

Complete Analysis

Benefits and Costs of a Subsurface Agricultural Drainage Water Management System



To Improve Water Quality and Increase Crop Production
In a
Public-Private Partnership

On Behalf of
Agricultural Drainage Management Coalition
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Complete Analysis

I. Introduction

Over the past decade, efforts to reduce agricultural nitrate pollution have focused on installing conservation practices, such as riparian buffers and filter strips, on or near cropland. Agricultural producers, as well as state and federal governments, however, have largely overlooked installing conservation practices to reduce pollutants from subsurface drainage water. Subsurface drainage water carries soil nutrients from the soil into streams, rivers, and lakes and some underground aquifers.

Over 50 million acres of highly productive agricultural cropland are artificially drained by underground pipes, tubes, and tile. Many of these, mostly clay tile, drainage systems have been in place for over one hundred years. Much of the Midwest gets its drinking water from rivers and streams fed by runoff and subsurface drainage from agricultural lands. Municipal and rural water systems increasingly have to use denitrification processes to lower nitrate levels to meet water quality standards. Nitrate-laden, surface waters have been identified as a major contributor to the formation of the hypoxia area in the northern part of the Gulf of Mexico.¹

In an effort to reduce nitrate runoff from agricultural lands, the agricultural community, as well as federal and state governments, have been promoting and installing a number of agricultural and environmental practices. Most are very expensive because they take valuable, productive land out of production (e.g., wetlands and buffer strips). Other plans reviewed by the President's Committee on Environment and Natural Resources (CENR) and its Hypoxia Work Group propose to limit nitrate use directly (or indirectly via taxation) with significant negative impacts on production and societal welfare. All of the strategies previously studied have significant net societal economic costs for both consumers and producers (Doering et al., 1999).

Managing agricultural drainage on 7.9 million acres can effectively reduce nitrate runoff by 128 million pounds (58 million metric tons) per year in the upper Midwest, overwhelming reductions proposed by other practices examined by the President's committee. Moreover, as this report explains, the benefits, public and private, of managed drainage far exceed the cost of installing the practice.

¹ Nitrate-nitrogen is a naturally occurring form of nitrogen and is an integral part of the nitrogen cycle in our environment. Nitrate forms from fertilizers, decaying plants, manure and other organic residues. Plants use nitrate and ammonia, but sometimes rain can move this nitrate into shallow groundwater or through subsurface drains to surface water bodies.

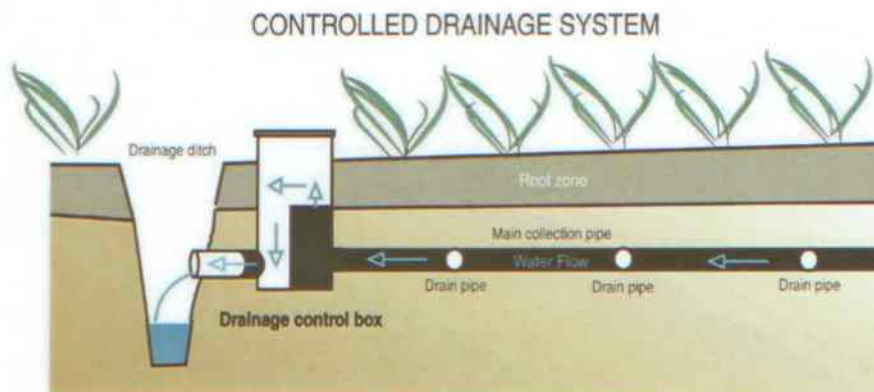
Drainage Water Management as a Management Practice

Drainage Water Management (NRCS Practice Standard 554) is a practice that can be cost-shared under the Environmental Quality Incentives Program (EQIP) and possibly other conservation practices administered by the U.S. Department of Agriculture. This technical practice 554 is designed to keep more nitrates and water in the soil, where they can be productively utilized by crops. Subsurface water can be retained in the soil profile of the crop fields by installing control devices that limit drainage discharge at various times of the year and to certain depths of the soil profile as needed to meet the operational needs of producers. The practice is most cost-effective on land that has very little slope (0 to 0.5 percent) because large areas can be managed by fewer control devices. Approximately 7.9 million acres in the Midwest would be classified as well-suited and cost-effective for this practice (Jaynes, 2003).

Managed drainage holds the nitrate-rich water table higher than free flowing, subsurface drain, creating a larger underground reservoir of soil water and nitrates for use by crops. This reservoir allows a greater percentage of the nitrate in the soil to be utilized productively, crops are less susceptible to short-term drought, and drainage is still managed to enable field operations and appropriate root conditions. This best management practice (BMP), as it may be defined, requires a substantial investment in new drainage control devices to retro-fit existing systems or, in most cases, installing new subsurface drainage mains and laterals. However, compared to alternative water quality practices which impair crop production by limiting nitrates, require producers to shift to lower return crops, or require producers to take valuable land out of production entirely, managed drainage is not only highly effective and cheaper, it has a high benefit-to-cost ratio.

