cores were drilled by Darling International for dredge disposal purposes. Cores 1, 2 and 3 were composited according to protocol and the resulting analysis detected both PCE and Methylene Chloride, consititents found on the McKesson site. Composite cores did not detect high levels of metals that could be associated with the Balbach site. PCBs were detected in the sediment and PCBs have been found in the Balbach fill from the former Bay Plant.

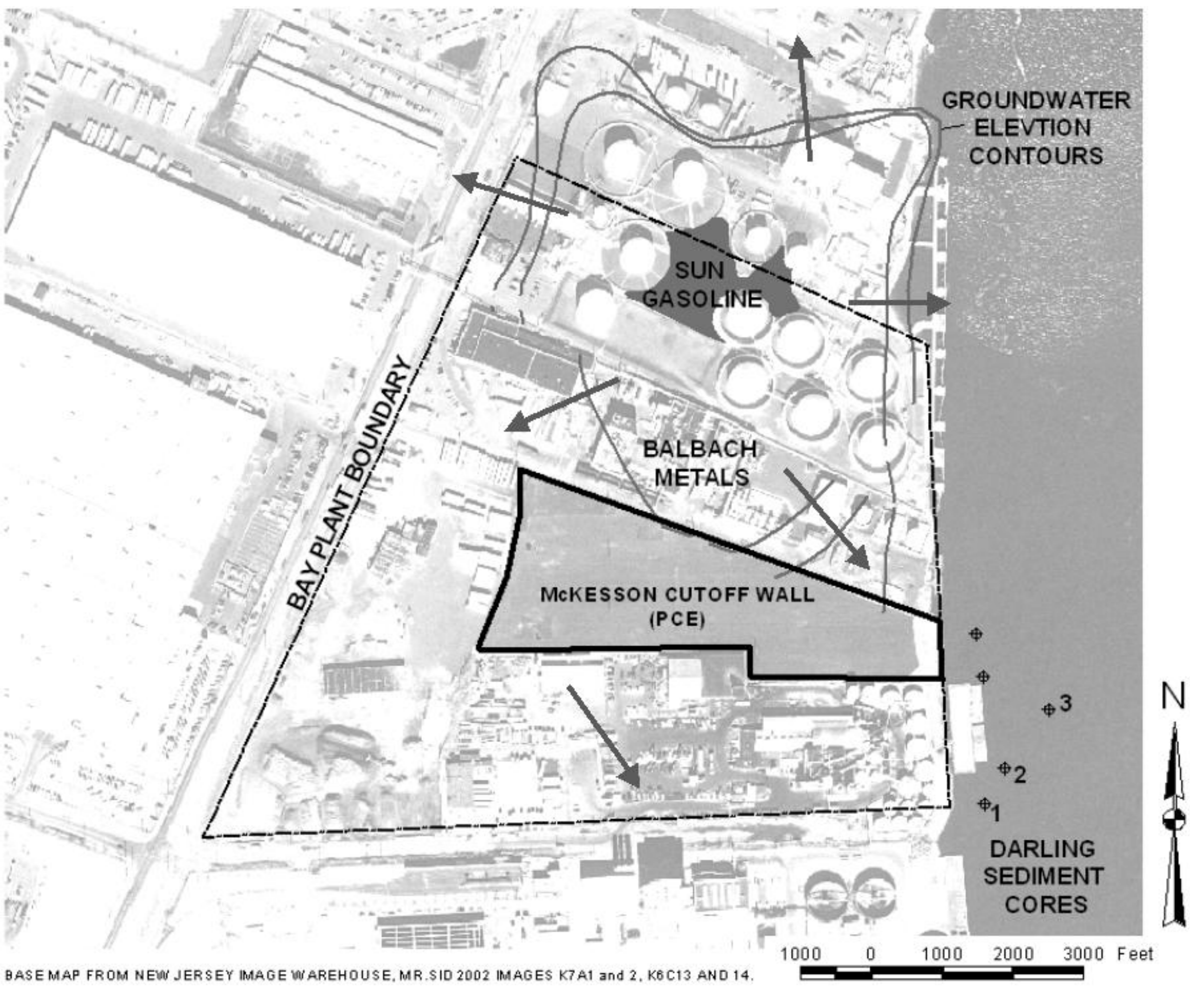

Figure 9. Groundwater conditions, Bay Plant

CONCLUSIONS

Balbach owned two high-volume smelting facilities that have received little attention. Both Balbach sites show soil contamination from a long industrial history. Although regulators acknowledge that groundwater contamination is likely at the River Plant site, it has not been investigated. Groundwater contamination is known at the Bay Plant site, but the majority of the property owners have not been required to investigate the metal content of the groundwater. Figure 10 shows the Balbach sites are both surrounded by other known groundwater contamination cases

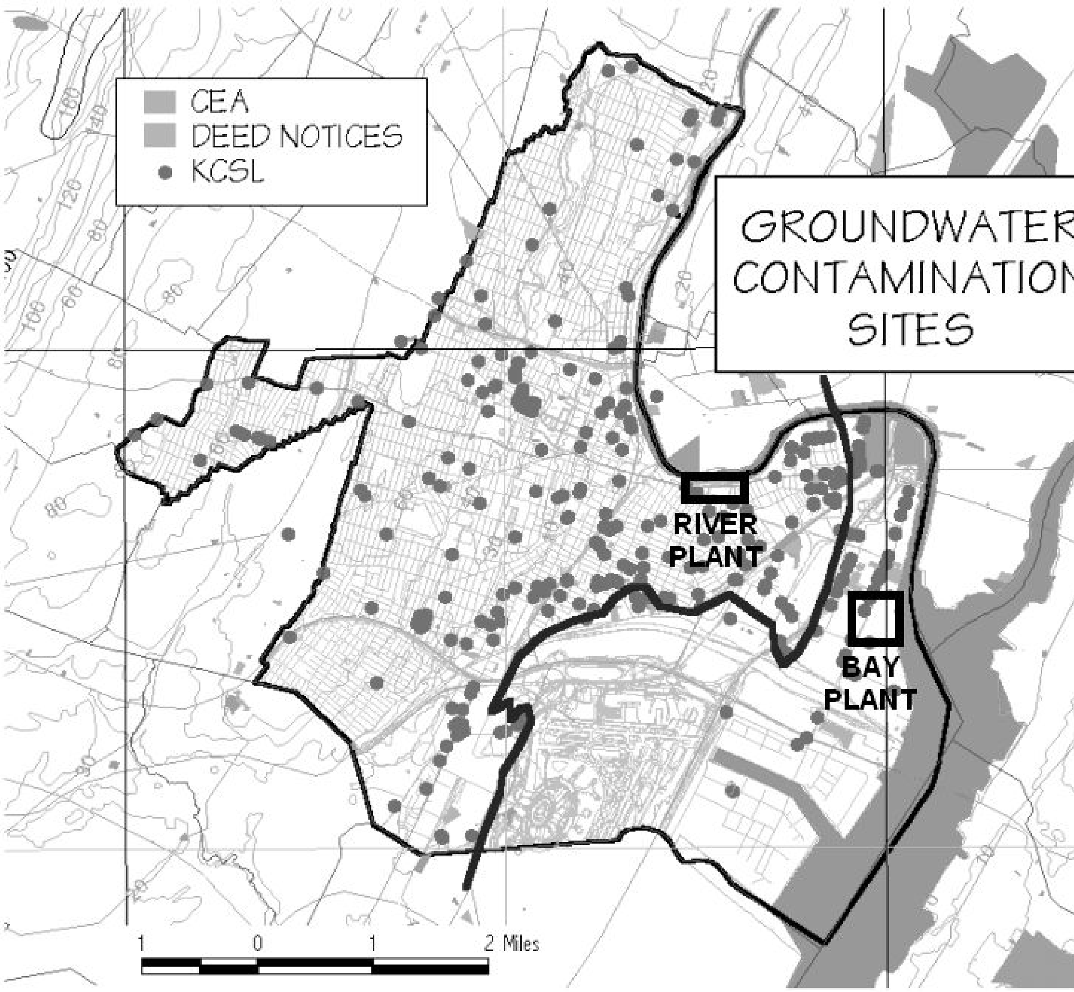

Figure 10. Balbach Sites and Newark Groundwater Contamination Cases, from NJDEP data, from Zdepski, 1992, updated 2002.

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A SPATIAL ANALYSIS OF LEAD CONCENTRATION IN THE SOILS OF PARKS IN JERSEY CITY, NJ

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ABSTRACT

Old industrial cities on the East coast have a legacy of heavy metal accumulation within their highly disturbed urban soils. Jersey City, NJ is an excellent case study of some of the urban environmental issues facing many of these older cities. Jersey City was the end of the tracks for numerous railroads due to its proximity to the port cities of Newark, NJ and New York. Industry was central in Jersey City for centuries; this left a legacy of contaminants, particularly heavy metals including lead and chromium. For decades Jersey City has been economically depressed. Low-income housing is co-mingled with working class and working poor, multi-family dwellings; recently, however, a resurgence has taken hold of Jersey City, with new construction and luxury office and residential buildings. Many of these building are built atop fill that was used to create new land or to raise the topographic elevation. The exact chemical and mineralogical composition of the fill is generally unknown, but regionally it is known to contain chemical waste, as well as ore processing waste.

In the spirit of community relations, a pilot project began in the spring of 2007 to test soil samples collected from several public parks, playgrounds, and ball fields in Jersey City. The aim of this project is to analyze the soils for lead, as well as to conduct a sedimentological and mineralogical assay. Hamilton Park and Van Vorst Park in historic downtown Jersey City, were founded in the early 19th century. Hamilton Park was surrounded by foundries in the late 19th and early 20th century. It also lies close to the NJ Turnpike and Holland Tunnel. Several GIS maps were prepared as part of the spatial analysis. They show historic fills, known contaminated sites, sample locations, and other locations of interest. Of the 29 samples collected in 2007, 12 exhibited values above the residential limit of 400ppm lead and all 7 2008 Van Vorst Park samples are above this level. One site, Hamilton Park, has lead levels at 550ppm, while another park, Ennis Jones Park has lead levels over 800ppm. To determine the source of the Pb, the < 63µm fraction will be digested and analyzed using an ICPMS and the Pb isotope ratios will be determined. The ratios of the Pb isotopes 206Pb/207Pb, will allow us to discern the source of the lead. Lead from smelters has higher ratios of 206Pb/207Pb, while lead from leaded gasoline has lower ratios (1).

INTRODUCTION

Jersey City, NJ

Located on a peninsula between the Hackensack and Hudson Rivers, Jersey City (39 km²) is 8km east of Newark, NJ and across the Hudson River from Manhattan. Jersey City is the second largest city in New Jersey with a population of 246,335 (2005 census) (2). The population is extremely diverse; 36% are White; 28% are Black; 19% are Asian; and 18% are some other race (2). In addition, 30% of the people in Jersey City are Hispanic (2).

In the beginning of the 19th century, Jersey City became an expansive industrial site. Railroad companies (Erie Lackawanna Railway Company & Pennsylvania Railway Company) (3) established an extensive network of rails and warehouses in the area. Jersey City's proximity to the Hudson River and New York Harbor made it an ideal location as a hub of transportation; with 11 miles of waterfront it is an important transportation terminal point and distribution center. The areas of Newport and Downtown Jersey City had an especially dense concentration of transport networks. The area around Hamilton Park (est. 1849) was occupied by at least 10 known smelters, metal-works and foundries at the turn of the 20th century (Figure 1).

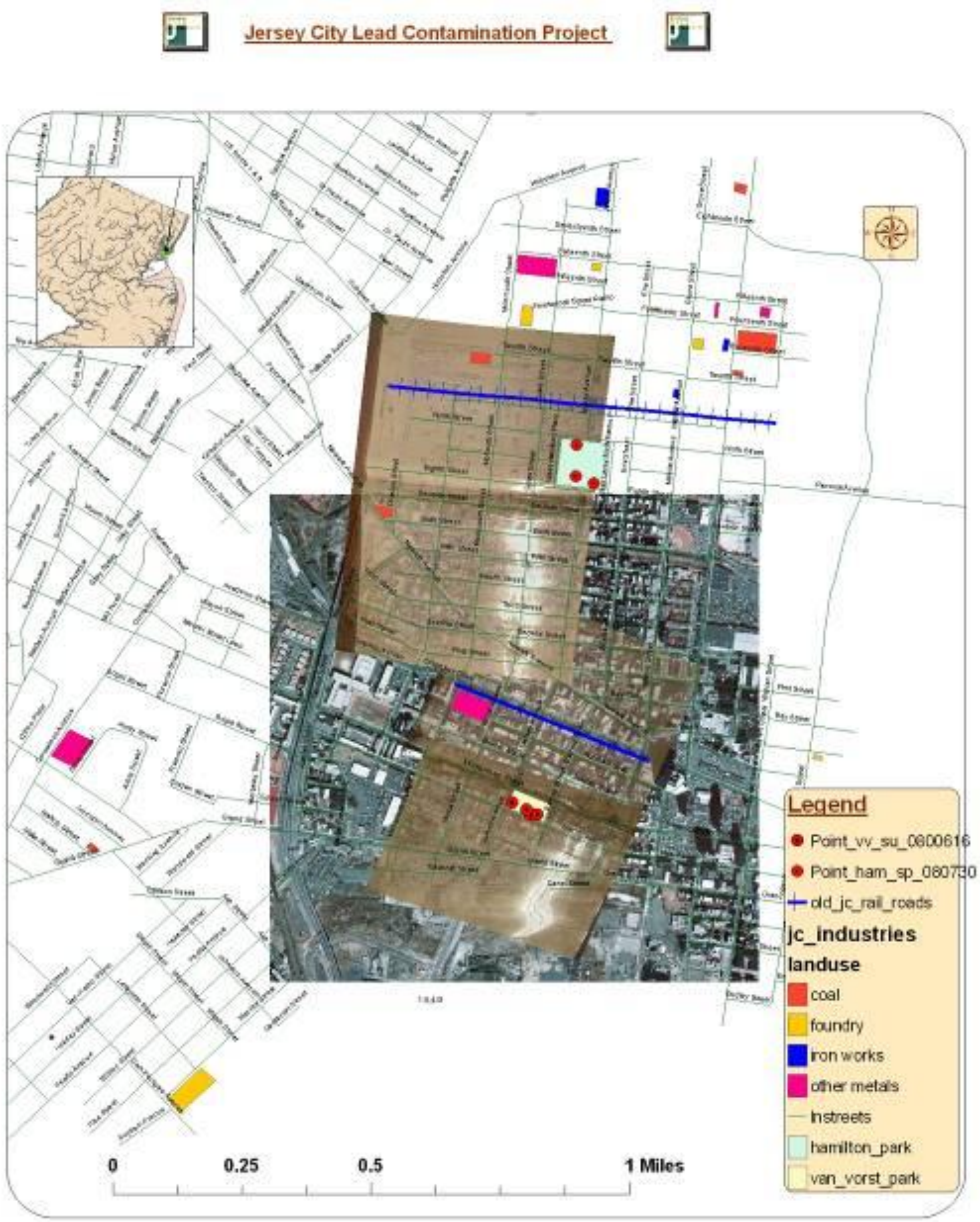


Figure 1. GIS map showing overlays of 19th century maps with land use (old foundries, metal works, Van Vorst and Hamilton Parks in Historic Downtown), present day aerial photograph, city streets and 2008 sample points. Jersey City location within the state of New Jersey in upper left hand corner. (Map produced by John Whitford).

In the 1880's an extension to an island in New York Harbor was built by the Lehigh Valley Railroad Company and a shipping depot was established (4). The depot was a munitions warehouse for the United States Army. During World War I, German agents set fire to the pier attached to the depot. The fire led to a giant explosion and shrapnel was sent over long distances (4). Jersey City continues to be a prime location for industry and immigration, 37% of the people living in Jersey City in 2005 were foreign born (2). The areas around Jersey City (Kearny, Harrison, Newark and Elizabeth) continue to house railroad shops, oil refineries, warehouses, and industrial sites that manufacture a diverse assortment of products, such as chemicals, petroleum and electrical goods, textiles, and cosmetics. There are 2 active metal works in the area and two remediated superfund sites and one active superfund site (Figure 2).

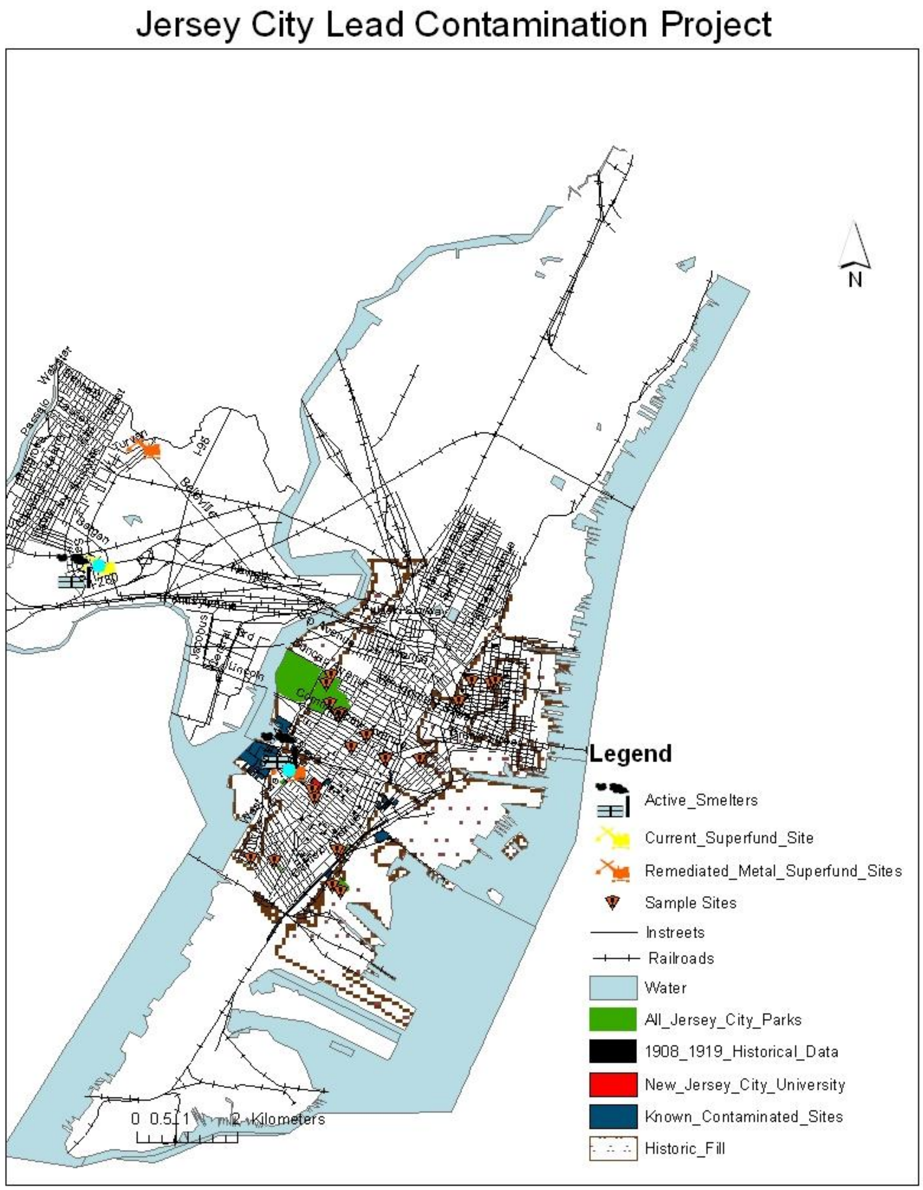


Figure 2. GIS map showing 2007 sample sites, current streets and rails, active smelters, current and remediated superfund sites, known contaminated sites, historic fill and NJCU. (Map produced by Michelle Oliver).

