Geology and Geomorphology of the Driftless Area

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1. The geology of the Driftless Area directly influences fluvial geomorphic processes, resulting in stream systems that are unique to the region but not uncommon worldwide.
2. Land management practices impact fluvial geomorphic processes in the Driftless Area streams by changing hydrology and sediment sources, transport, and deposition.
3. The complexity of interaction between climate, landuse, soils, geology, ecology and geomorphic processes in Driftless Area require careful consideration, and generalities regarding cause and effect should be avoided when making management decisions related to landuse and ecology.

Geology | Geomorphology | Sediment Transport and Deposition | Channel Geometry | Streambank Erosion | Riparian Vegetation

Fig. 1. Bedload originating from eroding streambanks is often deposited in channel immediately downstream of the eroding outer bend.

To understand the geomorphology of Driftless Area streams, we must consider not only fluvial geomorphology, or the form and processes of moving water on the landscape, but also the surficial geology and landuse history, particularly with regard to vegetation changes. This section examines basic fluvial geomorphic principles, and looks at how glacial and post glacial geology and landuse affects channel forms and processes in the Driftless Area.

Geology of the Driftless Area

The Driftless Area is a 24,000-mi^2 region in southeastern Minnesota, southwestern Wisconsin, northwestern Illinois, and northeastern Iowa that was spared the erosional and depositional effects of glaciation. Advancing glaciers essentially bulldoze the landscape under millions of tons of ice, picking up soil and stone along the way. Retreating glaciers leave behind their cargo of silt, clay, sand, gravel, and boulders in deposits called glacial drift. Glacial till and outwash deposits, layered gravel and sand deposits that are a part of drift left by glacial meltwater streams and common in the upper tier Midwestern states, are uncommon in the Driftless Area. In this region, erosion of bedrock over millions of years and the lack of glacial deposits, or drift, have resulted in a rugged landscape of rolling hills, rock formations, plateaus, and deeply carved river valleys (1).

Although in the final phases of the most recent Wisconsinan glaciation the Driftless Area was totally surrounded by ice (Splinter, page 5), geologists until recently believed that the area had never been covered by glacial ice. Generally, geologists restrict the boundary of the Driftless Area to the east side of the Mississippi River, whereas the Minnesota and Iowa portions have remnants of pre-Illinoian glaciation. However, fisheries management agencies define the Driftless area as including both the Minnesota and Wisconsin sides of the Mississippi. In the glaciated regions adjacent to the Driftless Area, the glacial retreat left behind deep drift deposits, which buried older hills and valleys. Within the Driftless Area, deeply incising valleys cut through a bedrock plateau overlain by deposits of windblown fine soils called loess. The larger river valleys, such as the Mississippi and Wisconsin Rivers, have high bluffs rising over 500-ft (150-m) above the level of the Mississippi. These large rivers and their tributaries have eroded through Paleozoic Era sedimentary rock, primarily Ordivician dolomite, limestone, sandstone and shale.

Karst topography is found throughout the Driftless Area, although it is more common in southeastern Minnesota. Karst geology is characterized by fractures and fissures in what is typically limestone bedrock, resulting in caves, sinkholes, losing and disappearing streams, underground streams, and numerous coldwater springs. In non-karst streams, drainage divides separate small tributaries that coalesce into higher order streams, and stream hydrology is related to drainage basin area and the effect of precipitation and groundwater recharge can be somewhat predicted based on slope, soil composition,

Statement of Interest

Riparian vegetation plays an important role in fluvial geomorphic processes and stream channel stability. Historically, gross generalizations have been made regarding grass versus forested riparian areas and streambank stability in the Driftless Area, and decisions are often clouded by competing goals of streambank stability, riparian grazing, and desires of anglers. Fluvial geomorphic principles and studies in the Driftless Area suggest that such gross generalizations are misguided, and that riparian management should be considered in a project-by-project basis and consider all interacting factors that determine what riparian vegetation type is likely to be most effective in meeting habitat improvement or restoration goals.

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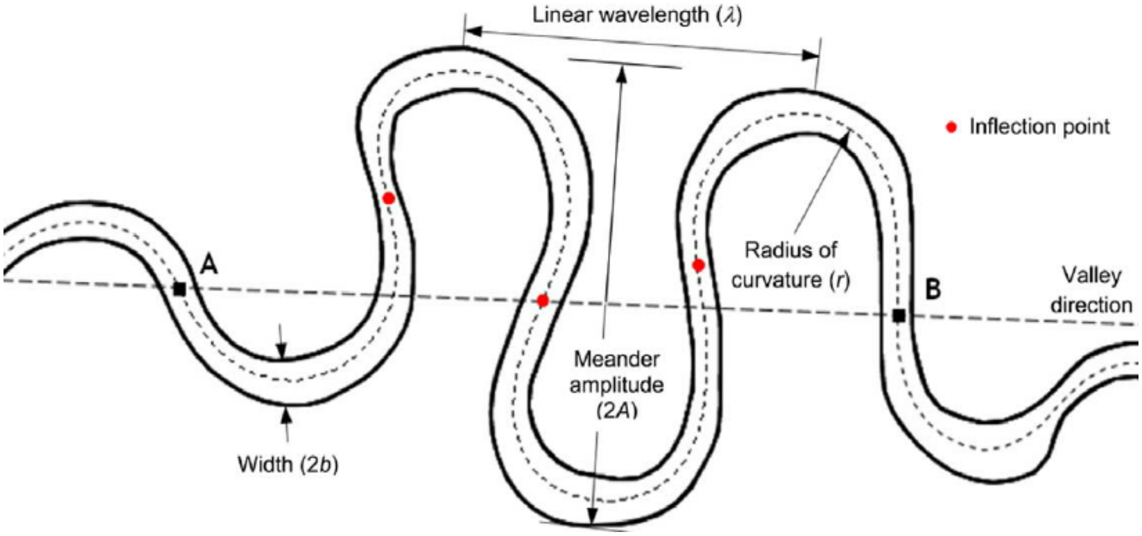

