Hypoxic Zones in Northern Gulf of Mexico: Improper Subsurface Drainage of Nitrates in Farming

By Hetal Karani

The Mississippi River has an average freshwater discharge of 380 $km^3\ year^{-1}$ into the Northern Gulf of Mexico. Due to farming and agricultural activities, the Gulf of Mexico receives a substantial amount of nitrogen from Mississippi's agricultural watershed, causing eutrophication and eventually a hypoxic zone with oxygen levels as low as ≤2 mgl^{-1}. Low oxygen levels threaten aquatic ecosystems and habitats, while high nitrogen levels in coastal and river regions are a threat to human health. While we cannot put a stop to the use of nitrogen laced synthetic fertilizer as they largely boost plant growth, researchers emphasize the importance of establishing an efficient subsurface drainage system in agricultural farms for optimal use of nitrogen in the farming process, the control of flow of nitrogen into waterways and the cost benefits related to subsurface drainage.

"The Mississippi River Basin accounts for 90% of Gulf of Mexico's total freshwater inflow, with an estimated 1.6 million tons of nitrogen annually. Agriculture accounts for 65% of the nitrogen flux to the Gulf, a large amount of which is due to improper ground water discharge."[1] (Figure 1) The excessive inflow of nitrates essentially reaches the Gulf of Mexico, causing a phenomenon called eutrophication that promotes phytoplankton blooms, peaking during summer months due to ideal growth conditions; eventually depriving benthic plants of sunlight required for photosynthesis. Due to the lack of sunlight, plant life eventually dies out at the bottom of the ocean, lowering oxygen levels beneath. Bacteria require oxygen to feed on plant and fish waste and decomposed algal bodies, decreasing the oxygen levels further. These conditions further exacerbated by ocean stratification, affect benthic or bottom dwelling organisms, eventually resulting in their death if they are immobile (oysters), or simply not fast enough (shrimp and crabs). Fishes tend to migrate or die of suffocation.

While this change does not favor most aquatic species as it is below their oxygen level requirement, certain organisms such as jellyfish, in other words "dead end species", may thrive, as higher-level predators may not consume them. Resulting in a decreased efficiency in the food chain, and what we commonly refer as a "dead zone" as there is no economic or

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[1] Restoration of wetlands in the Mississippi–Ohio–Missouri (MOM) River Basin: Experience and needed research, William J. Mitsch, John W. Day Jr.,

ecological service provided to humans by these areas with a lack of aquatic organisms. (Figure 2)

To find a solution to the looming and growing hypoxia issue, we must return to the source. "Mississippi farmlands, alone, account for 90% of the production of corn and soybean"[2] . (Figure 3) Due to high demand, nitrogen is used to increase yields of crops. Approximately a fourth of all these croplands are drained using subsurface and surface drainage. "Subsurface drainage methods are commonly employed to increase productivity of agricultural fields that have seasonally perched water tables or shallow groundwater"[3] A large concentration of nitrates are found in subsurface tile water, based on the water flow, resulting in high loss of nutrients from the soil. In the past century, the amount of drained land in the basin has increased from 5 to 70 million acres. (Figure 4)

The pouring of nitrates into reservoirs and ultimately the Gulf has environmental, ecological, social and economical consequences. An implication of drainage into rivers and streams may be that high nitrogen levels may be found in our drinking water. Nitrogen, although an integral part of human life, is extremely harmful if consumed in large doses. "When children consume water that has nitrate levels exceeding 10 mg/L, it may lead to a condition known as 'Methemoglobinemia', more commonly known as blue-baby syndrome, which could possibly be fatal in certain cases."[4] Nutrient overloading is particularly destructive for ecosystems as hypoxia results in extensive fish kills, hence waning fish stocks. This phenomenon could singlehandedly collapse local fisheries and reserves, especially in the Gulf of Mexico, where valuable fishery resources generate approximately $2.8 billion annually[5]. As the coasts have a rich variety of natural resources, livestock, agriculture, tourism and industrial activities; acid rain is particularly harmful to humans and ecosystems, as it may result in respiratory diseases such as bronchitis, pneumonia and asthma. "Studies of atmospheric deposition show that the pH levels found in rainwater in the Gulf of Mexico range from 3.8 to 5.6, which is significantly acidic"[6]. Excessive nitrates may be a significant contributing factor to the acidic levels. Furthermore, the contamination of downstream public reservoirs results in the inability of the public and tourists to use the space for recreational activities, as it is dangerous, causing social impact. The economical loss is tremendous on farmers as significant levels of nitrates are lost through uncontrolled drainage systems.