Despite the urban decline of the 1970's, Jersey City is in a renaissance. Many areas have been redeveloped or in the beginning stages of redevelopment. Thirteen percent of the housing units were built since 1990. The median income of households in Jersey City is $40,310, but that belies the distribution of wealth. The areas around historic downtown, due to their proximity to a direct subway line into Manhattan, have seen the most residential growth, with single family houses costing upwards of one million dollars (Figure 3). The areas close to the river has seen the most financial sector growth, with investment houses from nearby Wall Street making their mark there (Goldman Sachs Chase Manhattan Bank, Lehman Brothers, Merrill Lynch, Charles Schwab) (5). The finance, insurance, and real estate sector has grown more than 500% since 1993; about 85% of NASDAQ's sales volume is conducted in Wall Street West, Jersey City (6). Other areas of Jersey City have also undergone gentrification in an expansion ring centered on the historical and financial downtown areas. However, the boom has not reached all the population. Twenty percent of the population are dropouts (2) and in 2005, 18 percent of people were below the poverty line with 26% of children under 18 below the poverty level.

Metals in the Environment: The Case Against Lead

Sources of Lead. Industrial use of lead is for the production of lead batteries in the automobile industry (7). Other uses of lead include the production of lead alloys, sheet lead, pipes, and in ceramic glazes, paint, ammunition, cable covering, and other products (7). Other airborne sources include combustion of solid waste, coal, and oils, emissions from iron and steel production and lead smelters, and tobacco smoke (7,8) Potential for human lead exposure is linked to lead having been used as an additive in gasoline. Tetraethyl lead was used in gasoline to increase the octane rating. This use resulted in widespread dispersal throughout the environment through atmospheric deposition. Before the 1970 Clean Air Act, the amount of lead discharged from industrial sources was not restricted. Contaminants were released to the air from the stacks at industrial facilities, settled out of the air onto nearby soil, and accumulated over time. In the early 1970s, because of its effects on the environment, the EPA began to phase-out the use of lead in gasoline. The use of lead as a gasoline additive was gradually phased out in the United States beginning in 1986. Lead was eventually banned from use in gasoline in the U.S. by the EPA by 1996 (7). As a result of EPA's regulatory efforts to remove lead from gasoline, emissions of lead from the transportation sector have dramatically declined (95 percent between 1980 and 1999), and levels of lead in the air have decreased by 94 percent between 1980 and 1999. Transportation sources, primarily airplanes, now contribute only 13 percent of lead emissions (9). Lead was also widely used as a pigment in both interior and exterior paints, though its use in paints was banned in 1978.

Effects on Human Health. Lead poisoning has a large effect on human health. Lead is a neurotoxin. Infants and young children are at risk for exposure (10). Numerous studies indicate that blood lead concentrations above 10 µg per deciliter are associated with negative outcomes on intellectual functioning and social and behavioral conduct. Blood lead concentrations, even those below 10 µg per deciliter, are inversely associated with children's IQ scores at three and five years of age and associated declines in IQ are greater at these concentrations than at higher concentrations (11,12). Other effects include behavioral problems in preschool age children (13). Canfield et al. (14) suggest that more U.S. children may be adversely affected by environmental lead than previously estimated. Lead enters the body mainly through ingestion.

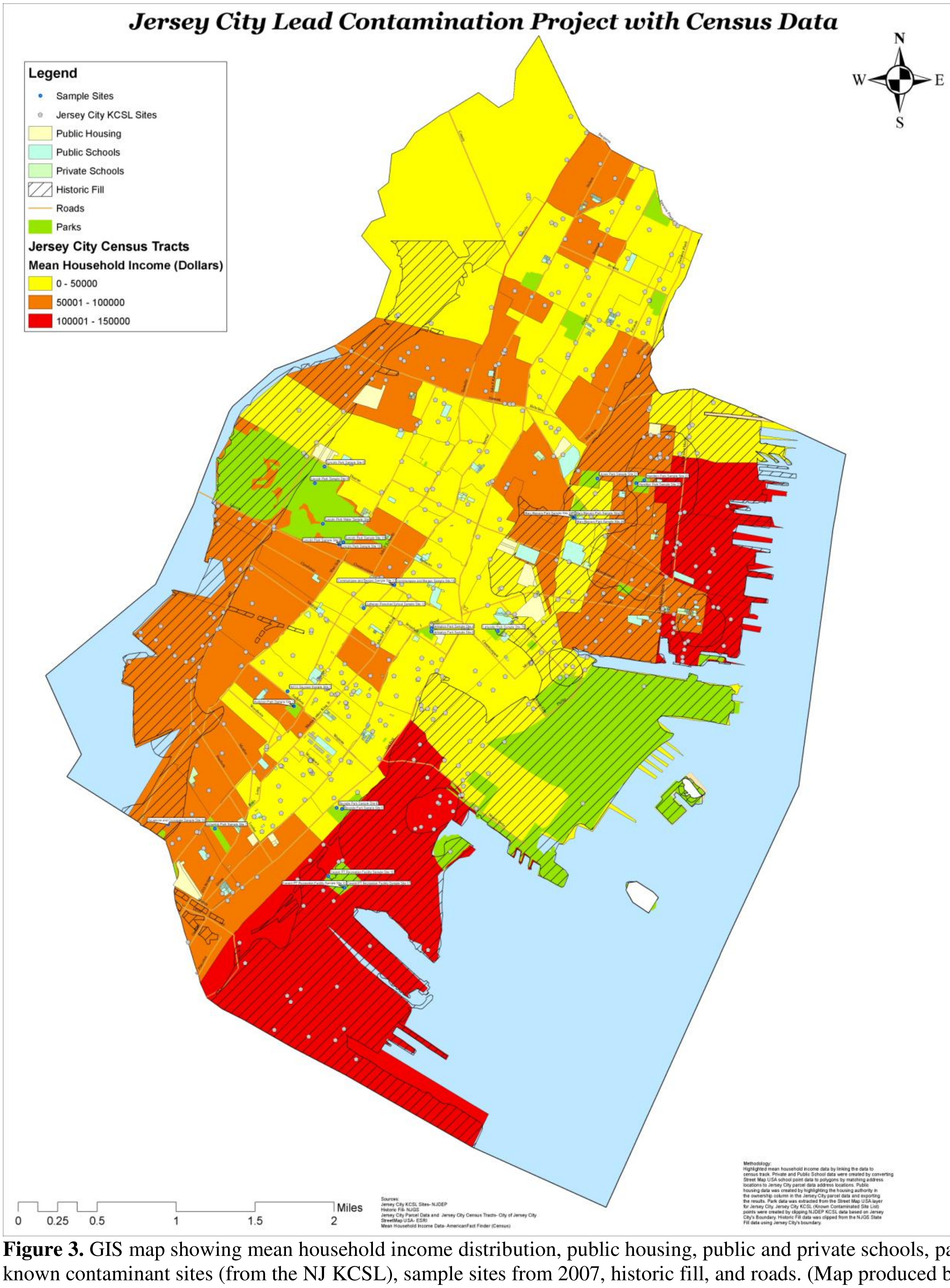


Figure 3. GIS map showing mean household income distribution, public housing, public and private schools, parks, known contaminant sites (from the NJ KCSL), sample sites from 2007, historic fill, and roads. (Map produced by Paul Kaczka).

This includes breathing in lead dust from soils or lead-based paint, through lead-based paint chips, from drinking water, or from traces found on toys and man-made products. According to the Environmental Protection Agency, lead is more dangerous for children than adults because infants and young children often place their hands or objects in their mouths unknowingly ingesting lead dust, a growing child's body absorbs more lead than an adults, and the damaging effects of lead are greater to a child's immune and nervous system than to an adults (15). Since there is no effective treatment for children with moderately elevated blood lead concentrations (16), Canfield et al (14) suggests that the collective evidence argues for a shift toward primary prevention of lead exposure instead of the almost exclusive emphasis on the treatment of children with elevated blood lead concentrations.

Why This Study?

Previous studies determined the main culprit of lead poisoning to be lead-based paints. Recently, however, studies have shown that lead dust in soils has more of an effect than lead based paint (17). Moreover, human absorption and retention of lead is a function of both particle size and chemical species (18). The smaller the particle, the more easily it is absorbed by the digestive system. Nearly half the exhaust emitted from gasoline was less than 0.25 μm in size, with most of the remaining emissions between 10 and 20 μm (18). In contrast, the particle size of lead in paint dust/chips ranges from 200 to 300 μm to the visible range. Hence, large particles containing lead such as paint chips are less easily absorbed and, therefore, less bioavailable (16). Therefore, due to location (Jersey City, NJ), high percentage of children and low percentage of park areas, the study aimed at analysis soils.

METHODS

The sites chosen are city parks and ball field near play areas (Figure 4). The samples were collected from areas where soil was exposed and where children would come into contact with it. Many of the parks rubberized play areas were cracked exposing the soils. The samples were collected using a 30 cm stainless steel corer following standard protocols (19). Two samples were collected at each site; one sample for textural analysis and the other for chemical analysis. Twenty-nine samples with four replicas were collected during the 2007 season and 14 samples and an 8 foot core was collected in 2008. The samples for chemical analysis were weighed and placed in a hood to dry. They were then washed with de-ionized water and placed through a less than 63 μm stainless steel sieve. The washed samples were then placed in an oven to dry and later placed into individually marked Whirl-pak bags. The samples for textural analysis were weighed, dried, re-weighed, and sieved according to Folk (20). The size fractions ranged from 4mm to less than 45 μm.

The graphic mean, mode, and median were calculated along with the inclusive standard graphic deviation (coefficient of sorting). All of the 2007 samples were tested for pH. All of the samples are tested with a Hellige-Truog Soil Reaction (pH) tester. All of the surface samples, were tested with a Sensafe™ Soil Chek™ test kit. This colorimetric test detects the presence or absence of lead in soils. All twenty-nine samples were sent out to an independent lab for analysis. The independent lab undertakes the following preparation for the samples; the sample (0.50 g) is digested with aqua regia for 45 minutes in a graphite heating block. After cooling, the

Figure 4. Mary Benson Park (A) and E.F. Jones Park (B) in Historic Downtown, note NJ turnpike extension in the background.

resulting solution is diluted to 12.5 mL with demineralised water, mixed and analyzed by inductively coupled plasma-atomic emission spectrometry for major elements analysis. The 2008 samples will be sent to an independent lab for lead isotope analysis in the near future.

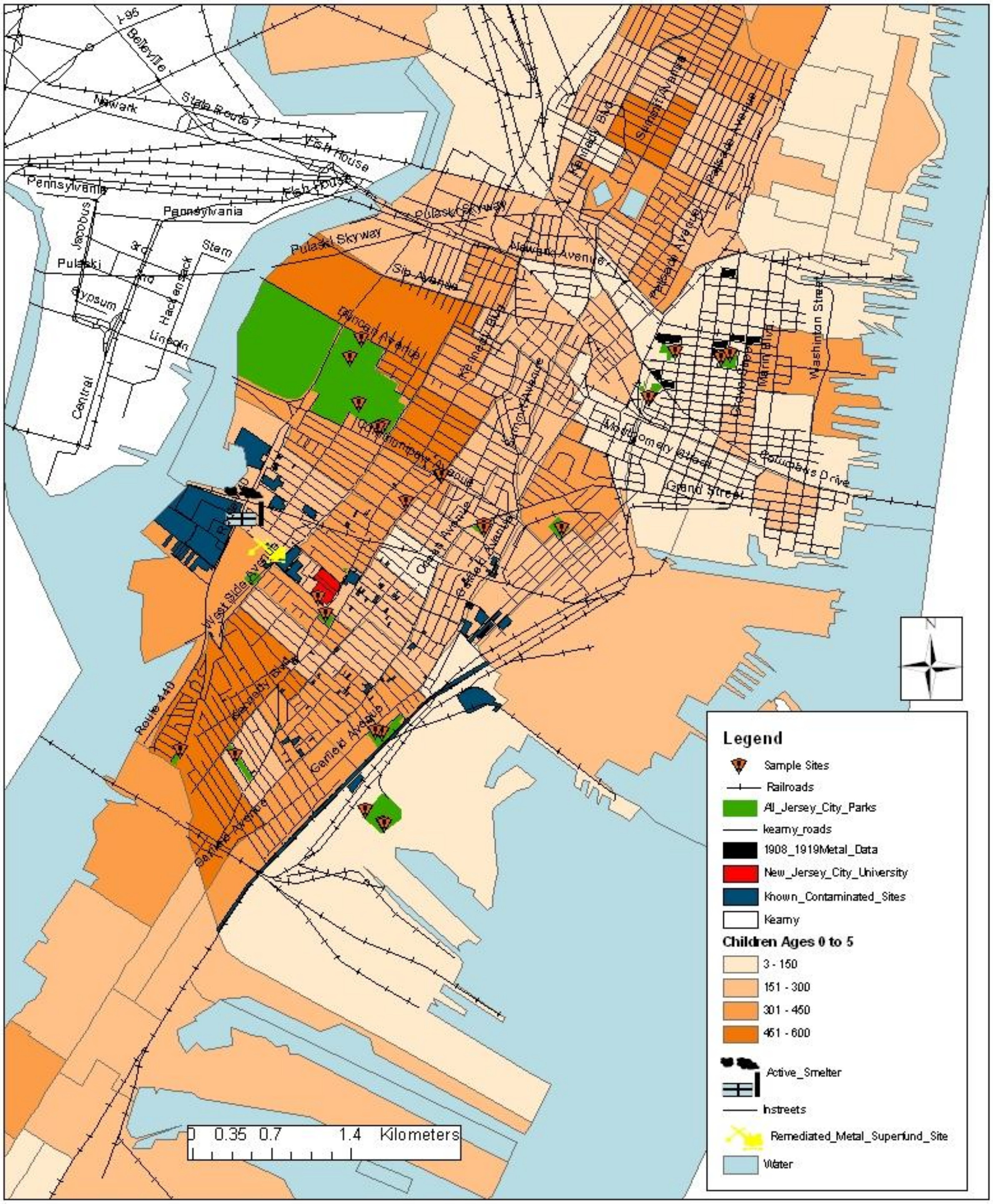
RESULTS

The graphic means for the 2007 samples ranged from 0.68 to 2.65 phi and the graphic medians ranged from 0.95 to 2.42 phi. The majority of the samples had a mode of 2 phi, meaning that the most frequently-occurring particle diameter was 250 µm. The coefficient of sorting for the samples indicated very poorly sorted or poorly sorted samples.

All the 2007 samples tested positive for lead over 300 ppm and many tested positive for lead over 400 ppm after using the Sensafe™ Soil Chek™ test kit, including the samples collected from NJCU campus. The federal regulatory limit for lead in residential soils is 400 ppm. In-house testing for presence/absence of lead from 2008 Van Vorst Park samples showed that lead levels are present over 400 ppm.

At this level the effects of lead are minimal, however lead at concentrations over this concentration can have negative health effects for children (Figure 5). The soil alkalinity ranged from medium acidity (pH5.5) to neutral (pH7) (Figure 6). Seven of the parks (twelve samples) in 2007, tested over the regulatory limit. Four samples tested over 400 ppm, six tested over 500 ppm, one tested over 600 ppm, and one tested over 800 ppm (Figure 7). Six of the soils that tested high in lead also tested high in other metals, such as arsenic (regulatory limit 20 ppm) and one also tested high in zinc (regulatory limit 1500 ppm), possibly inferring a correlation between the three metals.

