A Sustainable Chesapeake

BETTER MODELS FOR CONSERVATION

Edited by David G. Burke and Joel E. Dunn

THE CONSERVATION FUND

The case study you have downloaded is highlighted below. Other case studies from this Chapter of *A Sustainable Chesapeake: Better Models for Conservation* can be individually downloaded. The editors encourage readers to explore the entire Chapter to understand the context and sustainability principles involved with this and other featured case studies. The full publication contains 6 Chapters in total: Climate Change Solutions, Stream Restoration, Green Infrastructure, Incentive Driven Conservation, Watershed Protection and Stewardship.

CHAPTER 5 WATERSHED PROTECTION

Converting Poultry Manure from Waste to Resource

Using Manure and Paper Mill Waste to Reclaim Abandoned Mine Lands in Pennsylvania

Scientists and conservationists worked together to develop an abandoned mine land reclamation methodology that simultaneously uses waste materials to revitalize the soil, produce biomass, and solve nutrient management challenges.

CASE STUDY SUMMARY

The Pennsylvania Environmental Council and Pennsylvania State University have developed an innovative watershed protection methodology that uses poultry manure and paper mill sludge to amend the soil of abandoned mine lands and then cultivates biomass on those lands for the production of renewable energy. As a result, nutrient pollution is reduced from poultry operations and unproductive mined lands are converted into productive working lands that support the nation's need for green energy.

Laboratory and greenhouse-scale research on the reclamation methodology was initiated in 2004. Field-scale research and test plots were planted in Schuylkill County, Pennsylvania, in 2006 and are ongoing. Two larger demonstration projects of 13 and 7 acres were planted in Clearfield County in September 2008, and an additional 10-acre demonstration area was planted in the spring of 2009.

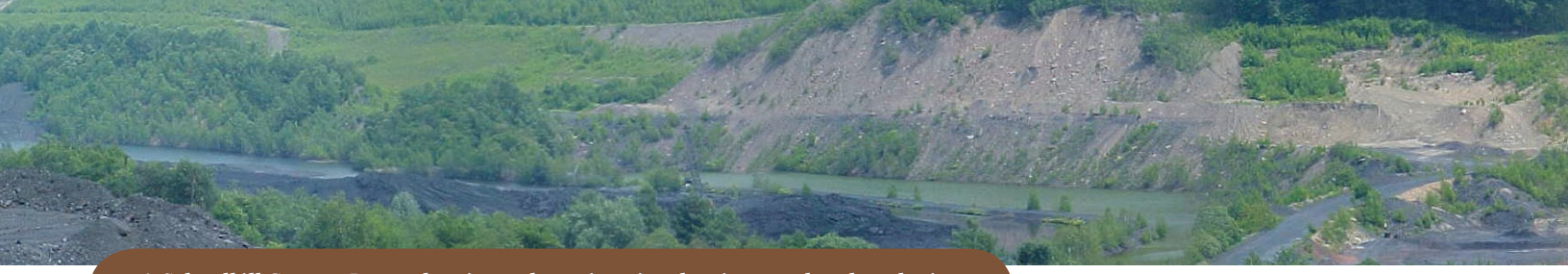
The reclamation methodology can be applied to any coal mining region in the eastern United States located near significant sources of excess poultry manure. Other animal manures and high-carbon, low-nitrogen waste streams such as yard waste, sawdust, and agricultural residues can be used as substitute soil amendments for mine reclamation.

RESOURCE MANAGEMENT CHALLENGE

This methodology offers a new environmental and watershed management tool that addresses three critical conservation problems: the reduction of nutrient pollution from livestock operations, the reclamation of nutrient-deficient lands degraded by historic and current mining activities, and the reduction of greenhouse gases from fossil fuel combustion.

Pennsylvania faces several environmental challenges related to intensive livestock agriculture. Foremost among them is the overloading of nutrient runoff (nitrogen and phosphorous) from livestock operations in the rich agricultural regions located in the Chesapeake Bay watershed. Consequently, many of the streams in Pennsylvania are on the Environmental Protection Agency's 303(d) list as impaired by nutrients and sediment. The Susquehanna River basin, much of which is located in Pennsylvania, is also the largest source of nutrients for the Chesapeake Bay. Pennsylvania's 2004 Chesapeake Bay Tributary Strategy calls for reductions of 37 million pounds of nitrogen per year and 1.1 million pounds of phosphorous per year from its portion of the Bay watershed.[1] This will require a reduction in the application of manures to Pennsylvania farmland.