Why is subsurface drainage so significant in the boosting of yield? It accelerates the removal of excess surface and subsurface water from fields that make roots well aerated whilst optimizing plant nutrient intake. Tile drainage comprises of a series of clay, concrete or perforated plastic pipes that are buried some feet below the surface. Tile drainage, if optimized and designed efficiently, can reduce loss of nitrates into waterways significantly. As transportation of nitrates primarily occurs at the subsurface level, it may hasten its

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[2] Corn. Rooted in Human History, 2012 World of Corn, NCGA

[3] Missing the Boat, Midwest Farm Drainage and Gulf of Mexico Hypoxia, Daniel R Petrolia

[4] Nitrogen Farming: Harvesting a Different Crop, Donald L. Hey, Ph.D

[5] Nitrates in Drinking Water, J.R. Self and R.M. Waskom

[6] Wet deposition in the Coast of the Gulf of Mexico, Rodolpho Sosa E.

transport to waterways. "During a 3 year study period it was found that subsurface tile drainage accounted for 99.1% of all nitrate losses, the remainder being due to run off."[7] Although subsurface is a major nitrogen contributor, it can conversely act as a major source of nitrogen abatement.

The primary amount of nitrogen content in subsurface drainage systems are characterized through two means; uncontrollable and controllable factors. Uncontrollable factors would include 'precipitation', and 'soil organic matter mineralization', which can be manipulated to a certain extent through tillage. Controllable factors may include cropping system used, rate of N applied and time of N application, placement method, use of nitrification inhibitors, tillage system and drain tile spacing. Precipitation may influence the annual nitrate levels losses are entirely dependent on climate based in the farmland area. A study done by researcher (Randall Et Al, 1997) shows the influence of growing season precipitation on the volume of drained nitrate losses. 3-month periods of April, May and June accounted for 71% of annual drainage volume, along with 73% of nitrate loss. (Figure 5). Another contributing factor, although partially controllable, is soil mineralization. Soil Mineralization can contribute to a significant loss in nitrates through leaching. Tile drainage from corn plots received only 20kg N/ha/year in Minnesota in the years 1973-1975. Drainage was extremely low in 1976 as it was a very dry year (Gast et al., 1978).

A study based on the Highwater Creek-Dutch Charlie Creek (HDCC) and Sleepy Eye Creek (SEC), minor watersheds based in Southwestern Minnesota drain themselves of 133,560 and 175,445 acres of nitrates respectively; analyzed the total cost, cost per acre and cost per pound of abated nitrogen level in tiled and non tiled land. The Agricultural Drainage and Pesticide Transport (ADAPT) model was used to simulate field-scale nitrogen loads for each THRU under each abatement policy. ADAPT (Chung, Ward, and Shalk, 1992) is a daily time step field-scale water table management simulation model, developed by integrating GLEAMS (Leonard, Knisel, and Still, 1987), a root zone water quality model, with subsurface drainage algorithms from DRAINMOD (Skaggs, 1978), a subsurface drainage model. It has been calibrated and validated at the field scale for a variety of Midwestern condition[8]. The watershed was modeled under the pretense that the impacts of drain plugging on one unit of land did not affect an adjacent unit. Thus in the case of plugged drains, the majority of excess water does not make its way into adjoining fields. Results show that a minimization policy using tiled drainage resulted in 10% reduction in nitrogen losses. Whilst the latter did not implement any drain plugging policy, showing declining nitrogen abatement rates.