Fig. 2. Planform morphology showing meander wavelength, radius of curvature, and meander amplitude (from Guneralp and Marston (3)).

soil moisture and vegetation. Karst stream hydrology differs in that bedrock derived spring flow is typically perennial, whereas surficial spring flow and runoff may be intermittent. Surface draining water, and even stream baseflow, can be drawn off or even lost completely into cracks in the underlying bedrock, sometimes reappearing down valley. Groundwater inputs and outputs can vary, however, and streams may simply lose or gain a percentage of baseflow depending on the density and size of subterranean fissures and conduits within the underlying bedrock (2).

Although unique locally, the driftless and karst geologies of the region are not unique to the Driftless Area. Large regions of the continental United States, northern Europe and Asia have never been glaciated and have rolling hill and plateau country with silt-dominated loess soils. Karst geology is also common, being found on nearly every continent. What makes the Driftless Area unique is that it is a distinct unglaciated area completely surrounded by glaciated terrain. Other unglaciated areas of the world offer opportunities for comparison of changes in hydrology, erosion, deposition, and channel form caused by human disturbance (1, 4, 5).

Fluvial Geomorphology of Driftless Area Streams

Streams and rivers do work in the form of linear transport of water and sediment. Because of gravity, headwater streams have stored energy that is dissipated as the water moves downhill. In energy systems, there is a tendency to dissipate energy by doing work in the most efficient means possible. In a linear system like a stream or river, energy is dissipated in a sine wave in both plan view, as meanders, and in profile, as steps or riffles and pools. The relationship between work and stream form can be illustrated in the movement of a downhill skier. The efficient downhill skier reduces the slope of her descent by moving in a sine wave pattern. The energy of the skier is dissipated as work in the form of moving snow. At the outside of each turn, snow is moved. In a similar way, streams do work by moving sediment. Sediment is removed from banks where velocities are higher, and then it is deposited in lower velocity (and thus lower energy) areas such as the insides of meander bends. Alluvial streams are those that flow through alluvium, defined as gravel, sand, silt, and clay moved and deposited by streams and rivers. In a classic meandering alluvial channel, erosion from streambanks is deposited mostly within the first few inside bends, or point bars, downstream (Fig. 1). This bar formation creates hydraulic constriction and results in higher velocity on the opposite bank, which also erodes, and so on down the line. If bank erosion and deposition are happening at roughly the same rate, the channel size stays relatively constant, but the channel itself moves within its floodplain. The floodplain is thus destroyed and recreated at the same time. Given enough time, a river could occupy every point in the floodplain. Thus, stable streams and rivers are often described as being in a state of dynamic equilibrium, where the location of the stream in its floodplain may change over time but the channel size, vertical location, and meandering patterns remain the same. As discussed below, channels pushed to disequilibrium by large floods or direct action by humans (i.e., hillslope and gullying sediment inputs, ditching, vegetation changes) tend to move toward a state of equilibrium until a natural or human caused event pushes the system again toward disequilibrium (6–10).

One of the guiding principles of fluvial geomorphology is that channel size and form (cross section geometry or *channel geometry*) can be predicted from the dominant or most frequent precipitation or runoff events and the size and amount of sediment it carries (11). Alluvial systems, or systems whose geomorphology is built with and dependent upon running water, often have a channel size that accommodates flooding that occurs most frequently, for example during spring runoff. These are the floods that shape the channel and transport the bulk of the annual sediment load. The most commonly used stream cross-section measurement is the *bankfull width*, which is a measure of the channel width at the elevation where the flows just start go overbank and onto the floodplain. The bankfull width can be identified using one or a number of field indicators, including: sediment depositional features (e.g., point or midchannel bars), slope breaks, water marks, and vegetation. It should be noted that these are general statements and do not apply to all cases. Depending on the hydrologic characteristics of the watershed in question, bankfull flows may or may not be the most important flow that determines channel characteristics, and there are also systems from which bankfull stage is significantly different

