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Establishment of an experimental wetland research complex

Background and goals

The environmental impact of agrichemical contamination of surface and ground water is a special concern in the Midwest. Better chemical management alone will not sufficiently reduce negative impacts on the environment. Another strategy—restoring wetlands in agricultural watersheds to serve as sinks for these chemicals—holds additional promise for reducing this contamination.

Although wetlands have been shown to act as sinks for a variety of compounds, including nitrate from cultivated fields, scientists need to understand the mechanisms responsible for transformation and loss of agrichemical contaminants before they can predict the long-term assimilative capacity of wetlands for these contaminants.

The investigators in this project recognized the need to conduct controlled and repeatable ecosystem-level experiments to develop a better understanding of the fate of agricultural chemicals in wetlands. Toward this end they have formed the Wetlands Research Group at ISU. This major new research initiative specifically addresses the water quality functions of wetlands in agricultural watersheds by using wetland "mesocosms."

Mesocosms are experimental systems large enough to approximate the structure and function of at least some of the critical processes and organisms in the wetland ecosystem. They offer several advantages for wetland research:

- Inputs of water and chemicals can be controlled.
- Mesocosms can be replicated in relatively large numbers and easily manipulated.
- Mesocosms can be dosed with both radioactive and staple isotope "tracer" substances to study the flow and fate of chemicals.
- Their destruction (to serve research goals) does not constitute a loss to existing U.S. wetlands.

Approach and methods

Construction of the mesocosm tanks: Investigators oversaw the construction of a complex of experimental wetland mesocosms at ISU's Hinds Irrigation Farm near Ames. The entire mesocosm complex measures 161.5 feet (ft) by 221.5 ft, or about 12,000 square yards. Forty-eight mesocosms were arranged north to south in eight rows of six tanks each. Each tank is 11 ft in diameter; the distance between them is 18.5 ft. Each tank is 3 ft deep; thus, each tank provides approximately 10.8 sqyards of wetland in each mesocosm (see Fig. 1).

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Budget
$37,300 for 18 months
(Leopold Center funding supported construction of 36 of 48 mesocosms.)

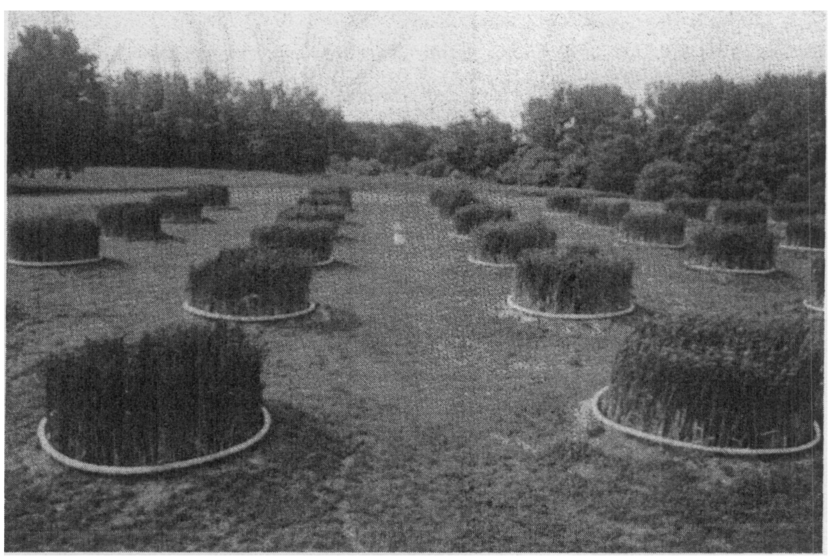

Fig. 1. Ground level view of experimental wetland complex.

Workers used ultraviolet-stabilized polyethylene tanks to construct the mesocosms, partially burying them to protect them from temperature fluctuations. A backhoe was used to dig circular holes, and workers placed the tanks into the holes by hand. The soil was graded to slope down from just below the top of the tanks. Each mesocosm was fitted with a polyvinyl chloride drainage system. Gravel three inches deep was placed over the drainage system in each mesocosm and leveled by hand. Woven drainage fabric placed over this gravel bed served as a base for wetland sediment that filled each tank about two-thirds full. (Before construction began on the mesocosms, approximately 300 cubic yards of wetland sediment had been excavated from a recently restored wetland marsh east of Ames. This material was used in all the mesocosms.) Like the gravel bed, the sediment was added with a front end loader and leveled by hand.

