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 6 STEWARDSHIP

Using Engineered Wetlands to Enhance Water Quality

A Natural Treatment System at the Philip Morris USA Property Along Virginia's James River

Philip Morris USA's new natural treatment system shows how private industries and municipalities can use man-made wetlands to further reduce harmful pollutants in processed wastewater before they enter the Chesapeake Bay or its tributaries.

CASE STUDY SUMMARY

Philip Morris USA (PM USA) has created 48 acres of engineered wetlands on their Park 500 property in Chester, Virginia, adjacent to the James River, which enhances the traditional on-site wastewater treatment process at this tobacco processing facility. The engineered wetlands assimilate pollutants by physical and biological processes aided by gravity. The benefits of this system include: improved water quality, reduced mass and hydraulic loads, and the creation of significant wildlife habitat.

Private corporate natural treatment systems like this one are uncommon in the Chesapeake region. The Chester plant directly withdraws water from the James River and is permitted through the Virginia Pollutant Discharge Elimination System (VPDES). While there is no flow limit or secondary treatment technology standard required in the permit, PM USA estimates a typical river withdrawal rate of 2.05 million gallons per day (mgd) and a wastewater discharge of 1.53 mgd. This water is used in the manufacturing process and is then treated for various substances present in the wastewater, such as nitrogen, phosphorus, and suspended solids. Over several months of the summer, excessive nitrogen and phosphorus have created a 100 mile-plus "dead zone" in the main stem of Chesapeake Bay that lacks sufficient oxygen to support aquatic life. In nutrient enriched shallow waters, and poorly flushed areas found in tributary systems like the James, algal blooms frequently occur during the summer. When the algae die off, low dissolved oxygen conditions are created that can reduce suitable habitat and kill or stress mobile species such as fish and crabs, as well as stationary bottom life like clams and worms. Reducing nitrogen and phosphorous loads to the James is essential to its restoration and removal from Virginia's impaired waters list.

In 2002, PM USA formed a "zero discharge team," to evaluate and institute changes to their wastewater treatment plant and improve environmental performance. The team evaluated a range of technologies in hopes of finding a way to reduce effluent flow by reusing or recycling the facility's wastewater. The team identified a number of options ranging from reverse osmosis to land application. Ultimately, PM USA decided to create a natural treatment system modeled after an existing one in Clayton County, Georgia. While this was not a zero discharge design, the company hoped it would significantly reduce pollutants in the wastewater.

In 2006, PM USA hired CH2M HILL, a leading construction and engineering firm, to design and build a natural treatment system based on engineered wetlands. The design employs shallow and deep water pools, with native plants and natural filtering techniques that absorb pollutants. The system was designed to further reduce total nitrogen discharge by 13% and phosphorous discharge by 34%. Initial results actually exceed these figures, but this preliminary data represents a period of rapid plant growth and pollutant uptake levels that are not likely to be sus-

Aerial view of the natural treatment system at the Philip Morris USA property known as Park 500, located on the James River in Chester, Virginia.

tained over time. The wetlands have also created new habitat for several wildlife species.

The entire system cost $7.175 million and was commissioned in June 2008. In 2009, the project was recognized by the Virginia Environmental Excellence Program for a pollution prevention approach that goes above and beyond the legal requirements.

RESOURCE MANAGEMENT CHALLENGE

The James River is one of America's most historic rivers, often referred to as America's Founding River, and lays claim to the first permanent English settlement at Jamestown, established more than 400 years ago. Development, pollution, and overfishing have now damaged the river ecosystem, particularly within the last 30 years.

Recent efforts have begun to reverse the river's decline and the state has laid out a plan to restore the river to full health—including the reduction of nitrogen and phosphorous pollution. However, pollution from across the watershed continues to have adverse impacts on the river.[1] In 2008, the James River Association gave the river an overall score of 52 out of 100. An "A" grade, or fully restored condition, would require a score from 80 to 100 points. Populations of native fish and shellfish, such as trout, shad, and oysters, remain far below historic levels. Moreover, at the current pace of development, Virginia will develop as much land in the next 40 years as it did in its first 400 years,[2] which will result in significantly more pollution entering the river.