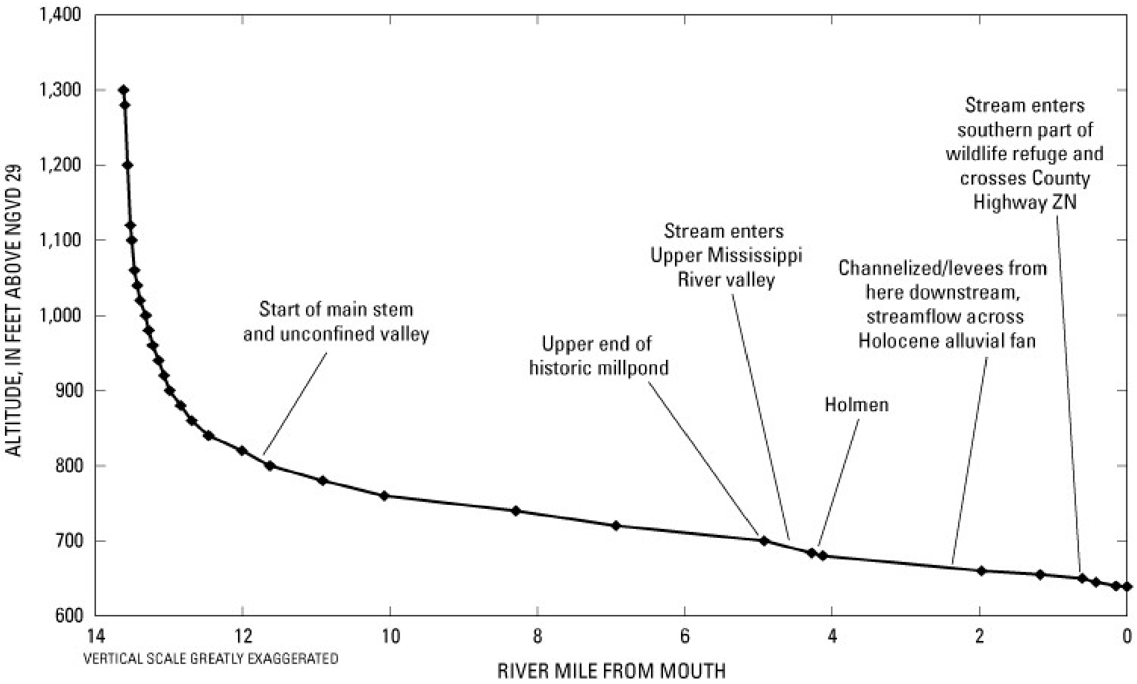

Fig. 3. Longitudinal profile of Halfway Creek, Wisconsin demonstrating the transition from steep headwaters to lower gradient mouth (from Fitzpatrick et al. (14)).

from commonly-referenced 1.5 - 2 year annual flood frequency, such as wetland streams and desert channels. Flood frequency and bankfull channel equilibrium are discussed in further detail in Dauwalter and Mitro (page 55) and Veilleux et al.(12)).

Alluvial channel planform geometry is frequently characterized by three main parameters: meander wavelength, meander amplitude, and radius of curvature (Fig. 2). *Meander wavelength* is the average down valley distance between the apices of meander bends on the same side of the stream, while *meander amplitude* describes the amplitude of meander bends off of the valley center. The average cross-valley distance between meander apices is termed the *radius of curvature*; it is simply the radius of a circle superimposed on a meander bend and is a measure of the tightness or degree of the meander. Planform geometry measurements can be converted into dimensionless ratios comparing bankfull channel width to each parameter. This allows comparisons to be made within or among watersheds. The degree of meandering and the shape of those meanders varies and is highly dependent on channel slope, surficial geologic controls, soils, and hydrology. Headwater streams in steeper, narrow valleys of the Driftless Area or in areas dominated by bedrock outcrops typically have narrow floodplains and low meander amplitude, whereas low gradient segments have higher meander amplitude.

Many streams in the Driftless Area start in steep headwater areas, transition through moderately steep reaches, finally converging with other river systems in lower gradient reaches (Fig. 3). This concave slope profile, or longitudinal profile, is explained by relating channel slope to the relative age of the stream network, and to controls on base level. To better explain this relationship and the current state of Driftless streams, we must first discuss the concept of *channel evolution* (13).

Channel evolution models are helpful in describing how stream and river channels change with age and do so by demonstrating channel form in stages (Fig. 4). Stream channels whose bed and banks are made up of soil, sand, gravel, and cobble respond to increased rate and volume of runoff in a predictable way. The Schumm channel evolution model involves first channel incision – often referred to as downcutting - followed by channel widening, but in areas where channel bed elevation is controlled, as in some streams of the Driftless Area, widening occurs first without incision. Streams are generally thought to be in equilibrium with their hydrology whereby channel size evolves to hold the most frequent floods, which in the Midwest are typically associated with spring and summer rainstorms. As discussed above, as part of the normal geomorphic process of streams, channels erode their outer banks where velocity and erosive power is higher and deposit sediment on the inside of meander bends where velocities are lower. This process thus naturally involves the entrainment and transport of sediment particles, both in suspension (fine silt and clay) and along the bed (sand, gravel, cobble). In a channel stabilized with vigorous vegetation growth on the banks, the increased runoff volume caused by agricultural or urban development first causes the less resistant channel bed to erode downward instead of the channel widening outward.