Census Data of Children between the Ages of 0 to 5



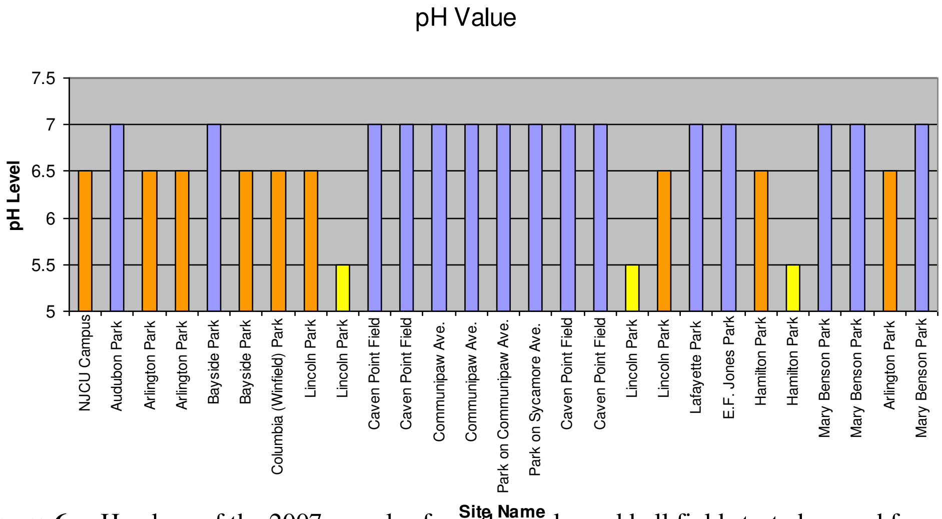


Figure 6. pH values of the 2007 samples from the parks and ball fields tested ranged from 5.5 to 7, while the 2008 surface samples had values ranging from 4.5-6.5 and the core had values of 5.5 to 7. The pH of soils is important because soils at certain pH levels can retain nutrients and heavy metals, making them inaccessible. pH levels of 6.5 (very slightly acidic) to 7 (neutral) bind lead in the soil and keep it from becoming soluble (21). The samples were tested for their pH levels because lead can be mobilized when soils have a pH greater than 7 (22). The pH tests showed samples pHs that ranged from 5.5 (medium acidity) to 7 (neutral). Had the soils had higher pH levels it would infer that the lead was being mobilized through the soil. However, since none of the pH levels exceeded 7 (neutral) this helps reinforce the idea that the lead remains bound to the sediment and thus available for subsequent ingestion and inhalation.

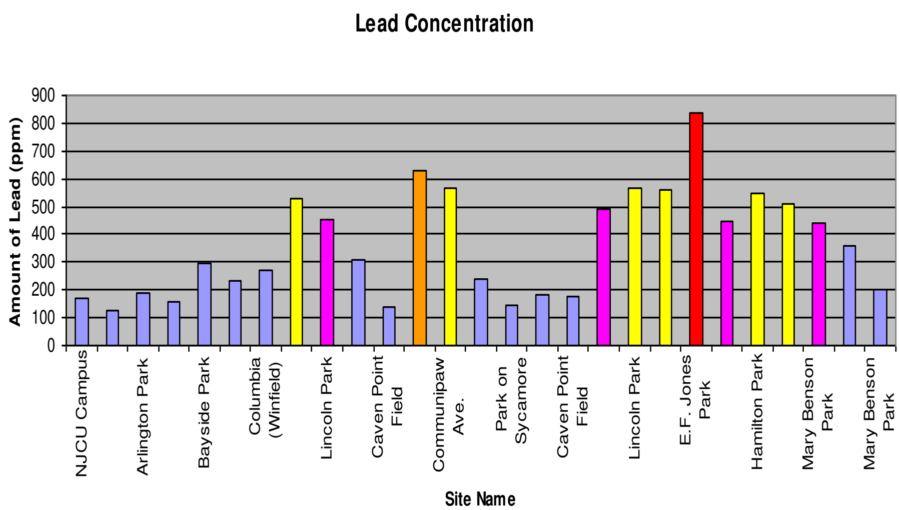
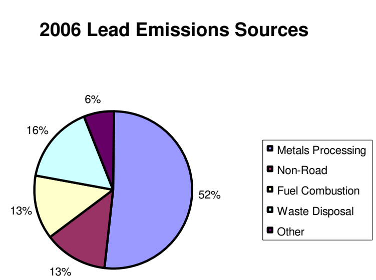


Figure 7. Total lead concentration in ppm for the 2007 samples. The regulatory limit for lead is 400 ppm in soils. Twelve samples exceed that limit. One sample, Ennis Jones Park doubled the limit.



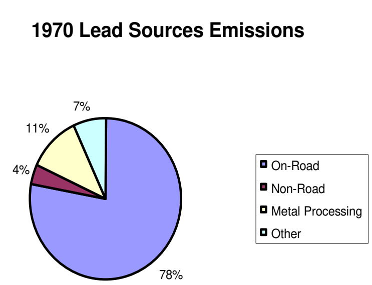


Figure 8. Charts from the EPA show that from 1970 to 2006 the amount of lead emissions from metal processing increased by 41%, while lead emissions from on-road sources completely diminished (23).

SUMMARY AND CONCLUSIONS

In the 1970's lead emissions due to leaded gasoline were greater than lead emissions from factories (23) (Figure 8). Despite the ban of leaded gasoline in highway vehicles by the EPA in 1995, damage to Jersey City soils had already been done. Jersey City is surrounded by long stretches of major roadways including the New Jersey Turnpike, the Pulaski Skyway, and the Holland Tunnel. Any lead emissions from before the 1970's and straight through to the 1990's had already settled out of the atmosphere and into the soil. However, after the ban of leaded gasoline the amount of emissions from transportation has dramatically declined and the lead levels in air have decreased (24).

Today the major source of lead emissions is from metal processing factories (23). Lead is also used in the production of metal products, such as sheet lead, solder (but no longer in food cans), and pipes, and in ceramic glazes, paint, ammunition, cable covering, and other products (25).

In the 1900's there was a thirty-five block radius which housed factories, foundries, and a coal plant (Figure 1). The factories were mainly iron factories and the foundries were mainly brass. They were all located in the area which now surrounds Hamilton, Mary Benson, and E.F. Jones parks. These three parks tested for lead levels over the regulatory limit of 400 ppm. Hamilton Park, one of the parks that tested high for lead (>500ppm), is a state protected park that has been in existence since the early 1800's. The plans for the park were initiated by John B. Coles in 1827. In 1848, after his death, his family claimed the park for personal use. The park was given to the township after a testimony of John Coles stated he wanted the park for public use. This history of Hamilton Park shows that the area was never industrial, which means the lead contamination is probably due to wind dispersal. Hamilton Park was surrounded by brass foundries in the 1900's and is in the path of the wind direction that carries the emissions from Kearny Point (26).

Another source for lead emissions was, and still is, coming from the highly industrial Kearny Point. Kearny lies to the west of Jersey City, with Kearny Point lying to the North West. On average the wind comes into Jersey City at 11 miles per hour from the west and northwest, carrying the emissions from the Kearny Point factories, among others (26). Kearny Point currently or previously housed a number of different factories including the Kearny Smelting and Refinery Company, the Interstate Metal Separating Corp., the Campbell Foundry Co., the American Modern Metals Corp., Pittsburgh Metal and Graphics, and two branches of Alpha Metals Incorporated. Kearny also had a facility (Western Electric) that produced lead coated telephone and telegraph wires, which closed down about twelve years ago. There were also two smelters, one of which was in Kearny and the other in Jersey City, that are remediated Superfund sites, also one of which is still active in Kearny. Superfund is the common name for the United

States environmental law officially known as the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). CERCLA was created to protect people, families, communities and others from heavily contaminated toxic waste sites that have been abandoned (27).

The idea of wind dispersal as a means of transport for lead emissions is not ruled out. For instance, a scrap metal recovery plant in Carteret, NJ was responsible for emitting eighty-six tons of lead annually that affected parts of New York City. To reduce the pollution of lead levels in nearby air, a tall stack was constructed. This stack however, exported the emissions to as far as Staten Island, NY creating high concentrations of lead in surface soils (28). Another case in which wind dispersal aided in the pollution of soils is in Pennsylvania. Emissions from zinc ores smelted in Palmerton, Pa have been dispersed 2 km from the primary smelter, which included zinc, cadmium, copper, and lead (29). A factory, located about a mile from the NJCU campus, in Jersey City transports lead and releases lead into the air. On average this facility transport about 64,104 pounds per year of lead and releases about 150 pounds per year of lead into the air. Although this amount is much less than the emissions from the plant in Carteret, this is a direct source of lead to the surrounding environment. There is also a smelting plant in Kearny that is operational, which contributes to the emissions being carried by the northwest winds. The additional data that will be provided by lead isotopes analysis will be able to tell us if aerial lead deposition from smelters, gasoline or another source is the prime suspect in the contamination of the soils, since the ratios of the Pb isotopes 206Pb/207Pb, will allow us to discern the source of the lead. Lead from smelters has higher ratios of 206Pb/207Pb, while lead from leaded gasoline has lower ratios (1).

ACKNOWLEDGMENTS

Funding for this project was made possible by a grant from the Office of the Vice President of Academic Affairs, New Jersey City University. Many thanks to all students who participated in this work: John Whitford, Satish Ramrup, Paul Kaczska, and Michelle Oliver who generated GIS and additional historical data maps of Jersey City. Other NJCU students include Raphael Pastor and Sadira Robles. The project so far has involved 7 undergraduate students and the collaboration of faculty from Chemistry (Yamaguchi) and the GIS lab (Montgomery) at NJCU. In the summers of 2007 and 2008, six high school students (including; Samuel Cruz, Jessica Reyes, Allison Contreras, Cindy Cruz, Christopher de la Cruz) from Union Hill High School (Union City, NJ) were added to the project. These students come from the American Chemical Society SEED program. Project SEED is designed to encourage economically disadvantaged high school students to pursue careers in the chemical sciences.

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GEOLOGICAL CONTROLS ON MEANS AND METHODS OF HARD ROCK EXCAVATION, NEW YORK CITY, NY

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ABSTRACT

A number of geological properties of coalescing importance dictate the destiny of hard rock excavation in the city of New York. Critical to both surface and subsurface geotechnical design engineering, a thorough investigation of such properties can provide important clues concerning performance and productivity during the bid and as-built stages of major construction efforts and help to avoid the expense and inefficiency of changed condition claims. Investigations over the past century have shown that the geology of NYC is complex with over a billion years of geological history emblazoned in the rock mass. NYC's former position at the core zone of convergent mountain building during Proterozoic and Paleozoic times has created a unique set of geological formations and variable rock mass properties that, when ignored (i.e. – "Rock" is "Rock" mentality), have proven to be an impediment to efficient mining and excavation and has resulted in claim hardships for owners and contractors. In addition to normal core data analysis and standard geotechnical testing for establishing rock mass properties, prudent contractors and design engineers must factor in intrinsic geological properties. Often overlooked, targeted petrographic microscopic analysis of mineralogy, texture, lithology, structure, and metamorphic fabrics are critical rock mass properties to establish. Megascopic study of stratigraphy, rock mass density, fabric orientation, ductile and brittle fault analysis and joint analysis are also paramount. Such allied studies hold the clues toward fully understanding the excavation behavior of the rock mass and will establish the proper means and methods for safe and efficient rock removal (roadheader, hydraulic ram, drill and blast, mini-mole, TBM, or a medley of methods).

INTRODUCTION

Rock does not equal rock when it comes to cost-efficient excavation of rock in NYC. Proactive geological investigations in the pre-bid and as-built periods can mitigate losses encountered during hard-rock excavation (Merguerian 2005a). Type I and II changed rock condition scenarios can be totally avoided early with professional geological study and risk sharing between owners and contractors. Drawing from three decades of standard geological mapping and rock analysis experience in NYC and from geological data gathered from the NYC Water Tunnels (Brooklyn, Queens, Manhattan), the Con Edison Utility Tunnel, East Side Access, South Ferry, World Trade Center and a multitude of shallow excavations throughout the city, this paper will offer suggestions to better mate various mechanical excavation means for variable geological domains of New York City (NYC). To better understand the geological controls on excavation, a thorough understanding of the geology of New York City is an important first step.

THE GEOLOGY OF NEW YORK CITY

NYC is situated at the extreme southern end of the Manhattan Prong (Figure 1), a northeast-trending, deeply eroded sequence of metamorphosed Proterozoic to Lower Paleozoic rocks that widen northeastward into the crystalline terrains of New England. Southward from NYC, the rocks of the Manhattan Prong plunge nonconformably beneath predominately buried Mesozoic rocks, younger Cretaceous strata, and the overlying Pleistocene (glacial) sediment found capping much of the region including all of Long Island and much of Staten Island.

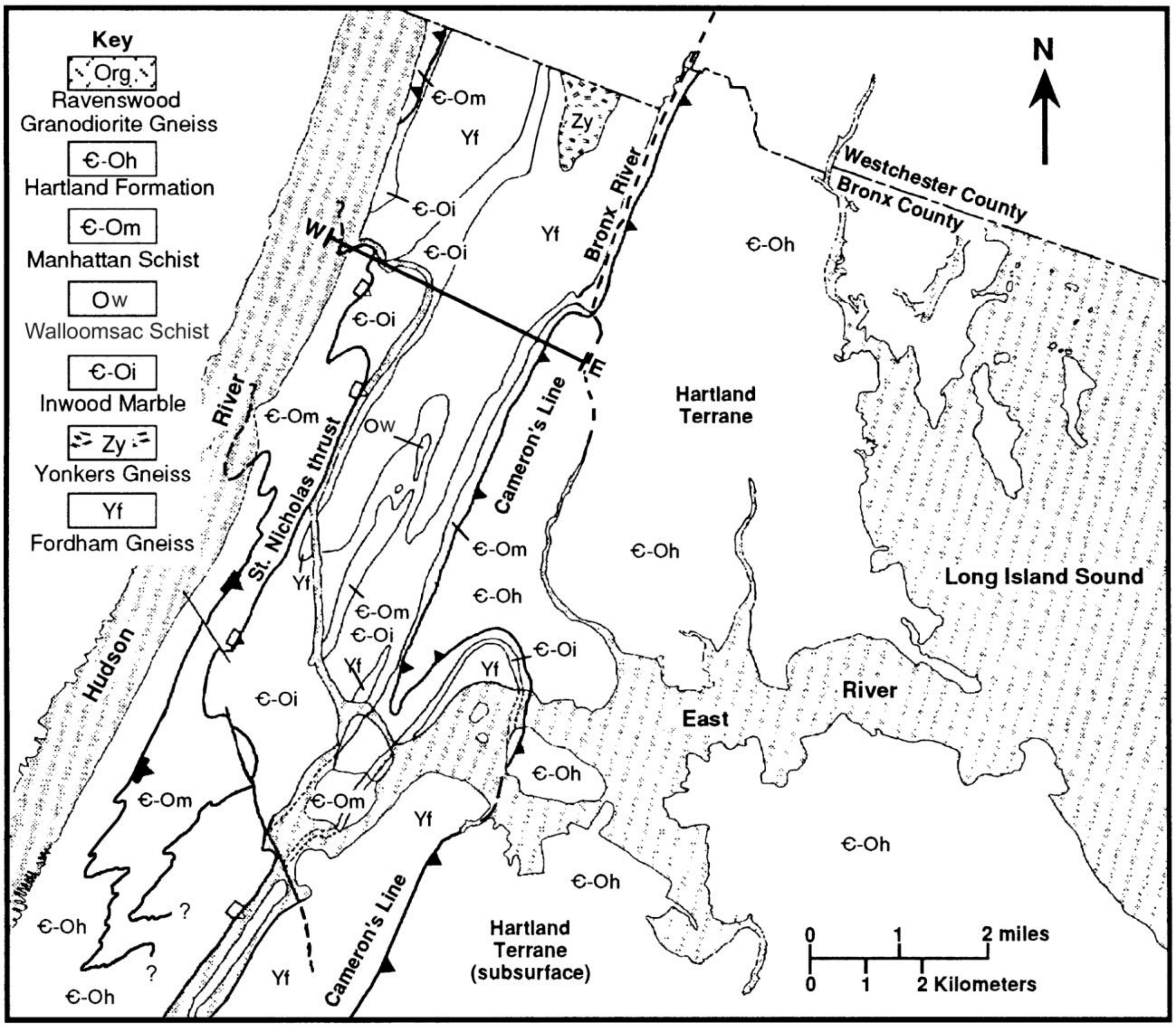

Figure 1 – Geological map of New York City showing the generalized structural geology of the region. Adapted from Merguerian and Baskerville (1987) and Merguerian and Merguerian (2004). Triangles show the dip of Cameron's Line (solid) and the St. Nicholas thrust (open) and the flagged triangles indicate overturned thrusts. Most faults and intrusive rocks have been omitted.

Will the Real Manhattan Schist Please Stand Up - Bedrock Stratigraphy of New York City

The history of NYC bedrock investigations appears elsewhere (Merguerian and Sanders 1991) so the following is a brief overview. In 1890, Merrill named the Manhattan Schist for the micaceous metamorphic rocks found on Manhattan Island and suggested, following the views of L. D. Gale (1839, 1843), and Professors W. W. Mather (1843) and J. D. Dana (1880), that they represent metamorphosed equivalents of the Paleozoic strata of southern Dutchess County, New York. Merrill and others (1902) produced the United States Geological Survey New York City Folio (#83) and following Dana, chose to use the name Hudson Schist (rather than Manhattan Schist) for the schistose rocks of NYC. This pioneering work by Merrill and coworkers set the stage for a series of detailed investigations by many geologists in the 1900's that helped define the details of lithology and structure of NYC bedrock units.

Based on study of over 700 natural exposures, a multitude of drill core and construction excavation analyses, my investigations of the bedrock geology of NYC since 1972 have portrayed a complex structural history and suggests that the Manhattan Schist formation exposed in Manhattan and the Bronx is a lithically variable sequence consisting of three separable map units known as the **Hartland, Manhattan, and Walloomsac** formations (Figure 1). These subdivisions agree with designations proposed by Hall (1976, 1980) but suggest the presence of a hitherto-unrecognized, structurally higher unit that is a direct correlative of the Hartland Formation of western Connecticut (Merguerian 1981, 1983, 1985, 1987). The three schistose units are imbricated along regional ductile faults known as the St. Nicholas thrust and Cameron's Line (Merguerian 1994, 1996) as indicated in the cross section across the northern tip of Manhattan into the Bronx (Figure 2).

Keyed to Figure 1, the W-E section of Figure 2 shows the general structure of NYC and how the St. Nicholas thrust and Cameron's Line overthrusts position the Manhattan and Hartland formations above the Walloomsac formation and the Fordham-Inwood basement-cover sequence. Late-stage major folds produce digitations of the structural- and stratigraphic contacts that dip gently south, downward out of the page toward the viewer. The N-S section illustrates the southward topping of tectonostratigraphic units exposed in central Manhattan and the effects of the yet younger NW-trending asymmetric folds. The structural geology of NYC is detailed in a later section and the stratigraphy is diagrammed in Figure 3.