The role of tile drainage and its implementation in terms of cost can also be analyzed through the study (Figure 6 & 7). Figure 6 plots the total cost data for each policy found in table 1 (solid curves) along with the corresponding portion of total cost attributable to tile-drained land only, at each abatement level. "The difference in total cost between the two policies is represented by the vertical distance between the two solid curves, and the difference in cost attributable to tile-drained land between the two policies is represented

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[8] Missing the Boat, Midwest Farm Drainage and Gulf of Mexico Hypoxia, Daniel R Petrolia

by the vertical distance between the two dashed curves."[9] Furthermore Figure 8 further summarizes the percentage change in net returns and N load from base when all cropland and only tile-drained cropland, respectively, come under nutrient management. Referring to figure 6, the results clearly show the large difference in abatement capability and cost between non-drained and drained croplands. "Tile Drainage acreage accounted for almost all initial nitrogen abatement, and accounted for more than half of abatement at subsequent levels. Thus, tile drained land accounted for a major amount of abatement in the study of watersheds even though it comprised of no more than 21% of all land in these water sheds"[10].

Results regarding subsurface drainage systems lead us to one conclusion, if the implementation and design is effective and wide spread; we could abate nitrate levels to waterways by a significant amount. We can either reduce the concentration of nitrates in drainage or irrigation, wholly controlling the amount that is absorbed and removed through subsurface drainage. Furthermore, in terms of technology, an automated gate structure can be placed inside the subsurface drain to control the amount of nitrates allowed into a waterway at a certain time (Figure 9). We could also control of depth of the soil column to the water table which may also be potentially useful in decreasing nitrogen loss by managing spacing and depth requirements to optimize crop yields and decrease nitrate loss. "In Indiana, nitrate losses from a field in continuous corn production through a subsurface drainage system with a spacing of 20m were 27% lower than losses through systems with a spacing of 10m and 46% lower than losses through a spacing of 5m (Kladivko et al 1991). Studies with sub irrigation in Michigan (Fausey et al. 1995) reported reductions in nitrate losses of 58-64%, compared with conventional drainage systems. [11]. Nitrate losses from tile-drained fields can particularly be reduced at the edge of the field using several methods. These may include, passing drainage pipes through wetlands to allow for the denitrification of nitrogen. Another method may be using forest or grass buffer strips to lower nitrate levels. "Grass buffer strips 4-18m long have been shown to reduce nitrate levels by 54-80%"[12](Dillaha et al. 1989, Srivastava et al 1996). In terms of scale, the practicality and feasibility regarding removal of current drainage system and implementation of the efficient subsurface drainage would prove to be considerably expensive, especially because drainage pipes need regular maintenance and in some cases replacement, which is an additional expense along with labor. However regarding the long term effects the flowing nitrates have on ecosystem services being affected in the area, it truly is a domino effect and must be prevented directly from the source, as hypoxia is a continuously growing problem. Certain political reforms by the government would be addressed, perhaps giving farmers incentive to acknowledge the importance of drainage systems and implement such systems to create a more sustainable dynamic for farming.

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[9] An Analysis of the Role of Tile-Drained Farmland Under Alternative Nitrogen Abatement Policies, Daniel R Petrolia and Prasanna H. Gowda, 2006

[10] Missing the Boat, Midwest Farm Drainage and Gulf of Mexico Hypoxia, Daniel R Petrolia and Prasanna Gowda

[11] Hypoxia in the Northern Gulf of Mexico, EPA Advisory Board, 2007

[12] Report for the Integrated Assessment on Hypoxia in the Gulf of Mexico, Robert J. Diaz and Andrew Solow