Downcutting of channel beds can also be caused by a change in base level in the channel or the receiving river. Such base level changes are often caused by channelization (ditching), whereby straightening decreases the stream distance between two points thereby increasing channel slope and erosive power. The erosive power of streams increases with depth. In an incised channel, because flows cannot spill overbank onto the floodplain and are confined in the incised channel, a feedback loop of increasing erosive power ensues, which causes the stream bed to incise further. In this Stage II of the channel evolution model, as the incising channel deepens, the erosive power of the channel continues to increase (Fig. 4). Driftless Area stream reaches that have either never incised or have not incised in many thousands of years occupy Stage III of the channel evolution model, when gravity eventually contributes

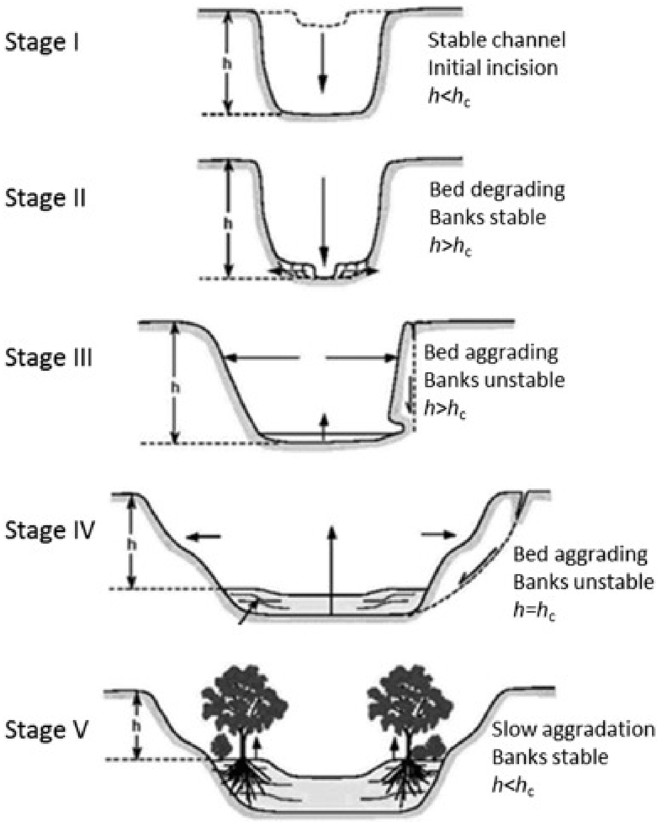

Fig. 4. The incised channel evolution model (from Schumm, et al. (10) and Simon (15)).

to bank failure and the stream begins to widen, or Stage IV when widening slows and the stream begins to stabilize. In Driftless Area streams, channel downcutting is limited in streams that have incised down to the relatively immobile late Holocene alluvial layer. This former streambed or valley bottom is armored with relatively erosion resistant limestone cobble. Channels in Stage III of the model tend to migrate laterally, sometimes dramatically, over this Holocene base layer that has never historically incised (Fig. 5).

Widening continues, which decreases the erosive power of the channel, and this, coupled with a winnowing of fines from the bed (armoring), results in the eventual stabilization of the channel at a new elevation (Stage IV). The channel forms a new floodplain at the lower elevation, whereas the former floodplain becomes what is now called a *terrace*. It should be noted that the model as described is simplistic, and that in reality, there are exceptions at each stage.

This model is more relevant to the headwater portions of Driftless Area streams where incision is an active process, versus in the wider valley bottoms where incision is limited. Larger magnitude flood peaks since settlement have caused erosion that also increased yields of both bedload and suspended sediment. Incision travels upstream, and the bed material eroded is transported downstream where it settles, either in the bed or as overbank or floodplain sedimentation, the latter leading to vertical accretion of floodplain sediments and increased floodplain elevation. The lower reaches on the longitudinal profile represent a relatively older state of the geologic process (Stage IV and V), whereas the actively incising and eroding reaches represent younger processes (Stage II and III; Fig. 4). Post settlement alluvial processes have been well studied in the Driftless Area, with up to 30-ft (9-m) of recorded sediment depths filling valleys near the Mississippi River (16–19). Sediment cores and exposed river banks often clearly show pre-settlement organic-rich floodplain soil buried by the lighter and less cohesive post-settlement sand and fine sediment (Fig. 6).

The channel evolution model is more relatable to geology if we express channel form in terms of geologic age. Headwater streams typically have smaller drainage areas, correspondingly lower water volumes, and armored beds where material is more difficult to entrain. In the Driftless Area, headwater channels can be ephemeral, with spring sources often present along valley sides at lower elevations. Occupying Stage II in the channel evolution model, headwater reaches periodically incise through active gullying during wetter climate periods. These channels are geologically young compared to downstream reaches, which typically have reduced slope and less erosive power.

Transitional reaches between headwaters and mouth tend to erode more sediment due to a combination of more concentrated runoff, moderate slope, erodible bed and banks, and a higher sinuosity than headwater channels (20). Because the erosive power is dependent on the slope and depth (and thus volume) of water moving through a given location, erosion is generally highest in these middle reaches, and these segments are sometimes known as *sediment source* reaches. The laterally eroding channel segments of these middle reaches occupy Stage II and III in the channel evolution model, but in the Driftless Area account for a relatively small percentage of the total sediment load compared to upland sources. Researchers have found that the large majority of sediment in Driftless Area streams comes from upland rill and sheet erosion as compared to tributary or gully erosion (21). Transported sediment historically has deposited in the downstream reaches where stream gradient was lower and the sediment transport capacity of the channel was exceeded; however, even after conservation practices are implemented legacy sediment continues to export from these systems (17).