The largest amount of pollution comes from runoff originating on farms and developed areas, which carries a toxic mix of bacteria, sediment, heavy metals, nitrogen, phosphorus, and pesticides.[3] Some of these same pollutants also come from sewage treatment plants and industrial discharges, such as from PM USA's Chester facility. All these pollutants combine to cause ecological and water quality problems for the James. The river's impaired condition and future development pressures require government, non-profits, corporations, and private citizens to each do their part to restore the river.

The Chester plant property is adjacent to Bermuda Hundred, a historic community which was established in 1613, and served as the early port of Richmond. PM USA's Chester facility opened in 1975 to reuse tobacco materials. Essentially a recycling facility, the plant processes small pieces of tobacco, such as stems and dust, from other facilities into a sheet product called reconstituted tobacco. This paper-like tobacco is shipped to other Philip Morris plants, shredded, and blended with virgin tobacco to make cigarettes. This process typically requires the use of up to 2.05 million gallons of water a day from the James River. The water is used in the reconstituted tobacco manufacturing process, then treated at an on-site wastewater treatment facility, and released back into the river.

The Chester facility is a direct discharger of wastewater. Therefore, the Virginia Department of Environmental Quality requires PM USA to obtain a discharge permit. The facility must demonstrate compliance with permit limits via monthly discharge monitoring reports. The plant uses conventional wastewater treatment technology (physical settling, and activated sludge and chemical treatment processes) to ensure compliance with all permit requirements before discharging treated wastewater to the river.

CONSERVATION VISION

PM USA managers had previously committed to reducing the environmental impact of their business and to promoting sustainability of natural resources. Recognizing the regional struggle to restore the Chesapeake Bay and its tributaries, PM USA specifically pursued avenues to reduce its total nitrogen and phosphorous loadings to the James River. Between 2001 and 2006, operational changes and incremental upgrades to their existing wastewater treatment facility reduced nitrogen by 46%, but PM USA leadership was determined to do better in order to meet shareholder and community expectations. They also hoped to address concerns raised by some stakeholders, like Chesapeake Bay Foundation, who sued the state in connection with the reissuance of the facility's discharge permit in 2004.

PM USA began formulating their conservation vision through the creation of a "zero discharge team," which worked to improve the environmental performance of their wastewater treatment plant. In 2002, the team evaluated several options that would result in fully recycling the discharge water and those that would reduce pollutants. They considered reverse osmosis, land application (silviculture and spray irrigation), municipal treatment, and reuse of boiler blow-down in cooling towers. The estimated costs for installing these options ran from $28 million to $500,000, with widely varying maintenance and operations costs. Ultimately, the company chose to pursue the natural treatment system.

PM USA's environmental and operational staff was already aware of the potential for wetland ecosystems to improve water quality. Natural wetlands have been used for wastewater collection for more than 100 years. Wetlands also have a high rate of biological activity and can transform harmful pollutants in wastewater to harmless byproducts and essential nutrients.[4]

Man-made or engineered wetlands are constructed ecosystems that also improve water quality, flood storage, and landscapes for active and passive recreation. The "zero discharge team" found that the ability of engineered wetland systems to treat municipal, industrial, and agricultural waste has been recognized for 30 years and studied extensively in North Carolina,[5] Michigan,[6] Florida,[7] New York,[8] and in many places in Europe. Such systems are now an accepted pollution control technology[9,10] and can be effective at decreasing the concentrations of nutrients, metals, pathogens, suspended solids, biological oxygen demand, and trace organics. In addition, natural treatment systems typically require fewer personnel, consume less energy, and have ancillary benefits. There are numerous demonstration projects across North America and Europe that have proved the concept.

