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Agricultural Drainage, Water Pollution, and Biotic Health in the USA Cornbelt

Joe Magner*

Department of Bioproducts and Biosystems Engineering, University of Minnesota, St. Paul, MN, USA

Abstract

A stable landscape balances geologic fragility, climate change and land use. In the USA Cornbelt, land improvement contractors have moved earth to fill wetlands, build ditches and plow in varying diameters of subsurface pipe to alter the hydrology and natural watershed plumbing. Non-point source (NPS) pollution from rural sediment and nutrients remains the most difficult challenge to meeting water quality standards in the USA. Cornbelt states have invested in nutrient management plans to reduce the nitrogen and phosphorus loads to the Gulf of Mexico, and most local levels of government are engaged in water quality planning to reduce sediment, bacteria, and nutrient impacts on local lakes and streams. Rural drainage systems constructed decades ago need upgrading because of changes in cropping technology and climate. However, drainage engineers/contractors need 21st century technology to upgrade water management. Downstream flooding, infrastructure damage and loss of aquatic habitat have been observed systemically in the Midwestern USA. States have set goals to reduce NPS pollution, yet a proposed drainage improvement could degrade ecosystem services. The drainage authority/engineer needs a protocol/model to better assess water management by examining the fluvial processes within, at and below the outlet of a proposed drainage project.

Keywords: Water quality, Drainage, Cornbelt, Nutrients, Fluvial, Channel

Introduction

A stable landscape balances geologic fragility, climate change and land use. In the Cornbelt, land improvement contractors have moved earth to fill wetlands, build ditches and plowed in varying diameters of subsurface pipe to alter the hydrology and natural watershed plumbing. This is a major land use change that has adversely impacted water quality. Superimposed upon the Cornbelt is a changing climate. In particular, higher magnitude, higher intensity storm events that exceed historically developed intrinsic water storage. Climate change can be problematic for agricultural drainage. To understand why - we need to begin with how the landscape was formed.

Landscape formation was glacially driven by ice advances over 12,000 years ago.[1] Ice advanced and retreated and left behind a relatively *young* landscape compared to landscapes eroded by water and wind over millennia. The young landscapes can be identified by the colored areas in Figure 1 which show portions of the Midwestern USA that were under ice and where glacial till and other glacially derived soil was left behind. Because the landscape is relatively young, many wetlands and lakes were created as glaciers retreated leaving behind ice blocks which may have been covered or partially impacted with sediment by subsequent ice advances. Eventually, the ice blocks melted leaving a depression on the landscape. Large ice blocks left behind lakes that today offer recreation to many Midwestern states, particularly Minnesota, Wisconsin, and Michigan. However, many more small ice blocks created small ponds and wetlands scattered from North Dakota to Ohio Figure 1.[1] The small wetlands were often hydrologically isolated and only overflowed into a large contributing drainage area under extreme precipitation.[2,3] Today, Midwestern USA has some of the most altered hydrology found anywhere in the world, with deepen natural channels, machine dug ditches and billions of linear meters of pipe buried typically 1 to 2-m below ground. Some of the pipe is over a century old constructed of clay tile, but most of the pipe is a black flexible, corrugated, perforated plastic tube with a sediment sock to filter excess silt from entering the buried drainage system.

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***Corresponding author:** Joe Magner, Department of Bioproducts and Biosystems Engineering, University of Minnesota, St. Paul, MN, USA

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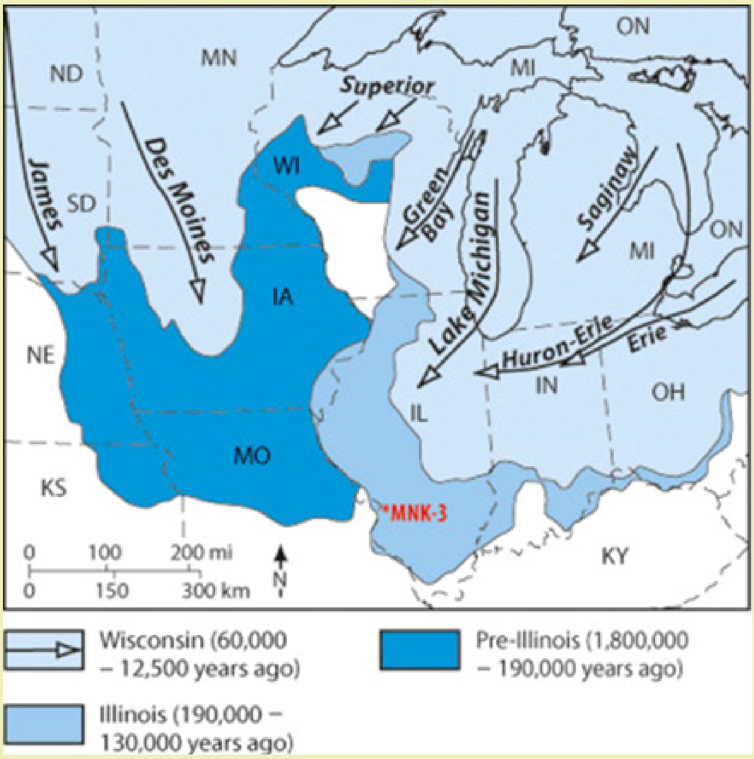