Many Driftless Area streams have essentially moved a large percentage of their transportable sediment downstream, but most of this sediment remains stored in the system. Trimble (21) reported that nearly 50% of human induced sediment in Coon Creek was stored in downstream floodplains, while only seven percent of the eroded sediment had left the watershed. This has created a situation in which the lower reaches have become *apparently incised*, or have the appearance and character of incised channels, because vertical accretion of floodplain sediments has increased floodplain elevations (aka, floodplain aggradation) despite channel bed elevations remaining largely unchanged. These reaches can now be categorized as Stage III (historically incised and now laterally eroding), and in some cases Stage IV, of the channel evolution model. In both field and laboratory studies, Stage IV channels can continue to erode if there is a continual sediment supply feeding the formation of bars within the Stage IV channels. This means that in the Driftless Area, continued excess sediment supply from upstream can not only add to floodplain aggradation, it can also cause downstream channel bed aggradation and intensify lateral erosion in the post-settlement alluvium reaches.

Woltemade and Potter (22) described how the incised na-

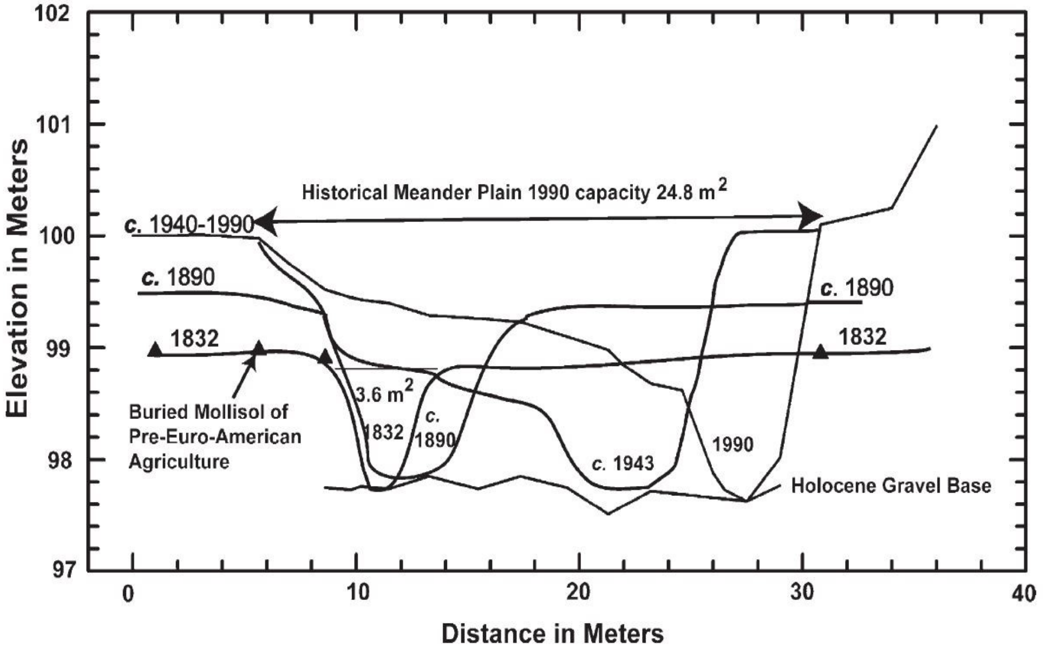

Fig. 5. Lateral channel migration and floodplain aggradation over a vertically stable Holocene gravel layer. The figure demonstrates post-settlement alluvial floodplain aggradation above the pre-settlement 1832 floodplain soils (Fig. 5 from Knox (16)).

ture of lower gradient downstream channel segments causes an increase in peak flood discharge and high shear stress. Under historical conditions, these reaches would have connected floodplains with lower peak floods and, therefore, lower shear stress. Deeply entrenched streams and meander belts in the Driftless Area can result in major channel changes, including avulsion and complete filling of abandoned channels on the scale of years to decades (23).

Channel Stability and Vegetation

The Driftless Area is dissected by extensive V-shaped valleys that formed after the pre-Illinoian glaciation nearly a million or more years ago. It is likely that the geomorphology of these streams changed very little between the end of the last glaciation (15,000 BP) and human settlement, when landuse practices began to change historical vegetation patterns. Stream form adjusts over time in response to dominant hydrologic conditions, foremost being the rate and volume of surface runoff (as opposed to infiltration). Surface runoff during and after rainfall and snowmelt is the principle process determining flood magnitude and the size of stream channels, but upland vegetation changes can drastically change the rate and volume of surface runoff (17, 24).

