Chapter 10

The Physical Environment and Risk Assessment

Studies of the Physical Environment

The abiotic (non-living) factors are important in determining the types and numbers of organisms that exist in that environment. When the soil, water, or atmosphere in a particular environment is contaminated, the impact can be dramatic due to the toxicity effects directly on a particular species or indirectly by impacting some aspect of habitat or the food chain. This, of course, is the case with the Lehigh Gap Wildlife Refuge – contaminated both by acid deposition and heavy metals both of which are harmful to plants and animals. In addition, in areas that were devoid of vegetation, there is little protection from intense sunlight or wind (other abiotic factors) that may also cause harm to plants and animals. Not related to the industrial factors that influenced the Refuge, the potential for climate change to alter habitat and ecosystem functions is significant. For these reasons, it is important for the LGNC and its partners to monitor and study abiotic factors including the distribution and persistance of the heavy metals in the region of the former zinc smelters, microclimates at the site, and long term patterns in temperature, wind, and precipitation.

Airfall of metals from the Palmerton, PA, zinc plant: Distribution and preservation

The stacks of the NJ Zinc Co. created airfall deposits throughout the 20th century in the region surrounding Palmerton, PA. The deposition of zinc, cadmium, lead, and arsenic, led to the destruction of a forest ecosystem along the neighboring Kittatinny Ridge and metals contamination in the town and surrounding area. Although the West Plant was closed in 1980, and primary smelting ceased at the East Plant that year as well, concerns linger over whether the soil remains contaminated with elevated levels of smelter-derived metals. The present concentration and distribution of metals in the soil is the result of the initial (20th century) concentration and the processes of leaching, erosion, and biological uptake and dispersal that have proceeded since the smelter was shut down. Drs. Dork Sahagian and Steve Peters of Lehigh University spearheaded a study that analyzes the current distribution of the metals in the region. Other members of the research team from the Lehigh Earth Observatory and department of Earth and Environmental Sciences included George Yasko, Jennifer Lofaro, Jill Burrows, Johanna Blake, and Kevin Smith.

This study was funded by the US EPA Brownfields program to determine the extent of contamination of soils in the surrounding "far-field" regions outside the superfund site. The Lehigh group also explored the metals concentrations in the soils of the West Plant itself, as this was excluded from the CERCLA process, so it can be investigated as a Brownfield. While much of this study was not conducted at the Refuge, persistent contamination in the region can impact wildlife that does not recognize property boundaries, plant materials (falling leaves, dispersed seeds, etc.) that can carry contamination to new places, and movement of the contamination through ground water and surface water. The Lehigh team members have been active participants in the LGNC Research Roundtable and provided input into this assessment, especially in the production of new maps since they were doing GIS work as a part of their study.

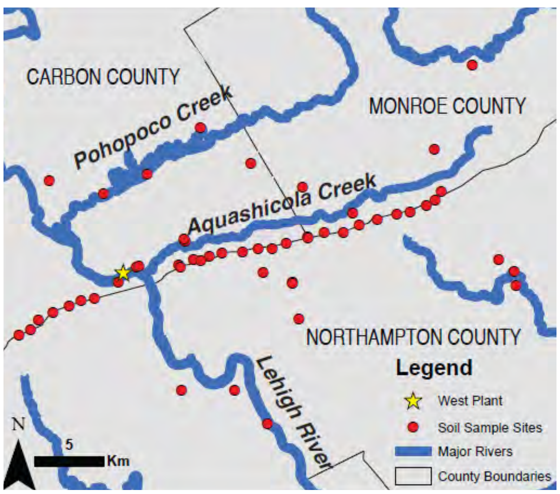
The West Plant Site (yellow) and the Lehigh Gap Wildlife Refuge (green)

Key questions considered in this regional study included:

1. What is the regional extent of contamination by smelter-derived metals in the Palmerton region? What are soil metal concentrations throughout the region? What are metal concentrations in local waters, plants, and animals? What is the regional extent of environmental concern regarding contamination?
2. How does vegetation affect water flux out of the soil and thus metal flux in the subsurface?
3. How do different vegetation types affect metal mobility out of the soil and into the human environment?
4. What is the flux of metals into the Lehigh River through ground water transport? What is the fate of these metals after they enter the river?
5. What types of plants are most and least successful in metal-contaminated soil environments? How do these compare to existing planted grasses and other landscaping around homes, business, and parks throughout the region?
6. How can the public be better informed regarding actual levels of contamination of soils and water, and how they can best minimize metals uptake on their properties?
7. How can the Palmerton region be used as a model for remediation of metal contamination at other sites throughout the country?