Having selected the natural treatment system as the best solution, PM USA contracted with CH2M HILL, a noted consulting firm with expertise in this treatment practice. CH2M HILL was tasked with conducting a feasibility study that provided three conceptual alternatives for the wetland design: maximum treatment potential; maximum aesthetic benefits; and combined habitat, aesthetics, and treatment. PM USA's primary objective was water quality treatment, so they chose the option with maximum treatment potential—a simpler design that maintained a high percentage of marsh over open water zones.[11]

IMPLEMENTATION RESOURCES

PM USA paid for the entire cost of developing their conservation strategy using a combination of in-house resources and a team of consultants; they also paid for constructing and operating the natural treatment system. The total construction cost was approximately $7.175 million, which included the construction of the wetlands, transmission pipelines, pump station, and outfall structure. This cost is approximately $150,000 per wetland acre or $2.40 per gallon of installed capacity. PM USA staff indicated that the figures shown in the tables here reflect the higher end of the cost continuum for a natural treatment system. Thus, others contemplating a similar project should not use these figures to benchmark their specific needs and situation.

PM USA had to obtain several permits before starting construction, including a land disturbance permit from the county and state. Installation began in August of 2007, and the system was first flooded with water in March of 2008. All wetland cells were planted by June of 2008.

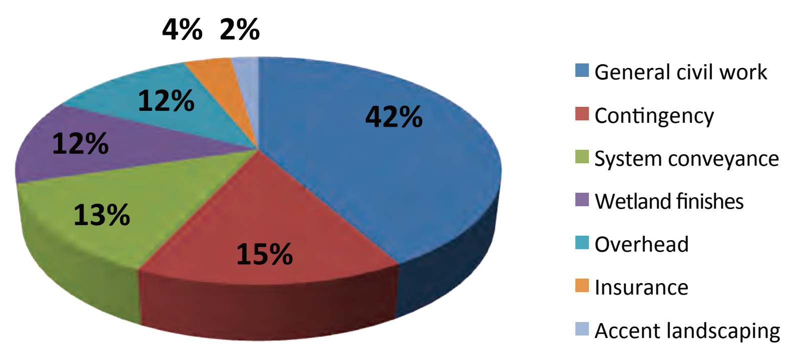
Principal costs for operating and maintaining the wetland are to power the pump, monitor the system, and maintain the levees. A large portion of the maintenance revolves around assuring that flows are consistent and that hydraulic control structures are operating at correct depth. Additional management efforts include consistent vegetation maintenance, periodic troubleshooting, and mosquito monitoring and control. The estimated cost for annual operation and maintenance is $139,950.

There were two primary constraints to implementation:[12]

- **Regulatory limitations:** Construction of the wetlands triggered the need for state and local permits, like those for erosion and sediment control. Operation of the wetlands also triggered a permitting analysis to determine future potential limits and regulatory requirements. The Virginia Department of Environmental Quality approved the project as experimental in nature and, as a result, did not incorporate it into the VPDES permit. In addition, treatment wetlands are generally considered a component of a wastewater treatment system, not jurisdictional wetlands, and therefore are not regulated by the wetland provisions of the Clean Water Act.
- **Land area requirements:** Engineered wetland processes are land-intensive because the wetlands are shallow and the water is expected to remain in the system for days or weeks at a time. According to CH2M HILL, a treatment wetland receiving 1 mgd with a design hydrologic residence time of 10 days and a design depth of 1.5 feet will require 20 acres. Because the Chester facility sits on several hundred acres of property, PM USA was able to meet this requirement.

The expertise of CH2M HILL was a critical resource for this project. The firm was intimately familiar with the design and construction issues of primary importance for natural treatment systems, including influent flows and loads to the wetland; wetland performance and the area and volume required to achieve treatment goals; and the physical and biological wetland system components needed to achieve pollutant processing rates. CH2M HILL also brought with them critical expertise in conventional civil engineering, mechanical design for measurement devices, and architectural/landscape design.[13]

