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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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.

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[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

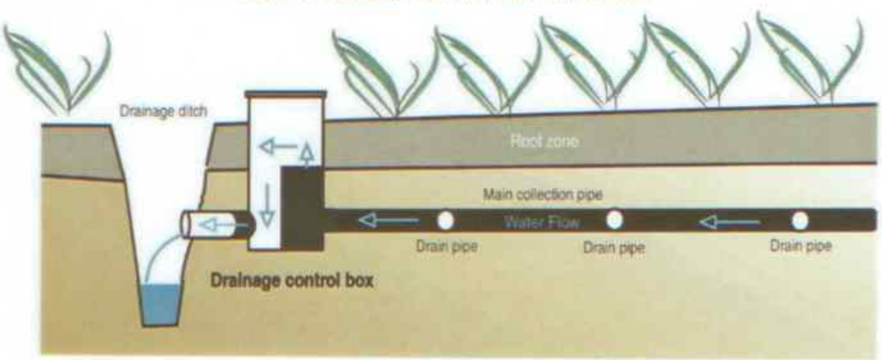
Drainage Water Management (NRCS Practice Standard 554) is a practice that can be cost-shared under the Environmental Quality Incentives Program (EQIP) and possibly other conservation practices administered by the U.S. Department of Agriculture. This technical practice 554 is designed to keep more nitrates 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.

CONTROLLED DRAINAGE SYSTEM



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 retro-fitting 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 retro-fitting 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.

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: Farm Benefits	Retro-fit Existing Systems: Public Benefits	New Drainage System: Farm Benefits	New Drainage System: Public Benefits
		($/acre)	($/acre)	($/acre)	($/acre)
Reduce water flow of 4 acre-inches @ 18 ppm					
-- Pounds of Nitrates NO3-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 ft^2 = 3630 ft^3 = 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.

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

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[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.

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.

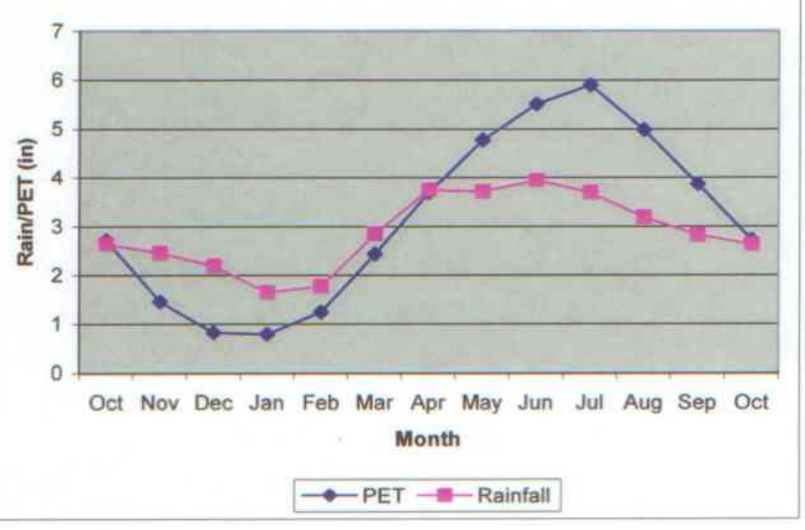
reduced hypoxia zone (e.g., $11.08 – $0.465). For comparison purposes, the comparative value of drainage management to each of these alternative programs (i.e., their unit costs times the nitrate-nitrogen reduced per acre by drainage water management) varies from $5.91 to $191.44 per acre. If the benefits of removing nitrate-nitrogen from the Gulf are close to these net economic costs, the contribution made by drainage water management is significant. Given that the buffer strip and wetlands programs are currently being funded and implemented, the lower value of $7.57 per acre is used as a conservative estimate of the benefits of a reduced hypoxia zone (i.e., a benefit-cost for hypoxia reduction of one (1.0)).