Pennsylvania also has approximately 180,000 acres of abandoned mine land (AML) that affect water quality by generating acid runoff and discharges.[2] AML is located primarily in the western bituminous region of Pennsylvania, and a lesser amount is found in the anthracite region in central eastern Pennsylvania. Approximately 4,600 stream miles in Pennsylvania are impacted by acid mine drainage,[3] and many of those streams are listed as impaired by low pH and metals due to acid mine drainage and runoff.

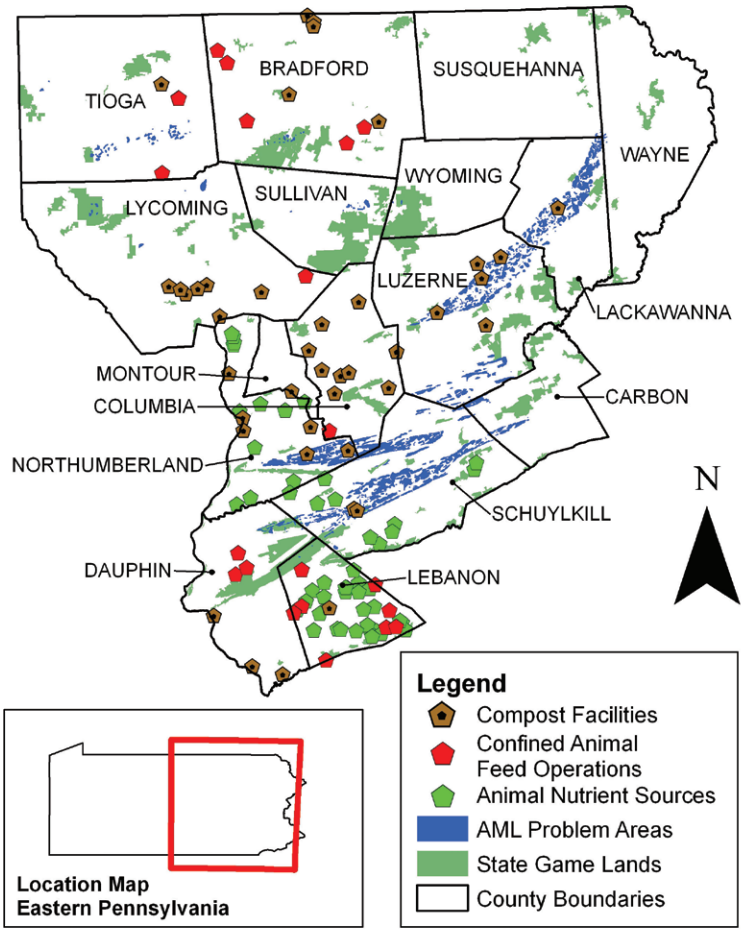


A Schuylkill County, Pennsylvania, reclamation site showing an abandoned mine area (above), and a reclaimed segment (next page).

Reclamation of these 180,000 acres is needed to reduce the sources of acid mine drainage impairing Pennsylvania waters. Pennsylvania has received $1.4 billion in federal funding for AML restoration, but some officials estimate the problem will cost $10 to $15 billion to address.[4]

Restoring healthy productive soils to abandoned surface mines can play an important role in this effort by effectively reducing acidic surface and subsurface runoff and drainage from those reclaimed mines—the methodology outlined in this case study not only achieves this goal, but can be used at operating surface coal mines as well. At an application rate of 35 tons per acre, the potential for exporting manure from nutrient-impaired regions represents a significant watershed management tool for relieving stressed watersheds of their excessive nutrient load and putting those nutrients to work in locations when they are needed.

Abandoned Mine Lands and Nutrient Locations in Eastern Pennsylvania



According to the U.S. Department of Energy, Pennsylvania ranks third in the United States for greenhouse gas emissions and contributes approximately 1% of total global greenhouse gas emissions.[5] Pennsylvania's government recently passed legislation to develop a climate change action plan, and the state is actively promoting the development of domestic renewable sources of energy to displace the use of fossil fuels for heat, power, and transportation. Pennsylvania forests, mine lands, and farms can provide a significant source of renewable biomass energy for the production of heat, power, and liquid transportation fuels. All energy generated from renewable biomass is considered to have a carbon-neutral effect, provided that all harvested biomass is regenerated on the same acreage that was originally harvested. If cultivated on a wide scale, biomass can significantly reduce the state's carbon footprint.