Hartland Formation. The structurally high Hartland formation (Ꞓ-Oh) is dominantly gray-weathering, fine- to coarse-textured, well-layered muscovite-quartz-biotite-plagioclase-kyanite-garnet schist, gneiss, and migmatite (Figure 4) with cm- and m-scale layers of gray quartzose granofels and greenish amphibolite±garnet. *(Note: Minerals in descriptions are listed in relative decreasing order of abundance.)* The formation consists of interlayered schist, gneiss, granofels, and amphibolite. The schistose facies is lustrous and consists of dense, aligned fine- to coarse-textured muscovite that splits readily along the foliation. The gneiss and granofels varieties are massive, commonly migmatitic, and may or may not show pronounced foliation. Although typically not exposed at the surface, the Hartland underlies most of the central part and southern half of Manhattan and the eastern half of The Bronx. Because it is lithologically identical to the Late Proterozoic to Ordovician Hartland Formation of western Connecticut and Massachusetts, I have extended the name Hartland into NYC (Merguerian 1983).

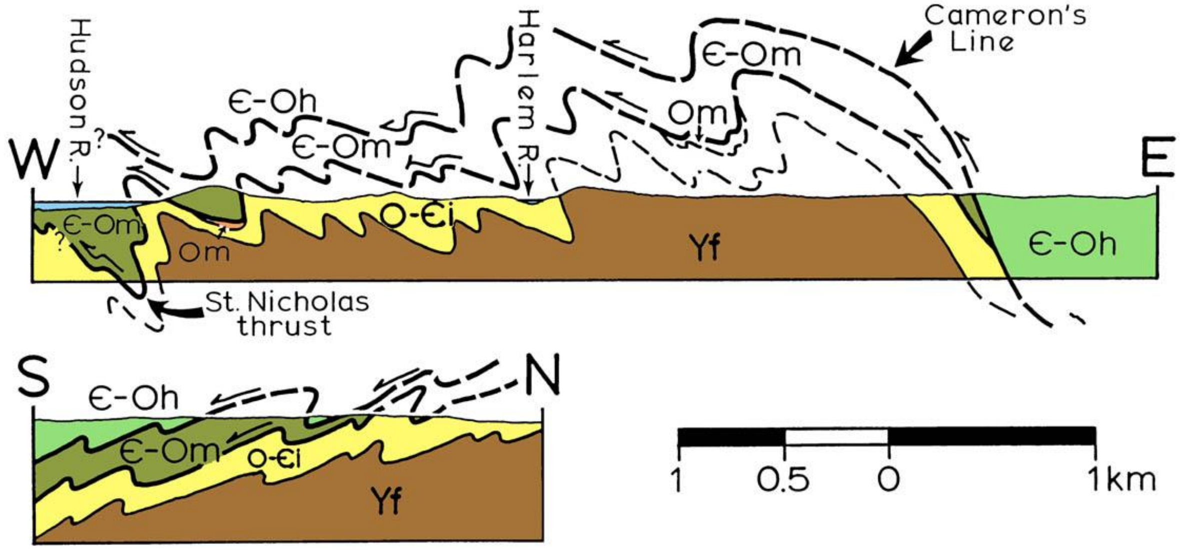

Figure 2 – Geologic cross sections across Manhattan and the Bronx showing the distribution of various tectonostratigraphic units in New York City and folded ductile faults (Cameron's Line and the St. Nicholas thrust). See Figure 1 for the line of the W-E section. The N-S section runs through the east edge of Central Park. Arabic numerals indicate field-trip stops of Merguerian (1996). Note – the unit Om is the same as Ow in this paper.

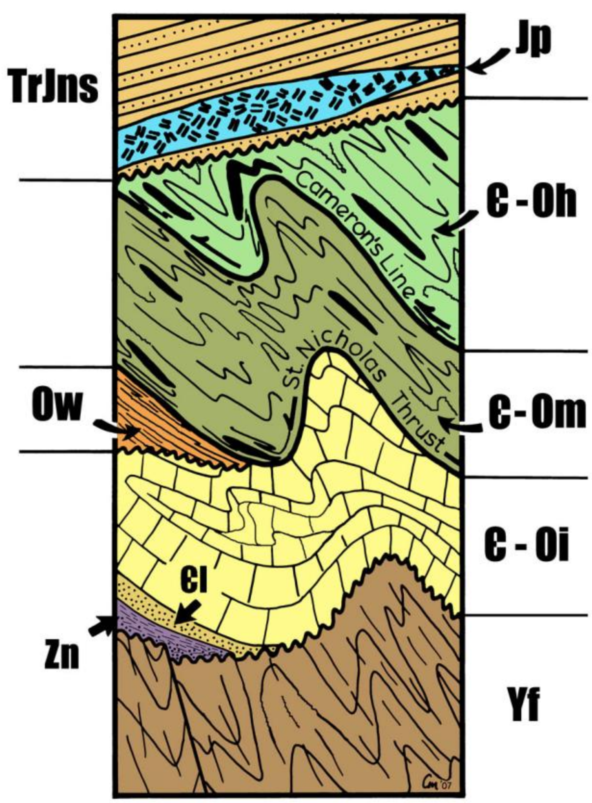

Figure 3 – Bedrock stratigraphy of New York City as described in text. Note that the polydeformed bedrock units are nonconformably overlain by west-dipping Triassic and younger strata (TrJns) and the Palisades intrusive (Jp).

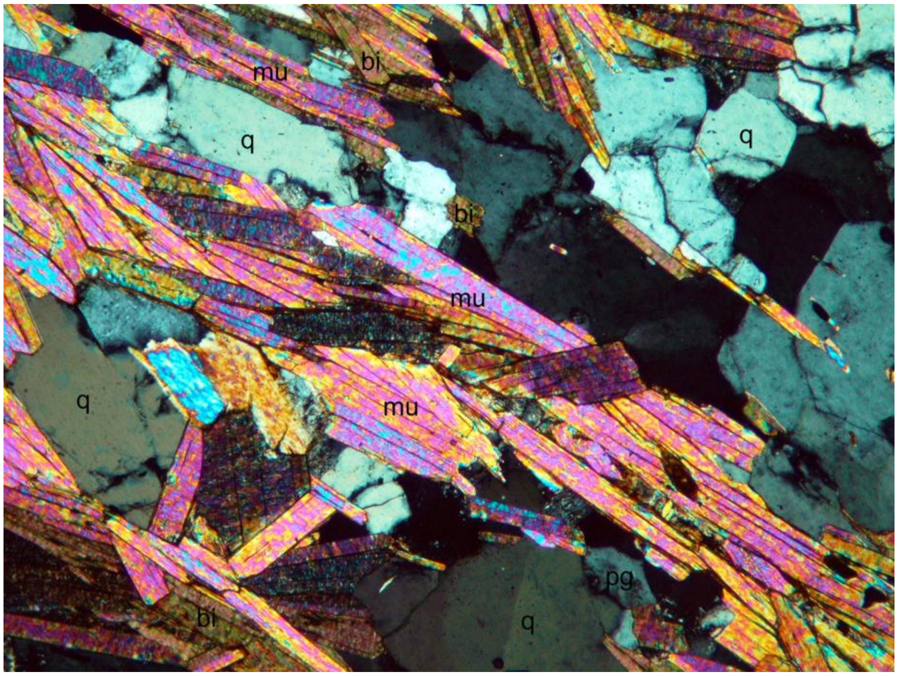

Figure 4 – Photomicrograph in cross-polarized light of Hartland schist (Ꞓ-Oh) showing a penetrative mica foliation consisting of intergrown and oriented muscovite (mu), biotite (bi), in a matrix of flattened quartz (q), and minor plagioclase feldspar (pg). Note the high mica content and prevalence of muscovite and quartz, diagnostic mineralogical characteristics of the Hartland. (Sample N125; 112th Street and Riverside Drive, Manhattan; 2 mm field of view.)

Manhattan Formation. The Manhattan formation (Ꞓ-Om) consists of very massive rusty- to sometimes maroon-weathering, medium- to coarse-textured, biotite-muscovite-plagioclase-quartz-garnet-kyanite-sillimanite gneiss, migmatite, and to a lesser degree, schist (Figure 5). The unit is characterized by the lack of internal layering except for the presence of kyanite+ sillimanite+quartz+magnetite layers and lenses up to 10 cm thick, cm- to m-scale layers of blackish amphibolite, and scarce quartzose granofels. The unit is a major ridge former in northern Manhattan, a testament to its durability to weathering owing to the lack of layering and presence of wear-resistant minerals quartz, feldspar, garnet, kyanite, and sillimanite.

The Manhattan Formation forms the bulk of the “exposed" Paleozoic metamorphic rocks of northern Manhattan including most northern Central Park exposures. The Manhattan is lithologically identical to Hall's Manhattan B and C and the Waramaug and Hoosac formations of Late Proterozoic to Ordovician ages in New England (Hall 1976; Merguerian 1983, 1985). These rocks, which contain calc-silicate interlayers in western Connecticut (Merguerian 1977) are inferred to represent metamorphosed sedimentary- and minor volcanic rocks deposited in the transitional slope- and rise environment of the Early Paleozoic continental margin of ancestral North America.

Walloomsac Formation. This discontinuous unit (Ow) is composed of fissile brown- to rusty-weathering, fine- to medium-textured, biotite-muscovite-quartz-plagioclase-kyanite-sillimanite-garnet-pyrite-graphite schist and migmatite containing interlayers centimeters to meters thick of plagioclase-quartz-muscovite granofels, layers of diopside±tremolite±phlogopite (“Balmville”) calcite and dolomitic marble, and hard calc-silicate rock. Garnet occurs as porphyroblasts up to 1 cm in size and amphibolite is absent. As shown in the photomicrograph of Figure 6, strongly pleochroic reddish biotite, pinkish garnet, graphite, and pyrite are diagnostic mineralogical features of the former pelitic portions of the formation.

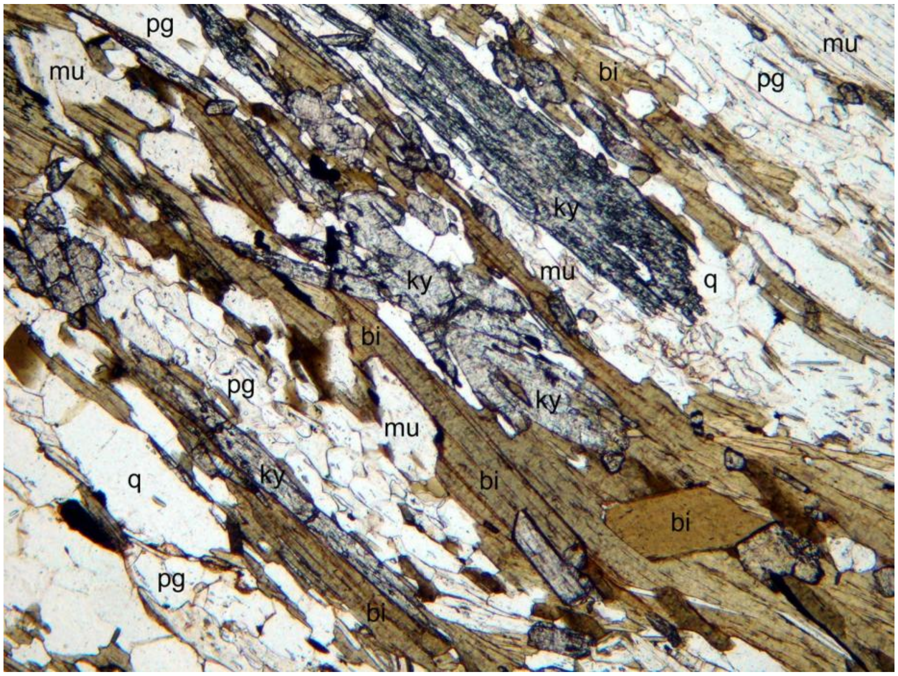

Figure 5 – Photomicrograph in plane-polarized light of the Manhattan Schist (Ꞓ-Om) showing an aligned intergrowth of biotite (bi), kyanite (ky), and muscovite (mu) in a fine-textured matrix of intergrown plagioclase (pg) and quartz (q). The penetrative foliation in this view, which consists of aligned micas and kyanite as well as flattened quartz and feldspar, is diagonal across the image and marks a structural discontinuity that may split readily. (Sample N217; South of George Washington Bridge approach, Manhattan; 2 mm field of view.)

Exposed Walloomsac Formation can be found interlayered with the underlying Inwood at five localities in Manhattan - (1) at the north end of Inwood Hill Park in Manhattan, (2) beneath the St. Nicholas thrust on the north and east sides of Mt. Morris Park (Merguerian and Sanders 1991), and (3) in the northwestern corner of Central Park (Merguerian and Merguerian 2004). The Walloomsac has also been detected sheared against Hartland rocks in numerous borings and excavations from (4) northern and (5) southern Manhattan (Merguerian and Moss 2006, 2007) including the new World Trade Center site (Merguerian and Moss [in press]).

In The Bronx, four areas of Walloomsac rocks have been found; (1) on the Grand Concourse and I-95 overpass (Merguerian and Baskerville 1987), (2) beneath the St. Nicholas thrust in the western part of Boro Hall Park (Fuller, Short, and Merguerian 1999), (3) below the St. Nicholas thrust in the north part of the New York Botanical Garden (Merguerian and Sanders 1998), and (4) in the northeastern part of Crotona Park (unpublished data). Because it is interpreted as being autochthonous (depositionally above the Inwood Marble and underlying Fordham gneiss), it is assigned a middle Ordovician age. The lack of amphibolite and the presence of graphitic schist and quartz-feldspar granofels enables the interpretation that the Walloomsac Schist is the metamorphosed equivalent of carbonaceous shale and interlayered greywacke and is therefore correlative with parts of the middle Ordovician Annsville and Normanskill formations of SE New York and the Martinsburg formation of eastern Pennsylvania (Merguerian and Sanders 1991, 1993a, 1993b).

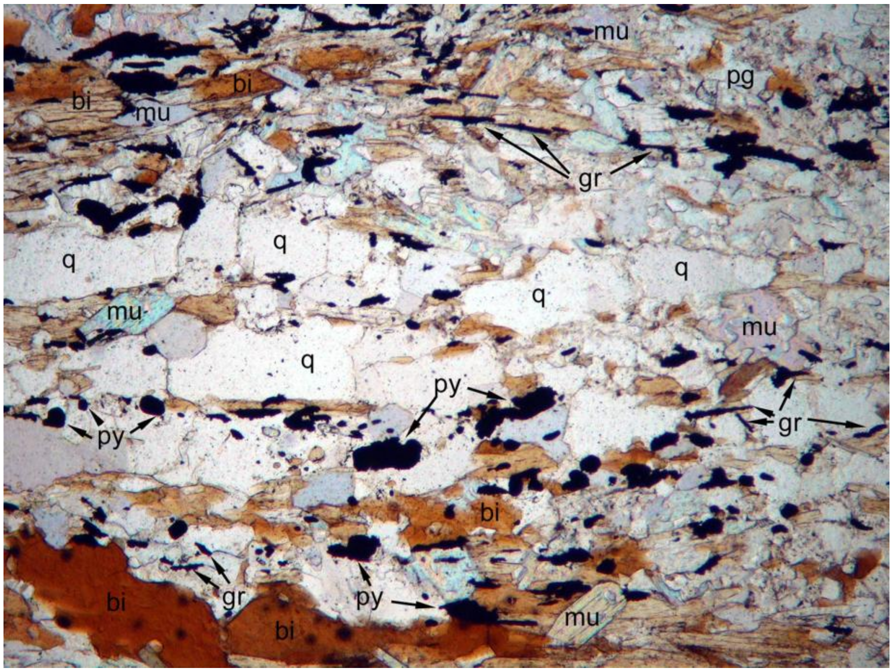

Figure 6 – Photomicrograph in plane-polarized light of the Walloomsac Schist (Ow) displaying a penetrative foliation (subhorizontal in this view) defined by aligned biotite (bi), muscovite (mu), lenticular quartz (q), graphite (gr), and pyrite (py). Late idioblastic muscovite crystals locally overgrow the foliation. Diagnostic petrographic characteristics of the Walloomsac include the presence of graphite and pyrite and strongly pleochroic red-brown biotite. (Sample N113-3L; Inwood Hill Park, at south footing of Henry Hudson Bridge, Manhattan; 2 mm field of view.)

Origins of the Hartland, Manhattan, and Walloomsac Formations

Now metamorphosed to amphibolite facies grade, the exposed metamorphic cover rocks of NYC (Hartland, Manhattan, and Walloomsac formations) were originally deposited as sediment and intercalated volcanic and volcaniclastic materials, though in vastly different environments (Figure 7). The Hartland Formation was originally deposited in a deep ocean basin fringed by offshore volcanic islands. The marginal ocean basin was the receptor of a huge influx of terrigenous and volcanogenic material. This produced a thick sequence of interlayered clay, silt, sand, and interlayered volcanogenic strata which resulted in a variable rock sequence after Paleozoic dynamothermal metamorphism. Compositional layering was preserved in the Hartland, forming a dominantly well-layered metamorphic rock mass consisting of interlayered and locally migmatitic schist, gneiss, granofels, and amphibolite.

The Manhattan Formation originated along the edge of the former North American continental margin as thick clay-rich sediment with occasional sand interlayers. (See Figure 7.) As a result, the Manhattan is often more massive in character than the Hartland. The Walloomsac Formation is mineralogically unique since it originated under restricted oceanic conditions and consisted of thick accumulations of carbonaceous and sulphidic clay-rich sediment with occasional sandy and calcareous interlayers. This has resulted in mineralogically distinct schistose rock enriched in biotite, graphite, and pyrite together with layers of calcite marble and calc-silicate rock. The contrast in internal compositional layering and mineralogy allows for separation of the three units in the field and also during routine core analysis though petrographic work is the most diagnostic.