Irrigation system: A deep irrigation well supplies the mesocosms with water having concentrations of anions and cations. Such concentrations are similar to those found in Iowa's wetlands, but nitrogen and phosphorus concentrations are kept low enough to allow addition of these two elements for experiments. Fertilizer injectors allow controlled addition of chemicals directly into the irrigation water. Each mesocosm is individually valved; water is supplied through spray nozzles around the inside circumference. Adapters for surface drainage are located about two inches above the sediment level to prevent loss of all water in case of a leak. Variable-height drainage standpipes maintain water level. Each mesocosm is also fitted with a drainage system that can provide a subsurface inlet or outlet for water. The mesocosms can be operated as either static (at rest) or "flow-through" systems (see Fig. 2). Water does not move through static systems; flow-through systems more closely resemble natural wetlands. Both flow-through and static systems are necessary in order for experiments to approximate the structure and function of some typical wetland processes.

The intricate plumbing system for each mesocosm includes a mesh screen and a blowout valve (for draining plumbing during the winter). In addition, at the start of each line is a vacuum breaker (to prevent backflow), a ball valve to control flow, a spigot, a fertilizer injector, and a flow meter. The irrigation system is entirely buried except for the irrigation valve, screen filter, blowout valve, fertilizer injector, and 3/4-inch (in.) tubing that

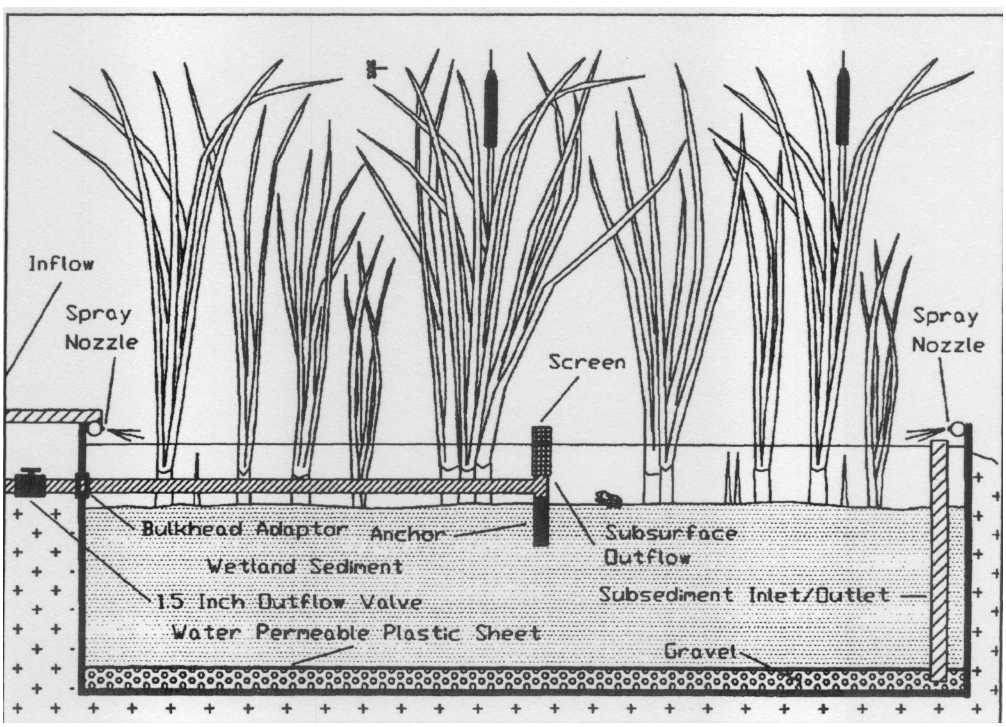

Fig. 2. Cross-sectional diagram of flow-through mesocosm.

extends from valves to tanks. Three valves at the base of the fertilizer injector allow it to operate independently of flow. When it is on line, 20 percent of the flow is drawn into the fertilizer injector through a suction tube. This water is then mixed with the one of five preset concentrations of solution mixture; the resulting dose then flows to the mesocosms' distribution system. Even more accurate dosings can be obtained by calculating the maximum flow rate, timing the injector's suction rate, and calculating the needed concentration mix.

Drainage system: Workers installed 1-in. polyethylene drains approximately 3 inches above the sediment in the center of half of the mesocosms. This allowed investigators to conduct the flow-through studies. In the other half, polyethylene standpipes drain water from the side of the tank to create static mesocosms. Water level in the latter can be adjusted by turning the standpipe on its side and allowing the water to drain to a new level.

Vegetation: In fall 1989, shortly after the construction phase, workers planted cattail rootstocks (2 plants per sq yard, or 15 shoots per tank) in 36 of the mesocosms and then flooded them. The following spring, they replaced any dead plants with live ones. Other wetland flora and fauna were allowed to develop on their own.

The establishment and growth of the cattails in the mesocosms was dramatic. By the end of the second growing season (fall 1991), the number of shoots in the mesocosms ranged from 62 to 92 shoots per sq yard. This compares to densities of 54 to 94 shoots per sq yard in a north-central Iowa marsh. Some of the mesocosms contained up to five other types of wetland vegetation; all of them contained abundant insects as well as toads and frogs.