Paper mill waste, typically disposed in landfills, is an underused resource. Scientists have demonstrated that the organic carbon content of such waste can have a beneficial effect on soil properties and thus on crop production.[6,7] Numerous studies have found that mill waste has the capability to increase the carbon content of soils, improve the structural stability of soils and their water-holding capacity, and potentially increase the productivity of farmland.[8,9,10,11] The main components of this waste sludge are short fiber cellulose (which is unsuitable for paper manufacture), along with clay and lime. The region's paper mills usually dispose of their waste sludge in a landfill, paying both the cost of

transportation to the landfill and a disposal or tipping fee. Converting the sludge into a useful by-product is an attractive alternative.

CONSERVATION VISION

The widespread application of this reclamation methodology can benefit both the sending and receiving watersheds. Transporting manure out of nutrient-dense watersheds will improve both soil and water resources by reducing application of excess nutrients to farmland. In the receiving watersheds, the use and sequestration of the nutrients for mine reclamation will improve water resources by stabilizing soil, reducing erosion, and potentially reducing acid mine drainage. Overall soil quality and productivity of mined lands will be improved and returned to productive use. This project also turns paper mill waste into a useful by-product and enhances atmospheric resources by increasing carbon sequestration in mine spoils and by producing crops for bioenergy.

Initial laboratory and greenhouse-scale investigations determined that poultry manure is a highly effective nutrient source for soil augmentation of AML sites and that paper mill sludge provides organic carbon needed to sequester manure nutrients in the minesoil. These studies, combined with field-scale research, have focused on developing the ideal mixture, application, and cultivation of soil amendments and mine spoil material to maximize biomass production and plant nutrient uptake and to minimize nutrient runoff and leachate.

In 2006, a field-scale research project was launched in Schuylkill County to refine the methodology. In the summer of 2008, a 20-acre demonstration project was launched at two active mining sites in Clearfield County, and an additional 10 acres was reclaimed in the spring of 2009. The Clearfield demonstration project will provide an opportunity to further evaluate the economics and commercial viability of the reclamation and biomass production methodology.

Working in conjunction with the Pennsylvania State University, Eastern Pennsylvania Coalition for the Reclamation of Abandoned Mines, Pennsylvania Foundation for Watersheds, Chesapeake Bay Foundation Capital Area Resource, Conservation and Development Program, and other partners, the Pennsylvania Environmental Council determined that there are a large number of agricultural operations in a sixteen-county region of central Pennsylvania within close proximity to abandoned mine lands in need of soil augmentation. This indicates at least one geographic area that could significantly benefit from the proposed methodology.

IMPLEMENTATION RESOURCES

In 2004, the Pennsylvania Environmental Council received funding from the Pennsylvania Department of Agriculture to investigate the use of composted poultry manure and mill sludge waste for soil augmentation on AML. Subsequent grants were provided by the U.S. Department of Agriculture, Pennsylvania Conservation Commission, Pennsylvania Department of Agriculture, and Foundation for Pennsylvania Watersheds.

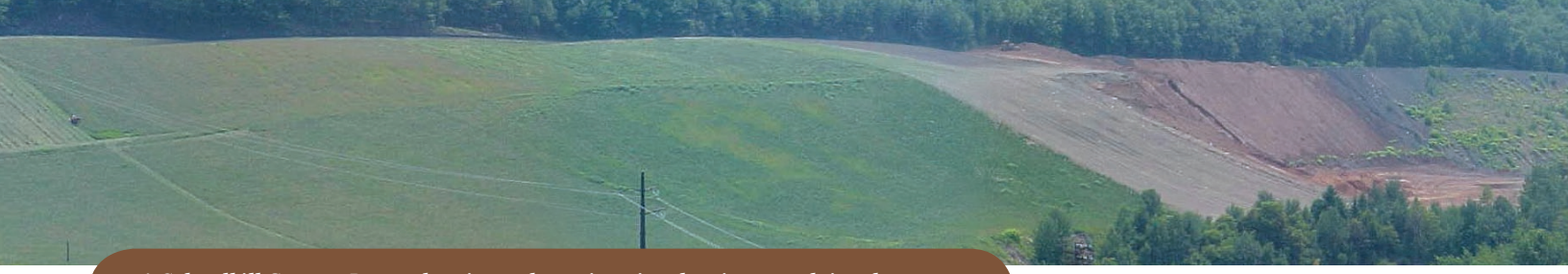
Most of the initial costs of developing the methodology have been associated with primary scientific research on the methodology for applying raw manure mixed with paper mill sludge and composted manure as soil amendments for the production of switchgrass. Other major costs have been project management and administration, grass seed, transportation, materials, and site reclamation activities (mixing, spreading, and seeding).

The Pennsylvania State University's Department of Crop and Soil Science played the lead role in developing and refining the reclamation methodology. The Eastern Pennsylvania Coalition for Abandoned Mine Reclamation provided assistance by developing GIS layers of abandoned mine lands and large sources of poultry manure in a 16-county region of central Pennsylvania.