Appendix

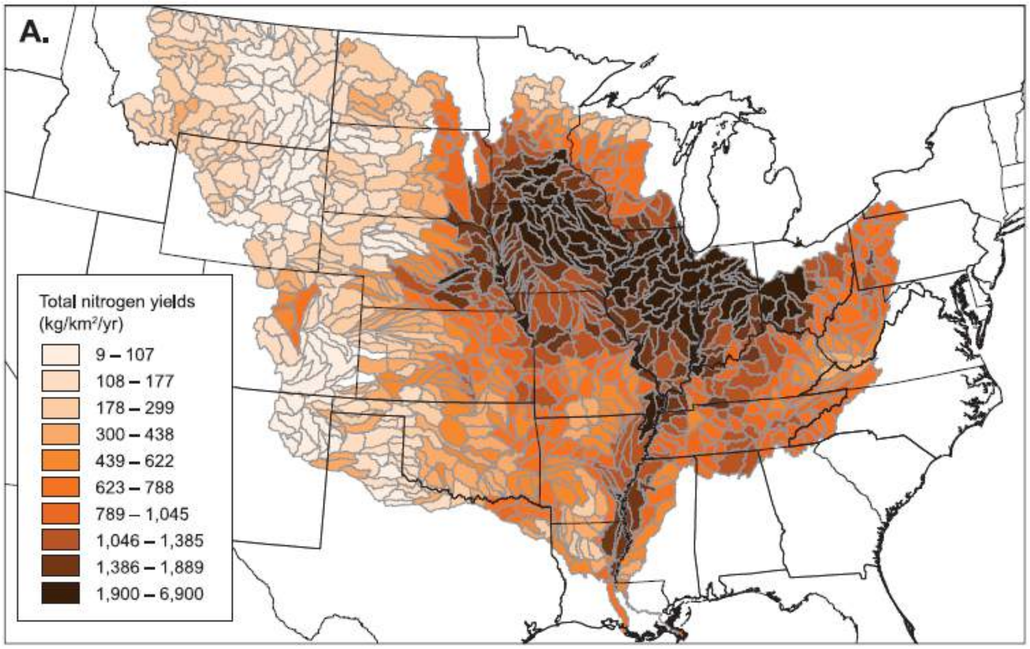


Figure 1: Total Nitrogen Yields in Mississippi in (kg/km^3/yr)