Figure 1: Glacial advances over time and the extent of glacial advances throughout the upper Midwest.[1]

Agricultural Engineering and Water Quality

Midwestern Cornbelt states have invested in nutrient management plans to reduce the nitrogen and phosphorus load to the Gulf of Mexico.[4] Farm field soil erosion loss has been a national concern for decades; however, we now understand that reducing upland erosion and the associated total suspended sediment (TSS) is not enough to meet water quality standards.[3,5] Historically, water quality has been defined by some concentration in mg/L of a chemical or TSS or load or coliform criteria (200 fecal coliform colony forming units per 100mL sample). Numeric criteria apply to a particular location and duration and frequency of detection. The numbers do not reflect the integration of pollution over space and time. Understanding multi-metric biotic health and the condition of a channel and riparian corridor should drive water quality planning at the local level. The cumulative influence of toxicity and pollutant load is best reflected in the relationship between land use and aquatic response to NPS pollution.[3]

Ohio was the first Midwestern state to adopt the use of an Index of Biological Integrity (IBI). Karr[6] developed the idea of using an index to quantify biological metrics that would fill a gap in how the 1972 amendments to the Clean Water Act (CWA) called for an assessment of biology to define clean water in the USA. Today many states use IBI as a means of understanding the health of aquatic ecosystems.[7] The construction of an IBI is based on a gradient of disturbance across a given region. The assumption is that natural ecosystem variation can be defined, and that human activity, superimposed upon the natural ecosystem can illustrate degradation or loss of ecosystem functions or biological integrity. The more intense the human activity or focus of pollutant delivery to the aquatic ecosystem the more destruction or loss of biological and habitat features inherit within a natural aquatic dynamic. This dynamic includes the interaction of physical and chemical components with the natural biology that evolved over time to produce a given ecosystem.[8]

Over a century ago, agricultural drainage engineers conducted their work without consideration of habitat and biological degradation of streams. Their mission was to manage water to optimize crop growth. Water quality was not a concern until the later portion of the 20th century when groups like the Izaak Walton League questioned farmers, government programs and technical experts who guided agricultural producers. Because the Environmental Protection Agency (EPA) and state governments have invested time and resources in water quality assessment. We now have data and an environmental push-back about past drainage activity and how we must think about the future of crop growth within a balanced ecosystem.[4,9] My observation over four decades notes a change in how we train agricultural engineers working with land and water. Most higher education programs across the USA now employ the name *biosystems engineering*. In Minnesota, we call our program Environmental and Ecological Engineering. The shift clearly demonstrates that today's agricultural engineer is also well trained in environmental and ecological principles. The more progressive consulting engineering firms working in the drainage space require new employees to not only have a comprehensive understanding of drainage engineering but also how to sustainably protect or restore the environment. This does not mean they will conduct fish surveys but understand what an IBI score means and use both field and computer models to integrate desired project outcomes.

The Future of Agricultural Drainage

In the 21st century there are fewer open ditches being built, and more subsurface pipes, often at a slightly larger diameter than the original "clay-tiles" that were laid end to end a century ago. A century ago, laying clay-tile pipes was labor intensive and only on the land which offered the best return of investment was tile-drained, but with limited capacity. Today that same land may have 2-4 times more corrugated black plastic pipe that was installed using a machine with laser technology. If that land produces a high yield corn and soybean crop, then the return on investment was positive. If climate change in the form of more intense, high magnitude rain creates water pooling in the field, then more and better drainage is required to meet the crop demand. This change now requires a governing body, like a watershed district, to not just oversee system finance and construction, but also balance competing interests. Examples of competing interest include downstream flood damage, violation of a TSS numeric criteria, and a loss of biotic habitat due aggradation. In Minnesota, drainage law calls for an adequate drainage outlet to proceed with a new drainage project – one that improves the efficiency of the drainage system. In Indiana, each county elects their own drainage engineer who has full authority to make decisions. Drainage engineers have historically focused on hydrology and hydraulic modeling to ensure system performance and prevent downstream damage. Given the investment by government at all levels, planning for water quality, hydrology and hydraulic modeling falls short of the necessary comprehensive watershed assessment that would account for biotic health. In particular – *fluvial stability* - because fluvial stability directly influences habitat and indirectly fish IBI scores. What is becoming clearer, whether a set of state statutes and rules or decisions by an elected drainage engineer, fluvial stability is intrinsic to having sustainable ecosystem services as defined and measured by biotic health.