The Coalition and the Pennsylvania Department of Environmental Protection Office of Surface Mining also helped to identify candidate sites for the demonstration projects in Clearfield County. The Chesapeake Bay Foundation coordinated and funded the delivery of 1,100 tons of composted manure to mine sites in Clearfield County.

CONSERVATION STRATEGY

The Pennsylvania Environmental Council's overall strategy for this project was to 1) conduct the necessary research, 2) demonstrate the environmental benefits, and 3) set new empirical standards that will allow its widespread use in the economy. The following narrative describes these strategies and the various agronomic and environmental issues associated with the techniques developed through this project.



A Schuylkill County, Pennsylvania, reclamation site showing a reclaimed segment (above), and reclamation in process (next page).

Methodology Development Costs						
Grass Seed						
Seed Type		**Lb./Acre**		**$/Lb.**		**$/Acre**
Switchgrass		8		$10		$80
Big bluestem		8		$18		$144
Atlantic coastal panic grass		8		$8		$64
Birdsfoot trefoil		8		$4.75		$38
Showy tick trefoil		8		$36		$288
Transportation						
Material	**$/Ton**	**Distance Hauled**	**$/Ton/Mile**	**Coal Backhaul**	**Appl. Rate: Tons/Acre**	**$/Trailer Load**
Raw manure	$35	150 mi.	$0.23	Yes	35	$427 (12.2 tons/load)
Paper mill sludge*		30 mi.			108	
Composted manure**	$31.67	190 mi.	$0.17	No	65	$875 (28 tons/load)
Materials						
Material		**$/Ton**		**Appl. Rate: Tons/Acre**		**Cost Per Acre**
Composted manure		$24		65		$1,560**
Paper mill sludge		$0*		108		$0
Raw manure		$0		35		$64
Reclamation						
Task		**Tons/Acre**		**$/Ton**		**$/Acre**
Raw manure mixing and spreading		35		$22		$770
Paper mill sludge mixing and spreading*		108		0		0
Composted manure mixing and spreading		65		$15		$975
Seeding		8 lbs.		$4.75 - $36		$150

** Paper mill sludge delivery, mixing and spreading costs paid for by mine operator.*

*** Composted manure delivered and provided at no charge to project.*

Strategy 1 - Conduct research required to determine AML reclamation standards: Research has demonstrated that organic amendments such as sewage sludge, paper mill sludge, and compost are highly effective for re-vegetation of mine spoil materials, due mainly to the addition of organic carbon.[12,13,14,15,16] But a problem with the use of sewage sludge or manure is that these materials have low carbon-to-nitrogen (C:N) ratios (often below 10:1). Thus, application rates intended to achieve desired levels of organic C input result in N application well in excess of the amount that the newly established vegetation can take up and also in excess of the amount that can be retained in the developing soil organic matter. This can lead to significant N loss, primarily due to nitrate leaching.[17,18] Stehouwer et al. (2006) measured nutrient concentrations in percolate water collected at a one-meter depth for two years following the application of biosolids for mine reclamation and found that more than 40% of the total N applied in biosolids was lost by leaching—

Critical Elements and Compounds at Work in the Reclamation Methodology	
Nitrogen (N)	A critical element for plant growth. Plants can utilize nitrogen when it is in the form of ammonium or nitrate. Almost all nitrogen in soils is organic nitrogen and is part of the soil organic matter. Before plants can utilize this nitrogen, microbes in the soil must convert it into ammonium and nitrate.
Nitrate (NO_{3-})	A form of nitrogen that plants can use for growth. Bacteria in soils convert ammonium to nitrate. Its negative charge means that it is very weakly retained in soils and can easily be transported to waterways.
Ammonium (NH_{4+})	A form of nitrogen that plants can use for growth. It is not a gas, nor is it volatile. Its positive charge means that it is held in soils and not easily transported to nearby waterways.
Ammonia (NH_3)	A volatile gas at normal atmospheric pressure and temperature. Some manure contains a significant amount of ammonia which can escape to the atmosphere if the manure is left on the soil surface. However ammonia is very soluble in water and in the soil environment, and it is rapidly converted to NH_{4+} (ammonium).
Carbon (C)	An essential element for life. In photosynthesis, plants convert carbon dioxide in the atmosphere into organic carbon compounds that build the plant and provide energy for organisms (animals and humans) that consume the plant material. This organic carbon also provides energy to soil microbes that decompose plant residues, recycle the nutrients, and build soil organic matter.

mostly of nitrate (NO_{3-}) and some of ammonium (NH_{4+}).[19] Nitrate leaching would also be expected with direct application of manure for mine reclamation.

