WETLANDS and WASTEWATER Treatment in Alaska

Why would anyone want to construct a marsh? Dave Maddux has created a business to do just that. Swamps and marshes, it turns out, are useful for more than wilderness habitat. Because wetlands act as biological filters they are great for cleaning up wastewater, even in subarctic Alaska, Maddux explained in a recent interview. As a SNRAS graduate student, Maddux earned his PhD at UAF studying the feasibilty of using constructed wetlands for sewage wastewater treatment in a subarctic environment. His work earned him an Arctic Research Consortium of the U.S. Award for Arctic Research Excellence in 2002.

Natural wetland: a sedge marsh in the Yukon Delta National Wildlife Refuge.
—PHOTO COURTESY U.S. FISH AND WILDLIFE SERVICE

A constructed wetland is essentially a man-made swamp or marsh designed to mimic natural wetlands, but for human use as a tool to treat wastewater or runoff, attract wildlife, or to rehabilitate disturbed lands. Artificial wetlands can also be part of flood control systems. Constructed wetlands are used in low-maintenance, low-technology systems throughout the world, primarily in areas with mild winters.

Maddux explained that his research showed that these systems, if constructed properly, can be used successfully in subarctic conditions as well. "Because they're simple to maintain and relatively inexpensive to build," he said, "they may be suitable for villages and small towns in Alaska that are unable to afford or do not need conventional water treatment plants."

The Nulato Wastewater Treatment Facility, featuring use of a natural wetland near the town of Nulato, Alaska. This photo shows the wetland's vegetation downstream from the holding lagoons. The wetland eventually discharges into the Nulato River.
— PHOTO BY DAVE MADDUX

Conventional sewage treatment facilities can be very expensive to build, particularly in areas off the road system. In rural villages, the issue of sanitation facilities is very important, and has been a political hot button for many years. Constructed wetlands may offer a relatively inexpensive and easy-to-maintain alternative for rural areas and so more such artificial marshes may be in Alaska's future.

Types of wetland

To understand how a constructed wetland works, it helps to have an idea of the different kinds of natural wetlands, and also of conventional water treatment systems.

A wetland is an *ecotone*, or bridge between two ecosystems: a dryland world and an aquatic one. This transitional environment may vary seasonally, going from dry to wet, or may consistently maintain some characteristics of both ecosytems. Wetlands are characterized by hydric soils, where free oxygen is used up by microbial action at least part of the time. Thus, plants living in wetlands must be tolerant of an absence of soil oxygen—and, of course, soggy conditions. Wetlands are recognized for their importance as wildlife habitat, particularly for waterfowl; for their capacity to protect terrestrial areas from the force of floods, storms, and tides; and for their ability to filter sediments from water. Wetlands can be an important source of fuel (peat), food, or other products, such as sedges used for thatching.

different wetland types:

bayou or **slough**: tributary stream, swamp, or shallow lake system, featuring trees and bushes (sometimes the term slough is applied to the channels in a river delta).

bog (also known as a **muskeg** or **moor**): a wetland fed primarily by precipitation, featuring peat from moss or lichen.

fen: a wetland midway between a bog and a marsh, fed by groundwater and runoff or flooding, often containing peat.

mangal, or mangrove swamp: saltwater shore forest, important as fish breeding habitat and protection of shorelines from tidal and storm erosion. (Alaska, despite its huge coastline, has no mangals, but does have saltwater marshes.)

marsh: features shallow water (fresh, brackish, or saline) with grasses, sedges, rushes, typhas such as cattails, or other herbaceous plants.

swamp: a permanently inundated area with woody vegetation such as trees or shrubs, featuring slow-moving water and often with dryland islets or hummocks.

Compost pile and conveyor belt at Utilities Services in Fairbanks, Alaska.