At the site of the smelter, analyses of samples from 141 shallow soil pits had zinc concentrations up to 95 mg/kg, with a mean value of 14 mg/kg. Lead concentrations in the same soils had concentrations ranging up to 250 mg/kg, with a mean value of 72 mg/kg.

The Lehigh team has now sampled a suite of soils from the "far field" region up to 25 km away from the smelter site to determine the spatial extent of remaining metals contamination. Soil pits were dug and samples collected from the shallow O-horizon, the underlying A horizon (typically 2-4 cm depth), and the B-horizon at about 20-30 cm to determine not only the geographic distributions of metals, but also the depths at which these different metals are now found in the subsurface.



Regional soil sampling locations

Key findings from these studies:

- Concentrations of zinc and cadmium decrease with distance from the West Plant and metal concentrations to the east of the West Plant are higher than to the west consistent with the prevailing wind in that area.
- Lead levels do not decline with distance from the smelter indicating that there is likely an additional source of lead contamination.
- Significant concentrations of metals are still found in the soil at the Refuge property.
- Zinc is primarily in the shallow layer of soil, suggesting that plants in this layer take up zinc and release it through decomposition, perpetually keeping higher levels of zinc in the top most layer of soil.
- After rain events, there is in increase of zinc and cadmium concentrations as the discharge of the springs (Railroad, Smilax and Hidden Springs, see map above) increases. However, the concentrations of these contaminants found in the water at LGWR are small, and concentrations of all metal contaminants are well below US EPA drinking water standards.
- Low concentrations of contaminants seen in the water at LGWR also indicate that, while soil samples were found to have significant concentrations of metals, they are not very mobile and are not a significant source of metals to the Lehigh River.
- A decrease in pH of soils and groundwater is highly likely within Lehigh Gap Nature Center due to the acidity of precipitation; the pH of precipitation will continue to decrease with rising atmospheric CO_2 levels. Plants also secrete organic acids which can lower soil pH.
- According to a model from this study, a decrease in soil pH by as

little as 0.5 could result in a 50% decrease in the mole fraction of zinc that remains adsorbed to soil particles (i.e. the contaminant zinc in the soil is solubilized and has increased bioavailability).

- Samples from springs at the Refuge were found to contain no alkalinity, lowering the ability of these systems to buffer a change in pH.

- Zinc concentrations in the Lehigh River are influenced by run-off and groundwater from the West Plant industrial site and the lands surrounding Aquashicola Creek which flows into the Lehigh River.

Additional details of the Lehigh project are included as appendices:

- Appendix K-1: A technical report entitled: **Report on Lehigh University Research Activity in the Palmerton Region from 2005-2010.**

- Appendix K-2: A research poster entitled ***"Assessment of Zinc, Arsenic, Cadmium, and Lead in the Environment Surrounding Palmerton, PA"***

- Appendix K-3: An educational pamphlet entitled ***"Assessment of Metals in the Environment Near Palmerton, PA"***

This research also resulted in two master theses:

"The fluxes and transport mechanisms of groundwater and surface water contaminants (Zn, Pb, Cd, As, and Cr) into a fluvial system: Palmerton, PA"

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April 30, 2010

"Assessment of Natural Attenuation of Arsenic, Cadmium, Lead and Zinc Using Hydrograph Separation"

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April 30, 2010

The far field data distribution can provide information for local communities regarding soils chemistry and help to guide land use practices within residential, business, and agricultural properties throughout the region. Concerns regarding contamination from metals airfall have played a role in depressing local economies, further exacerbating and perpetuating the economic impact of the closure of the smelter itself. These analyses can potentially ameliorate such concerns by providing the actual distribution and concentrations of metals in the region surrounding Palmerton.