Fluvial Stability

Principles of channel evolution models (CEM) developed by Schumm,[10] and Simon[11] can be used to estimate the likely direction of channel adjustment. This modeling approach was developed because row-crop agriculture was changing the runoff characteristics of managed terrestrial landscapes. In other words, we have known, for decades, that corn and soybean production in the Midwestern USA will alter stream channels. The CEM illustrates fluvial processes which proceed toward channel incision (downcutting) and enlargement (widening). However, the CEM approach is mostly theoretical and requires some quantifiable measurements to properly calibrate field observations with respect to stage of channel evolution determined from CEM. Rosgen's[12] stream classification system has been used to provide systematic and quantifiable field measurements of channel adjustment conditions. Rosgen's system considers the annual peak streamflow with a 1 to 2-yr recurrence interval (RI), (average = 1.5-yr RI) to be the bankfull flow that also is considered to be the primary flow associated with channel formation.[13] However, does the drainage engineer need to conduct a full-scale Rosgen level 2 channel classification to implement a proposed drainage design that protects downstream ecosystem services? No, but the drainage engineer does need to gather some field data.

A Win-Win Protocol

In this communications brief, I propose a quick assessment approach to account for fluvial stability as it relates to sediment supply, transport and biotic habitat. The CWA requires all states, territories and tribes to have standards that protect water from excessive suspended sediment. This is why stormwater erosion control practices are commonly implemented when contractors open up the earth and expose soil. Biotic habitat protection or restoration is less well understood and is a growing environmental discipline related to fish and invertebrate indices such as the IBI and natural channel restoration. The purpose of this protocol is to provide guidance to the Midwestern USA drainage authorities and/or drainage engineers on how to estimate the relative channel stability within the project area and beyond the proposed drainage outlet.

Step 1 – Examine historical records including as built plans and aerial photos. Compare past and present channel and riparian corridor features.[14] Does the comparison show similar features? If the current aerial photos show an enlarged downstream channel or other evidence of instability, then contact the appropriate regulatory agent (elected drainage engineer) or agency such as the department of natural resources (DNR) staff to request a joint field visit, if possible. Then fly a drone over the reaches of concern to validate aerial photo data. Natural channel restoration may be required before a drainage project could be considered. If regulatory folks are not required to conduct a field visit, then go to Step 2.

Step 2 – If the aerial photo analysis or drone imagery does not reveal any egregious instability of the natural downstream channel, then obtain the appropriate regional hydraulic geometry curve (RHG) from DNR or Wildland Hydrology[12] or other and estimate the approximate channel forming or bankfull geometry and flow for the current drainage system based on *contributing drainage area* and the proposed drainage system. Does the contributing drainage area change?

Step 3 - Lisle and Hilton[15] developed quick and simple way to estimate bed load material being transported. A 2-m long x 1-cm diameter copper or rebar rod (*sed-rod*) is pushed into the bed sediment with constant pressure until resistance exceeds human force. Then the depth of sed-rod penetration can be measured to estimate the accretion of loose fine sediment over the basal geology. A hand auger soil boring can be made to classify the sediment soil texture. This measurement infers a relative sediment density, particle packing and resistance to shear that could be defined as the overall critical shear strength of the natural or as-built channel bed.

Step 4 – Based on evidence of channel disruption arrange a field visit with the appropriate regulatory staff or *approved technical services provider*. The field visit is designed to validate and synchronize the RHG curves with field fluvial evidence. Conduct a Bank-Height Ratio (BHR) analysis:

$\mathrm{BHR} = \mathrm{LBH}/d_{bmx}$

Where LBH = to the lowest bank height and d_{bmx} is the bankfull maximum depth.[3]

If the field visit indicates the natural downstream channel is evolving to a more erosive state or class, then go back to step 1 and seek grant funds for channel protection/restoration. If the field results indicate no major channel downcutting or widening, but a channel with an active flood prone area for energy dissipation and frequent flood storage advance to the next step.

Step 5 – Conduct a *modified* Pfankuch Stream Reach Inventory and Channel Stability Classification.[16] The Pfankuch stability ranking (PSR) is designed to qualitatively estimate the dynamic of boundary shear and critical shear strength of the channel bed, lower bank and upper bank of natural channels. The PSR was originally used in the Rocky Mountains, but across the Midwestern USA landscapes varying modifications will be needed to build a region specific PSR. If regulatory management lacks the skill to develop and implement a modified PSR, then an external technical services provider should be hired to perform the work.

If the outlet occurs in a trapezoidal constructed channel, then use MADRAS[17] to estimate the geotechnical stability of the channel banks. If the field assessment results yield a low ranking, then the proposed project has an adequate outlet under current drainage. Nevertheless, modeling must show that the runoff volume or velocity will not change. The clear implication is that water storage will be required at strategic watershed locations to maintain channel integrity.

The future of successful agricultural drainage will depend upon intrinsic watershed management. Watershed managers and funding entities must see the larger comprehensive picture and the sequence of implementation activity. This means that watershed models must guide the drainage engineer in where and how to implement water storage to prevent downstream flood damage, habitat and ecosystem services loss.

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Conflicts of Interest

Regarding the publication of this article, the author declares that he has no conflict of interest.

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