Findings

In order to be useful in studies of agrichemical fate and effects, mesocosms must be large enough to approximate the structure and function of at least select critical processes and organisms occurring in wetlands. Yet the mesocosms must remain small enough for investigators to control the repeatability and other conditions necessary to allow measurement of ecosystem-level responses.

After only two years, the mesocosms had developed cattail densities characteristic of field populations in the area. On the basis of (1) macrophytes present (plants observable to the unaided eye), (2) litter decomposition, (3) aerobic metabolism by microorganisms at the mesocosms' bottom level, and (4) levels of denitrification (the reduction of nitrate to nitrite by anaerobic organisms), the mesocosms reasonably simulate prairie pothole wetlands. Moreover, the mesocosms have proven to be remarkably replicable in both flow-through and batch-dose, or static, modes of operation.

These mesocosms have already been used in studies of factors affecting the assimilative capacities of natural and restored wetlands for nitrate. These studies have confirmed the considerable capacity of freshwater wetlands to transform nitrate. Even under highly aerobic (oxygenated) conditions not generally considered conducive to denitrification, nitrate concentrations in overlying water declined rapidly in all mesocosm experiments. In mesocosm batch-dose studies, nitrate has been typically observed to decline rapidly; these results were confirmed by longer-term, flow-through studies (which evaluate how in-flow replaces what flows out, is unknown, or lost). Over approximately one week, for instance, mesocosms loaded with 3 to 15 mg/L of nitrate-nitrogen retained more than 80 percent of the nitrate.

Studies using isotopically labeled nitrogen as a tracer confirm that denitrification is the dominant loss process. Denitrification rates are controlled by the rate of nitrate flux to underlying anaerobic (oxygen-free) sediments. This finding is consistent with denitrification models developed for agricultural streams. These models suggest that in the presence of high nitrate loads, denitrification rates are controlled by the nitrate concentration in the overlying water and the length of the diffusion path between the overlying water and the primary denitrification site in underlying anaerobic sediments. However, contrary to these models, the data from this project suggest that nitrate concentrations in the overlying water also significantly affect the activities and/or population densities of denitrifying bacteria in the underlying wetland sediment.

Future research: The results to date have demonstrated the principal processes involved in nitrate loss in wetlands and identified the major factors affecting rates of loss. Additional research planned for the mesocosms should allow the investigators to estimate the assimilative capacity of wetlands draining agricultural watersheds and thus recommend site selection criteria for wetland restorations. The investigators are particularly interested in defining the effectiveness of wetlands as nitrate sinks with different size watersheds. Mesocosms will be configured as flow-through systems and loaded to simulate different watershed/wetland acreage ratios.

The fate of nitrate will be analyzed from a combination of mass balance studies and direct measurements of transformations. Mass balance budgets will be constructed on the basis of measured loading to, and export from, mesocosms. Flows are precisely controlled; thus, mass balance budgets can be calculated quite simply from flow rates and input and output concentrations of the compounds being studied. In addition, net storage and accumulation within the mesocosms will be estimated from measurements of pool sizes. Nitrogen and pesticide fate will also be measured using stable and radioisotope tracer techniques.

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Implications

A better understanding of the potential water quality functions of wetlands is critical. In 1986, U.S. waterfowl populations were at their lowest level in 30 years. A waterfowl management plan between the United States and Canada aimed at increasing populations 60 percent by the year 2000 calls for protection and restoration of 1.1 million acres of U.S. wetlands. Initiatives such as the farm bills of 1985 and 1990, which consisted (in part) of the Conservation Reserve Program and the Wetland Reserve Program, respectively, have assisted farmers in restoring and protecting wetlands across the Midwest.

Concern over waterfowl loss has motivated restoration efforts to date. But now, scientists realize that wetlands may also have great value in agricultural watersheds because of their water quality functions. In the prairie pothole region of Iowa and Minnesota in particular, sites for wetland restoration have not generally been selected on the basis of this important latter factor.

The mesocosms constructed in this project represent a significant and unique facility for studies of the fate of agrichemicals and their effects in freshwater wetlands. This project set the stage for significant additional, federally funded research—from the Iowa State Water Resources Research Institute for research on mesocosms; the Army Corps of Engineers; the U.S. Fish and Wildlife Service; and a four-year, multi-investigator, $830,000 project from the U. S. Environmental Protection Agency to study the fate and effects of agricultural chemicals in wetlands. This federal funding, when combined, exceeds $1 million. This research has already confirmed the considerable capacity of wetlands as nitrate sinks and demonstrated the dominant role microbes play in transforming chemicals that represent a threat to water quality.