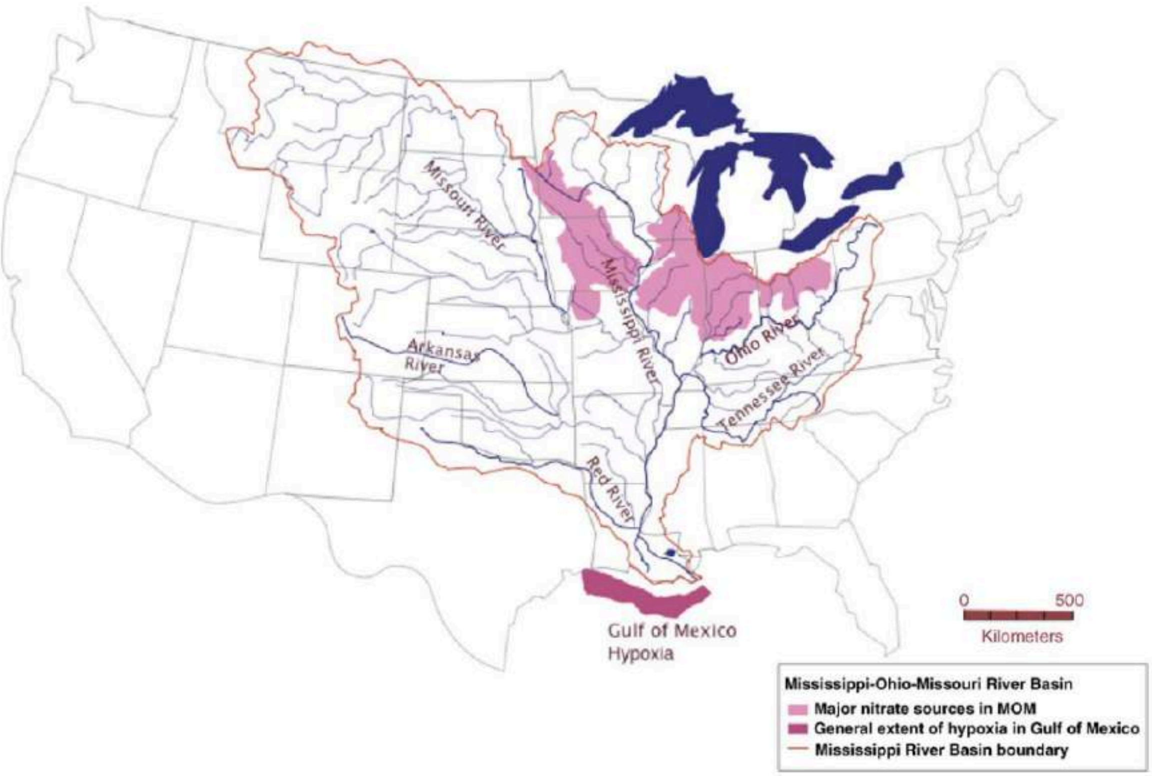


Figure 2: Hypoxia extent shown in MOM boundary

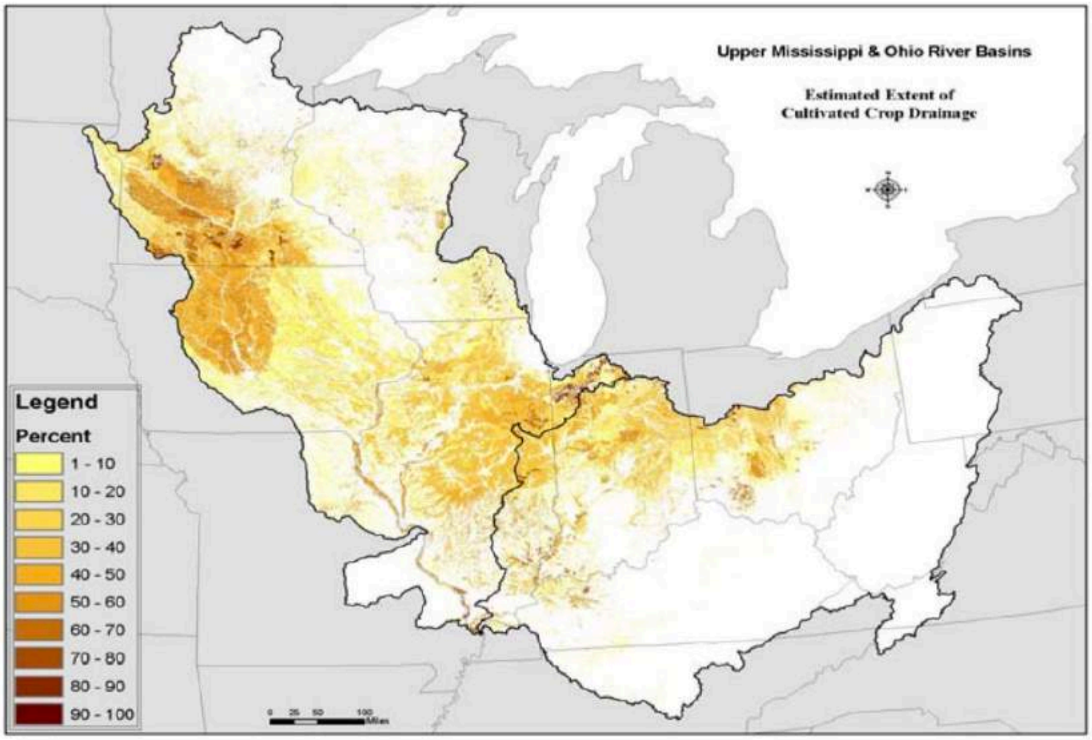


Figure 3: Estimated extent of agricultural drainage based on the distribution of row crops, largely corn and soybean, and poorly drained soils