Other Risk Assessment Studies

As part of the ongoing monitoring and risk assessment of the Palmerton Superfund Site, the springs on Refuge property were also monitored by Arcadis staff in October 2007 and May 2008. The springs were analyzed for pH, conductivity, turbidity, dissolved oxygen, temperature, salinity and estimated flow.

Scientists from the U.S. Geological Survey and Columbia Environmental Research Center (John M. Besser, Bill Brumbaugh, and Chris Ingersoll) prepared a presentation for the Palmerton Zinc Site Natural Resources Stakeholders on June 5, 2009 entitled *Ecotoxicology studies with sediment, pore water, and surface water from the Palmerton Zinc site*. The objective of this study was to update the findings of a 1997 study. Samples were collected in August 2008 to document current levels of metal concentrations and associated toxicity in stream water, sediment, and sediment pore water at sites in Aquashicola Creek (including an uncontaminated tributary, Buckwha Creek), and Lehigh River.

The U.S. Fish and Wildlife Service (along with multiple state and federal agencies as partners) have produced Fact Sheets on various ongoing studies related to the Palmerton Superfund Site. These studies are part of the Natural Resource Damage Assessment (NRDA). Fact sheets include Aquatic Investigations: *Evaluation of Injury to Aquatic Habitat Resulting from Metals Contamination*— a study which examined macroinvertebrates, periphyton (algae, bacteria, and fungi attached to the stream bottom) and fish communities; Forest Investigations: *Evaluation of Injury to Forest Habitat Resulting from Metal Contaminated Soils*; and an Appalachian Trail Hiking Study: *Assessment of Hiking Activity in Areas Potentially Impacted by Contamination*.

Studies for previously mentioned risk assessment reports and the EPA five-year review reports are aimed at constantly reviewing the human and environmental risk associated with this Superfund site.

Soil

As part of the recommended monitoring goals, the EPA has indicated that metals monitoring should include the determination of soil metal concentrations from soil composites from the A Horizon (personal communication with EPA staff). The Lehigh University project contributes important information as have other studies.[1]

Since the long-term success of plant growth is intimately linked to soil characteristics, the EPA monitoring recommendations also include further analysis of soil characteristics including:

- Amendment/soil depth – to assess whether soil structure is developing;
- Organic material in surface soil –

[1] 2007. Data Report for the Scoping Study on Metal Contaminant Levels in Forest Soils and Concurrent Habitat Evaluation for the Palmerton Zinc Natural Resource Damage Assessment, Palmerton, Pennsylvania, The Palmerton Natural Resource Trustee Council; and Anonymous. 2004. Preliminary Human Health and Ecological Risk Evaluation and Data Summary Report – Warm Season Grass Remediation Area. BBL, Inc., Annapolis MD.

to assess conversion of plant matter to soil which is an indirect assessment of soil biota health;

- Soil pH – to assess acidification over time as lime amendment degrades and the impact of ongoing acidic deposition from precipitation;
- Nutrient composition (N, K, P) – to determine if plant requirements are met;
- Micronutrient composition (Fe, S, Mg, etc.) – to determine if plant requirements are met; and
- Microbial respiration and microbial community composition – a biotic indicator of soil health and to determine the success of inoculants

Besides its critical role in supporting growth of the primary producers and hosting decomposers, soil is increasingly being recognized for its importance in carbon acquisition and sequestration. Disturbance (removal) of vegetation from soil – be it in forests or coastal wetlands, increases the rate of carbon release into the atmosphere. Theoretically, restoration of vegetation to a denuded area should help to not only capture carbon, but help maintain carbon in the soil.[2]

Microclimate at LGWR

Impending global climate change will typically impact specific regions by changing the temporal and spatial weather patterns (i.e. climate) of temperature, wind, and precipitation. While scientists have predicted changes in global and regional average conditions, there have also been predictions for changes in weather extremes and weather variability. Ecosystems are likely to be impacted at multiple scales. Significant microclimate variations in temperature, wind, and moisture are known to occur on spatial scales of meters to kilometers, both horizontally and vertically and on temporal scales ranging from seconds for wind vortex cycles to diurnal for solar and infrared flux, to weekly and seasonal for changes in insolation and air mass properties. Less well studied are interactions among microclimate, vegetation, and soil properties: each can influence the others over time.