—PHOTO BY STERLING MUTH

Conventional sewage treatment: activated sludge

Conventional municipal or agricultural wastewater and sewage treatment involves three stages: primary treatment to reduce solids and oils, secondary treatment to reduce biodegradable contaminants, and tertiary fine filtration and disinfection. In conventional treatment facilities, these processes are often mechanized, although secondary treatment requires biologic processes and uses bacteria, fungi, and protozoa to break down organic matter. Sewage and wastewater or runoff are increasingly treated separately in municipal facilities. Equipment used in conventional treatment systems includes storage and aeration tanks, aerators, air separators, agitators, pumps, and sterilizing equipment such as lamps or chlorine storage tanks.

In the first stage of treatment, grit and stones that could damage equipment are removed using a channel, followed by screening to remove light solids. Sometimes these are macerated for further treatment. Then the sewage is allowed to settle in tanks or ponds. Floating material such as oil or plastic is skimmed off. The main purpose of this first stage is to create a homogenous liquid or slurry that can be treated biologically in the second stage, along with a sludge that can also be treated.

In sludge treatment, either aerobic (employing oxygen) or anaerobic (without oxygen) digestion may be used to break down the solids and to reduce the amount of pathogens present. According to Wayne Urban of Utilities Services, Inc., the company treating Fairbanks' sewage, anaerobic digestion systems are usually used for large cities because they can reduce the percentage of solids 50–60 percent, compared with 30–40 percent for aerobic systems. The greater amount of sewage in a large city also enables a treatment plant to produce recoverable quantities of methane. Methane-producing digesters are also used in agriculture, to treat manure and to produce electricity.

In the secondary stage, aerobic processes are encouraged in the sewage by using air or oxygen and biota growing on a substrate to create an environment suitable for digestion of organic materials in the wastewater or sewage. Air or oxygen, used by the digesting microorganisms, is forced through the liquid or allowed to percolate up through the filter beds from drains at their base. Urban said that his company uses a 90 percent oxygen mixture, which, although more expensive than compressed air, enables the microbes to digest the sewage much more rapidly. The microbes break down the soluble organics such as fats, sugars, short-chain organic molecules, and so on, into carbon dioxide and water; and, to some extent, they also convert ammonia to nitrate. After the sewage is aerated and decomposed, another settling stage, clarification, produces an effluent with minimal solids at the top and a flocculated or thickened sludge. This is composed of particle aggregates of up to a millimeter or more in diameter (flocs) that are created by floc-forming organisms adhering to filamentous organisms. This process of aggregation is called bioflocculation.

Flocs are living microbial communities. This biologically active sludge, or activated sludge, is sludge with a mixed community of microorganisms thriving in an aerobic, aquatic environment. Some of the sludge is returned to the filter beds or aeration tanks to seed incoming sewage with the helpful microbes, which compete with or prey upon dangerous ones, such as *Escherichia coli* bacteria. The presence and population density of these protozoans indicates the condition of the activated sludge, and ciliated species are especially instrumental in removing *E. coli* from the sewage. Even viruses (to a large extent) are removed by activated sludge. Microbes used in this secondary stage are mesophilic (preferring temperatures between 0–40°C).

During the third treatment stage, the clarified effluent is filtered (using sand, lagooning, or reed beds) and detoxified. Nutrients, such as nitrogen and phosphorus that in high concentrations can be toxic to fish or produce algae blooms,

An active pile with PCV piping blowing air into the compost every ten feet. The pipe is unperforated outside of the pile, but perforated in the portion under the pile to ensure good oxygenation.
— photo by Sterling Muth

are removed. This is done with either chemical precipitation or by using living organisms to convert nitrogen to nitrate and then to nitrogen gas. These thermophilic bacteria require a higher pH and higher temperature (40–60°C).

If required, the wastewater is then disinfected with ozone, chlorine, or ultraviolet light. Because chlorine disinfection can produce carcinogenic or other harmful chemicals that then have to be removed, many treatment plants use ozone. This can be produced as needed using oxygen and electricity, although it may be more expensive than chlorine disinfection. From here, the treated water is discharged into waterways or allowed to percolate through the ground into the water table.

Compost it!