As stated previously, vegetation changes in the watershed impact hydrology and result in geomorphic instability, and conversely, it is well known that changes in stream geomorphology such as incision and erosion cause river and riparian ecosystem degradation worldwide (25–28). Most of the research on vegetation change in response to changes in channel morphology has focused on the important feedback between fluvial-geomorphic forms and processes and the ability of certain types of vegetation to become established, resist flow, and tolerate inundation (15, 29–31).

Channel stability associations with vegetation are often focused on lateral erosion, or Stage III of the channel evolution process. In reality, changes in stream flow and sediment load are the primary drivers of bank stability. Research has shown that mass failure of cohesive banks often occurs when a critical bank height is reached and can be independent of fluvial entrainment of bank materials (10, 24, 32–34). After a critical height is reached, then banks can slump from block or other failures. Widening is then completed by subsequent fluvial erosion of the failed materials, and once that material is removed, erosive power is reduced because the channel is wider and shallower (35).

Following glaciation up to the period of European settlement, Driftless Area vegetation consisted of tallgrass prairie and bur oak *Quercus macrocarpa*-savanna on ridgetops and drier plateaus, maple-basswood *Acer-Tilia spp.* and oak *Quercus spp.* forest on wetter or north facing slopes, and wet prairies and marshes along rivers and floodplains. Some watersheds, like the Kickapoo River, were more forested than others, and there was generally more prairie and savannah south of the Wisconsin River. At the time of the first government land surveys, the Platte River watershed was approximately 70% forested and 30% prairie, with shrub thicket and forests in narrow divides and higher relief areas. Prairie was restricted primarily to the broader ridge tops or plateaus, which were unfavorable sites for trees due to thin soils and shallow bedrock, rapid drainage, and desiccating winds; all conditions conducive to wildfires. Natural fire is essential for sustaining the ecological processes of prairies, and overall likely created a patchwork of various vegetation successional states within these broad patterns depending on natural landforms and fire breaks such as large rivers (17, 36, 37). In the absence of fire or disturbances such as grazing, succession of riparian vegetation generally follows a grass/forbs to willows/alders *Salix/Alnus spp.* to mature trees (box elder *A. negundo*, etc). Second and old growth trees follow suit, with flood tolerant trees persisting long term, such as silver maple *A. saccharum*, cottonwood *Populus spp.*, black willow *S. nigra*, swamp white oak *Q. bicolor*, bur oak, and others.

Fig. 6. An exposed eroding river bank on Mill Creek in southeastern Minnesota showing a pre-settlement floodplain soil layer overlain by the lighter and less cohesive post-settlement sand and fine alluvium (Credit: M. Melchior).

Post settlement agricultural development after 1850 included widespread conversion of forest cover to pasture, and conversion of plateau prairies to row crop corn (17). Research has shown that undisturbed prairie and forest cover yields very little overland flow (runoff) during precipitation events, particularly under drier conditions when soil infiltration capacity is high. Conversely, row crop agriculture and pasture has been shown to increase runoff, thereby increasing peak flows as much as five times over pre-settlement vegetation conditions (38–41).

Increased hillslope erosion during rainstorms caused by changes in vegetation resulted in significant loss of farmland and in some cases buried settlements or entire towns, as in the infamous case of Beaver, Minnesota (42). In the Platte River system, Knox (18) found that vegetation removal and soil changes caused by agriculture resulted in peak flows three times or more as high as those during pre-settlement. Knox generally found that historically, when vegetation cover was low due to drought or human disturbance, peak runoff and sediment yield increased. As discussed above, these increased flows caused an increase in yield of both bedload and suspended sediment, resulting in varying levels of post-settlement alluvial deposition (18, 19, 43, 44). The shape of the valley also contributes to aggradation levels, with floodplains in wider valleys having more aggradation than narrow valleys due to comparably decreased ability to move sediment particles (4, 22). Using General Land Office notes, sediment coring, and carbon dating of wood in depositional features, paleohydrologists have determined that pre-settlement channels in the Platteville and other Driftless Area stream systems were found to be significantly smaller in the headwater and middle reaches, but larger in the downstream reaches when compared to present-day conditions. The latter is thought to be a result of sediment load overwhelming channels and causing narrowing (17, 18).

Modern Riparian Vegetation Management. There is a common misconception in the Midwest that trees cause erosion and that grasses are better at stabilizing banks. The belief in this generalization has been influenced by a number of factors, including historical riparian management practices that combine habitat improvement with necessary bank clearing to facilitate habitat work, a desire to manage livestock in ways that allow for water access, and recreational fishing, predominantly by fly-casting anglers. The idea that trees cause erosion is partly based on a limited number of published works claiming that forested streams are generally wider and more shallow than streams with grass as the dominant riparian vegetation (45). It should be noted again that historical vegetation mapping suggests that riparian forests in sections of the Driftless Area may have been rare or at least intermittent, and that riparian zones were largely wet prairie or wetland derived. The factors listed above, combined with the desire for historical reference vegetation conditions has resulted in widespread removal of woody riparian vegetation in favor of grasses and forbs.

The scientific truth is that the effect of riparian vegetation on stream stability is much more complex than can be explained with a sweeping generalization. Although it is well understood that vegetation is correlated to geomorphic stability (28, 39, 46), there is limited supporting data to support either the generalization that grass is superior to trees in stabilizing streambanks or that trees and large wood recruited to the stream cause erosion. A few studies have addressed the issue, either directly or indirectly.