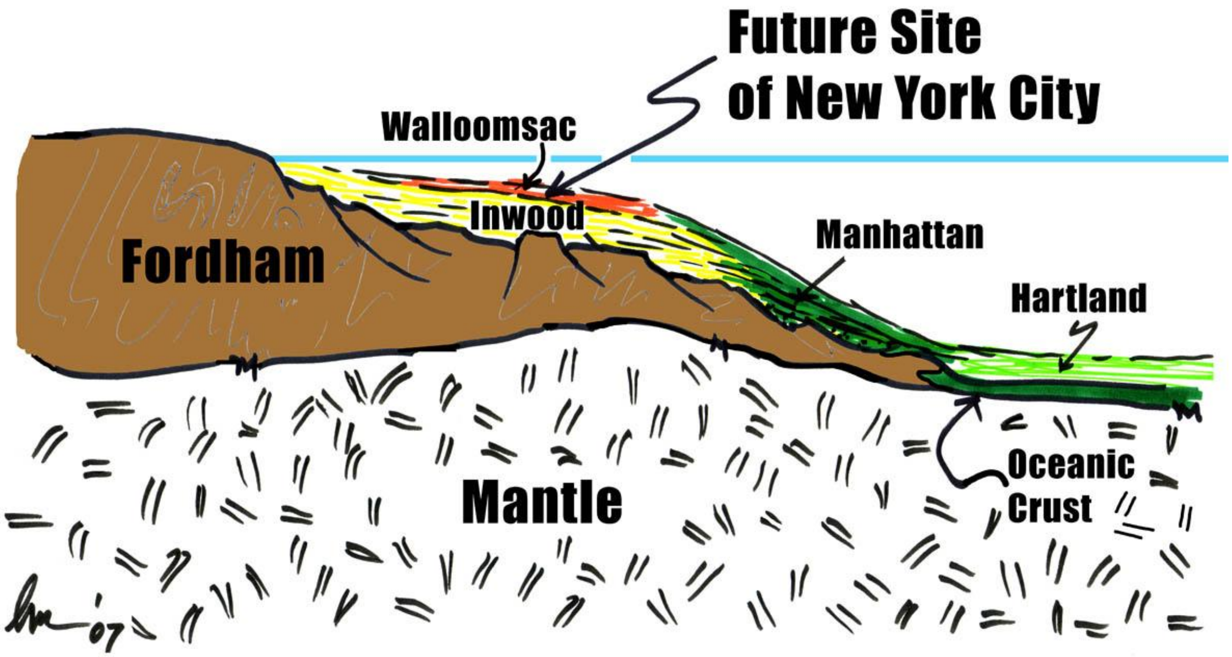

Figure 7 – Diagrammatic cartoon of eastern North America after rifting from Rodinia and during deposition of the Paleozoic strata that are to become the Hartland, Manhattan, and Walloomsac formations. Note the correlation of units and their relationships to the underlying units of the partly coeval Inwood and older Fordham.

NYC Bedrock Formations Beneath the Hartland, Manhattan, and Walloomsac Formations

The metamorphic rocks described above are in structural or unconformable contact with the predominately older units described below.

Inwood Marble. The Inwood (Ꞓ-Oi in Figures 1, 2, and 3) consists of typically white to bluish-gray fine- to coarse-textured calcitic and dolomitic marble locally with siliceous interlayers containing tremolite, phlogopite, actinolite, quartz, and diopside (Figure 8). Layers of fine grained gray quartzite with a cherty appearance are also locally present. White and bluish-gray fine- to coarse textured dolomitic- and calcite marble form subordinate members. The unit is found in the Inwood section of northern Manhattan, the Harlem lowland NE of Central Park, in thin belts in the East River channel, in the subsurface of southeastern Manhattan, and also crops out in The Bronx and Westchester County. The Inwood is correlative with an outcrop belt of Cambro-Ordovician rocks found along the entire Appalachian chain of North America.

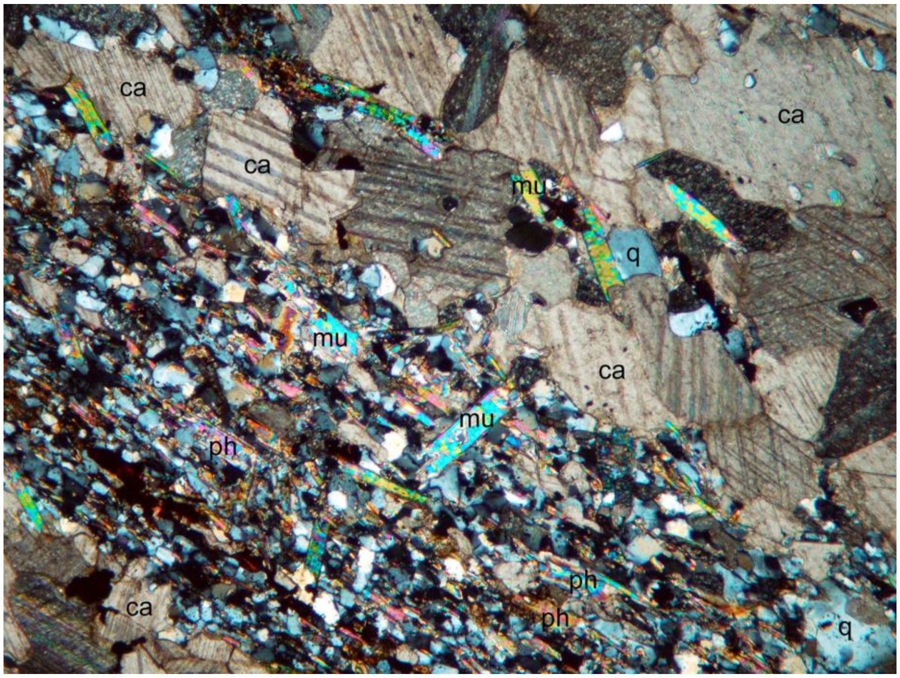

Figure 8 – Photomicrograph in cross-polarized light of the Inwood Marble near the contact with the Walloomsac showing the granoblastic texture produced by recrystallized twinned calcite (ca). A fine-textured mica-rich zone cutting diagonally across the slide defines a foliation which here consists of aligned muscovite (mu) and phlogopite (ph) in a matrix of recrystallized quartz (q), calcite, and biotite (bi). Normally the Inwood is quite pure and consists of coarse textured granoblastic calcite or dolomite. (Sample N113-4; Inwood Hill Park, at south footing of Henry Hudson Bridge, Manhattan; 2 mm field of view.)

Fordham Gneiss. The Fordham Gneiss (Yf in Figures 1, 2 and 3) constitutes the oldest underpinning of rock formations in the NYC area and consists of a complex assemblage of Proterozoic Y ortho- and paragneiss, granitoid rocks, metavolcanic- and metasedimentary rocks. In NYC, only a few attempts have been made to decipher the internal stratigraphic relationships, hence, the three-dimensional structural relationships remain obscure. Based on detailed studies in the Queens and Brooklyn NYC water tunnels (Merguerian 2000; Merguerian, Brock, and Brock 2001; Brock, Brock, and Merguerian 2001) the Fordham consists of predominately massive mesocratic, leucocratic, and melanocratic orthogneiss with subordinate schistose rocks. They have been metamorphosed to the high pressure granulite facies which has produced a tough, anhydrous interlocking mineral texture consisting of primary pyroxene, plagioclase, and garnet that has partially resisted hornblende and biotite grade retrograde regional metamorphism (Figure 9).

The Fordham is found in the Bronx, in the subsurface of SE Manhattan, the East River channel, and western Queens and Brooklyn, and underlies most the entire region at greater depth. (See Figure 7.) Occurring locally between the Inwood and Fordham are two minor units. One is the very local Lowerre Quartzite (Norton 1959) and the other an areally restricted late Proterozoic unit known as the Ned Mountain Formation (unit Zn in Figure 3) of Brock (1989, 1993). The Ned Mountain is correlative with Proterozoic Z rocks mapped as the Yonkers Gneiss (Scotford 1956) and the Ravenswood Granodiorite Gneiss (Ziegler 1911) found in Westchester County and in western Queens, respectively. They have little bearing on the primary focus of this paper and are referenced for sake of academic completion but will not be discussed further here.

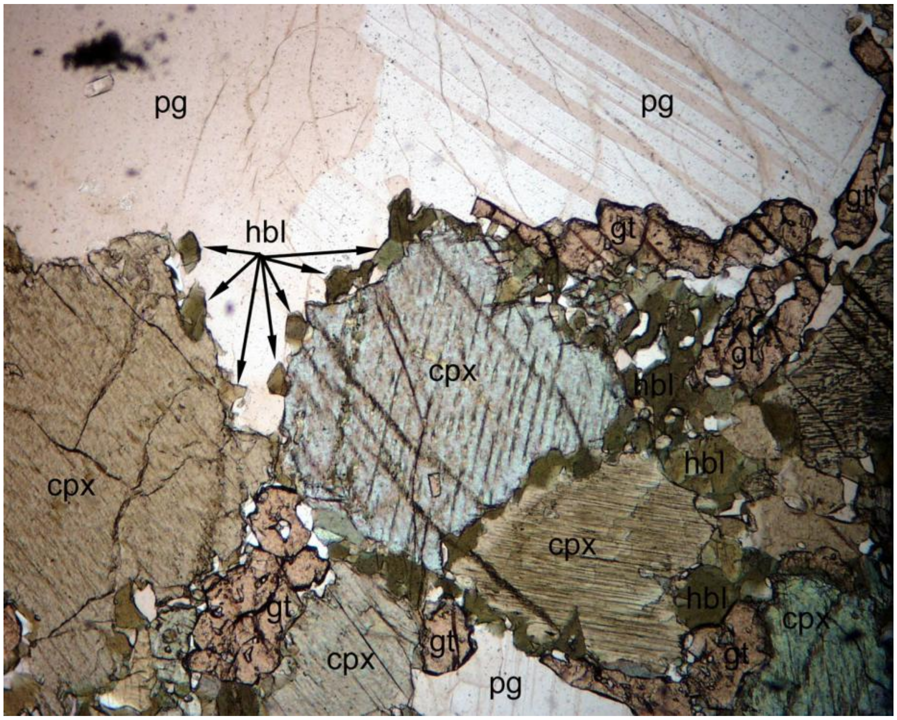

Figure 9 – Photomicrograph in plane-polarized light of Proterozoic mafic orthogneiss showing a coarse-textured granular intergrowth of clinopyroxene (cpx), plagioclase (pg), and garnet (gt) produced during an early stage of metamorphic recrystallization of a former mafic igneous rock. Granular hornblende (hbl) was produced during a secondary metamorphism but the older interlocking metamorphic texture has prevailed. (Sample Q114; Queens Tunnel Station 015+90; 2 mm field of view.)

Other Rocks Associated with the Bedrock Series

Serpentinite. In addition to the famous Staten Island serpentinite, many scattered bodies of serpentine rock have been encountered in the subsurface of NYC over the years (Figure 10). In addition to a few bodies known in Manhattan near 59th Street and 10th Avenue, the Bruckner Boulevard/Cross Bronx Expressway/Hutchinson River Parkway interchange at the north end of the Bronx-Whitestone Bridge approach in The Bronx, and a few bodies that were penetrated during construction of the Brooklyn Tunnel (Schnock 1999). Serpentinite has also been found in a building construction site at 43rd Street and Sixth Avenue in midtown Manhattan (Merguerian and Moss 2005) and in northern Manhattan (Merguerian and Moss 2007). These sheared masses are interpreted as ophiolitic scraps and are commonly found in ductile fault contact with the surrounding Hartland Formation or near the Manhattan-Hartland contact (Merguerian 1979). The serpentinites are black to greenish fine grained rocks containing serpentine group minerals including chrysotile, chromite, magnetite, orthoamphibole, magnesite, talc, calcite, chlorite, and relict olivine and pyroxene.

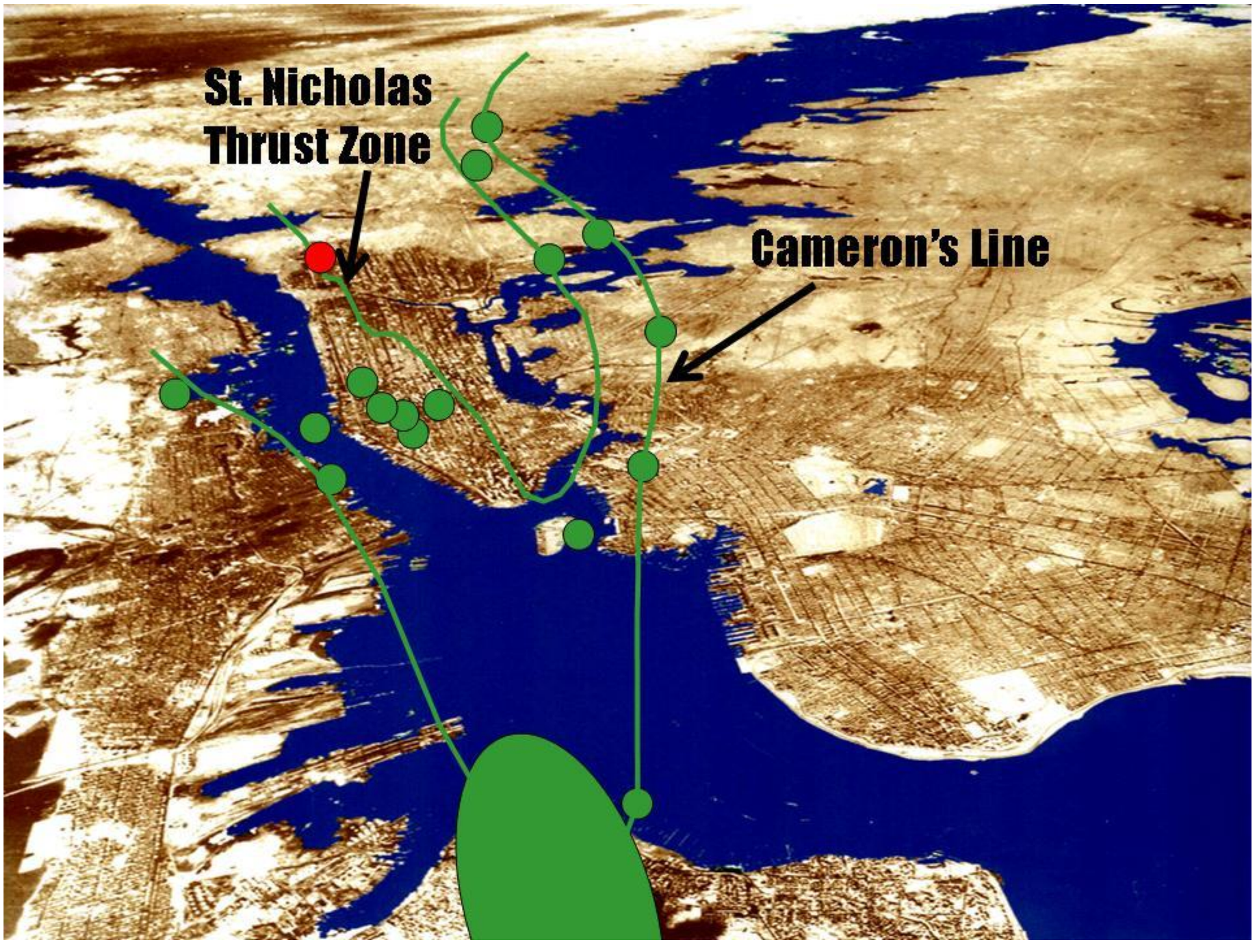

Figure 10 – Cartoon showing distribution of 18 known areas of serpentinite in the New York City area with the site of this report shown in red. The green lines surround areas of serpentinite defining a zone of sheared rock broadly coincident with the St. Nicholas thrust and Cameron's Line, two important elements of the Taconian suture zone in New York City. The red dot shows the location of a newly discovered serpentinite in northern Manhattan described by Merguerian and Moss (2007).

Granitoids. All units of the NYC bedrock described above have been intruded by granitoids that range from foliated and internally sheared pre- and syn-tectonic intrusives to post-tectonic bodies. They range from fine-textured to pegmatitic and occur as dikes, sills, stocks, and small plutons consisting of essential microcline, orthoclase, quartz, plagioclase, biotite, hornblende, muscovite, and subordinate garnet. Minor tourmaline and beryl are also reported.

Rhyodacite. Found exclusively beneath the area of Woodside, Queens, a swarm of five thin sub-parallel rhyodacite dikes, all displaying pristine igneous textures, were penetrated during construction of the Queens Tunnel (Merguerian 2000, 2001). They occurred as tabular, discordant injections roughly oriented N53°W and average roughly 3 m in thickness. The larger dikes vary from 5.3 m down to 1 m and taper off to thinner dikelets. The rhyodacites are reddish, glassy to aphanitic igneous rocks with no metamorphic fabric and low average density (2.58 g/cm^3).

The unique devitrified texture of the groundmass and the presence of vesicles unequivocally identify the Queens Tunnel rhyodacite as a hypabyssal rock. The dikes are Permian in age (295 Ma) and crosscut folded Proterozoic Y granulite facies rocks of the Queens Tunnel Complex with which they are genetically and temporally unrelated. The injection of a suite of Permian rhyodacite dikes that are chemically, texturally, and temporally unrelated to their bedrock hosts, mark an anomalous geological formation that adds a new chapter to the evolution of the NYC area.

Mapping in conjunction with construction of NYC Water Tunnels # 1 and 2 also defined mafic and alkalic dike rocks (Berkey 1911, 1933, 1948) and I have seen mafic dikes in the Queens Tunnel and elsewhere in NYC and throughout New England. Some of them are foliated and of Ordovician age and others contain pristine igneous textures and are most likely associated with the early Jurassic Palisades intrusive epoch.