Benefit of Increased Production

Managed subsurface drainage maintains a higher water table in the soil profile than would be found with unmanaged subsurface drainage. While research is ongoing to calibrate hydrological and nitrate flow models, like DRAINMOD-N (Breve et al., 1999), to greater numbers of soil types, farming practices, and geographic locations (with varying weather patterns), on the average, approximately an extra four (4) inches of water can be retained during the growing season in Central Illinois (Cooke, 2003), two (2) inches being available for crop use. Of course this amount depends greatly on the recharge from rainfall that occurs after planting and fieldwork and during the growing system until crop maturity (Jaynes, 2003). A common rule of thumb is that it takes approximately 22 inches of water to produce 150 bushels of corn per acre. An extra two inches of water thus translates into an extra 6.82 bushels of corn (i.e., the nitrate-nitrogen in the extra water is not a limiting factor nor does the increased production require added nitrates to be surface applied due to the retention of the nitrate-nitrogen in the soil water).

During an average growing season, particularly in the central and western Corn Belt states, evapo-transpiration by the growing crop usually exceeds precipitation. In some (drought) years, the water deficit severely reduces yields. To satisfy its water needs, the crop draws on soil water in the soil profile. During most of the summer, agricultural crops would benefit from the higher water table and enhanced nitrate uptake. In Chart 1, showing average conditions for Springfield, Illinois, evapo-transpiration exceeds precipitation during the growing season (Cooke, 2003).

Chart 1. Rainfall/PET, Springfield, IL



Nearly all of the excess precipitation falling between October and April must be captured to sustain crop growth during the growing season. If this water is allowed to drain, during periods of drought stress the ultimate yield impact is likely be much greater than average, due to the law of diminishing returns working in reverse.

Benefit of Decreased Yield Variability

Managed subsurface drainage retains approximately four (4) inches overall, of which two (2) inches of water are available for plant use in the soil profile. This added water is of much greater benefit in the drier climate of the Central and Western Corn Belt than the generally wetter Eastern Corn Belt. However, the extra two inches can be easily converted into additional yield in most crop years, particularly during droughty periods within the growing season. The extra water not only increases average yields but it does so by significantly increasing yields during drought.

Managed subsurface drainage in Illinois research plots during drought stress years increased corn yields 7 percent and 45 percent (Fisher et al., 1999).[7] Thus, lower variability of yields due to a verifiable practice such as drainage management means federal insurance premiums can be reduced under Section 523(d) of the Federal Crop Insurance Act. Managed drainage could easily be identified as a risk-reducing practice, similar to irrigation practices in more arid regions.

The federal crop insurance program is currently heavily subsidized by the USDA with the producer only paying about one-third of the cost of the program. Thus, reduced yield variability translates into out-of-pocket savings for both the farmer and federal treasury. A reduction in drought losses (70 percent of all crop losses) could result in a 10 percent reduction in the cost of insurance. At a farmer paid premium cost of $ 7.50 per acre, a ten percent reduction in base premium saves the farmer $0.75 per acre and the federal government $1.08 per acre (50 percent of the 10 percent reduction, plus a small reduction in formula-based reimbursed administrative costs).

Benefit of Improved Efficiency and Effectiveness of Existing Programs

A number of agricultural and environmental practices, including filter strips, riparian buffers, and wetlands, have been aggressively promoted and implemented to filter sediment and suspended and soil absorbed nitrates in run-off from cropland. For the most part, filter strips and riparian buffers are a surface water treatment, and if installed adjacent to cropland that has subsurface drainage, much water and soluble nitrates, like nitrate-nitrogen, simply bypass the filters and buffers. In the case of constructed wetlands, subsurface drainage outlets may sometimes be rerouted to discharge to the wetland basin, or may also simply bypass the basin. By combining drainage water management with proper nitrate management strategies, producers are efficiently and effectively managing the significant pollution pathways. From a practical standpoint, drainage control devices can, in many cases, be located in filter strips, buffer strips and grass waterways, further protecting the strips and waterways from inadvertent damage or disruption and providing better access to the control devices for operation and management.

[7] Greater yields might be expected in the Western Corn Belt and lower yield improvements in the wetter Eastern Corn Belt.

Overall, drainage water management reduces nitrate-nitrogen loading to surface waters runoff by simply reducing the overall water flow from cropland. With less water throughput, the surface and subsurface biological processes work better, last longer and more efficiently to produce cleaner water.

III. Costs

Drainage in the upper Midwest is a very major economic issue. On average, yields improve by 25 percent if adequate drainage is used. The increasing use of harvesting monitors and yield maps by producers has revealed significant yield differences because of inadequate subsurface drainage (Pitts, et al.). As a result, many producers with inadequate subsurface drainage are considering making changes to their drainage systems to maximize productivity. In making their decisions, they will consider whether retro-fitting or replacing entire systems or partial systems makes economic and agronomic sense.

