Clean Again, Naturally

Constructed wetlands change the face of petroleum remediation at former BP refinery site.

Why Wetlands Work
Petroleum wastes naturally degrade in wetland environments. This is because the microbial community associated with wetland environments supports the breakdown of many volatile organic compounds. Engineered wetland systems offer the benefits of natural wetlands, but can be tailored to meet the treatment and construction needs of each individual site.

Wetland bioremediation systems require much less operation and maintenance than conventional mechanical treatment systems. Their visual impact is minimal, allowing them to be easily integrated into site re-use opportunities, such as brownfields redevelopment, in contrast with obvious mechanical treatment systems. Assuming that there is enough space for a treatment wetland and the economics are favorable, acceptance of wetland treatment by the general public and neighboring landowners is often quite high. With proper attention to hydrology and plant selection, they can be designed as visually attractive “amenities” that enhance the value of surrounding areas. Because of their low visual impact, wetland treatment systems are ideally suited for integration into parks, golf courses, prairies, and other open spaces.
An 18-hole golf course on the former site of a refinery in Casper, WY.

Surface or Subsurface?
Two types of constructed wetlands are currently used for remediation applications: surface-flow systems and subsurface-flow systems.

Surface-Flow Wetlands
A surface flow system is an engineered wetland with areas of open water similar to that of a natural marsh. These systems are typically designed to support the growth of emergent wetland plants, such as cattails and bulrushes, although deeper, pond-like areas may be incorporated in the design. Surface-flow systems are less expensive to construct than their subsurface-flow counterparts. They also typically create more waterfowl and wildlife habitat than can subsurface-flow systems.

Subsurface-Flow Wetlands
In subsurface-flow wetlands, the water level is kept below the surface of the bed and is not exposed during the treatment process. Water flows horizontally through the bed, which is planted with emergent wetland plants. Due to the higher surface area present in a gravel bed, subsurface-flow wetlands can provide better treatment per square foot than surface-flow systems can.

One of the features of the project was the construction of surface-flow wetlands, which were designed to handle up to 11,000 cubic meters per day of gasoline-contaminated groundwater.
Left: The golf course and other features planned for the former refinery site. Below: Radial-flow wetlands designed to address subsurface-flow distribution.

Removal of BTEX (benzene, toluene, ethylbenzene, xylene) compounds happens through volatilization and aerobic biodegradation. A recent development by North American Wetland Engineering in wetland remediation systems has been to add Forced Bed Aeration to subsurface-flow wetlands. Aerated subsurface-flow wetlands have been demonstrated to be more effective than non-aerated systems in removing these hydrocarbon compounds from contaminated groundwaters, a critical factor in the growing popularity of this application. Due to their simplicity of operation, low maintenance needs and high treatment efficiencies, aerated wetland systems are gaining in popularity.

**Biology Versus Mechanics**

Wetland systems provide biological complexity instead of mechanical complexity. Advances in wetland design (such as aerated wetlands) are now blurring the line between "passive" and "active" treatment systems. Economics are also playing a role in this decision process, because plants and bacteria work for free; people and machines do not. The economics of wetland treatment is most favorable for site managers who can trade space for mechanical complexity, and who must operate a treatment system over a
This chart shows the distribution of LNAPLs on the remediation site, where a large refinery had operated from 1908 to 1991. More than 34,000 cubic meters of light non-aqueous phase liquids have been removed from the groundwater since 1981.

long period of time. A larger site with ample open space is more favorably suited for a wetland system than a tightly constrained site in the middle of a major metropolitan area.

Depending on the type of contaminant, capital costs for wetland systems can be comparable to their mechanical counterparts. The cost of wetland systems is highly dependent on the cost of local labor and materials (earthwork, gravel, plants, etc.). Areas with low costs for land, labor, and local materials will be better candidates than areas with high material costs. In addition, if material from the jobsite can be recycled for use in the wetland, such as was done by British Petroleum (BP) in Wyoming (see project profile), capital costs dramatically drop.

Project Profile: Wetland Remediation in Wyoming
A wetland system implemented by BP in Casper, WY, is the largest constructed remediation wetland in the US. The site was one of the oldest and largest Amoco Oil Co. refineries in the West, which began operation in 1908. It was the largest refinery in North America during the 1920s and continued operation until 1991. As a result of common operating practices during the first 50 years of operation, much of the site is underlain with residual hydrocarbons. Since 1981, over 34,000 cubic meters of light non-aqueous phase liquids have been removed from the groundwater.

The patented wetland aeration system, seen here being tested during construction, accelerates the treatment of BTEX and MTBE compounds in the treatment cells.