Composting presents a solution to this problem by combining manures with materials that have a high C:N ratio. This increases the overall C:N ratio, stabilizing the organic fraction and reducing mineralization rates.[20,21] Stehouwer and Macneal (2002) utilized compost for remediation of incinerated soil at a field rate equivalent of 100 tons/acre.[22] Initial leachate NO_{3-} reached 80 mg N/L but decreased to less than 1 mg N/L in subsequent leachings. In a greenhouse experiment, composting poultry layer manure was found to effectively eliminate N loss by leaching[23] while significantly increasing switchgrass growth on minespoil material.

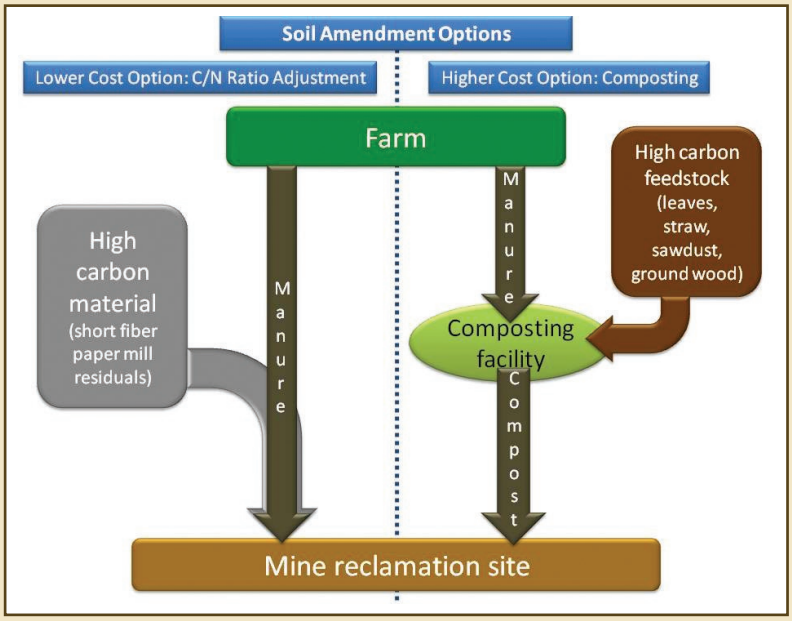


Chart depicts manure stabilization options for mine reclamation. Lower Cost Option: C/N ratio adjustment - Paper mill sludge and manure are applied together on the mine site (in-situ) to increase C/N ratio to 20-25:1 to reduce leaching losses of inorganic N and yield other important environmental benefits including rapid increases in soil quality and greater switchgrass growth. Higher Cost Option: Composting - Manure is composted prior to application on the mine site to reduce leaching losses of inorganic N.

Composting, however, increases costs due to additional materials handling and operational expenses. A much lower cost alternative is direct application of the composting feedstocks (manure and high organic C material) to the mine spoil, so that decomposition and mineralization occur in the mine spoil rather than a compost pile. The research team called this process *in-situ* "composting." In addition to economic benefits, such *in-situ* composting has potential ecological and environmental benefits. Slower fungal-based decomposition in the field may retain more added C in the soil and lead to more rapid increases in soil quality than application of pre-composted material.[24] However, *in-situ* composting requires finding the right balance between N and C mineralization and N immobilization, such that the potential NO_3 leaching loss is limited, yet sufficient inorganic N is available for vegetative growth. In the preliminary greenhouse experiment cited above, the research team found that adding raw manure to mine spoil together with short fiber paper mill sludge to increase the C:N ratio from 7:1 (raw manure) to 30:1 resulted in a 6.7-fold reduction in leaching losses of inorganic N.[25] Switchgrass growth was also doubled compared to composted manure amendment.

Strategy 2 - Demonstrate the environmental benefits: ***Schuylkill County Field Research Project:*** The ongoing field research experiment in Schuylkill County investigates the use of manure, paper mill sludge, and composted manure as soil amendments for mine reclamation and switchgrass production. Normal mine reclamation practices in Pennsylvania will apply inorganic N fertilizer at about 100 lbs. N/acre. Researchers compared this N rate with much larger N application from composted layer manure and layer manure mixed with paper mill sludge. The application rates and quantities are given in the Schuylkill Project table.

The researchers collected leachate water from these amendments for three growing seasons and measured nutrient loss via leaching. Switchgrass was established one year after amendments were applied.

The results and data obtained during the second year of research (summer 2007) were used to establish the manure reclamation approach for the full-scale reclamation demonstration project (composting approach and application rate) in Clearfield County.