The cost of drainage management is highly dependent upon the local topography. The flatter the field (0 to 0.5% slope), the larger the area influenced by each water level control structure, and the lower the per acre investment cost. Retrofitting existing systems can be much more economical than installing new systems although knowing the location and layout of century-old drainage lines can be problematic.

When considering drainage water management for partially drained fields where potholes and isolated areas have been drained (random drainage), a totally new system may have to be designed and installed for the maximum nitrate-nitrogen reduction benefit. However, hydrological models, like DRAINMOD-N (Breve et al., 1997), can be calibrated to local soil, weather, topographic, and cropping practices to simulate crop and water management performance over time.

Installation and Investment

The greatest potential and lowest investment per acre costs are found in poorly drained soils with zero to 0.5 percent slope. It is estimated from STATSGO data for five Midwestern states that 7.9 million acres fall into this target category (Jaynes, 2003). Exhibit 3 displays the distribution of these acres in five major Corn Belt states.

Exhibit 3. Estimated Number of Acres with Greatest Managed Drainage Potential

Drainage Class in VP, P, VP-P, or P-VP and Hydrologic Unit A/D, B/D, or C/D
and Slope Class = 0-2%

	State Total Land (acres)	State Row Crops (acres)	Row Crop %	State Cropland 0-2% Slope	State Cropland 0-0.5% Slope	Row Crop %
OH	26,383,127	16,347,905	62.0%	2,207,777	551,944	3.4%
IN	23,159,849	18,206,691	78.6%	2,303,055	575,764	3.2%
IL	36,044,987	29,089,341	80.7%	5,149,577	1,287,394	4.4%
IA	35,997,224	32,279,356	89.7%	5,957,764	1,489,441	4.6%
MN	53,985,483	26,591,889	49.3%	15,930,253	3,982,563	15.0%
Total	175,570,670	122,515,181	69.8%	31,548,426	7,887,106	6.4%

Source: Jaynes (2003) July 24, 2003.

The geographic distribution of subsurface-drained agricultural land across the five major Corn Belt states is displayed in Diagram 2 based on STATSGO and soils data.

On relatively flat, undrained cropland, a typical installation in a square 40-acre field would consist of the following:

- Three (3) drainage control structures ($1,250 each, including anti-seep collars and couplers). The capital investment is $3,750 or $93.75 per acre.

- A main drain line ($3,125: 1250 ft of 8-inch pipe ($2.50 per ft.) including outlets and couplers). The capital investment is $3,120 or $78 per acre.

- A field of ten 4-inch lateral lines at 60-foot intervals and 2,400 feet in length (24,000 ft, including couplers, junctions, and end caps at $0.45 per foot). The capital investment is $10,800 or $270 per acre.

- The total investment cost of the project is $17,670 per 40 acres or $441.74 per acre.

The drainage control structures can be automated to ensure that subsurface drain flow is reduced or eliminated whenever possible to provide the greatest environmental benefit while still serving the operational needs of the producer.