Composting is another method of sludge treatment. Composting can produce significant heat, which helps to sterilize the sludge. The resultant product, if properly digested and composted, can be safely used for agriculture. In the Fairbanks area, composted sludge is available for sale to the public. Michele Hébert of the Cooperative Extension Service (CES) teaches in the master gardener program at University of Alaska Fairbanks, and works with CES programs on invasive plants, sustainable agriculture, and composting in Alaska. She said that even in her master gardener classes, many people are unaware that composting is possible this far north, so she shows them the composting operation at Utilities Services, one of the nation's premier examples of sludge composting.

The composting program began only six years ago. Dave Dean of Utilities Services said that the Environmental Protection Agency rated the quality of their compost as "exceptional," which means it is safe for use in vegetable gardens. The company tests for heavy metals and pathogens to ensure its safety and uses temperature probes to assure that the compost gets hot enough. It is proving so popular, Dean said, that this summer the company actually ran out. (The University of Alaska, which was doing landscaping in summer 2004, proved to be one of the largest customers.)

The treated sludge is pressed to remove excess water, mixed with wood chips (to provide carbon) and piled in large trapezoidal pyramids with air lines in it to keep it oxygenated. The compost piles are outside, and are covered with a layer of wood chips to keep them insulated from the winter cold. Utilities Services purchases the wood chips from a local supplier, Northland Wood. The wood chips must be purchased because they need to be made large enough for good air flow, according to Hébert. They are much larger than sawdust (which might be available for free from local sawmills) or the small sawdust-like chips from a shredder. The mixture composts for several months, at minimum 60 days, and then the chips are screened out of the resultant compost and reused. After another 30 days for curing, the compost is tested for pathogens. While the sludge is treated year round, the finished compost is stockpiled during the winter and sold only during the summer, as the water content of the material freezes the conveyor.

Although there are several commercial and municipal composting programs in Alaska, composting everything from dog yard wastes to lawn clippings to seafood processing wastes, the Fairbanks plant has the only sewage composting program in the state. Yet, several Alaska communities now have constructed wetlands to biodegrade their wastewater and sewage in a natural environment.

Constructed wetlands: what they are, how they work

Natural wetlands have long been used for wastewater dumping and clarification. Constructed wetlands were first used for wastewater treatment in Australia in 1904, according to a report by Fujita Research, but they didn't begin to gain in popularity for another 60 years or so. In the early 1970s, the United States increasingly began using the technology.

When constructed wetlands are used for wastewater or sewage treatment, they use treatment stages similar to conventional methods, but rely upon plants instead of filter beds to provide a substrate for the biota, and rely upon natural oxygenation and aeration instead of artificial mixing. Biological oxygen demand is a measure of how much oxygen microbes need to decompose organic matter, and is used as a parameter by regulatory agencies to indicate whether wastewater is appropriately treated and ready for discharge into the environment. Since there is usually a very large air surface to water volume ratio in wetlands, they are very good at providing sufficient oxygen to meet this demand. Maddox said that artificial sterilization is generally not needed because the process is slower than conventional treatment and harmful microbes (fecal coliforms) die out before they can reach a human host.

Maddux described two types of wetlands constructed for pollutant removal: surface-flow and subsurface-flow. In a surface-flow wetland, the effluent flows on top of the soil through the plants, as it would in a natural wetland such as a marsh. The wetland is landscaped, often with berms that create cells to control the wastewater flow rate and direction. These wetlands tend to look and function like natural wetlands. This type is the one Maddux recommends for use in subarctic regions.

In a subsurface-flow wetland, the effluent moves through a constructed medium of gravel or sand topped with plants that send their roots into the filtration bed and further remove pollutants and waste. The direction of effluent flow may be either horizontal, through and beneath the planted layer, or vertical, from the planted layer down through layers of gravel and sand and out. Subsurface-flow wetlands take less area to treat the same output of wastewater. Maddux said that this type is not practical in the far north, because the medium freezes during the wintertime. Although the subsurface-flow wetland thaws in summer, the gravel medium takes longer to thaw than does the surface water and the top soil layer of the surface-flow wetland.