Clearfield County Demonstration Project: A full-scale mine reclamation demonstration project using poultry layer manure was launched in 2008 near Morrisdale in Clearfield County. The 30-acre demonstration project is the largest and most advanced experimental use of this reclamation methodology. The ongoing field-scale research is continuing to provide results that inform the development and refinement of the techniques.

The project initially reclaimed 20 acres at two mines. Thirteen acres were reclaimed with approximately 450 tons of raw poultry manure mixed with paper mill sludge at two sites. Seven acres were reclaimed with approximately 455 tons of composted manure at one of the sites. Both sites were seeded with oats to establish green cover, and they were reseeded with switchgrass and a mix of warm season grasses in June 2009. The project team reclaimed an additional 10 acres utilizing 650 tons of composted layer manure in June 2009. Approximately half of the total 30 reclaimed acres were seeded with switchgrass and the remaining acreage was seeded with a mix of warm season grasses in June 2009. Long-term research conducted on degraded lands in Minnesota has shown that such stands can be established on degraded lands, that they are sustainable, that they produce more biomass fuel per acre than monocultures of corn or switchgrass, and that they sequester more soil carbon than monocultures.[26] High diversity stands also have greater potential than monocultures to serve as wildlife habitat, if managed appropriately.

A local paper mill paid for the transportation and application of 1,405 tons of paper mill sludge that was applied to approximately 13 acres at an application rate of 108 tons per acre. The paper mill sludge was mixed with raw poultry manure and residual top soil and spread over the land prior

Schuylkill Project: Application Rates and Quantities

Reclamation Soil Amendment (T/A: tons/acre)	Quantity of Total N Added (Lbs. N/acre)
Lime (6 T/A) and fertilizer	100
Composted poultry manure (35 T/A dry weight)	1,890
Composted poultry manure (70 T/A dry weight)	3,780
Poultry manure (22 T/A dry weight) mixed with paper mill sludge (46 T/A) to achieve C:N ratio of 20:1	1,890
Poultry manure (22 T/A dry weight) mixed with paper mill sludge (82 T/A) to achieve C:N ratio of 30:1	1,890

Extensive soil amendments are necessary to reclaim abandoned mine lands. In this photo the reader can see composted manure (dark brown) and raw manure covered with paper mill sludge (very light grey material) along with one pass of the chisel plow behind the tractor.

to seeding. The local paper mill paid for the delivery and spreading of the paper mill sludge at a cost that was competitive with the conventional delivery and disposal of the material at the landfill. The application of the sludge is acceptable to the mine operator because the alkaline nature of the sludge makes it a good substitute for lime, which would have been used in a conventional reclamation process in combination with commercial nitrogen fertilizer. The paper mill sludge also helps retain soil moisture and adds carbon to the soil.

The Clearfield site will be monitored to ensure that nutrient and carbon flux, and switchgrass and native grass production is similar to results obtained in the field experiment. This will be done by periodic collection and analysis of soil samples, measurement of harvest yield, and tissue analysis.

This project will include an evaluation of the commercial potential of the reclamation methodology on both operating and abandoned coal mine lands. The evaluation for operating coal mines, scheduled for completion in 2010, will compare conventional reclamation techniques to the poultry manure technique. It will also examine the revenue potential from both environmental credit markets (carbon sequestration and water quality trading) and sales of biomass for energy production. The evaluation of the project for AML reclamation will include an assessment of state and federal funding sources for reclamation projects.

Strategy 3 - Set new empirical standards: Composting poultry manure is a highly effective way to stabilize the added nitrogen and sequester it in the soil. Leachate analysis over three growing seasons showed that less than 1% of N added as compost was lost via leaching during this period, even with the application of 3,780 lbs. N per acre. Adding fresh poultry manure mixed with paper mill sludge was less effective than composting at retaining the added N. Most of the loss was due to nitrate leaching in the late fall of each year. Nitrate leaching was greatest in the first year, much smaller in the second year and almost zero in the third growing season.

Although significant N leaching occurred with the combined manure and paper mill sludge amendment, the amount of N lost over two growing seasons with the 20:1 ratio treatment is comparable to N leaching losses from two seasons of conventionally produced corn on agricultural fields. And while leaching loss has essentially ceased after two years, it is an annual event in production agriculture fields. The manure and paper mill sludge amendment was also very effective at sequestering added N. The 20:1 treatment lost only 8% via leaching, and soil analysis confirmed that most of the added N was still present in the soil.

The Schuylkill County AML site prior to reclamation in April 2006.