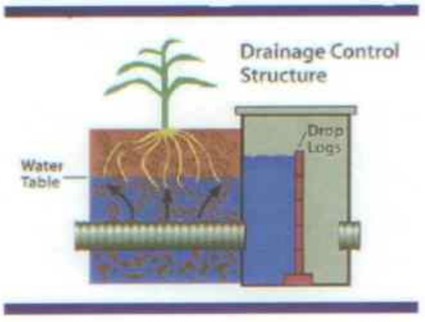
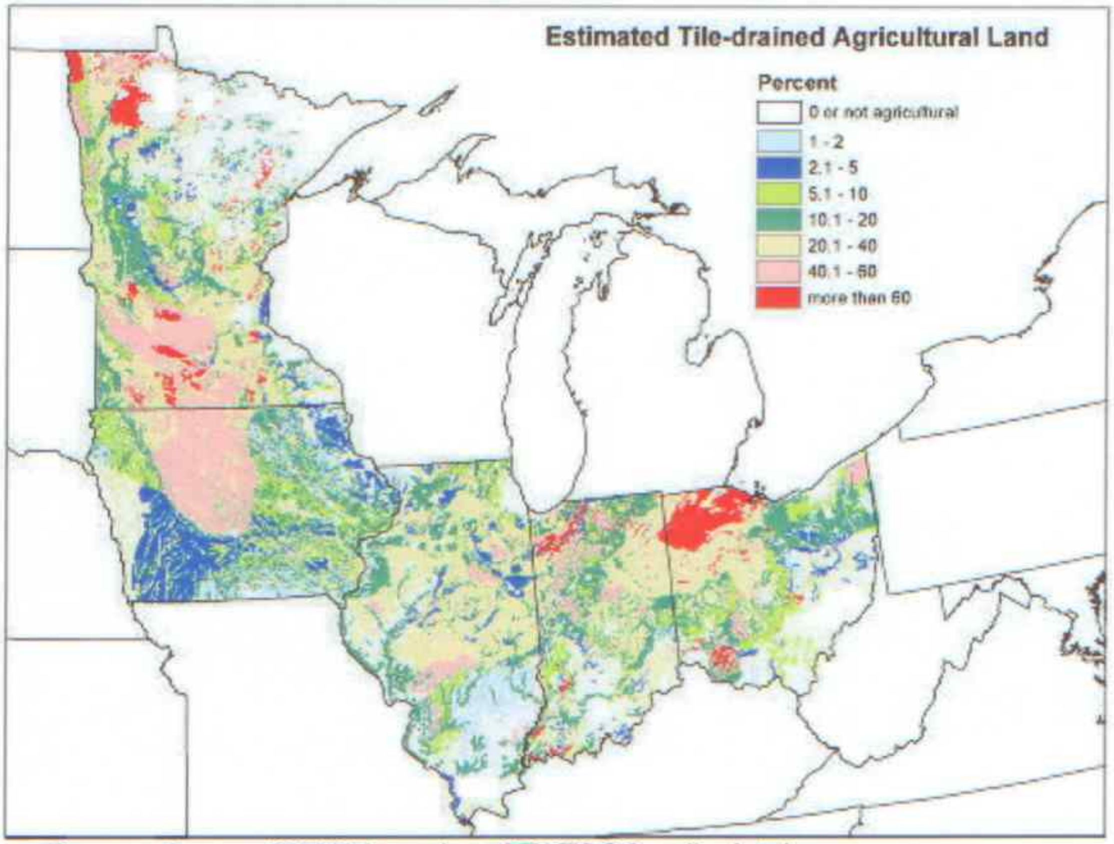


Diagram 2. Locations of Potential Subsurface-Drained Cropland in the Midwest.



Source: Jaynes (2003) based on STATSGO soils database.

The costs displayed in Exhibit 4 assume that the control devices and main line adjustments are cost-shared 100 percent by federal and state dollars on retro-fitted fields. For a new drainage system, an 80 percent cost-share by federal and state dollars is assumed. The investment costs are amortized over a 30-year time period (although the economic life is usually much longer).

Exhibit 4. Estimated Annual Costs of a Managed Agricultural Drainage Practice, New and Retro-fit.

	Installation Investment (per acre)	Managed Agricultural Drainage					
		Retro-fit Existing Systems			New Drainage System		
		Public Cost/ Share	Farm Costs ($/Acre)	Public Costs ($/Acre)	Public Cost/ Share	Farm Costs ($/Acre)	Public Costs ($/Acre)
Costs Per Subsurface Managed Acre							
Controlled Drainage Control System	40 ac.						
-- Drainage Water Management Structures (1)	$ 93.75	100%	$ -	$ 3.13	80%	$ 0.63	$ 2.50
-- Drainage Main Line (2)	$ 78.13		$ -		80%	$ 0.52	$ 2.08
-- Lateral Field Lines (no cost-share) (3)	$ 270.00		$ -			$ 9.00	$ (0.23)
-- System Maintenance			$ 1.00			$ 1.00	
Verification of Practice				$ 1.00			$ 1.00
Total Costs Per Managed Acre			$ 1.00	$ 4.13		$ 11.15	$ 5.36
Total Costs Per Managed Acre by System			$ 5.13			$ 16.50	

Footnotes:

(1) Installation cost of $3,750 (3 units @ $1,250 each) managing a 40 acre area. Cost is amortized over 30 years at zero percent interest.

(2) Installation cost of $3,125, managing a 40-acre area. Cost is amortized over 30 years at zero percent interest.