Vegetation and Streambank Erosion. It is generally accepted that both grassy and woody vegetation can improve soil and bank stability. Bank stability is influenced by bank height and slope. However, Simon, et al. (24) also demonstrated that soil water pore pressure is one of the most important factors in contributing to cohesion of bank sediments and, thus, to streambank erosion, but this research did not take into account the mitigating effects of vegetation such as interception, tran-

Fig. 7. Tree root mass is concentrated typically within the upper 3-ft (1-m) of soil, but riverine species can form dense root masses parallel to stream flow (Credit: M. Melchior).

spiration, evaporation, and storage. It is extremely important to consider that all vegetation has an upper limit with regard to the amount of stabilization that can be imparted. The majority of stabilizing roots in grass plants, both native and non-native, are within the first 1-ft (0.3-m) of soil, and density decreases below. Thus, in small streams with bank heights less than 1 to 2-ft (0.3 to 0.6-m), grasses can contribute to bank stability.

Tree roots can extend several feet (>1-m) into the soil, but most riparian and flood tolerant trees such as silver maple, red maple *A. rubrum*, and various willow species have their densest roots within 3-ft (1-m) of the ground surface. Grasses do not train their roots along river banks, but woody vegetation, particularly longer-lived trees, will grow roots parallel to shorelines, thus imparting additional bank stability (Fig. 7). Stability is provided by the fibrous roots binding soil and is complemented by the stability imparted by the structure of the roots themselves. When grass lined banks erode, the grass plants fall in and are typically washed away, whereas bank erosion near trees is more noticeable. Falling trees take soil with them and create hydraulic conditions that sometimes result in bank scour near eddies or turbulence caused by the bole in contact with flowing water. When bank heights exceed 3-ft (0.9-m) and beyond the depth of tree roots, undercutting can occur. Conversely, in banks under 3-ft (<0.9-m) in height, the bank stability provided by black willow and other tree willows can withstand extremely high shear stresses, can provide essentially erosion-proof banks, and in small streams can limit channel incision.

It is important to recognize that different types of grasses provide higher root densities and depths than others, as do some tree species. Similarly, primary colonizing trees such as boxelder or black walnut *Juglans nigra* do not provide dense root systems comparable to willow or cottonwood species. The role of canopy shading should also be quantified when considering the stabilizing effects of vegetation. Larger trees have larger root systems, but mature second and old growth forests can have relatively bare understories. Primary growth or early second growth forests can still maintain dense riparian shrub systems, depending on the width of the stream and the amount of sunlight reaching the banks.

Previous Studies. Several studies have compared stream channel characteristics between sites that have forested versus grass riparian vegetation. Zimmerman, et al. (47) reported that vegetative characteristics influenced mean width of riffle-pool and plane bed channels in Vermont, when the drainage area was less than 5-mi^2 (13-km^2), with forested channels being wider than grass-lined channels.

Trimble (45) originally examined the physical attributes of four reach pairs on Coon Creek in southwest Wisconsin. Based on measurements of bankfull width, base-flow width, base-flow cross-sectional area, average base-flow depth, and channel width-to-depth ratios, he concluded that riparian forests significantly affect the channel shape and bank and channel erosion. Trimble indicated that forested reaches are wider and may contribute significant amounts of sediment downstream.

Several items should be noted about the Trimble (45) publication. The author directly related sediment storage to channel cross-sectional area but does not fully explain how. He also assumed that the channels became larger with riparian forestation, rather than the reverse, in which grass-lined streams became narrower after deforestation. Rather than comparing bankfull widths, the author compared base flow width which is not a reliable indicator of geomorphic channel size and can instead be influenced greatly by local sediment deposition and recent flows. The author's analysis correlates base flow width with vegetation type, but then immediately labels forest cover as a causative agent worse than cattle grazing. There is little or no mention of the other possible causative factors, such as increased runoff from agricultural fields. There is also no information given on how the channel measurements were selected or measured, or how parameters such as bankfull width were measured. The author also drew conclusions based on a relatively few measurements (i.e., low sample number). Trimble asserts that this finding should be considered in current stream bank protection and restoration projects and plans, and, like other authors who have reported similar results, inappropriately made the claim that if grassy areas are allowed to return to a woody successional state then the streams would release a large volume of sediment. This is a generalization with many confounding variables that would determine the actual outcome.

In response to Trimble (45), Montgomery (48) pointed out that there are a number of factors that are important in assessing the most appropriate riparian cover for a given stream including: the interplay of sediment supply, size, and lithology; the magnitude and frequency of water discharge; the nature of bank materials; the type of vegetation on the banks; and the effect of obstructions such as large wood. Montgomery acknowledges the salient points that Trimble raises, yet strongly advises putting this information in context, such as considering all interacting factors instead of making gross generalizations, and erring on the side of managing for more rather than fewer forests.

Horwitz, et al. (49) examined forested and unforested riparian zones in Piedmont streams and looked for correlations between riparian vegetation and fish abundance. The authors concluded that the forested reaches were usually wider than unforested reaches, but that there was no significant difference between total numbers of fish per length of stream.