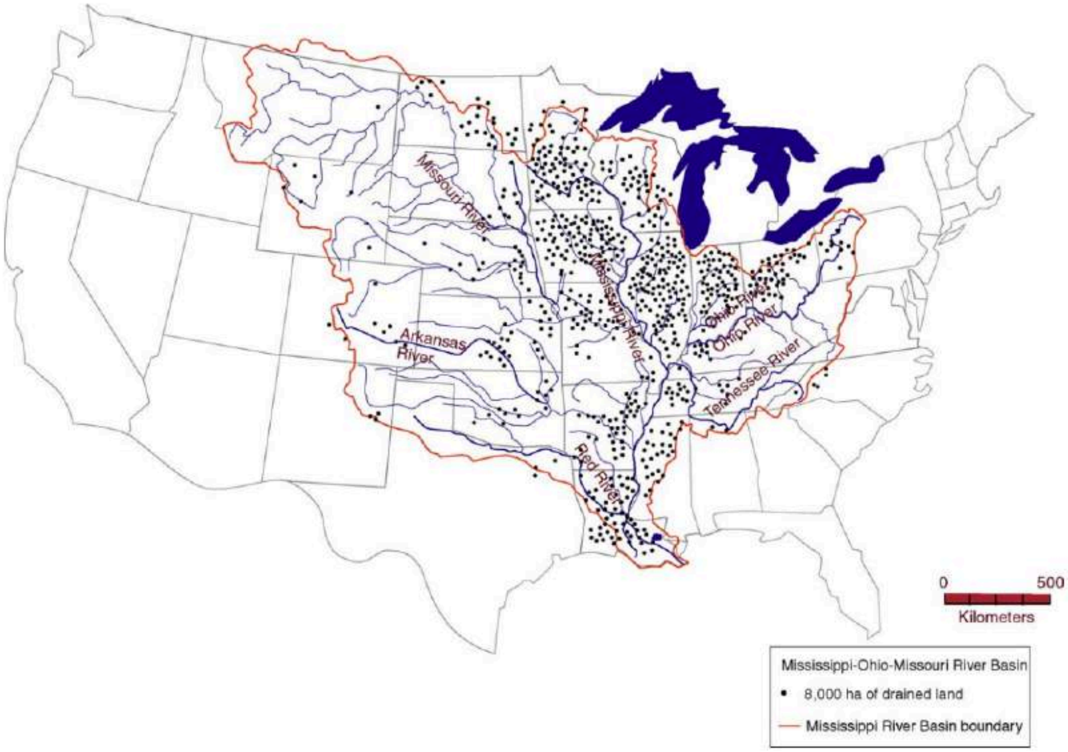


Figure 4: MOM River Basin Drained Land in HA.

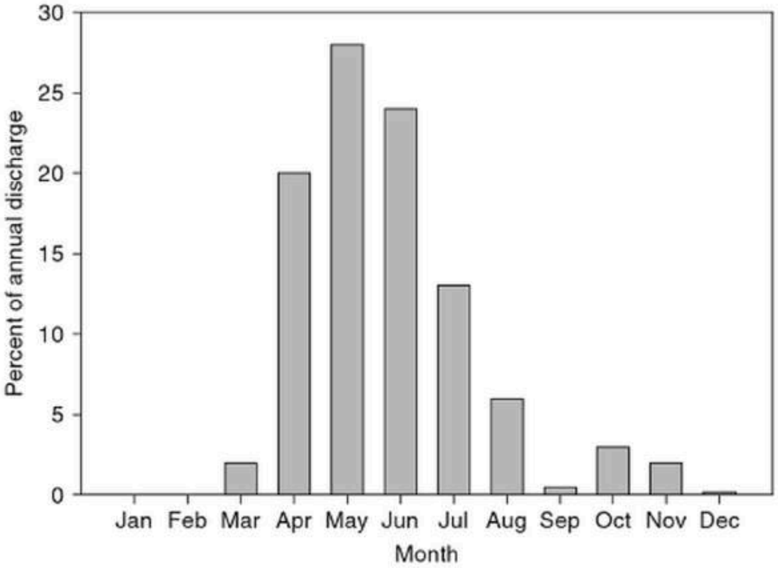


Figure 5: Monthly distribution of subsurface tile drain discharge averaged across a 15 year (1987-2001) period for a corn-soybean rotation