Both composting and the combination of manure and paper mill sludge were very effective at sequestering added phosphorus (P). Leaching loss of P was very small and over two growing seasons amounted to less than 2% of the added P. Both of the organic amendments produced excellent vegetative growth during all three growing seasons. Switchgrass was established in the second growing season (2007). Both compost and the combination of manure and paper mill sludge produced much larger yields than the conventional reclamation practice of lime and inorganic fertilizer. These two-year stands of switchgrass are comparable to two-year stands on high quality agricultural soils.

Based on these results, the research team decided to decrease the manure application rate to 14.3 tons per acre (T/A) dry weight (approximately 30 T/A wet weight) for a total N application of 1000 lbs. per acre. The manure was combined with paper mill sludge applied at a rate of 42 T/A dry weight (approximately 114 T/A wet weight). This application will produce an overall C:N ratio of approximately 20:1 in the applied material. The researchers believe the 35% reduction in the total amount of N applied will further decrease the potential for nitrate leaching while still maintaining adequate nutrient and carbon addition for good biomass production.

RESULTS

The experimental results and new empirical standards determined through research and demonstration projects will facilitate the implementation of this methodology across Pennsylvania, benefitting both AML reclamation statewide and management efforts in nutrient-impaired watersheds. While only 30 acres have been restored through this project, the Pennsylvania Environmental Council and Pennsylvania State University have laid the foundation for future efforts to turn harmful pollutants from the livestock and paper industries into the essential nutrients needed to restore mine land. Approximately 1,100 tons of composted manure and 455 tons of raw poultry manure were imported and applied at the three mine sites. The switchgrass and warm season grasses that are grown on the sites may be used in biomass-ready boilers for heat and power production and potentially as a feedstock for cellulosic ethanol. The next step is to facilitate larger-scale implementation for AML and conventional surface coal mine reclamation in both the anthracite and bituminous coal regions of Pennsylvania.

KEYS TO SUCCESS

- **Leadership:** Throughout its 40-year history, the Pennsylvania Environmental Council has demonstrated leadership by convening key stakeholders from academia, state and local agencies, and the business community to develop innovative policies and projects to address Pennsylvania's leading environmental challenges.
- **Funding:** Project partners succeeded in obtaining state and federal grants to support the research and demonstration components of the project, with matching cash and in-kind contributions from private foundations, conservation organizations, and the private sector.
- **Partners:** Project success is a direct result of working with key partners in the agricultural community; the mining industry; local, state and federal agencies; the state university; and private conservation organizations.
- **Communication:** Using poultry manure to reclaim AML and

The Schuylkill County AML site after reclamation in October 2009. Photo shows vigorous switchgrass growth resulting from manure and paper mill sludge applied together (in situ) to increase C/N ratio to 20:1.

produce renewable energy represents a win-win-win solution that resonates as an economic development and environmental restoration story.

PHOTOS AND FIGURES

Page 201, 207-209: Photos, Dr. Richard Stehouwer
Page 202-205: Photos, Eastern Pennsylvania Coalition for Abandoned Mine Reclamation (EPCAMR)
Page 202: Figure, Burke Environmental Associates/The Conservation Fund, adapted from EPCAMR
Page 205: Figure, Dr. Richard Stehouwer

REFERENCES

[1]Pennsylvania Department of Environmental Protection. 2004. *Pennsylvania's Chesapeake Bay Tributary Strategy*. Pennsylvania Department of Environmental Protection, Harrisburg, PA. Available online at: http://www.depweb.state.pa.us/chesapeake/lib/chesapeake/pdfs/tribstrategy.pdf.

[2]Pennsylvania Department of Environmental Protection. 2009. DEP Restores 960 Acres of Abandoned Mine Lands, Degraded Streams in 2008. Press release (March 3, 2009). Pennsylvania Department of Environmental Protection, Harrisburg, PA. Available online at: http://www.redorbit.com/news/business/1648265/pennsylvania_dep_restores_960_acres_of_abandoned_mine_lands_degraded/.

[3]Pennsylvania Department of Environmental Protection. 2009. *2008 Pennsylvania Integrated Water Quality Monitoring and Assessment Report*. Pennsylvania Department of Environmental Protection, Harrisburg, PA.

[4]WJACTV.com. 2009. Statewide Conference Focuses On Mine Contamination. Available online at: http://www.wjactv.com/news/20062896/detail.html. (Accessed 2010)

[5]Energy Information Agency. 2009. Emissions Details by State. U.S Department of Energy, Independent Statistics and Analysis, Washington, D.C. Available online at: http://www.eia.doe.gov/oiaf/1605/state/state_emissions.html.