Natural Treatment System Costs (excluding design) Total = $7,175,000



Approximate Estimated Annual Operation and Maintenance Costs for Natural Treatment System				
Item Description	Unit	Cost	Quantity	Item Cost
Routine maintenance of pumps, inlets, weirs, pipelines	each	$210	110	$23,100
Vegetation Management	acre	$575	ND	as needed
Mosquito monitoring/control	grtly	$2,000	ND	as needed
Weekly monitoring	each	NA	364	NA
Sediment metals (annual)	each	$300	12	$3,600
Annual reporting	annual	$50,000	1	$50,000
Total operations, maintenance, and monitoring costs				$139,950

CONSERVATION STRATEGY

Initial Environmental Scan

The PM USA team realized that their vision for improving water quality would also disturb a substantial portion of the site. To ensure that construction activities would result in minimal harm to historical, cultural, and environmental resources, PM USA officials consulted with state officials and private consultants to understand the full scope of potential resource management issues.

- **Cultural Resource Inventory:** Given the rich history of the Bermuda Hundred community, PM USA retained a cultural resources consulting firm, Gray and Pape, Inc. The firm assessed the current state of knowledge regarding previous archaeological and historical research conducted within the project area; they conducted field reconnaissance to determine the condition and integrity of the identified cultural resources and to evaluate the potential for those that were unrecorded. A full technical report outlined protocols for the treatment of unanticipated archaeological discoveries and the documentation of cemeteries or human remains. An archaeological sensitivity model divided the project area into four zones that represented the relative potential for presence of cultural resources. High and moderate zones signaled the need for higher sensitivity, and two low-sensitivity zones guided the level of cutting/grading and fill material used during the construction process.
- **Pre- and Post-Construction Ecological Survey:** During the summer of 2007, PM USA worked with Virginia Commonwealth University, Department of Biology, to conduct ecological inventories where the future natural treatment system would be built. A "baseline" survey was performed to evaluate and document changes in the ecological communities associated with the site both during and after construction.[14] Surveyed elements included vegetation, mammal fauna, avifauna, herpetofauna, odonata, lepidoterans, and soil characteristics. The survey identified ecological threats to the future natural treatment facility that included potential problems such as herbivory of the wetland

A treatment cell at PM USA's Chester facility with open water and adjacent wetlands.

A pumping station at the natural treatment system used to pump effluent as needed during high flows.

vegetation from resident geese populations, deer, and other mammals. Several species of exotic and native invasive plants both on-site and in the vicinity were noted as having the potential for outcompeting both the native upland herbaceous plant species and future wetland species intended for the natural treatment system.

Engineering Feasibility Study

In September of 2005, PM USA asked CH2M HILL to evaluate the feasibility, benefits, and concerns associated with initiating a natural treatment system at the Chester facility. The consultants laid out the following objectives for the study:

- A review of the available land in the vicinity of the PM USA wastewater treatment plant to identify candidate sites;
- A description of how a natural treatment system could improve the effluent water quality, while achieving secondary benefits such as wildlife habitat enhancement and public education;
- An analysis and comparison of three conceptual designs and preparation of a preferred alternative;
- An outline of the potential planning, design, construction capital, and operational and maintenance costs associated with the project; and
- Recommended steps for moving forward.

Site Evaluations: In December of 2005, staff from PM USA and CH2M HILL conducted a workshop to narrow down the list of six candidate sites identified by the consultant. Using preliminary renderings of wetland system designs and information developed during the site reconnaissance, two areas emerged as the most logical locations. Concerns over the location of existing utilities, proximity to local residential neighborhoods, and piping challenges were cited as reasons to eliminate four of the six sites.

Review of Potential Benefits: CH2M HILL was familiar with the technical literature assessing the effectiveness of using wetlands to treat wastewater. They provided important background information that summarized the three general types of shallow vegetated ecosystems being used for water quality treatment: 1) natural wetlands, 2) constructed surface flow (free water surface), and 3) subsurface flow (submerged vegetated bed).[15] The consultants noted that although observed treatment efficiency varies by wetland type, engineered wetlands significantly lower concentrations and mass loads of biochemical oxygen demand, total suspended solids, and total nitrogen concentrations. Removal efficiencies vary more widely for total phosphorus, metals, and organic compounds.[16] System performance is limited by the form and concentration of the constituents, amount of wetted area, water flow rates and residence time, inflow water qualities, plant communities, the presence of oxygen, substrate type, and the entire chemical makeup of the water to be treated. Engineered wetlands can be designed to regulate water depth and residence time, two important factors in treatment efficiency.[17]