Faced with the rising cost of environmental cleanup, Amoco decided to close the refinery in 1993. Due to the residual hydrocarbons on the site, BP was faced with a potentially $350 million liability due to court injunctions and citizen lawsuits. Rather than embark on the typical path of lengthy litigation with a timeframe of 10–15 years, the company decided to engage in an
The center-feed radial-flow design of the subsurface-flow wetlands cells had never been used in North America. The system, which went online in May 2003, has been hydraulically loaded at roughly 2,600 cubic meters per day.

innovative remediation strategy, accelerating the entire remedy process into a six-year window. With the sobering realization that the remediation of this site will continue for the next 50–100 years, the traditional solutions of a mechanical system with high operation and maintenance costs was not an attractive option. The cost and benefits of eco-technology were apparent. In the case of the Casper project, construction of an engineered wetland system saved BP over $12.5 million compared to a conventional mechanical plant.

Over the first 50 years of site remediation, the lower operating costs associated with constructed wetlands is anticipated to save an additional $15.7 million.

In 1999, the Wyoming Department of Environmental Quality finalized a consent decree establishing the framework for site remediation. In order to clean up the site, BP negotiated an innovative agreement with the City of Casper. BP would demolish the old refinery structures and convert the property into an 18-hole premier golf course—designed by Robert Trent Jones II LLC), complete with an office park, riverfront trails, and a whitewater kayak course—designed by Recreation Engineering and Planning of Boulder, CO.

A constructed wetland was identified as a low-maintenance alternative to conventional options that was also aesthetically compatible with the golf course on the property. The design team was challenged to create a remediation treatment system that could handle up to 11,000 cubic meters per day of gasoline-contaminated groundwater, blend into the middle of a premier golf course, and have a lifetime operation of more than 100 years.

Redevelopment of the 300-acre refinery site was a vast project. At the peak of construction, over 50 engineering teams and over 250 full-time construction personnel were involved in the project. Over 200 miles of underground pipes were excavated and recycled. Over 300,000 tons of concrete were recovered from tank foundations, crushed onsite, and re-used as aggregate for the wetland treatment system. Construction of the golf course required over 1 million cubic yards of grading, and over 60 dual-phase recovery wells feed the treatment system. All design and construction elements were completed in a three-year period.

Bear Lake, MN, was selected to design the wetland treatment system. NAWE had pioneered the development of insulated, cold-climate wetlands, and they were comfortable designing a wetland that could operate in Casper's -35°F winter temperatures. They could also incorporate their patented wetland aeration process (US Patents 6,200,469 and 6,406,627) to accelerate the treatment of BTEX and MTBE compounds in the wetland treatment cells.

The wetland treatment system design was based on the results of a pilot system operated at the project site. In order to meet site objectives, the potential iron fouling of the wetland media—identified during the pilot operation—needed to be addressed. To solve this problem in the full-scale design, NAWE designed the initial stages of
the treatment process to include a cascade aeration system (for iron oxidation) and a surface-flow wetland (for iron precipitation). Treatment of BTEX compounds is completed in subsurface flow wetland cells.

To address flow distribution in the subsurface cells, an innovative radial-flow wetland configuration was adopted. Because the gravel media for the wetland was made of recycled crushed concrete from structures on the site, it was possible to tailor the media to provide an appropriate hydraulic conductivity. Since the pilot testing had demonstrated that aerated wetlands were more efficient in removing constituents of interest, a patented Forced Bed aeration system designed specifically for the wetlands by NAWE was implemented.

The project has substantially advanced the field of engineered wetland treatment systems. In the pilot-testing phase, the project was one of the first in North America to determine degradation rate constants for BTEX under aerated and non-aerated conditions. Scaling up from the pilot system required a 1,200-fold increase in reactor volume. As a result the full-scale subsurface-flow wetlands were designed using an innovative center-feed radial-flow design to optimize hydraulic efficiency. This radial-feed design had never been used in North America before this project.

The full-scale system was put online in May 2003. Since startup, the system has been hydraulically loaded at approximately 2,600 cubic meters per day and system performance to date has exceeded expectations.

The sustainable wetland treatment systems were integral to the project and reflect BP’s environmental stewardship commitments. Perhaps more importantly, the Casper project has transformed a site that once seemed destined to remain an unused property near downtown Casper into a landmark helping to redefine the community. Recreational facilities created by this project will benefit the citizens of Natrona County and Casper for years to come, and in a powerful symbol of support, the Wyoming Oil and Gas Conservation Commission—the state agency regulating oil and gas development—became the anchor tenant on the property by opening their new building in March 2004.

**Implications for Compliance Managers**

Compliance managers at many industrial sites are now settling in for the long haul. The sobering realization is that remediation systems at many sites will have to be actively operated and maintained for the next 50 to 100 years. Even if in situ strategies such as bioremediation or phytoreme-