STRUCTURAL GEOLOGY OF NEW YORK CITY

Deformational Episodes. All bedrock units in NYC have shared a complex Paleozoic structural history which involved three superposed phases of deep-seated deformation (D_1-D_3) followed by three or more episodes of open- to crenulate folds (D_4-D_6). The synmetamorphic juxtaposition of the various units occurred very early in their structural history (D_2) based upon field relationships. The Fordham harbors a more complex history as a result of its great age. It has experienced deformation and metamorphism during the Grenville orogeny (~1.1 Ga) in addition to the three Paleozoic orogenies (Taconian, Acadian, and Allegenian) experienced by the overlying Inwood, Walloomsac, Manhattan, and Hartland rocks. Below, I will restrict my discussion to the Paleozoic deformation with the understanding that the Fordham is more complexly deformed and highly metamorphosed.

The obvious map scale folds in NYC are those with steep N- to NE-trending axial surfaces (S_3) and variable but typically shallow plunges toward the S and SW. (See Figures 1 and 2.) The folds are typically overturned to the NW with a steep SE-dipping schistosity (Figure 11). Shearing along S_3 axial surfaces typically creates a transposition foliation of S_1, S_2, and S_3 that is commonly invaded by granitoids to produce migmatite during both the D_2 and subsequent D_3 events. The third-generation structures deform two earlier structural fabrics (S_1 and S_2). The older fabrics trend roughly N50°W and dip gently toward the SW (except along the limbs of overturned F_3 folds). I suspect that all of these structures (D_1, D_2, and D_3) are products of the protracted middle Ordovician Taconic orogeny (Merguerian 1996).

During D_2, the rocks acquired a penetrative S_2 foliation consisting of oriented mica and intergrown sillimanite and kyanite with flattened quartz together with staurolite and garnet porphyroblasts. Distinctive layers and lenses of kyanite+quartz+magnetite developed in the Manhattan formation and very locally in the Hartland during D_2. Near ductile fault contacts the S_2 fabric is highly laminated with frayed and rotated mica and feldspar porphyroclasts, ribboned and locally polygonized quartz, lit-par-lit granitization, and quartz veins all developed parallel to the axial surfaces of F_2 folds. The D_3 folding event, a period of L-tectonism, smeared the previously flattened kyanite+quartz layers and lenses into elongate shapes parallel to F_3 axes.

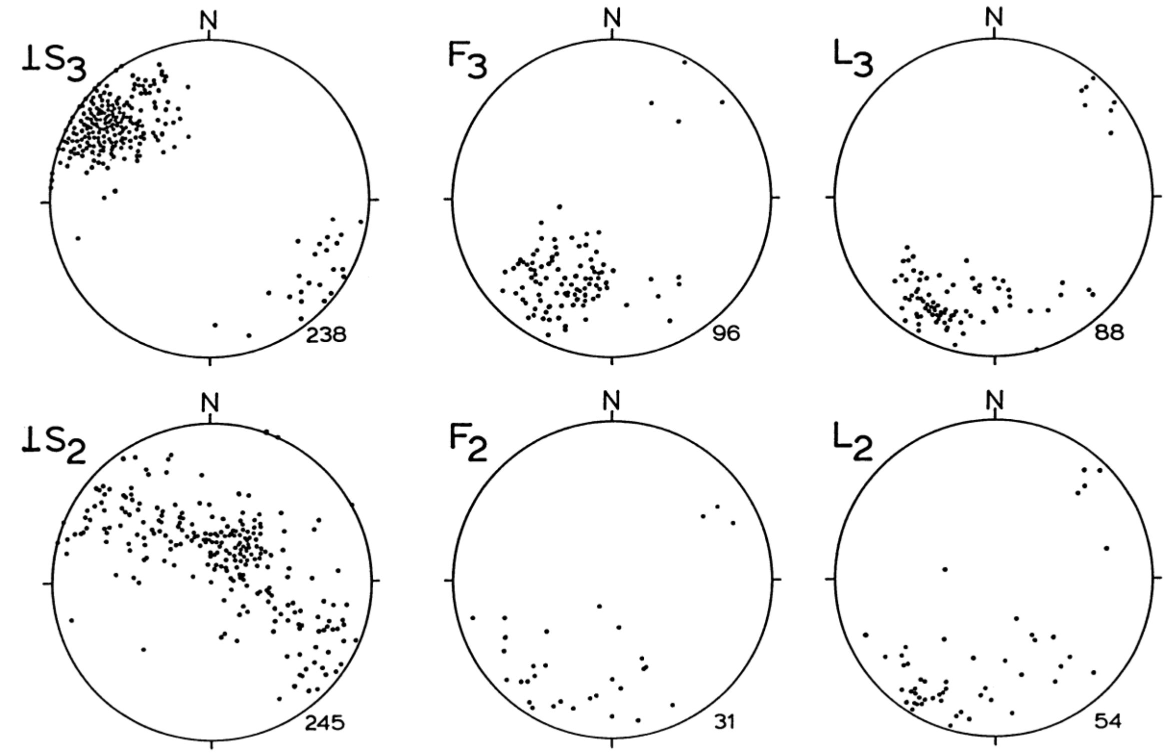

Figure 11 – Equal area stereograms showing the distribution of poles to S_2 and S_3, the orientation of F_2 and F_3 fold hingelines, and the orientation of L_2 and L_3 lineations. The number of plotted points indicated to the bottom right of each stereogram. (Adapted from Merguerian and Sanders 1991, Figure 26, p. 113.)

Although the regional S_2 metamorphic grain of the NYC bedrock trends N50˚W, the appearances of map contacts are regulated by F_3 isoclinal- to tight folds overturned toward the west and plunging SSE to SW at 25˚. (See Figure 11.) S_3 is oriented N30˚E and dips 75˚SE and varies from a spaced schistosity to a transposition foliation often with shearing near F_3 hinges. The F_3 folds and related L_3 lineations mark a period of L-tectonite ductile flow that smeared the previously flattened quartz and kyanite lenses and layers into elongate shapes. Metamorphism was of identical grade with D_2 which resulted in kyanite overgrowths and annealing of former mylonitic textures (Merguerian 1988).

Originating within the convergent walls of a major subduction zone formerly situated off shore from proto-North America, the D_1 to D_3 folds and crosscutting fabrics formed during the Taconic orogeny are overprinted by two- and possibly three fold phases that, based on their style and general lack of attendant foliation, undoubtedly took place at much-higher crustal levels than did the three Taconian fabrics. The younger fold phases record the effects of the Acadian- and terminal-stage Appalachian orogeny. A geological map of Central Park (Merguerian and Merguerian 2004) shows the F_4 folds as a series of warps and open folds with axial traces that strike roughly N30°W and exhibit dominantly steep dips to the SW. The effects on map contacts of these late features is negligible but the scatter of poles to S_3 and localized northward plunges of F_3 fold axes and L_3 lineations are the result of post-D_3 deformation. (See Figure 11.) Brittle S_4 cleavages in the bedrock may have helped localize the late stage brittle NW-trending faults that cut the region. Idioblastic muscovite pseudomorphs after D_3 kyanite are common throughout Central Park. Their abundance suggests a major post-Taconian retrograde metamorphism, presumably coincident with the intrusion of wet Devonian granitoids throughout the Manhattan Prong as discussed by Brock and Brock (1999).

Brittle Faults and Joints

Five generations of brittle faults and joints cut polydeformed bedrock units of the NYC area (Merguerian 2002). The brittle faults include NW-trending gently SW-dipping faults **(Group A)**, younger ENE-trending faults with moderate to steep dips **(Group B)**, subhorizontal faults and fractures **(Group C)**, and a steep dip-slip NNE-trending fault set **(Group D)** with thick clay- and zeolite-rich gouge zones. These are cut by NW- to NNW-trending strike-slip faults of the "Manhattanville" fault set **(Group E)**. Reactivation of older faults is quite common. The two youngest brittle fault sets (Groups D and E) cross cut all metamorphic structures in NYC and cut the late Paleozoic (295 Ma) glassy rhyodacite dikes.

The NYC Water Tunnel #3 cuts through the 125th Street "Manhattanville" fault beneath Amsterdam Avenue in Manhattan. Here, in an abrupt zone of highly fractured Manhattan Schist 40 m wide, the Manhattanville fault dips 55˚ to 75˚ SW and cuts orthogonally across the tunnel line and the steeply dipping foliation in the schist. In the crown of the tunnel, 2 to 3 m blocks of the Manhattan, which remained internally coherent within the broad zone of cataclastic rock, showed a minimum of 90˚ rotation about a vertical axis. Clearly, this observation indicates that along the Manhattanville fault, much of the motion has been strike-slip. Indeed, slickensides indicate that right-lateral, normal, oblique slip was the most recent offset sense. Cross-fault offset of the prominent Manhattan ridge indicates over 200 m of composite right-lateral slip.

Joint Orientations. Protracted brittle faulting in the NYC area has developed three mutually intersecting fracture orientations (NW, NNW, and NNE) that together produce a pattern of crustal weakness. Five joint sets, which are parallel to the brittle faults, are found in the NYC area. These include:

1) NW-trending, NE-dipping joints and their conjugates. The NW-trending joints are A-C joints related to southward-plunging F_3 folds.

2) NNE-trending joints with steep dips related to Group D faults. Also includes foliation parting joints and conjugate joint surfaces. Typically with a NE trend these are found more commonly in areas of regional F_3 fold limbs where parallelism of axial surfaces of folds, compositional layering, and foliation occur.

3) Gentle SW-dipping foliation joints developed parallel to SW-dipping foliation and original compositional layering at F_3 fold hinges.

4) Subhorizontal unloading joints and joints related to subhorizontal shear zones.

5) Steep ENE joints related to the oldest brittle fault set.

Although fracturing generally aids in the excavation of rock, in TBM endeavors zones of intersecting fractures are related to working face, crown, and sidewall instability, slippage of TBM grippers, downtime for installation of additional support and ring steel, and high water inflows. Intersecting joint sets can cause similar problems in traditional excavations and therefore careful study and analysis of core and regional trends are important preludes to job bidding and initiation or approach.

GEOLOGICAL CONTROLS AND EXCAVATION CHARACTERISTICS OF NYC BEDROCK

The combined effects of metamorphism and structural deformation has transformed the bedrock units of NYC into a complicated rock mass of varying physical and mechanical properties. Indeed, mineralogy, lithology, texture, metamorphic grade, and structure have a controlling influence on the way rocks break and therefore provide a fundamental link to the methods and means of efficient excavation. A discussion of the influence of these controls follows.

Mineralogical Controls

Construction efforts that rely on penetration through and excavation of rock must take into account the physical properties of minerals. During the pre-bid stage, the mineralogy and hardness index of a rock mass is simply established using standard petrographic techniques on existing drill core. In this method a thin slice of the core is mounted on a glass slide and ground to a specific optical thickness of 30 microns by any number of firms specializing in such work. Petrographic analysis by a trained specialist can establish the volume percentage of component minerals and a weighted hardness value based on Mohs Hardness Scale can easily be calculated for comparison to previous excavation experience.

Minerals common to NYC bedrock are listed alphabetically in Table 1 along with their Mohs hardness, cleavage, and specific gravity. Softer minerals that exhibit cleavage tend to split or break more readily under stress than those that are harder and exhibit fracture. Rocks enriched in hard minerals such as quartz, garnet, kyanite, and sillimanite tend to inhibit penetration by any means and methods and can foster the production of excessive fines.

The density or specific gravity of rocks is a simple litmus test for predicting rock excavation especially by means of mini-mole or TBM. (See Merguerian and Ozdemir 2003; Figure 5, p. 1026.) Rocks consisting of higher density minerals such as garnet, pyroxene, sillimanite, and kyanite are less penetrable by TBM mining or any other excavation method. A density profile along any tunnel alignment can help identify variations over the planned TBM course and can help plan machine design parameters. All other things being equal, denser rocks tend to be more difficult to excavate in terms of breakage and off-site transport. The volume % of dense, abrasive, hard minerals needs to be determined as their presence above background levels (a few %) can negatively impact excavation rates and enhance the production of excessive fines.

Table 1 – Physical properties of minerals common to NYC bedrock units.

Mineral	Hardness	Cleavage(s)	Sp. Gr.
Amphibole	5-6	Two @ 60° and 120°	2.8-3.45
Biotite	2.5-3	One	2.8-3.2
Calcite	3	Three @ 75°	2.72
Chlorite	2.0-2.5	One	2.6-2.9
Diopside	5-6	Two @ 87° and 93°	3.2-3.3
Dolomite	3	Three @ 74°	2.85
Feldspars	6	Two @ 90°	2.54-2.75
Garnet	6.5-7.5	Fracture	3.5-4.3
Graphite	1-2	One	2.3
Kyanite	5-7	One	3.56-3.66
Muscovite	2-2.5	One	2.76-3.10
Phlogopite	2.5-3.0	One	2.86
Pyroxene	5-6	Two @ 87° and 93°	3.15-3.5
Quartz	7	Fracture	2.65
Sillimanite	6-7	One	3.23

Lithologic Controls

Rock type has a major influence on any decision concerning removal. During the process of dynamothermal metamorphism, increasing metamorphic grade transforms parent materials into hard rock with the transition from slate to phyllite to schist to gneiss to migmatitic gneiss a prelude to total internal melting and production of magmatic fluids. In NYC, owing to the metamorphic grade of the rocks, slate and phyllite are not found but schist, gneiss, and migmatite are common along with the associated rocks (amphibolite, serpentinite, granitoids, and dike rocks) mentioned earlier. The mechanical properties of schist and gneiss are well understood by contractors and the recent use of terms schistose gneiss, gneissic schist and the like in boring logs are confusing without definition. According to the venerable **American Geological Institute Glossary of Geology** (1982), the term **schist** is defined as *"A strongly foliated crystalline rock, formed by dynamic metamorphism, that can be readily split into thin flakes or slabs due to the well developed parallelism of more than 50% of the minerals present, particularly those of lamellar or elongate prismatic habit, e.g. mica and hornblende".*

The AGI Glossary of Geology defines the term **gneiss** as *"a foliated rock formed by regional metamorphism, in which bands or lenticles of granular minerals alternate with bands or lenticles in which minerals having flaky or elongate prismatic habits predominate. Generally less than 50% of the minerals show preferred parallel orientation. Although gneiss is commonly feldspar- and quartz-rich, the mineral composition is not an essential factor in its definition. Varieties are distinguished by texture (e.g. augen gneiss), characteristic minerals (e.g. hornblende gneiss), or general composition and/or origins (e.g. granite gneiss)."*

The AGI Glossary of Geology defines the term **migmatite** as *"a composite rock composed of igneous or igneous-appearing and/or metamorphic materials, which are generally distinguishable megascopically."* Migmatites are metamorphic rocks that are stewed in their own juices with injection of melted granitic fractions, an important part of the processes that tend to stitch together, strengthen and solidify any original rock type. Migmatitic rocks are difficult to excavate because of their recrystallized texture and pervasive interlocking of minerals.

Very clear definitions of the common rock types found in NYC exist in the literature and by experience all contractors know that schists are more readily removed by any method compared to gneiss or migmatite. Luckily, the determination of schist vs. gneiss is an easy process with careful core study and petrographic analysis and both should accompany any Geotechnical Baseline Report. Careful stereoscopic analysis of split core is also helpful in this regard but no substitute for careful petrographic analysis by skilled technicians.

Foliation Controls

The nature and orientation of foliation (or the lack thereof) holds a first order control on efficient mining by mechanical means. Most foliated rocks are rich in mica (a soft mineral with hardness ~2.5 on Mohs' scale) that tends to provide structural weakness in the form of a perfect basal cleavage. Although mica is the most common foliation-producing mineral, not all foliated rocks are micaceous. Amphibole (hornblende is the common variety) can produce a foliation in rocks in much the same way that spilled box of pencils can flatten out into a planar orientation on the floor. In addition to mica and amphibole, highly sheared rocks that are not subsequently recrystallized contain highly flattened or lenticular quartz, feldspar, and other phases that impart a preferred parallel orientation to the rock texture. Such rocks impart a foliated texture despite the fact that the common phases mica and amphibole are not in excess of 50% of the rock volume. (see Figure 6). In NYC, owing to the degree of late-stage metamorphic recrystallization, such textures are usually annealed (Merguerian 1988). Highly foliated rocks, such as schist and phyllite, tend to split readily along the foliation thus providing a discontinuity (planes of weakness) that help facilitate rapid excavation (Figure 12). Poorly- to non-foliated rocks (granofels, gneiss, migmatite) resist breakage as a result of stable, interlocked crystal boundaries, typically the result of high grade metamorphism and a lack of alumina (= low clay content in original parent material) to produce mica or amphibole (Figure 13).

Metamorphic Controls

Most of the bedrock of NYC was metamorphosed under amphibolite facies conditions. In formerly clay-rich strata this resulted in the growth of oriented mica along with kyanite and sillimanite in a matrix of flattened and recrystallized quartz, plagioclase, and garnet to produce a foliated schistose rock (see Figure 12). Interlayered former sandy units recrystallize into mica-poor layers known as granofels, consisting of intergrown quartz and plagioclase. Mafic volcanic and pre-tectonic dike rocks recrystallize into foliated amphibole- and plagioclase rich rocks known as amphibolite.

Deep-seated metamorphism is a dehydration reaction that tends to drive water out of minerals. At higher metamorphic grades (upper amphibolite or granulite facies) this results in the total destruction of hydrous phases (mica and amphibole) and the replacement of these foliation- producing minerals by dense, anhydrous phases that include garnet, ortho- and clinopyroxene, kyanite, and sillimanite, often with the liberation of quartz. The growth of these phases in a rock mass can transform a foliated rock mass into compact mica-poor rock mass consisting of equigranular minerals showing 120° crystal intersections and no preferred orientation. As such, original foliated rock masses can be transformed by high-grade metamorphism into non-foliated (granoblastic) rock masses. At the highest metamorphic grades (granulite or high pressure granulite facies), thorough recrystallization results in an anisotropic rock mass (see Figure 13). Such textures, easily identified by the petrographic microscope, produce tough rock masses that are legendary for poor penetration rates, production of blocky ground and excessive fines.