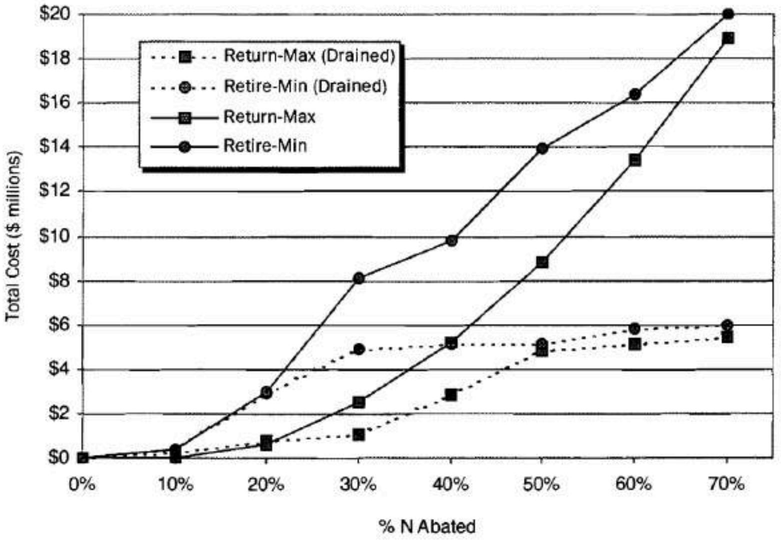


Figure 2. Total cost of abatement for all acres and for drained acres only, under each policy for each abatement level

Figure 6: Total cost of abatement for all acres and for drained acres only, under each policy for each abatement level

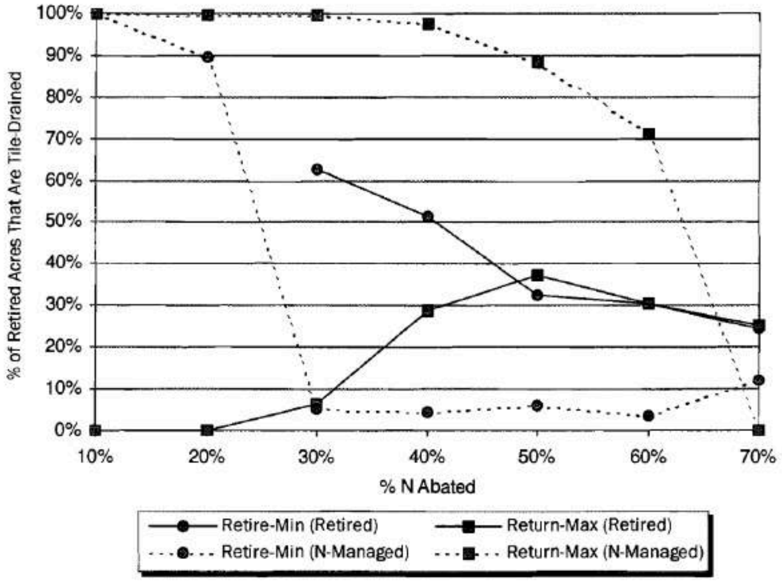
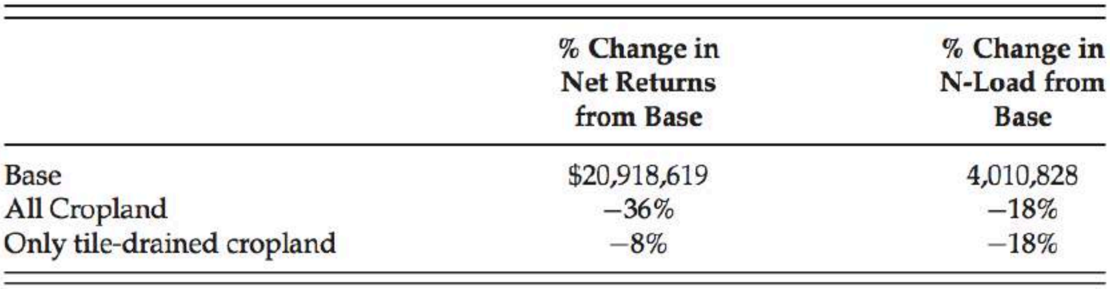