In terms of ancillary benefits, CH2M HILL found that more than 800 animal species have been reported from constructed treatment wetlands. Notably, they cited that the diversity of wetland-dependant raptors and bird species—such as shorebirds, wading birds, diving birds, and waterfowl—is one of the most popular public aspects of wetland treatment systems.

Pre-Implementation Actions: With the feasibility study completed, CH2M HILL recommended three important actions that were necessary to build the project:

- Performing a detailed hydrologic data collection and modeling analysis to confirm the preliminary groundwater infiltration rates described in their report;
- Confirming groundwater monitoring and performance criteria for the site from the Virginia Department of Environmental Quality; and
- Preparing a detailed design and construction schedule consistent with regional seasonal variation for optimum results during the wetland planting and grow-out period.

Alternatives Analysis: After PM USA decided to maximize treatment potential with a constructed surface-flow wetland, five flow scenarios were modeled. The flow scenarios ranged from 0.5 mgd up to the 3.0 mgd capacity of the plant. The wetland model was run with incrementally greater total wetland area to create a curve showing how water quality performance changes with increased area.

System Design: Based on the analysis and recommendations, PM USA chose to move forward with a constructed surface-flow wetland design. The natural treatment system, including cell sizes and boundaries, was developed using Geographic Information System (GIS) software. Wetland cells were shaped to maximize cell areas and minimize excavation volumes, which was a significant portion of the

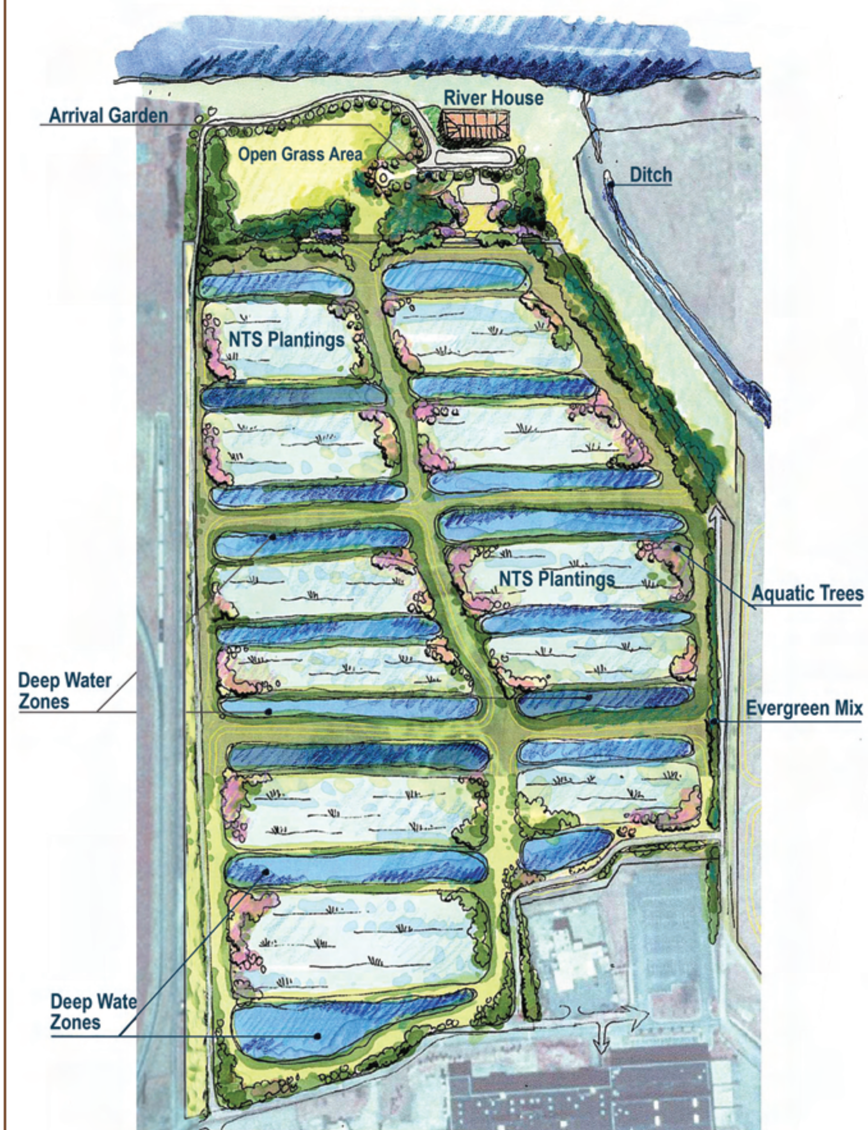
Pickerelweed plants are incorporated into the natural treatment system. The plants respond well to additional nutrients and are resistant to damage from insects, disease, birds, or mammals.