[6]Curnoe, W. E., D. C. Irving, C. B. Dow, G. Velema and A. Unc. 2006. Effect of spring application of a paper mill soil conditioner on corn yield. *Agronomy Journal*. 98:423-429.

[7]Bellamy, K. L., C. Chong and R. A. Cline. 1995. Paper sludge utilization in agriculture and container nursery culture. *Journal of Environmental Quality*. 24:1074–1082.

[8]Chantigny, M. H., D. A. Angers and C. J. Beauchamp. 1999. Aggregation and organic matter decomposition in soils amended with de-inking paper sludge. *Soil Science Society of America Journal*. 63:1214–1221.

[9]Nemati, R., J. Caron and J. Gallichand. 2000. Using paper de-inking sludge to maintain soil structural form: Field measurements. *Soil Science Society of America Journal*. 64:275–285.

[10]Zibilske, L. M., W. M. Clapham, and R. V. Rourke. 2000. Multiple applications of paper mill sludge in an agricultural system: Soil effects. *Journal of Environmental Quality*. 29:1975–1981.

[11]Foley, B. J. and L. R. Cooperband. 2002. Paper mill residuals and compost effects on soil carbon and physical properties. *Journal of Environmental Quality*. 31:2086–2095.

[12]Pichtel, J. R., W. A. Dick and P. Sutton. 1994. Comparison of amendments and management practices for long-term reclamation of abandoned mine lands. *Journal of Environmental Quality*. 23:766-772.

[13]Pietz, J. R., C. R. Carlson Jr., J. R. Peterson, D. R.. Zeng and C. Lue-Hing.

1989. Application of sewage sludge and other amendments to coal refuse material: I. Effects on chemical composition. *Journal of Environmental Quality*. 18:164-169.

[14]Pietz, J. R., C. R. Carlson Jr., J. R. Peterson, D. R. Zeng, and C. Lue-Hing. 1989. Application of sewage sludge and other amendments to coal refuse material: II. Effects on revegetation. *Journal of Environmental Quality*. 18:169-173.

[15,17]Sopper, W. E. 1993. *Municipal Sludge Use in Land Reclamation*. Lewis Publishers, Boca Raton, FL.

[16]Stehouwer, R.C. 1997. Amendment of acidic coal refuse with yard waste compost and alkaline materials: Effects on leachate quality and plant growth. *Compost Science and Utilization*. 5(3):81-92.

[18]Cravotta III, C.A. 1998. Effect of sewage sludge on formation of acidic ground water at a reclaimed coal mine. *Ground Water*. 36(1):9-19.

[19]Stehouwer, R. C., R. L. Day and K. E. Macneal. 2006. Nutrient and trace element flux following surface mine reclamation with biosolids. *Journal of Environmental Quality*. 35:1118-1126.

[20]Hsu, J-H. and S-L. Lo. 1999. Chemical and spectroscopic analysis of organic matter transformations during composting of pig manure. *Environmental Pollution*. 104(2):189-196.

[21]Inbar, Y., Y. Chen and Y. Hadar. 1989. Solid-state C-13 NMR and infrared spectroscopy of composted organic matter. *Soil Science Society of America Journal*. 53:1695–1701.

[22]Stehouwer, R.C. and K.E. Macneal. 2002. Use of yard trimmings compost for restoration of saline soil incineration ash. *Compost Science and Utilization*. 11(1):51-60.

[23,25]Stehouwer, R. 2009. Unpublished Data. Pennsylvania State University, Department of Crop and Soil Sciences. 417 Agricultural Services and Industries Building, University Park, PA 16802. Phone 814-863-8043, Email: rcs15@psu.edu.

[24]Tiquia, S. M., T. L. Richard, and M. S. Honeyman. 2002. Carbon, nutrient, and mass loss during composting. *Nutrient Cycling in Agroecosystems*. 62:15-24.

[26]Tilman, D., J. Hill and C. Lehman. 2006. Carbon-negative biofuels from low-input high-diversity grassland biomass. Science. 314:1598-1600.

FOR MORE INFORMATION

Project Contacts:
Scott Van de Mark
Director, Special Projects
Pennsylvania Environmental Council
22 Terminal Way, Pittsburgh, PA 15219-1209
Phone: (412) 481-9400 | E-Mail: svandemark@pecpa.org | www.pecpa.org

Dr. Richard Stehouwer
Associate Professor of Environmental Soil Science
Department of Crop and Soil Sciences, Pennsylvania State University
417 Agricultural Sciences and Industries Building, University Park, PA 16802
Phone: (814) 863-7640 | E-Mail: rcs15@psu.edu