As shown in diagram 1 below, the water table can be maintained at a programmed level above the bottom of the drain (as long as plant requirements do not exceed precipitation). Drainage pipes, tubes, or tile drains are dug deep into the soil profile in order to avoid being snagged by tillage equipment or crushed by heavy machinery. They are also laid deep in order to have some slope even in flat fields. With control devices, water level is retained until the water table rises above the "drop logs", but drains before the higher water table rises into the root zone and causes crop damage.

Diagram 1.



zone and harms crop development. An unmanaged water table drains down to the bottom of the subsurface drain even when precipitation is not recharging the root zone from above. By holding a higher water level, managed subsurface drainage reduces the total amount of subsurface drain water outflow by 40 to 50 percent. The reduced outflow, however, has no effect on the nitrate concentrations in the subsurface drain outflow water (Evans, 1996). Because the annual outflow is reduced by 40 to 50 percent, the annual nitrate load is also reduced by 40 to 50 percent.

The following analysis is a more detailed breakdown of the benefits and costs of an expanded program of agricultural subsurface drainage water management.

II. Benefits

Private and Public Benefit Cost Sharing

Agricultural producers, the general public, and the environment can benefit from drainage water management by receiving enhanced water quality, and sustained or increased crop production. Although some off-farm private and municipal entities may benefit directly from managed drainage, they generally do not share the costs of obtaining those benefits with individual producers. Therefore, for this analysis, public benefits include all off-farm benefits and assumes that the state and federal governments will pay a share of their costs. This report analyzes two scenarios to demonstrate the benefits and costs of agricultural drainage water management systems.

The first scenario assumes an existing drainage system which requires only a retrofitting of water level control devices where the lateral drains connect to the drainage main line. The second scenario assumes an entirely new installation of water level control devices, drainage main lines, and lateral drains. The benefits and costs vary with significantly more investment, but greater total benefit, involved in the latter.

Exhibit 1 displays a summary of the benefits involved with both scenarios. The first scenario analysis assumes a 100 percent public (federal and state) cost-share on retrofitting the water level control devices to an existing drainage main line. The second scenario analysis assumes an 80 percent cost-share on the control devices and drainage main lines for a new system (no cost-share on lateral drains).

The analysis starts with an assumed reduction in subsurface drain water outflow of four (4) inches of water per acre per year with a nitrate-nitrogen concentration of 18 ppm. This reduced subsurface drains outflow reduces the annual stream load by 16.272 pounds of nitrate per acre (Cooke, 2003).² This nitrate and water, instead of being flushed out of the soil, is stored in the soil profile, where it is assumed that half of it is available for crop use.³

² A reduction of four inches is a conservative estimate. Monitored fields in Illinois have reductions in excess of eight inches per acre.

³ Obviously, if only one-half of the nutrients are utilized, over a period of years on continuous practice, there would be a substantial buildup of nutrients. Some of the nutrients would breakdown in a process of denitrification, but one-half availability in the long-run is a conservative estimate.

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Exhibit 1. Estimated Annual Benefits of Managed Agricultural Drainage Practices, New and Retro-fit.

Types of Annual Benefits Per Managed Acre	Analysis Parameters	Managed Agricultural Drainage			
		Retro-fit Existing Systems		New Drainage System	
		Farm Benefits	Public Benefits	Farm Benefits	Public Benefits
		(\$/acre)	(\$/acre)	(\$/acre)	(\$/acre)
Reduce water flow of 4 acre-inches @ 18 ppm – Pounds of Nitrates NO ₃ -N (1)	16.272 lbs /ac/yr				
Reduced Nitrate-Nitrogen in Drinking Water					
– Fixed Costs of Denitrification (2)	\$ 3,700,000		\$ 85.53		\$ 85.53
– Operating Costs of Denitrification (3)	\$ 6.00 lbs		\$ 42.96		\$ 42.96
Subtotal			\$ 128.49		\$ 128.49
– Municipal Use Downstream (4)			\$ 12.85		\$ 12.85
Reduced Hypoxia in Gulf of Mexico (5)	Comparable		\$ 7.57		\$ 7.57
Increased Crop Prod. Due to Managed Drainage (6)	6.82 bu/ac	\$ 8.69	\$ 2.90	\$ 8.69	\$ 2.90
Increased Crop Prod. Due to Drainage only (7)	37.50 bu/ac			\$ 23.91	\$ 7.97
– Corn (bu.) (net transportation & harvesting) (8)	\$ 1.70 bu/ac				
– Marginal Tax Rate	25%				
Decreased Yield Variability (9)	Crop Ins.Premium				
– 10% reduction in federal crop insurance	\$ 7.50 /ac	\$ 0.75	\$ 1.08	\$ 0.75	\$ 1.08
Total Benefits by Benefactor		\$ 9.44	\$ 152.89	\$ 33.35	\$ 160.86
Total Benefits by System		\$ 162.33		\$ 194.21	