overall construction cost. The wetland configuration was based upon general guidelines provided in Kadlec and Knight (1996)[18] and from CH2M HILL's previous wetland project experience.

The configuration uses two parallel north-south flow paths. Each flow path contains a series of three wetland cells, for a total of six separate wetlands encompassing 48 acres of wetlands on 70 acres of land. Flow from the existing wastewater treatment plant is pumped to the inlet of the wetland system. From there, water moves through the natural treatment system by gravity. The parallel treatment paths add operational flexibility to the system while the multiple cells in series improve treatment efficiencies. To ensure the wetland system performed as a surface water flow system, dense clay was used as the bottom layer of each of the cells. The system includes a series of small, deep water zones interspersed with shallow marsh zones. The marsh zone is covered with grasses and plants that grow in shallow water. The system relies on natural physical, and biological processes such as uptake and chemical synthesis to remove nutrients such as nitrogen and phosphorous. It takes an average of 9 to 14 days for the water to traverse the entire wetland system.

The vegetation used for this system was limited to native species that are readily available from local nurseries or planting contractors. There are more than 150,000 plants in the six cells of the natural treatment system. Typical species include: arrowhead (*Sagittaria latifolia*), pickerelweed (*Pontedaria cordata*), giant bulrush (*Scirpus californicus*), three square bulrush (*Scirpus americanus*), cattail (*Typha latifolia*), water lily (*Nymphaea odorata*), and spatterdock (*Nuphar luteum*). A mixture of hardwoods and evergreens were incorporated into the design for site privacy and aesthetics. In the upland areas, there are about 945 plants, including more than 350 trees such as red maple (*Acer Rubrum*), eastern redbud (*Ceris Canadensis*), dogwood (*Cornus florida*), Bald cypress (*Taxodium distichum*), sweet crabapple (*Malus coronaria*), and others. Wetland tree and shrub species were installed in locations to create resting and nesting habitat for wading birds and aquatic animals.[18]

Natural Treatment System



Schematic of the natural treatment system used by PM USA.

RESULTS

PM USA's natural treatment system is fully operational and functioning properly. The treated wastewater previously sent to the James River is now diverted to the constructed wetlands for additional treatment. The water flows through the cells and through hundreds of thousands of native plants that absorb some of the remaining pollutants. The reclaimed water from the wetlands then is returned to the James River.

PM USA is collecting data on the performance of the system and expects it to reach full potential once the wetland vegetation is fully established. Initial results observed from July 2008 to June 2009 indicate that the system has been extremely successful in removing ammonia, phosphorous, and nitrogen, although the first year of data represents a period of rapid plant growth and uptake levels that are not likely to be sustained at this level over time. It is important to note that the initial results are based on a small number of data sets; thus PM USA has characterized these results as unrepresentative of the system's long-term performance.