One ecological pattern predicted to occur in response to global climate change is the shift toward higher latitudes and higher elevations of current climate-dependent species ranges and biome boundaries because of changes in average or extreme weather conditions. The LGWR is an ideal place to study such changes and to become part of a larger network of ecological observatories because it straddles an important biogeographic feature, the Kittatinny Ridge. The SW-

[2] See for example, Lal, R. 2004 Soil Carbon Sequestration Impacts on Global Climate Change and Food Security. *Science* 304: 1623-1627; 2009. Blue Carbon Report, UNEP and Soil Carbon Research information from the Rodale Institute http://www.rodaleinstitute.org/20090716/gw2

to-NE trending ridge with roughly 1000-foot elevation relief, together with the Lehigh Gap through which the Lehigh River flows, create extreme variations in spatial and temporal microclimate. The previous loss of vegetation and soil caused by heavy metal pollution together with the recent experimental restoration of grasslands and the existence of legacy forest patches (especially on the southern slopes) provide an opportunity to document current and future microclimate-vegetation interactions while also exploring the impact of microclimate on restoration efforts. In short, microclimate variations are expected throughout the Refuge because of its steep topography, variations in vegetation cover and soils, and location near the Lehigh Gap along the Kittatinny Ridge. Microclimate can influence all types of wildlife including the potential for colonization of new organisms.

To characterize the LGWR microclimate a network of weather stations (three sites) and supplemental sensors (at the station sites plus 3-6 other sites) has been installed. Funds from the WRCP of the DCNR, supplemented by a grant from the U.S. Dept. of Education, supported this project. The network was designed and installed by Dr. Bruce Hargreaves of Lehigh University, with help from a number of LGNC interns. It provides broad spatial coverage of LGWR at high temporal resolution. The Davis Instruments Vantage Pro2 system of stations and sensors was chosen based on its low cost for solar-powered wireless sensors combined with its ability to create extended radio networks using multiple radio repeaters equipped with Yagi antennas.

The current network of weather stations and satellite sensors (installation began in February 2009 and was completed in July 2009) continuously record spatial patterns from ridge to river at a temporal resolution of 5 minutes. The 3 weather stations record air temperature, wind speed and direction, humidity, precipitation, and leaf wetness at 2m above ground, plus soil temperature just below the surface. Three satellite stations record a subset (air temperature, humidity, leaf wetness, also at 2m above ground, plus soil Temperature) at 3 other sites. One weather station also records solar radiation (broadband incoming radiation and UV-B radiation). Station consoles also record barometric pressure at the base station in the Osprey House (see maps on pages 10-9 to 10-10). All sensors are connected by a radio network and data are automatically stored on local computers, archived, and graphs of 24-hour patterns are automatically sent to a web site.[3] Data is also shown on the LGNC website.[4] A combined database will be designed to facilitate analysis and web dissemination of all data.

[3] See http://www.lehigh.edu/~brh0/LGNC/.
[4] http://lgnc.org/resources/weather

Overview of LGWR microclimate network (24July09)
Flag=repeater radio, star=weather station, snowflake=T/RH station

LGWR microclimate network 2, view from NE (24July09)
Flag=repeater radio, star=weather station, snowflake=T/RH station, green line=LGWR boundary, red=AT, white line=radio path

Distinct patterns are evident already for elevational and along-river gradients in temperature, humidity, dew point temperature, precipitation, leaf wetness, including periodic night density flows of cool air (up to 15^{o}F difference) from high to low elevation when the sky is clear and wind is light. There is a tendency for somewhat higher precipitation and cooler air temperature on average at the higher elevation. Surprisingly, there was little correlation between wind speed on the ridge and wind speed on the deck of the Osprey House.

A proposed expansion of this microclimate network will allow for four sets of paired measurements at 2-3 m and at 0.5m above ground to capture the impact of vegetation on the fine scale atmospheric boundary layer and will add soil moisture measurements (at 1-2 depths) at 4-8 sites for a semi-quantitative index of the interactions of vegetation, soil, and microclimate. It is proposed that a fourth weather station and paired satellite station be added in the grassland restoration area. The rationale for horizontal sensor placement is to cover vegetation patterns and topographic variation by our horizontal choice of sites (forest on south slope, elevation impact on ridge with two sites to account for proximity of Lehigh Gap, grassland restoration, northern exposure, and non-restored land cover on north slope). The rationale for simultaneous paired measurements at 0.5 and 2-3 m above ground is to capture the effects of vegetation on the boundary layer while accounting for the extreme topographic variations.