Figure 3. Percentage of retired and N-managed acres that are tile-drained acres, under each policy for each abatement level

Figure 7: Percentage of retired and N-managed acres that are tile-drained acres, under each policy for each abatement level



	% Change in Net Returns from Base	% Change in N-Load from Base
Base	$20,918,619	4,010,828
All Cropland	−36%	−18%
Only tile-drained cropland	−8%	−18%

Figure 8: Percentage change in net returns and N load from base when all cropland and only tile-drained cropland

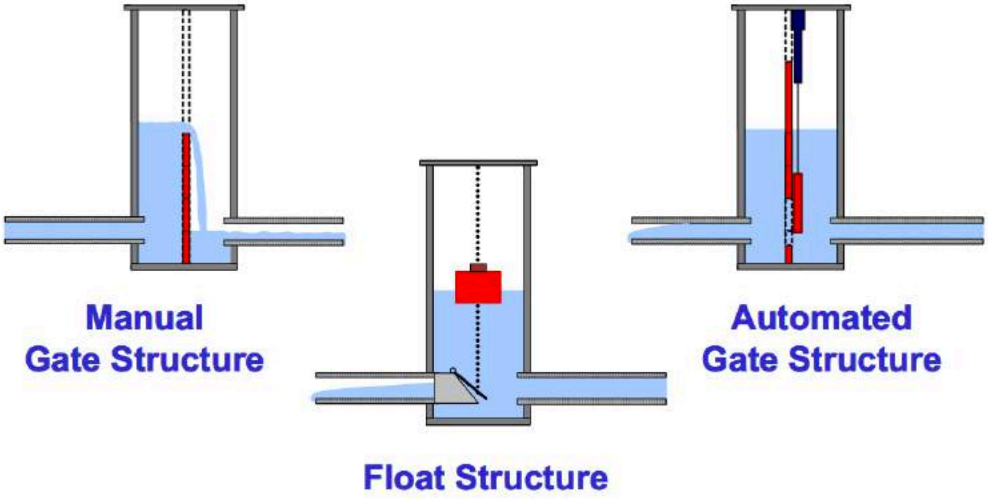


Figure 2. Types of water table control structures

Figure 9: Drainage Technology Structure

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Figure 2: W.J. Mitsch, J.W. Day Jr/ Ecological Engineering 26 (2006) 55-69

Figure 3: (per D. Jaynes, National Soil Tilth Lab, Ames, IA).

Figure 4: W.J. Mitsch, J.W. Day Jr/ Ecological Engineering 26 (2006) 55-69

Figure 5: Nitrogen in the Environment
edited by J.L. Hatfield, R.F. Follett

Figure 6,7,8: An Analysis of the Role of Tile-Drained Farmland Under Alternative Nitrogen Abatement Policies, Daniel R. Petrolia and Prasanna H. Gowda
http://ageconsearch.umn.edu/bitstream/8621/1/31030580.pdf

Figure 9: DRAINAGE WATER MANAGEMENT: A PRACTICE FOR REDUCING NITRATE LOADS FROM SUBSURFACE DRAINAGE SYSTEMS

http://water.epa.gov/type/watersheds/named/msbasin/upload/2006_8_24_msbasin_symposia_ia_session2.pdf