Storage tanks or lagoons may be used in northern regions to hold wastewater until spring, when the winter's accumulation is pumped or allowed to flow into the wetland. On his company website, Maddux explains that although our summers are short, Alaska's longer days "allow for almost continuous photosynthetic production, which in turn drives microbial transformations of pollutants and gaseous exchange between the rhizosphere and the atmosphere."

A typical wetland constructed for sewage or wastewater treatment has three main sections: first, lagoons or tanks to hold and help settle out the solids; second, cells of marshes (often lined to prevent seepage) through which the effluent slowly filters; and third, a final filtration through sand and rocks before the end product is released into nearby

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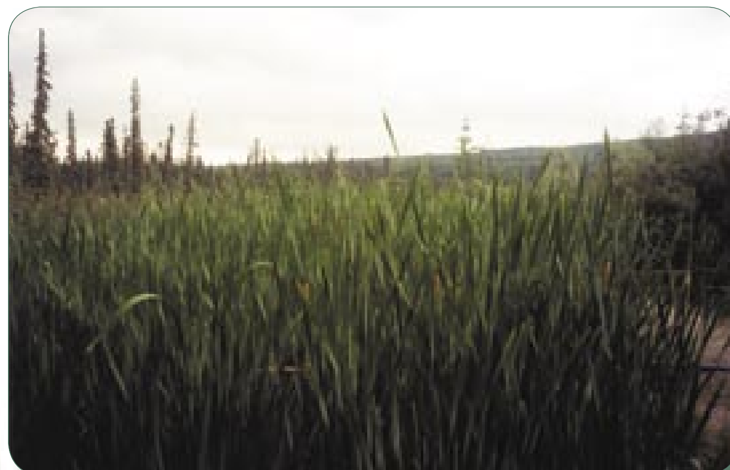
Left: Talkeetna constructed wetland: cell #1 with Typha latifolia *just planted prior to flooding of cell, mid-June 2003.*

Center oval: Cell #1 in the same system, showing the growth of Typha latifolia *midway through first treatment season, July 1, 2004. Note the fence: this is to prevent animals and people from wandering through the system. In particular, it helps keep moose from devouring the cattails, and prevents them from puncturing the liner with their hooves. The white PVC piping is the discharge header that distributes the effluent evenly from one side of the cell to the other. The gravel supports the discharge header, rather than soil which would turn muddy and unstable for support purposes when wet.*

—PHOTOS BY DAVE MADDUX

Above: Camp Li-Wa constructed wetland, showing cell #1 with Typha latifolia *just planted, prior to flooding of cell, July 8, 1999.*



Camp Li-Wa again: midway through the 2000 treatment season, showing one year's growth.

Below: same location: midway through the 2002 treatment season. Note the increased density of Typha.

—PHOTO BY DAVE MADDUX

Sandhill crane, Grus canadensis, *in the Yukon Delta National Wildlife Refuge. Marshes and other wetlands, artificial or natural, offer habitat to a wide variety of bird and animal life.*
— U.S. Fish and Wildlife Service

nurseries specializing in wetland flora, so Maddux relies on some local gathering from the wild and on providers from outside the state to supply him with enough for the initial plantings in his constructed wetlands. As the system becomes established, the plants reproduce and other plants seed themselves, creating a varied community suited to the characteristics of the site and the nutrients from the effluent flowing through the wetland.

Maddux uses a variety of native Alaska plants for his constructed wetlands: buckbean *(Menyanthes trifoliata)*, bulrush *(Scirpus validus)*, carex (a type of sedge, a grasslike plant), cattail *(Typha latifolia)*, and pendant grass *(Arctophila fulva)*. In his experiments, Maddux chose the local plants mainly because of their availability. Bulrushes, sedges, and cattails are used in constructed wetlands worldwide for a broad range of wastewater treatment applications, ranging from tannery to mining to petroleum to meat packing plant wastewater and runoff, so he naturally chose to include those. Maddux found no indication that buckbean or pendant grass had been used before, but decided to try them out since they were local. They worked well in a greenhouse experiment he conducted, where the controlled conditions allowed him to determine which pollutants were introduced and how much of each type the plants took in. Bulrush did well at heavy metals uptake, as did the cattails and buckbean; in fact, Maddux said, buckbean was surprisingly good at it. In a sewage treatment situation, the important measure for the user is how clean the resultant water is, not necessarily the exact means whereby the pollutants are removed. "You're trying to remove the target pollutant from the wastewater stream," he explained, so that is what is measured at the end of the process.