Control of Folds and Metamorphic Fabrics

Folding in response to mountain building results in reorientation and recrystallization of new minerals (typically micas in rocks of appropriate composition) in a direction perpendicular to maximum compressive stress (Figure 14). Such deformation can produce a foliation in a rock mass because of rotation, growth, and parallelism of new mica in the axial regions of folds (the plane of maximum compression). A penetrative axial planar foliation can result if the rocks are aluminous enough to produce micas (abundant original clay in the parent rock is a necessary element). In alumina-poor parent starting materials no degree of strain can produce a mica foliation because the chemistry will not support mica growth. Even within a schistose formation, mica-poor rocks can occur as a result of original compositional variations including clay poor silty or sandy facies, turbidites, or clean quartzose sand interlayers.

Superposed deformation can produce numerous generations of crosscutting metamorphic fabrics that can be traced in the field and also verified by petrographic examination. The history of a rock mass can be deduced in this fashion since different deformations typically produce their own unique set of distinctive minerals based on extant pressure-temperature conditions. Thus, cross-cutting relationships establish the relative age of metamorphic fabric elements and allow for the interpretation of complex terrains such as found in NYC.

In rocks that experience high shear strains, excessive ductile flow can disrupt folds with attendant shearing and dislocation along the limbs and axial surfaces of folded structure. Figure 15 shows a typical example of this phenomenon wherein folded layers in the upper part of the diagram have been dislocated with respect to the lower part of the diagram. Such structures are well-known in highly sheared metamorphic rocks. Examples of sheared out folds and intense localized folding have been recorded at many places in NYC. They disrupt stratigraphy and can introduce different rock facies within a thin interval. As a result, widely spaced vertical borings may not adequately define the rock mass for a particular contract, especially when the major geological features are steep to vertical in orientation.

Such ductile superposed fabrics are found in localized areas of NYC (near ductile shear zones such as Cameron's Line and the St. Nicholas thrust). In the areas where intense shearing has taken place induced deformational fabrics and injection of migmatizing fluids tends to stitch together the rock texture and toughen the rock mass because of the destruction of foliation and replacement by granitic material to produce migmatite. Careful regional and site-specific geological mapping and examination of core by petrographic methods can readily identify such areas and avoid the hardship of poor excavation rates.

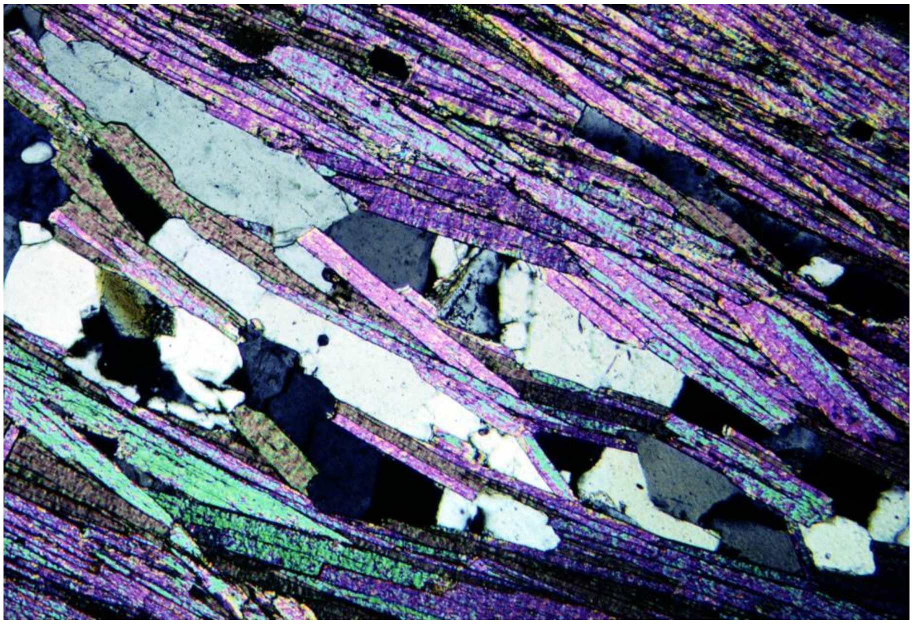

Figure 12 – Photomicrograph in crossed nicols of aluminous Hartland schist (N403-1; World Financial Center site, lower Manhattan). The section shows fine-grained lenticular quartz and minor plagioclase separated by aligned muscovite and minor biotite (highly colored crystals). Such directional mineral growth results in a penetrative micaceous foliation.

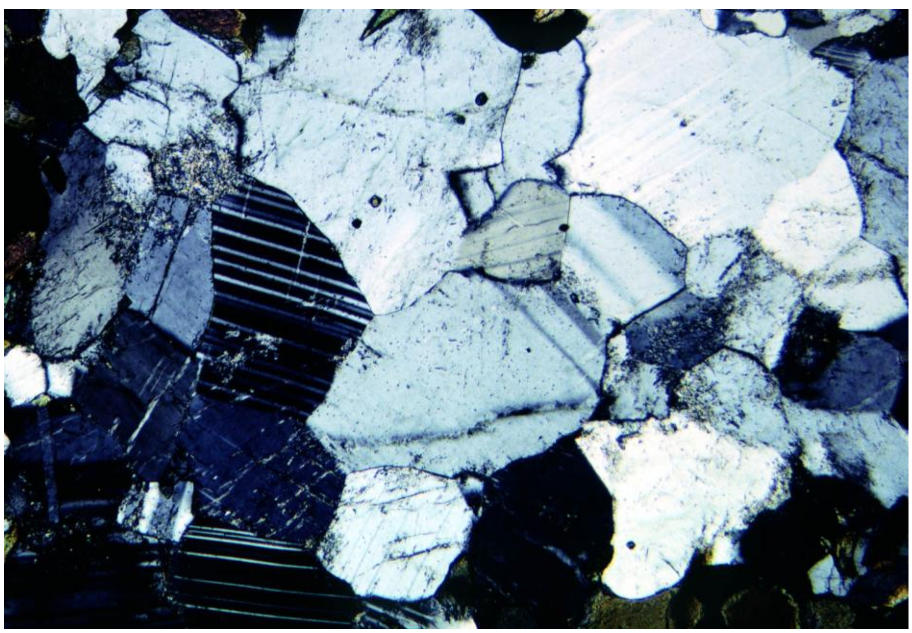

Figure 13 – Photomicrograph in crossed nicols of Queens Tunnel gneiss (Q085; Station 159+80) showing granoblastic intergrowth of plagioclase and minor quartz. Note the medium-grained granular texture, the stable 120° grain boundaries of the interlocking plagioclase, and the lack of any penetrative foliation. Both photomicrographs are 2 mm across.

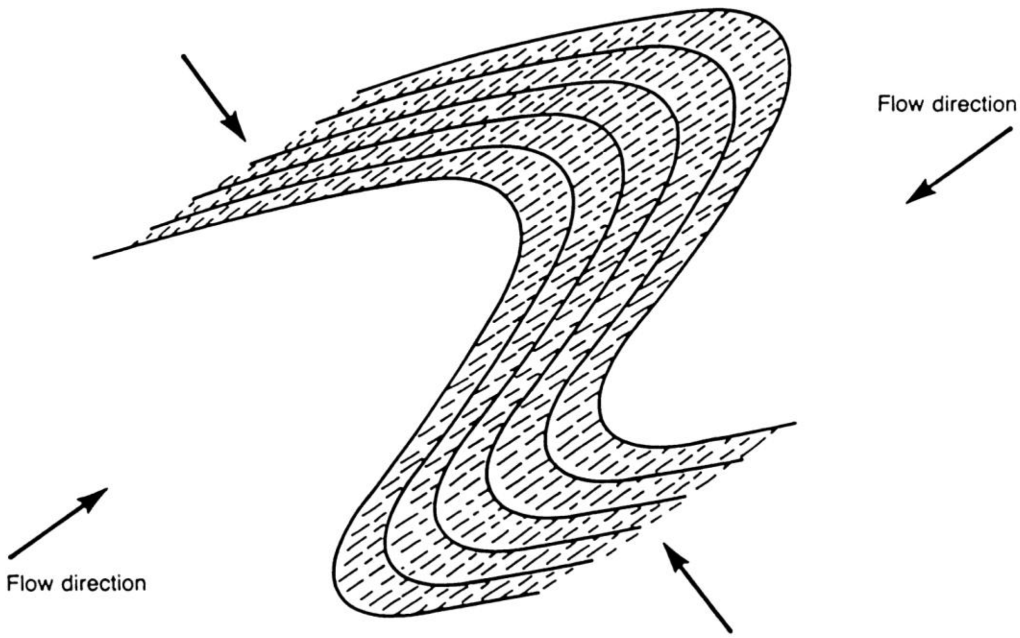

Figure 14 – Sketch showing how strain related to maximum compressive stress (black arrows) deforms bedrock into folds with flow and recrystallization perpendicular to the maximum compressive stress orientation. In metamorphic rocks, the rotation of existing fabric elements and the growth of new minerals bisects the fold in half along a new orientation parallel to the flow direction producing an axial planar foliation (in rocks of appropriate composition!).

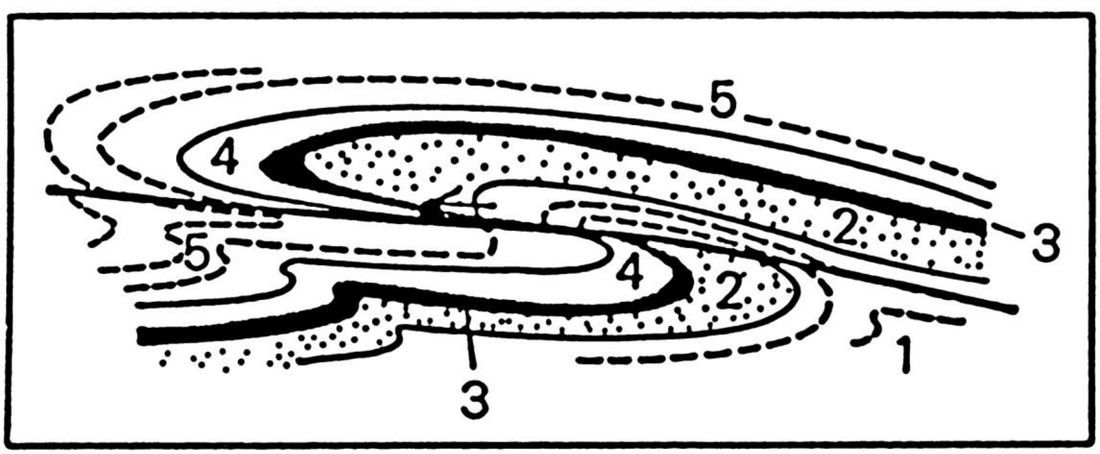

Figure 15 – Sheared overturned fold broken by a low-angle thrust fault, schematic profile section. Units are numbered in order to illustrate dislocation across shear surface.

Control of Superposed Fold Structures

The rocks of NYC display intense localized isoclinal- and shear folding in association with the development of the primary (S_2) regional foliation. In some places ductile shear zones developed initially during D_2 and subsequent D_3 deformation and produced a shredded, ductile fault fabric that was hardened by annealing during subsequent recrystallization. Thus, the combined effects of intense isoclinal folding and recrystallization are to produce composite parallel fabrics in the rock mass and to create a tough rock that resists breakage. Note in Figure 16, the massive nature of the rock mass, the result of intense localized folding, shearing, and migmatization. The rock, Hartland migmatitic gneiss from the South Ferry subway excavation in southern Manhattan, exhibits the effects of protracted deformation and shearing in the form of shear folds and the production of parallel S_2 and S_3 fabric elements. Note the older S_2 foliation (yellow lines in Figure 16) is discontinuous and associated with quartzofeldspathic granitoid. The quartz+feldspar laminae were formerly separated by thin mica folia but they were subsequently subjected to intense F_3 shear folding. Metamorphism coincident with the F_3 folding annealed the S_2 ductile fabrics and produced F_3 shear folds with characteristic sheared out limbs yet preserved the S_2 granitoid layers in the fold hinge area. Owing to the similarity in metamorphic grade between the D_2 and D_3 events, some garnet is flattened and deformed by the F_3 fold while some of the garnet is equant and overgrows the S_2 fabric as porphyroblasts.

Another type of structural control involves less intense F_3 folding (crenulate folds). Here, because of the effects of superposed F_3 folds, the older S_2 fabric is highly dislocated and warped into irregular complex patterns. Figure 17 is a composite diagram showing a large slab of mica gneiss from the South Ferry subway excavation in a number of petrographic views. Pane A shows the rock structure in plane polarized light with obvious deformation of a sparse mica foliation outlined by biotite and muscovite. Note the abundance of mica is much less than 50%, hence qualifying the use of the term gneiss because of the predominance of quartz and feldspar (gray, yellowish, and clear minerals in crossed polarized light (Pane B). The S_2 foliation is strongly folded by F_3 folds (Pane C) and the S_2 mica foliation is overprinted by S_3 mineral growth parallel to the axial surfaces of the F_3 folds. At this location, the complex intertwining of S_2 and S_3 metamorphic fabrics resulted in a complex rock texture dominated by multi-directional growth of discontinuous zones of mica. The effect of this was to “stitch” or “knit” the rock mass together and increase the resistance to breakage by mechanical means.

Detailed petrographic examination of the same South Ferry sample shows the knitted nature of the rock texture (Figure 18). Here, the growth of older biotite in numerous orientations is quite obvious as is the growth of younger muscovite mica at contrasting directions. The lower pane (B) shows that quartz and feldspar are also locked together as sutured crystals and as interlocking crystals with stable 120° boundaries. The short, discontinuous micas grown at various directions serve to “knit” the rock mass together (in much the same way that soft fiberglass fibers strengthen concrete) and the stable 120° crystal boundaries in the hard minerals resist fracture. This variety of knitted texture results in poor excavation rates regardless of method. The contractor at this job had tremendous difficulty removing the rock by hydraulic ram and mechanical means as specified in the contract and had to resort to limited blasting. The loss in time and increased construction costs resulted in an acrimonious dispute between the contractor and the NYC MTA.

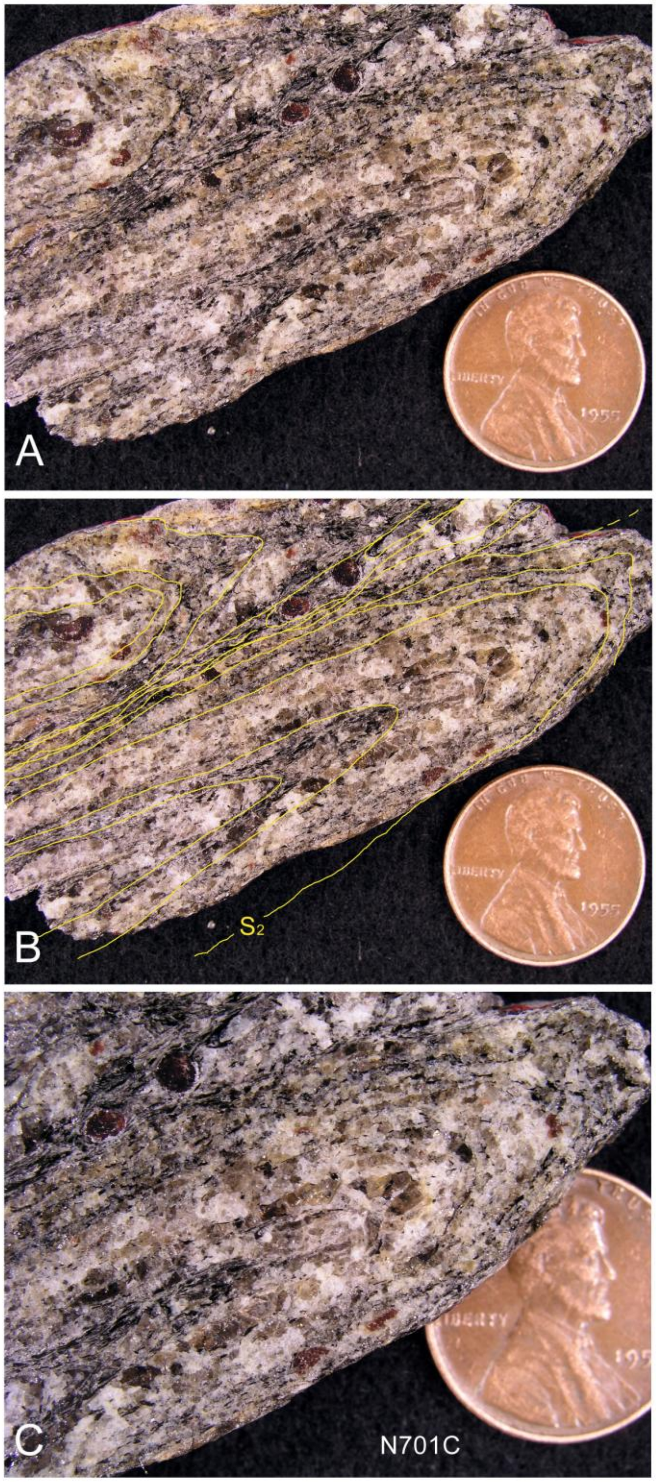

Figure 16 – Series of images showing F_3 shear folds from the South Ferry subway excavation where Hartland migmatitic gneiss predominates. Pane A shows a sawn and polished slab from southern Manhattan. Pane B shows the deformation of older S_2 fabric (in yellow) that is stitched together by quartz-feldspar segregations produced during D_2. The S_2 ductile fabric is deformed by D_3 shear folds that exhibit marked dislocation along the limbs of the fold and growth of parallel S_3 fabrics including garnet. Pane C is a close detail of the fold hinge area showing preservation of the older S_2 fabric. Elsewhere S_2 and is bent into parallelism with S_3 along the F_3 fold limbs.