(3) Installation cost of $10,800, managing a 40-acre area. Cost is amortized over 30 years at zero percent interest.

Public costs include a net tax benefit based on 10% profit margin and 25% tax rate.

Maintenance and Verification

Some maintenance may be required on drainage systems to assure proper operation. Particular attention must be directed at the above ground structure to watch for damage inadvertently caused by field operations or other activity. A small annual maintenance payment, assumed here at $1 per acre, may be available to the producer on a per acre basis.

In additional to the private benefits, managed drainage practices can be verified by a third-party monitoring the control structures. Control structures can be programmed with timing devices that require little or no human intervention. Access to the timers can be made tamper resistant and, with additional instrumentation, local benefits, including drainage water quality, can be measured directly. An annual monitoring cost of $1 per acre is included to provide verification that the practice is being operated as recommended.

Private and Public Cost Sharing

Since the benefits of controlling drainage accrue both to the private operator and the public good, a cost sharing arrangement is economically most efficient. If private operators are required to bear all of the costs, operators will not invest or will under-invest, and both private and public benefits will be lessened. The most efficient allocation of resources is when investments are made up to when the total private and public marginal cost is equated with the total private and public marginal benefit. In order to encourage private action, the public can provide more than its equal share to prevent or avoid producers not installing these devices at all. Public cost sharing of 80 percent or more can produce favorable benefit-cost ratios, while encouraging private investment and action.

IV. Public and Private Benefit Cost Ratios

The private (producer) and public benefits and costs are summarized on a per-acre basis in Exhibit 5. The benefits to the farmer are largely improved productivity and reduction in yield variability. The public benefits are improved water quality in terms of the drainage water going into municipal water supplies and ultimately the Gulf of Mexico. Costs are largely the investments needed to install the practice and the sharing of those costs between public and private sources. As demonstrated, the benefit cost ratios are very favorable, even when the public bears a higher percentage of the cost.

In both scenarios, as shown in Exhibit 5, the benefit-cost ratios for the producer and the public are substantially greater than one. Benefit-cost ratios greater than one are generally acceptable. Public benefit-cost ratios in excess of 3 are fairly rare investments. A benefit-cost ratio exceeding three is a clear public opportunity. Measured as a rate of return on investment, both plans, privately are positive and commercially competitive. The public rate of return is almost unbelievable high.

Exhibit 5. Estimated Benefit Cost Ratios and Return on Investment

	Public & Private Investment (per acre)	Managed Agricultural Drainage			
		Retro-fit Existing Systems		New Drainage System	
		Farm Benefits ($/Acre)	Public Benefits ($/Acre)	Farm Benefits ($/Acre)	Public Benefits ($/Acre)
Total Annual Benefits		$ 9.44	$ 152.89	$ 33.35	$ 160.86
Total Annual Costs		$ 1.00	$ 4.13	$ 11.15	$ 5.36
Farm & Public Benefits to Cost Ratio		9.44	37.06	2.99	30.02
Total Benefits to Cost Ratio		31.67		11.77	
Rate of Return on Investment – Drainage Water Management Structures – Drainage Main Line – Lateral Field Lines (no cost-share)	 $ 93.75 /ac $ 78.13 /ac $ 270.00 /ac	No Investment	158.68%	7.29%	113.09%

Regional Differences and Accumulated Effects

As managed drainage practices accumulate to the watershed, some external effects may be felt. Higher water tables in fields may increase lateral movement of water into streams and percolate downward into shallow aquifers. These external effects have not been well studied but are not a great concern particularly in the region and on the soils targeted here (Jaynes, 2003).

Total Program Cost and Benefits

It is estimated from the STATSGO soils database that approximately 6.4% of cropland, approximately 7.9 million acres, in the five states of Iowa, Illinois, Indiana, Ohio, and Minnesota would be best-suited for a managed drainage practice (Exhibit 6). With an installation cost of $ 93.75 per managed acre for water control devices and $78.13 per acre for the drainage main line, a 100% installation on the most feasible acres would cost $739 million. The annual total amortized cost (private and public) of retro-fitting existing systems would approach $40.3 million ($7.8 million private plus $ 32.5 million public) and the annual total benefits are estimated at $1.28 billion ($74.5 million private plus $1.2 billion public). The public and private benefit ratio for retro-fitted systems is calculated as 31 to 1 primarily due to the high alternative cost of denitrifying municipal water supplies.. Farmers would have a 9 to 1 benefit cost ratio to retro-fit their drainage systems. The program would reduce nitrate in the water by *128 million pounds (58 thousand metric tons) per year*, even when targeting a small percentage of the total area of subsurface drained cropland.