Microorganisms living on the tangle of underwater vegetation feed on the nutrients and pathogens in the wastewater, as in conventional activated sludge treatment systems. This "consortium of microbes," as Maddux puts it, is termed the periphyton. "The plants' main

waterways or allowed to percolate into the soil. The wetland has to be big enough to accommodate the winter's waste accumulation without being overwhelmed. Maddux found in his research that pollutant reduction appeared to be limited by the size of the wetland, and not by the extreme climatic conditions.

In the first stage, the effluent is directed into the constructed wetland. Because the water moves slowly, suspended solids settle out, creating sediment at the bottom of the constructed wetland, just as in a natural marsh. Many pollutants, such as phosphorus, attach to these suspended particles, and thus end up in the mud or substrate of the wetland. Microbes in the sediment help remove and transform nitrogen compounds to less harmful and more biologically available forms, breaking down ammonia and releasing nitrogen to the atmosphere. As the effluent moves past the stems and other parts of the plants, more minerals, nitrogen, and phosphorus are removed as they are absorbed by the plants.

In many areas of the United States and Canada, wetland plant nurseries cater to the needs of commercial landscapers, nonprofit and governmental agencies, or others requiring aquatic and emergent plants. In Alaska, however, there are as yet no commercial

Bulrushes in the Yukon Flats National Wildlife Refuge: emergent vegetation in a wetland.
—photo courtesy National Fish & Wildlife Service

purpose is to provide a substrate for the periphyton to attach to. They provide a carbon source, which is also important." When the plants die and decay in the fall, carbon, along with minerals or heavy metals, is released and made available to the microbial community in the wetland's sediment and water. The plants, he adds, are "only a storage place for the pollutants in the summertime." They remove about 7–10 percent of the pollutants; the rest is removed by microorganisms and natural chemical processes. For example, if the wetland bottom is oxygenated phosphorus will settle out and remain in the sediments.

In an anoxic environment, phosphorus will be released. This is why algae blooms in highly polluted lakes or streams can be so dangerous: they will use up oxygen, releasing more phosphorus and other nutrients, which in turn feed more oxygen-reducing biological cycles, which releases more phosphorus, and so on. It can take a long time for a polluted, anoxic wetland environment to return to a healthy, oxygenated one. A properly designed constructed wetland, with its controlled intake of organic matter and wastewater, and its maintainenance of an oxygenated environment, avoids this problem.

The water moving through the wetland can take anywhere from three days to three weeks to flow through the system. The longer the better, as the lower the pollutant load will be. Near Nulato, for example, there are 350 acres of natural wetland with no outlet that the village uses for wastewater and sewage treatment. Maddux helped the village create the system, the first in Alaska. Lagoons are used to store and settle the waste during the winter, and in spring and summer they empty into the wetlands. The village discharges about 72,000 gallons of waste per day into the wetland. After the water has passed through seven acres of the wetland, it can't be distinguished from the clean background water. The hydraulic retention time (hrt, or time required for water to move through the system) of most constructed wetlands is five to seven days. Nulato, with its huge acreage of wetland, has an hrt of 46 days or so, plenty of time for thorough reclamation.

In Talkeetna, where Maddux contracted with the town to create a constructed wetland for their water treatment, there is limited property available. The resulting wetland is only 3/4 acre, but processes 105,000 gallons per day. The hrt is only 3.2 days, yet the resulting water is cleaner than required by the Environmental Protection Agency, and is released into a nearby stream.