Footnotes:

- (1) 1 acre-in = 1/12*43560 ft² = 3630 ft³ = 102,802 liters = 226,635 lbs; 1 ppm of 226,635 is 0.226 lbs of NO₃-N. 18 ppm (18 * 0.226) = 4.068 lbs of nitrate-N per acre-inch.
- (2) Cost of building Des Moines Water Works Denitrification Plant (\$3.7 mil amortized (30 years @ 6% int.), operating 45 days @ 0.25 tons/day) 18 ppm reduced to 10 ppm (8/18 = .44); 16.272 lbs * 0.44 = amount of NO₃-N removed from source water.
- (3) Cost of Operating Des Moines Water Works Denitrification Plant (removing 500 lb. of NO₃-N per operating day at \$3,000 per day). Reducing the nitrate in the water approximately 5.88 ppm. (500 lb / 10 million gals of treated water @ 8.5 lbs/gal)
- (4) Combined Cost of owning and operating a second municipal water treatment plant downstream. (10% chance)
- (5) Benefit estimated at the net societal cost of installing wetlands to reduce nutrient loads. See Exhibit 2.
- (6) 22 inches of water is required to produce 150 bu. of corn. Two inches more available water equals 2*150/22=6.82 bu.
- (7) Poorly drained soils show a average crop yield improvement of 25%. Increased nutrient costs, etc. reduce the net added revenue to 12.5%. Public benefit equals 25% of the gross benefit.
- (8) The increase in yield (150*4/22 for management: 25% of 150 for drainage) is valued at market price less harvesting, drying, transportation, and taxes.
- (9) 10 percent reduction in farmer-paid premium. Public benefit equals reduction in premium subsidy plus A&O savings.

Benefit of Reduced Nitrates in Drinking Water

The nitrate-nitrogen to water use ratio for corn production infers a minimum of approximately 21.7 ppm or over twice the maximum containment limit (MCL) for drinking water (10 parts per million (ppm)) (USEPA, 1989).⁴ Plants absorb nitrogen passively via water transpiration. A relative rich mixture is necessary in soil water to transport the necessary amount of nitrogen (e.g. a net 0.72 lbs of N per bushel of corn) to the plant for grain production (Baker, 2004). Soil water nitrates in the root zone can measure at times 60 to 80 ppm. Subsurface drainage water quality, coming out of the soil well

⁴ A common rule of thumb is 22 acre-inches of water and 4.9 lbs of nitrate per 150 bushels of corn per acre.

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below the root zone, varies, but measures approximately 15 to 20 ppm of nitrate depending largely on the natural organic content of the soil (i.e., not fertilizer usage per se).

The Des Moines Water Works (DMWW, 2003) which draws water from the Des Moines and Raccoon Rivers has invested \$3.7 million in a denitrification plant (built 1990-91) that removes nitrate from the municipal water supply to maintain safe drinking water according to EPA quality standards. The plant is activated on an average of 45 days per year, varying from 0 to 106 days, depending upon the quality of the water at the plant intake, at an operating cost of a reported \$3,000 per day. The DMWW estimates the denitrification plant removes 500 pounds tons of nitrate-nitrogen from approximately 10 million gallons of water per day of operation.⁵ The denitrified water is mixed with untreated (high nitrate) water to meet EPA maximums. Since the nitrate limit is about one-half of the nitrates in subsurface drainage water, only slightly less than one-half of the total nitrate load (8 /18ths or 44 percent) is credited as an expense reduction.

As shown in Exhibit 1, amortizing the plant over a 30-year period and adding average operating costs, the peak benefits in reduced costs attributable to the DMWW are approximately \$128.49 dollars per acre. The DMWW currently flushes the removed nitrate back into the Des Moines River, raising the downstream nitrate level only slightly due to the large volume of water (and nitrate) in the river. Therefore, there is the chance (say, 10 percent) that the approximately 500 pounds of the nitrate-nitrogen, on the margin, could be processed at least once more as it flows downstream to the Gulf of Mexico, adding an additional \$12.85 (10 percent of the first denitrification) benefit due to a foregone second water treatment.⁶

Benefit of Reduced Nitrate Loads in the Mississippi Basin

At the mouth of the Mississippi River and extending at times over 7,000 square miles into the Gulf of Mexico and across to Texas is a fluctuating area of hypoxic (low oxygenated) water. It is strongly suggested that this hypoxia is due to nitrate rich water that promotes excessive algae bloom. The algae then dies, decomposes and uses up oxygen at lower depths. Stratification of the Gulf waters (due to variants in salinity and calm seas) prevents oxygenated surface water from mixing with the lower, oxygen-depleted layers. The oxygen-depleted water drives away mobile sea life, like fish and shrimp, and kills immobile bottom dwellers, like clams and shellfish.