For new drainage systems, an 80 percent public cost share would provide a benefit-cost ratios of 2.99 (private) and 30.02 (public). Rates of return on the private investment are competitive to commercial investments. These benefits do not include the multiplier effects of potentially $4.57 billion in public and private investment.

Exhibit 6. Estimated Maximum Annual Program Benefits and Costs

		Agricultural Water Drainage Management			
	Eligible Acres	Retro-fit Existing Systems		New Drainage System	
	7,887,106 ac.	Farm (000)	Public (000)	Farm (000)	Public (000)
Total New Investment in Drainage		$ Zero	$ 739,416	$ 3,485,115	$ 1,084,477
Total Annual Program Benefits		$ 74,479	$ 1,205,857	$ 263,031	$ 1,268,708
Total Annual Program Costs		$ 7,887	$ 32,534	$ 87,908	$ 42,262
Net Annual Program Benefits		$ 66,592	$ 1,173,323	$ 175,122	$ 1,226,446
	Nitrate Reduction	Total Net Benefits		Total Net Benefits	
Annual Totals	128,338,996 lb.	$ 1,239,915		$ 1,401,568	

Footnotes:

The two drainage systems are mutually exclusive, so the estimated farm and public benefits would be a weighted sum of the two systems.

Additional Research

While subsurface agricultural drainage management is a proven best management practice, additional research is underway (e.g., Jaynes, 2001). For example, the DRAINMOD-N model is being recalibrated for the Midwest, particularly the drier regions and soils of the Central and Western Corn belt. It has been successfully used in the Midwest to predict nitrogen losses (Northcott, et al., 2001). DRAINMOD (Breve et al,1997) was developed in North Carolina where drainage ditches run full and the model permits backward flow of ditch water as sub irrigation (an attribute that does not generally occur in the Midwest). Other aspects of the model such as transpiration and the impact of cultural practices, like minimum tillage and no-tillage soil parameters are being developed to accurately model specific farm sites across the Corn Belt (Jaynes, 2003). DRAINMOD-II is being developed with an enhanced nitrogen cycle that provides modeling for anhydrous ammonia, the effect of nitrification inhibitors, etc. While this research is likely to develop more accurately the benefits of drainage management, the overall conclusion that drainage management systems are effective and sound investments is not disputed.

The Agricultural Research Service (ARS) and the National Resources Conservation Service (NRCS) have created the Agricultural Drainage Management Systems (ADMS) Task Force to develop a national effort to market and transfer subsurface agricultural drainage management technology and practice to agricultural producers and landowners. As a first step, ARS and NRCS are in the process of recrafting its Drainage Water Management practice standard. Upon completion, producers can receive NRCS technical and financial assistance. While the ADMS wants EQIP to provide cost-share funding, the program is already oversubscribed. Drainage water management must at a minimum be given a higher priority ranking for funding purposes.

Energy Savings

As previously stated, an additional 16.3 pounds of nitrate might be retained in managed drainage systems and utilized by crops. This 16.3 pounds of nitrate that is usually lost but now utilized because of drainage management is nitrogen fertilizer that would not have to be produced, purchased, and applied.

The energy consumed to produce, transport, and apply nitrogen fertilizer is significant and varies by the type of nitrogen material. As shown in Exhibit 7, the amount of energy required to produce nitrogen varies from 6,527 kcal/lb for anhydrous ammonia to 9,154 kcal/lb for ammonium nitrate. The diesel fuel equivalent of this energy is 0.177 gallons per pound and 0.248 gallons per pound, respectively.