With the weather/microclimate monitoring system in place, the LGNC with its partners have begun a long-term record of microclimate variations. Temperature and moisture differences across the elevation range of LGWR caused by the atmospheric lapse rate and wind-ridge interactions should be observed. It is being determined whether the instruments allow researchers to examine boundary layer consequences on vegetation growth (in terms of a scale of feet and inches of vegetation height rather than the kilometer scale of atmospheric science). The effect of re-vegetation efforts on surface conditions over time and space might also be possible to study. As noted by John Dickerson, the seed rain over the decades had no success in establishing native vegetation on the mountainside. However, within 1 to 2 years after the grass was planted the recruitment came on rapidly. The fastest change to the physical environment (due to the grass presence) was likely to temperatures, air movement and humidity at the surface, ameliorating these factors enough to allow for seed germination. Short and long-term weather data will also be important as the LGNC begins phenology monitoring. This resource should help to further our understanding of ecological response and adaptation to climate change on the Kittatinny Ridge at Lehigh Gap.

The LGWR Physical Environment and Education

As with other aspects of the ongoing research at the Refuge, the LGNC and its partners are continually finding ways to link research and education. The weather stations described above are just one example. Major aspects of the physical environment at the Refuge are the unique geological features (which also create some of the challenges for restoration work). State geologists from Pennsylvania have been to the site and have helped to develop geology-based field exercises for K-12 students and helped to run a workshop for teachers and the public. Some of the resources they provided led to an article in the *Wildlife Activist*, the LGNC publication.

A unique project entitled "Engagement in Science and Media Literacy: Sixth Graders Solving Problems and Researchers Listening" run by Andrea J. Harmer, Director of Web-based Education at Lehigh University involved the LGNC and presented at the May 2009 LGNC Research Roundtable. This project was a three-year, research program that engaged sixth-grade students in the authentic, environmental and health concerns resulting from the 83 years of zinc smelting activities at the Palmerton Superfund Site. Students chose soil and plant samples from the Site and were provided with the opportunity to remotely operate a scanning electron microscope from their sixth grade classroom. The students researched current EPA solutions to remediate the polluted site, which includes various attempts at re-vegetation, and further studied a new, university-based technique that includes using iron nanoparticles to neutralize heavy metal toxins in other polluted areas. A central question in this project was "What happens when middle school students and university faculty join forces to try and solve a community, environmental problem using the latest techniques in scanning electron microscopy and nanotechnology?" The answer was that real time, engaging, learning takes place for both parties involved.

Designed to foster learner engagement, this method used an online, problem-based, science inquiry that investigated the Lehigh Gap, Palmerton Superfund Site during five weeks of collaborative classroom sessions. The inquiry prototype was authored in *WISE*, the Web-Based Science Inquiry Environment headquartered at UC, Berkeley. Online materials, readings, and class sessions were augmented with the remote access to an electron microscope to analyze Lehigh Gap samples. An introduction to nanoscale science and nanotechnology through the *ImagiNations* Web site at Lehigh University was also used. Students contributed the artifacts they generated during their research to a university database and presented them to researchers at the university working on the same problem. This approach proved highly engaging and generated design and development guidelines useful to others interested in designing for student engagement and introducing nanoscale science and electron microscopy in middle school science.

This study further found that students' engaged in science inquiry both behaviorally and emotionally and on several different levels. The various levels appeared to create two hierarchies of engagement, one based on behavioral criteria and the other based on emotional criteria. It was found that five factors most prominently contributed to the students' engagement; cutting-edge technology, creative freedom, collaboration with scientists working on the same problem, contribution to the problem solution, and communication of the students' results outside of the classroom.

Finally, at the 2009 LGNC Research Roundtable, the entire group of participants was educated on the history of the zinc smelting operations and a 1980 National Cancer Institute study by Dr. Patricia Bradt of Muhlenberg College.