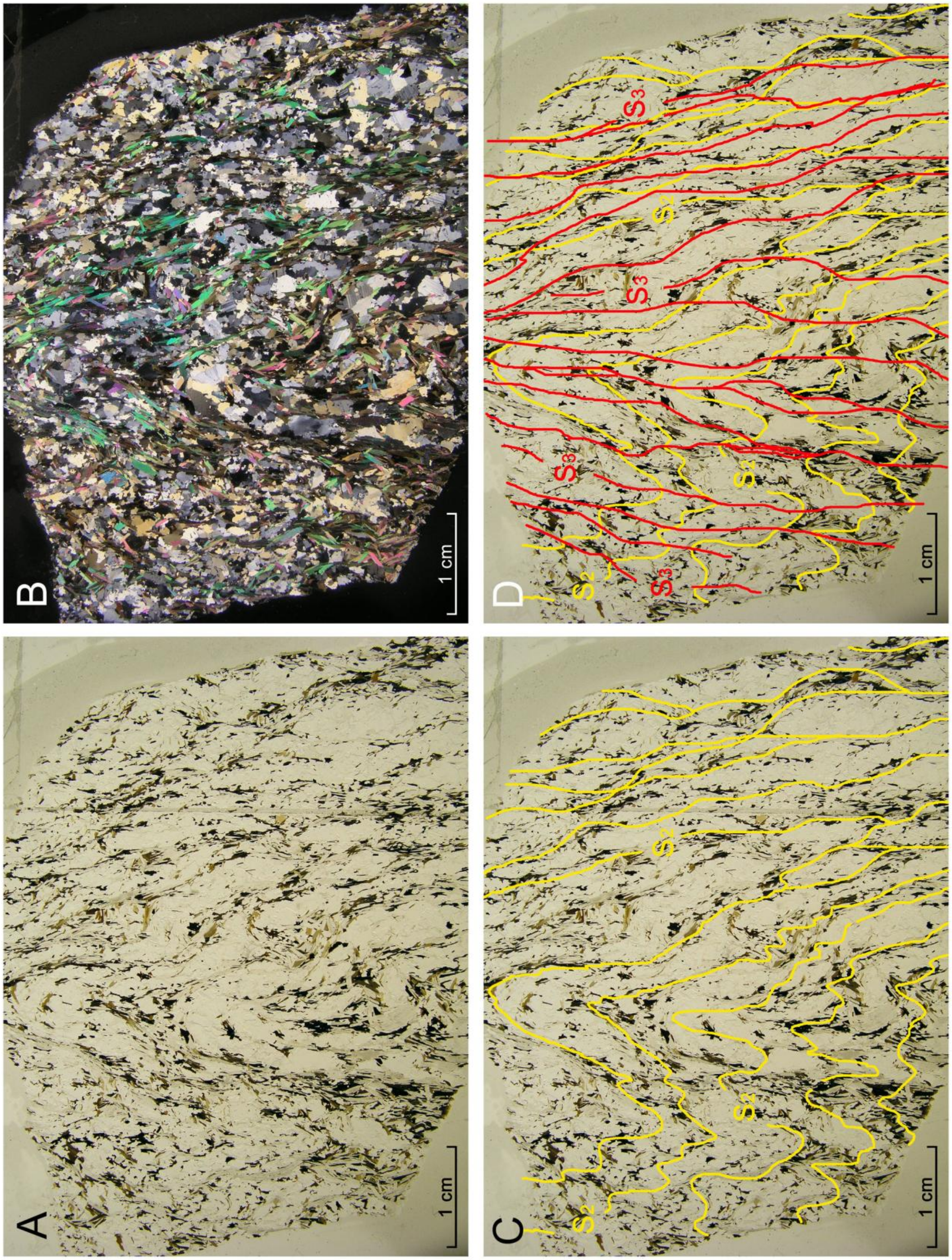

Figure 17 – Macroscopic images of large sawn sample of Hartland migmatitic gneiss from the South Ferry excavation in Manhattan showing a complex texture produced by superposed S_2 (yellow) and S_3 (red) fabrics.

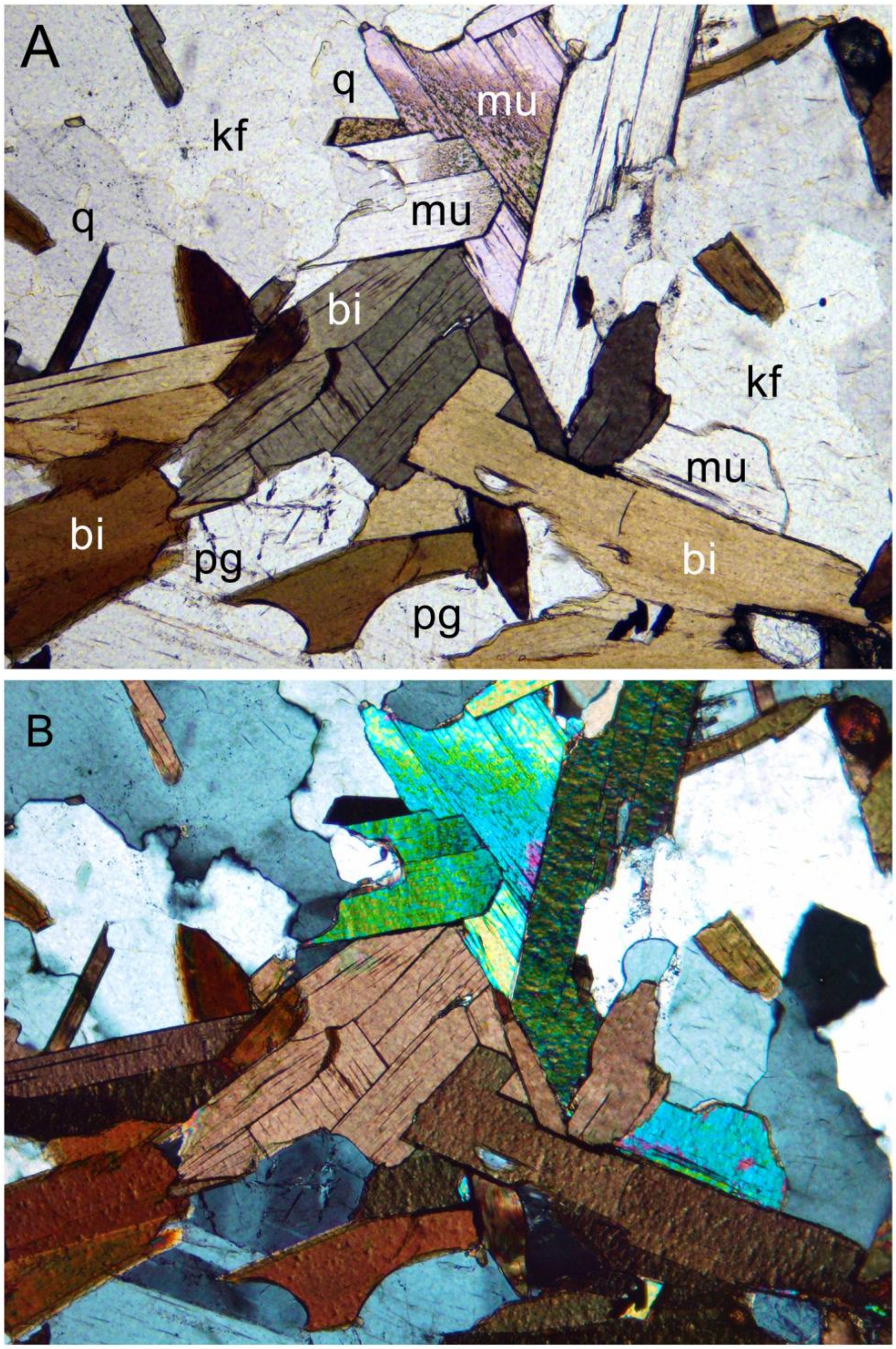

Figure 18 – Photomicrographs in plane-polarized (A) and cross-polarized light (B) showing the fabric of a sample from the South Ferry excavation in southern Manhattan. (Same sample as Figure 17.) Note the multi-directional nature of the individual mica crystals and how biotite micas are overprinted by late muscovite – also at odd growth angles. The lack of parallelism of constituent micas and interlocked texture of the hard minerals (quartz and feldspars) controlled poor penetration in highly folded rocks at this site. The short, discontinuous micas knit the rock mass together and the stable 120° crystal boundaries in the hard minerals resist fracture. Notation in plane-polarized view (A) is as follows: q = quartz, pg = plagioclase feldspar, kf = K-feldspar, mu = muscovite mica, bi = biotite mica. (Field of view 1.6 mm across.)

EXCAVATING CRYSTALLINE ROCKS

Regardless of means and method (roadheader, hydraulic ram, drill and blast, mini-mole, or TBM) the excavation of crystalline rock relies upon the failure of discontinuities in the rock mass under stress. Naturally, a thorough understanding of the joint density, orientation, and spacing (RQD and recovery values from core examination) are of great importance in this matter except for the recognition that RQD values of 100 do not specify actual spacing of fractures greater than 4 inches. The overall composition of the rock mass holds a first order control on excavation. Stated simply, the more mafic (iron- and magnesium-rich) the rock mass the lower the penetration. Careful petrographic core analysis and density measurements and tabulation should discriminate between felsic, intermediate, and mafic lithotypes at the excavation horizon.

The nature and orientation of foliation (or the lack thereof) also holds a prominent control on effective rock removal regardless of method. Most foliated rocks are rich in mica, a soft mineral (See Table 1) that tends to provide internal weakness in the form of a basal cleavage. The mineralogy of the foliation is of paramount importance including recognition of unique textures or structures. Although mica is the most common foliation-producing mineral, not all foliated rocks are micaceous and foliation can be produced by flattened mineral species such as lenticular quartz and feldspar. Amphibole (hornblende is the common variety) can produce a foliation in rocks in much the same way that spilled box of pencils can flatten out into a planar orientation on the floor. Deformation can produce planar and linear anisotropies in rocks in the form of grain-shape flattening (lenticular quartz), strain hardened mylonitic textures, and crystallographic lineations (aligned c-axes of quartz, aluminosilicates, and amphiboles). Lineated metamorphic terrains are isotropic in that penetration parallel to the lineation is less than across the lineation although this will depend on the actual mineral and its individual properties.

Highly foliated rocks (slate, phyllite, and schist) tend to split readily along the slaty cleavage or foliation. Compositional layering, related to original sedimentary deposition can also provide planes of weakness that help facilitate rapid excavation. Favorable orientations of foliation or compositional layering occur when these fabric elements dip steeply away from or toward the advance direction with the strike more or less perpendicular to the advance (Merguerian and Ozdemir 2003). Regional mapping and oriented core study will alert contractors to the prevailing orientation and adjustments in advance direction may enhance excavation. Unless exposed bedrock is available for field study, stereonet analysis of oriented core is the most effective method of understanding the variation and prevailing orientation of foliation and fractures along a given terrain.

Excavation Destiny of NYC Rocks

In terms of mechanical excavation of bedrock units that underlie NYC, the schistose portion of the **Hartland Formation** is relatively easy to excavate because of its high mica content, pervasive foliation, and presence of interlayered lithologic components. Two recent TBM contracts in Manhattan (Con Edison steam tunnel between 36th and 20th Streets along First Avenue and the Manhattan tunnel of NYC Water Tunnel #3 bored southward from 30th Street and 10th Avenue) experienced average penetration rates in excess of 3.5 m/hour in this well-layered formation. This unit was readily excavated at many sites by hydraulic ram from midtown Manhattan southward to the World Trade Center and vicinity. The **Walloomsac** schist, owing to the presence of graphite and fissile foliation is another unit that will yield high penetration rates but this unit is thin and sparsely distributed throughout NYC. The formation also contains layers and lenses of hard calc-silicate rock that is difficult to excavate. Of the three Paleozoic metamorphic cover units in NYC, the schists of the **Manhattan Formation** would be less penetrable than the Hartland or Walloomsac owing to the abundance of hard minerals (quartz, garnet, sillimanite, and kyanite) which often occur in layers and lenses, the general lack of internal layering, and resulting massive character.

Not all subunits in the Hartland, Manhattan, and Walloomsac formations are true schists as defined by the American Geological Institute. Gneissic and granoblastic rock interlayers or migmatitic zones within these formations offer a challenge to excavation for the textural and structural reasons described in a previous section and a thorough understanding of the lithologic variation and spatial distribution of such rocks can help in selecting the proper means and methods for efficient excavation.

The **Inwood Marble** offers excellent TBM penetration potential owing to the abundance of calcite and dolomite, two relatively soft and internally cleaved minerals. (See Table 1.) Recent NYC DEP Water Tunnel #3 contract alignments in Westchester County purposely avoid this formation based on poor experience in drill and blast tunneling operations. TBM mining would clearly benefit from the relatively soft mineralogy of this formation but mechanical means (roadheader and hydraulic ram) would be less effective given the massive nature and overall granoblastic texture of the rock mass.

Average TBM penetration rates of <2 m/hour were encountered in the **Fordham Gneiss** during excavation of the Queens Tunnel with significant periods of down time the result of cutter, machine, or conveyor damage. Despite the fact that pre-bid documents provided by the NYC DEP indicated that the Hartland Formation was anticipated along the tunnel alignment, as-built structural, lithologic, and petrographic studies showed that the rocks of the Queens Tunnel consisted of orthogneiss of mesocratic, leucocratic, and mafic composition. These metaigneous rocks developed coarse-textured fabrics during Grenvillian granulite facies metamorphism, and retained their nearly anhydrous, poorly foliated character during subsequent high-grade Ordovician and younger deformation and retrograde metamorphism. Lacking a penetrative foliation, the coarse granoblastic rock texture and extraordinary garnet content (up to 50% in some zones) together proved an impediment to efficient chip production and resulted in bimodal production of blocks and excessive fines (Merguerian and Ozdemir 2003). Depending upon the scope of the excavation endeavor, traditional drill and blast methods might be more efficient in this older formation.

Serpentinite masses are typically small isolated bodies generally less than 40m in extent. Because of their internal weakness and soft component mineralogy (rich in talc and serpentine group minerals) they are known to cause sidewall instability, diameter changes in bored tunnels and deep excavations, and to create zones of slippage for TBM grippers. In addition, they are a source of airborne asbestiform minerals during drilling and mining and can pose severe environmental problems during various phases of removal and transport.

The mining of **granitoids** presents no special problems except when they are metamorphosed to the granulite facies and harbor tough, granoblastic textures. On the positive side, very coarse-textured rocks (pegmatitic textures have individual crystals > 10 mm in size) tend to break more readily as the large crystals tend to fail along their cleavage surfaces or along adjacent crystal boundaries. Moderate textured rocks with phaneritic textures (1 mm – 10 mm) break with moderate ease depending upon the texture and whether the rocks have been annealed by high-grade metamorphic reheating.

Dike rocks (rhyodacite dikes, mafic dikes, etc.) are hard and flinty with a multitude of smooth cooling joints whose intersections produce loose cobble- to boulder-sized multifaceted blocks and slabs that exhibit short stand up times. Fine-textured aphanitic igneous rocks (1 mm – 0.05 mm) and glassy textured rocks (no crystals) have proven to be an impediment to efficient mining because such rocks do not produce TBM chips or fail as readily as coarse-textured or foliated rocks. Instead they tend to produce sharp, angular blocks that clog grizzlies and damage cutters and belted conveyance systems. Glassy textures, as found in shallow-level dike rocks, are highly injurious to cutters. The rhyodacites were associated with loose, blocky ground and created unstable crowns, sidewalls, and headings during TBM mining of the Queens Tunnel.

CONCLUSIONS

NYC will continue to be the focus for significant hard rock excavation in the foreseeable future. Crystalline terrains provide an unforgiving medium for effective utilization of equipment and excavation rates regardless of means and method. A clear understanding of the geology of any construction project is the simplest and most cost-effective method to mitigate potential losses encountered during excavation in such terrains. The excavation of NYC rocks is strongly dependant upon the mineralogy, texture, metamorphism, and structure of the rock mass. In addition to standard core study, geotechnical testing, and analysis, detailed study of the mineralogy and texture of component minerals in rocks by competent geologists should be considered an essential prelude to bidding work since these allied studies hold the clues toward predicting excavation destiny. Excavation in crystalline terrains can best be evaluated on the basis of soft mineral content (volume % muscovite, biotite, calcite, graphite), rock mass density, lithology, structure, and metamorphic history. Field analysis and petrographic study can best identify textural properties that will negatively impact mining.

ACKNOWLEDGEMENTS

My experiences in the tunneling industry in NYC have been aided by many individuals from Grow Tunneling, Mueser-Rutledge Consulting Engineers, and the Schiavone Construction Company. Support provided by the Geology Department of Hofstra University is gratefully acknowledged. **J. Mickey Merguerian**, **H. Manne** and the rest of the staff at Duke Geological Laboratory have been instrumental in developing the ideas presented in this paper.

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TEACHERS WORKSHOP

WATERSHED AWARENESS: TEACH GEOGRAPHY, GEOLOGY, PUBLIC POLICY, AND CHEMISTRY THROUGH MONITIORING WATER QUALITY IN LOCAL STREAMS

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DESCRIPTION

This project is designed to influence the education of the surrounding community of the Rahway River in an effort to increase the awareness of the factors that contribute to water quality. The slide library, test kits, and resulting lesson plan will be used to help community groups to further monitor the state of the river. The Rahway River is made up of two branches, the East Branch, which flows through the suburban areas of South Orange and the West Branch, which flows through the forested South Orange Reservation and meet up in the town of Springfield, NJ. The importance of the river is extremely great as the water from the river supplies the drinking water for the city of Rahway. The quality of the water depends upon the conditions of the environments through which the river flows. Contaminants such as fertilizers, pet wastes, and residues washed from roads (salt, oil, etc.) get caught in the watershed enter the flowing river, where they will ultimately end up in the Reservoir. Testing the water for different chemicals and the abundance of certain macroorganisms can help in determining the quality of the water, which will in turn help educate the people in the area as to how to properly take care of their water source. The goal of the project was to develop a method for testing the water quality that can be used by community groups.

TOPICS COVERED

1. Use Google earth to fly over your local watershed
2. Identify features that contribute to water quality
3. Trace the path of local streams and rivers
4. Hands-on practice using LaMotte water quality test kits