In 1997, the President's Committee on Environment and Natural Resources (CENR), through its Hypoxia Work Group, began a scientific assessment of the causes and

⁵ DMWW uses a process called "ion exchange." A resin material, that has sodium and chloride ions on it, is in each of eight (8) Nitrate Removal Facility vessels. As the nitrate-laden water passes through the resin material, the nitrate ions are captured in the resin and a chloride ion is released into the water. The nitrate-reduced water is then blended with treated drinking water in a clear well to produce safe, clean drinking water with nitrate concentrations below the 10 mg/l MCL. This ion exchange process is similar to a home water softening device that removes calcium and magnesium ions from the water, exchanging them for sodium ions.

⁶ The flushing of the nitrate back into the river is permitted by special permit and adds only 0.007 percent to the existing nitrate concentration in the river flow. It is important to note that this valuation assumes that all subsurface drainage water retained and utilized by drainage management would have been otherwise been used for drinking water or at least subject to EPA MCL requirements (i.e., every additional pound of nitrate retained in the soil profile and utilized by crops or naturally decomposed is a pound of nitrate that does not need to be retrieved by a water denitrification plan.

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consequences of Gulf hypoxia and the economic costs and benefits of reducing nitrate loads to the Gulf (Doering, et al., 1999). A Council for Agricultural Science and Technology (CAST) study (1999) also concluded that a strong connection exists between river nitrates and hypoxia, with nitrate-nitrogen identified as the “most damaging” river-borne nitrate. These studies acknowledge that there is limited economic data with which to quantify the benefits of a reduced hypoxia zone to the Gulf shrimp and fishing industry. While it is logical to assume that a smaller dead zone would improve shrimp and other fisheries, the economic activity of the gulf fishing industry has not been directly related to the fluctuating size of the hypoxia zone. A “dual” approach is to look at costs of reducing nitrate loads and reducing the hypoxia region by other means. The Hypoxia Work Group (CENR) provided an economic assessment of alternative programs, as summarized in Exhibit 2.

The proposed programs analyzed by the CENR vary in the net costs per pound of removing nitrogen-nitrate from \$0.302 to \$11.765. Mandated nitrogen loss reduction, forced reductions in fertilizer use, and 500 percent taxes on fertilizer are very expensive due to the loss of production and higher commodity costs transferred to consumers. Wetlands reduce nitrogen loads by uptake and anaerobic denitrification. Buffer strips also increase uptake and reduce erosion. In contrast, the net cost of drainage water management is a negative \$10.615 (i.e., a profit) without considering the benefit of a

Exhibit 2. Summary of Economic Impacts of Alternative Programs to Reduce Nutrient Loads to the Gulf and Comparable Value of Drainage Management.

Implemented and Proposed Nutrient Reduction Programs	Net Social Cost \$ Millions	N-Loss Reduction 1000 Metric Tons	Net Unit Cost \$/MT	Net Unit Cost \$/lb.	Comparative Value of Drainage Mgmt. \$/acre
N-Loss Reduction 20%	753	941	\$ 800	\$ 0.363	\$ 5.91
Fertilizer Reduction 20%	335	503	\$ 666	\$ 0.302	\$ 4.91
Fertilizer Tax 500%	14,893	1,027	\$ 14,501	\$ 6.577	\$ 107.01
Wetland Acreage 5 mil acres	359	350	\$ 1,026	\$ 0.465	\$ 7.57
Buffer Strips	17,952	692	\$ 25,942	\$ 11.765	\$ 191.44
Drainage Water Mgmt. 16.272 lb/ac 7,887,106 acres	NA	58	\$ (24,576)	\$(11.145)	par

Source: Doering, Otto C. et al. (CENR) 1999. Table 6.1. p. 70. (except Drainage Water Mgmt.)
Drainage Water Management assumes 100% new systems.

reduced hypoxia zone (e.g., \$11.08 – \$0.465). For comparison purposes, the comparative value of drainage management to each of these alternative programs (i.e., their unit costs times the nitrate-nitrogen reduced per acre by drainage water