- **Ammonia (NH3)** - This compound can be toxic to fresh water organisms at concentrations ranging from 0.53 to 22.8 mg/L. Plants are more tolerant of ammonia than animals, and invertebrates are more tolerant than fish. Initial results indicate that PM USA has reduced ammonia concentrations in the wastewater by 91%.
- **Phosphorous** – This is a key element necessary for growth of plants and animals. Nevertheless, an excess of phosphate stimulates hyper-growth of algae and aquatic plants, which causes eutrophication and ultimately leads to low dissolved oxygen levels in the water, also known as "dead zones." Initial results indicate that PM USA has reduced phosphorous concentrations in the wastewater by 81%.
- **Nitrogen** – This is one of the most abundant elements found in the cells of all living things. Nitrogen-containing compounds act as nutrients in streams, rivers, and reservoirs. Like phosphorous, excessive nitrogen stimulates hyper-growth of algae and aquatic plants, which causes eutrophication and creates "dead zones." Initial results indicate that PM USA has reduced nitrogen concentrations in the wastewater by 36%.

Initial Pollutant Reduction Rates

	In (ppm)	Out (ppm)	Percentage
Ammonia	0.22	0.02	91
Phosphorous	0.52	0.1	81
Nitrogen	9.6	6.16	36
Organic N	8.5	6	29
Inorganic N	1.1	0.16	85

ppm: parts per million

PM USA has worked with the Rice Environmental Center at Virginia Commonwealth University to monitor the ecological health of the system. Researchers documented the baseline ecological conditions of the fallow farm field as well as conditions before, during, and after construction. Overall, the researchers saw a large increase in the diversity of wildlife after completion of the natural treatment system. They have identified more than 37 new species using the wetland in the early months of the system's operation (18 birds, 7 reptiles and amphibians, 7 dragonflies, 4 butterflies, and 1 damselfly).

PM USA has encountered some invasive plant growth, notably purple loosestrife and common cattails. These unwanted plants are being removed until the desired plants are established. Geese can also uproot young plants, so netting was installed until the vegetation matures and takes root to prevent this from happening.

KEYS TO SUCCESS

- **Early engagement of key stakeholders.** PM USA devoted time and effort in outreach to citizen and government stakeholders. Through these efforts, critical concerns were identified in advance of the project. In the end, the time required to implement the project was reduced and the results were superior. For example, the Bermuda Hundred community initially expressed concern that groundwater may be adversely impacted from the system. While engineering studies showed that this would not be the case, PM USA responded to the neighbors' concerns by arranging to extend the Chesterfield County public water system to the Bermuda Hundred homes, which were served by well water.
- **Support from the Virginia Department of Environmental Quality.** The natural treatment system was an unconventional idea that raised many questions. An open-minded attitude and technical support from the Virginia Department of Environmental Quality gave PM USA the reinforcement needed to move forward with the project.
- **Support from corporate management.** The project clearly matched the company's environmental objectives and has served as a catalyst in improving their overall environmental management system.
- **Communication with employees.** Periodic meetings were held to inform PM USA employees on the progress of the wetland construction. This resulted in greater internal and external awareness and support for the project.
- **Project management team.** The interdisciplinary approach used by PM USA provided the full range of experts needed for success. PM USA's integrated team, including representatives from various functional areas such as environmental compliance and engineering, plant and waste water treatment management, engineering, communications, and community affairs provided leadership and expertise throughout the project.

- **The right implementation partner.** CH2M HILL was the best partner to implement the project because of their experience with designing, building, and maintaining natural treatment systems.

PHOTOS AND FIGURES

Page 243, 247-249: Photos, David Burke
Page 244: Photo, Phillip Morris USA
Page 246: Figure, Joel Dunn
Page 250: Figure from CH2M Hill 2006

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FOR MORE INFORMATION

Project Contact:
John Pickelhaupt
Manager of Environmental Services
Altria Client Services
Phone: 804-335-2664 | Email: John.Pickelhaupt@altria.com

Further Reading:
http://www.philipmorrisusa.com/en/cms/Responsibility/Reducing/Reducing_Our_Environmental_Impact/case_studies/NTS_Case_Study/xx