At Camp Li-Wa, a small, summer youth camp off Chena Hot Springs Road near Fairbanks, Maddux built a small wetland system designed to treat the 1100–1200 gallons of wastewater generated per day. The constructed wetland is small, only 35 by 45 feet, and takes seven days to produce treated water. Yet, this is not the smallest system Maddux has designed: home systems with primary treatment in septic tanks are quite feasible. For water usage of around 1000 gallons a month, the wetland need only be approximately 12 by 16 feet or so: a backyard marsh.

Side effects: mosquitoes and that swampy smell

Constructed wetlands don't generally produce unpleasant odors, although the primary stage lagoons may be a bit pungent during spring and fall effluent turnover. In conventional treatment the sewage is in an enclosed space, whereas wetlands and lagoons are in the open air, and this helps disperse odors. The aerobic environment and water movement of a healthy wetland is important for limiting odor. In anaerobic digestion of sewage, methane, which is very stinky indeed, can be a desired byproduct of conventional treatment, but constructed wetlands rely on aerobic processes and so there is none of this distinctive odor in a properly functioning wetland.

Mosquitoes, on the other hand, can be a significant problem in warmer areas or in places where previously there were no wetlands. The control over a constructed wetland's design, however, enables the builder to reduce its favorableness as mosquito habitat. Situating it in an open or windy area, away from the community, and the lack of stagnant water helps reduce mosquito populations. Stocking the wetland with native predators such as fish and frogs can also help. Subsurface-flow wetlands are much less suitable for mosquitoes, as there is no or little water surface available for them. Maddux wryly comments on his website, "In Alaska, where the mosquito is ubiquitous no matter where you go, the increase in the mosquito population is neglible."

The future of constructed wetlands in Alaska

The construction of wetlands for wastewater treatment, land reclamation, and creation of wildlife habitat has been growing in popularity, particularly in Australia, Europe, and the United States. By 1999, there were a thousand wetland treatment systems in operation in North America, but the technology was thought to be unfeasible in Alaska until the research conducted by Maddux and others, such as William Schnabel of the University of Alaska Anchorage, showed that the technology could be practical here. In the state's rural areas and most villages without sewage treatment facilities, disposal of sewage has been problematic. A few places, like Nulato, are near natural wetlands that might be adapted for sewage treatment. Elsewhere, when high water tables prevent the use of outhouses, sewage is dealt with using the "honey bucket method" by which domestic wastes are collected and hauled to a collection lagoon. This can result in spillage and the spread of disease. Snow melt and flooding in river plains can bring sewage-contaminated water into the community, also contributing to outbreaks of disease, such as hepatitis. Home septic systems are also common, but still result in wastes that must be removed periodically, and too many in an

Background image: Cattail, Typha latifolia *sp.*
— USDA-NRCS PLANTS Database / Britton, N.L., and A. Brown. 1913. *Illustrated flora of the northern states and Canada.* Vol. 1: 68.

Canada Geese in an Alaska wetland.
—PHOTO COURTESY ALASKA FISH & WILDLIFE SERVICE

area can contaminate the local water table. In areas of limited drainage or permafrost (much of Alaska, in other words), septic tanks may be unfeasible.

At present, very few treatment systems using constructed wetlands have been built in Alaska: there are less than ten in the state, according to Maddux. Only three of these are for secondary sewage treatment, all designed by Maddux; the rest are used for landfill drainage (Kodiak), roadway runoff (Soldotna), and stormwater runoff (Anchorage). Yet, their relative simplicity and low cost may answer a longstanding and urgent problem for rural Alaska.

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Web resources on constructed wetlands & alternative water treatment

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Ecological Engineering Group. A private firm specializing in water systems and landscaping, their website provides useful background on alternative water treatment and definitions of concepts at: http://www.ecological-engineering.com/defs.html.

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Wikipedia.org. This online cooperatively edited encyclopedia provides an ever-expanding and continuously (if idiosyncratically) updated overview of a broad range of subjects. Searches on sewage treatment, wetlands, and related topics will provide background information for interested readers.

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