Exhibit 7. Energy Required in Producing and Transporting Nitrogen Fertilizer.*

Nitrogen material	Energy per unit mass of nitrogen	Diesel fuel equivalent**
	kcal/lb.	gal./lb.
Urea, solid	8625	0.233
Urea, solution	8603	0.233
28% liquid (1/2 urea, 1/2 NH4NO3)	8465	0.229
Ammonium nitrate, solid	9154	0.248
Ammonium nitrate, solution	8328	0.225
Anhydrous ammonia	6527	0.177

* Source Hoeft and Siemens (1975)
** Based on 36.958 kcal/gal of diesel fuel

The actual amount of nitrate equivalent that enters the soil varies with the nitrogen material and soil and weather conditions under which it is applied. For example anhydrous ammonia is a low cost nitrogen source (partially due to its low energy requirement to produce), but it must be carefully applied (and higher amounts are applied), under restrictive soil conditions, or much of the material can be lost to the atmosphere during the application process. Nitrogen recommendations commonly use ammonium nitrate as the standard nitrogen material. Thus, if we use the energy amount for ammonium nitrate as a basis for the nitrates saved in managed soil water, then the energy savings is 14,921 kcal or the equivalent of 4.04 gallons of diesel per acre of managed drainage. The energy savings quickly add up when these 4.04 gallons are multiplied times the 7.9 million acres of highly suitable drainage management cropland.

Conclusion

Federal and state agencies have invested heavily in reducing nonpoint source nitrate pollution from surface areas, such as cropland and intensive animal operations. Yet, these agencies have not made corresponding investments in dealing with nitrates, specifically nitrate-nitrogen, emanating from subsurface drainage. While managed drainage provides benefits to both producers and the environment over the long run, the initial out-of-pocket costs required to install or retro-fit drainage systems preclude producers' interest. Increasing producer interest in drainage, spurred by precision farming technology, does not necessarily include investments in managed drainage techniques and practices. Therefore, federal and state agencies should strongly consider drainage water management as a primary and complementary practice in cost-share assistance and incentive based programs to help producers shoulder these costs.

Managed drainage systems are a proven technical practice and, in many cases, a best management practice that can reduce nitrate discharge into streams and shallow aquifers by 30 to 50 percent, with a cumulative reduction of nitrate pollution of 128 million pounds per year. Managed drained fields can yield 5 to 10 percent more product per acre without additional inputs and fertilizers by keeping more nitrate and water in the soil profile. Yield variability can also be reduced by increasing soil moisture during dry periods within the growing season.

Total (private and public) net annual program benefits of the installation of managed drainage practices on 7.9 million acres could easily exceed $1.2 billion dollars and as much as $1.4 billion dollars in the Corn Belt region. Private benefit-cost ratios exceed 2.5 to 1. But without using some of the public benefits for cost-sharing, farmers may not invest or under-invest in this highly beneficial practice, particularly those operators short of capital. Public benefit-cost ratios exceed 25 to 1, not including economic stimulus of higher productivity and the multiplier effects of billions in new investment, but primarily due to the high cost of denitrifying municipal water supplies. The public can provide 100 percent cost-sharing on retro-fitted systems and 80 percent cost sharing on new systems and still maintain a benefit-cost ratio substantially greater than 2.5. Combining new drainage with subsurface water management has a competitive return for public long-term investment (greater than 15 percent).

Compared to the costs, the benefits to the public and private sector from investing in managed drainage are significant. Investing 100 million dollars per year over 10 years (1,000 million dollars) will yield 12 billion dollars in economic benefits over 30 years for the Midwest Region. Water bodies could receive 128 million pounds less nitrogen if 100 percent of the targeted acres use drainage management or 64 million pounds less if only 50 percent of the targeted lands use it. In any case, the nitrate loads are reduced.

As a program to enhance water quality, while improving productivity, subsurface agricultural drainage management systems are efficient, profitable, and verifiable. They do the job in a way that virtually no other farming/land practice can solidly demonstrate. Benefits and costs will vary across the Corn Belt, but continuing research shows that by implementing drainage water management today, we have a unique opportunity to elevate drainage to a new level of technical efficiency that simultaneously provides food and fiber for a hungry world at maximum efficiency while being environmental responsible for generations to come.

Drainage management not only reduces a water quality pollutant, but enables the utilization of that pollutant with energy savings of the potentially the equivalent of 30 million gallons of diesel on the most highly suitable acres alone.

Agricultural drainage water management should be given a higher priority for public funding purposes—it is a more cost effective practice, particularly when used in conjunction with surface practices.

For More Information:

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Note: Drafts of this analysis have been reviewed by the Agricultural Drainage Management Systems (ADMS) Task Force members and the author has incorporated and greatly appreciated their comments and suggestions. The final draft is however the responsibility of the authors and is not approved in whole or in part by the ADMS Task Force.

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