A paper that is frequently cited as justification for favoring grasses over trees is the Lyons, et al. (39) review of published literature addressing the differences in grass versus tree riparian management. It is important to note that this paper does not include empirical data collection or analysis, but is a review paper. Grassed versus forested riparian cover is reviewed in relation to specific stream characteristics including: bank and channel habitat, water quality and quantity, and biota. They conclude that in certain areas of the country, grassed banks may better achieve specific management goals. They caution against removal of existing forests but encourage land managers to carefully investigate all the options before choosing a management strategy. The paper is a good source for citations, but readers should be cautioned that the paper itself makes several generalizations or repeats generalizations made by other authors (not atypical of a review paper).

Murgatroyd and Ternan (50) found afforested British streams to be wider, while Stott (51) the opposite to be true. Anderson, et al. (52) showed larger forested streams were generally narrower than non-forested streams of the same watershed area, while streams in watersheds less than 3.9-mi^2 (10-km^2) showed forested streams being wider than non-forested streams. They include in their analysis previous studies by Davies-Colley (53) and Hession, et al. (54) that showed the same trend in small streams. In similar log-log plots, contrastingly, the Anderson, et al. (52) analysis of Hey and Thorne (55), Soar (56) and Simon and Collison (57) data showed that thickly vegetated forested streams were narrower than thinly forested streams. This study only examined stable stream systems, and the study analysis included a variable amount of potentially controlling variables such as vegetation type, coverage or density, substrate characteristics, and large wood loading. There is not enough detail in the study or base studies to correlate stem density or type of vegetation to channel width or to determine the influence of other geomorphic drivers.

Drawing Management Conclusions. One of the great dangers of applying scientific study results to management is mistaking association for causation. The authors of the above papers all point out the limitations of their data, but those limitations are not fully understood by the general public or are often ignored when discussing conclusions. Clearly, there is variability in the data, and the studies cited do not fully examine the geomorphic drivers or sedimentation history that may be at work in each system. It is thus inappropriate to attribute bank stability simply to the type of vegetation cover grown in the riparian zone within the past 30-50 years. It may be appropriate to say that grass-lined channels with low bank heights may be more stable depending on the slope, planform geometry, hydraulics, hydrology, soil makeup of the channel, and other factors.

Implications for Future Assessment. Generalizations regarding the geomorphic response of forested versus grassed riparian areas are difficult to make for Driftless Area streams that have been managed (habitat improvement, or restoration). This is because most Driftless Area habitat management efforts involve use of hard stabilization of at least the streambank toe to improve stability. In such cases, lateral bank erosion is arrested and no comparisons can be made regarding the effectiveness of established grasses versus trees alone. Future projects that compare riparian vegetation with stream stability need to include appropriate controls and examine confounding variables. Any conclusions made about woody versus grassy riparian areas should consider the actual woody and grassy species of interest, role of erosion in habitat formation, multiple life stages of focal fish species, the many benefits of both grass and wood riparian areas, temperature effects, sediment storage in stream and in floodplains, and most importantly, the actual geomorphic drivers of instability in each particular system.

Driftless Area streambank stabilization and habitat improvement and restoration strategies over the past half century were driven largely by trout stamp dollars and federal and state aid related to erosion reduction. Thus, projects were designed around limited funding, and hard stabilization became a critical element of projects. Large-scale earth-moving projects required to create floodplain connectivity were cost prohibitive, and large-scale upland landuse projects were limited to cooperative landowners. The history and relationship of landuse and ecology are covered in detail in Vondracek (page 8) and Trimble (58).

Conclusions

This section is concluded here with a note about complexity. Fluvial geomorphology is complex even in the most stable systems. Erosion, sediment transport, and depositional characteristics vary greatly with slope, valley shape, local geologic controls, channel capacity, and hydrology. In the Driftless Area, each of these variables can be in flux at any given time, further complicating matters. In order to predict a biological response such as fish abundance, we must first add to this soup the geomorphic influence of vegetation and human landuse, and the influence of climate on vegetation. Despite this complexity, humans have a tendency to look for patterns that explain what we are seeing and help point us toward solutions (59). Bank stability, as demonstrated above, is in itself a complex process dependent on many factors. It is thus inappropriate to attribute bank stability simply to the type of vegetation cover grown in the riparian zone within the past 30-50 years. Each stream system and each locality has its own idiosyncrasies, and geomorphic stability must be analyzed in each situation before applying solutions (see Melchior, page 87).

Thankfully, the geomorphology of the Driftless Area is one of the most well-studied in the world, and we can glean important insights from this body of research. Geomorphology can in this case help to recommend potential solutions. First, it is logical to conclude that improved upland land cover can increase infiltration and reduce peak flows and sediment inputs into tributary channels (60). This assumption comes with the understanding of the complexity of vegetation in the Driftless Area landscape, both past and present, and of geologic constraints. Second, stabilization of sediment source areas such as bank erosion in tributaries and incision in gullies will likely reduce sediment inputs. Last, restoration of floodplain connectivity and the attendant habitat benefits can likely be achieved through removal of stored post-settlement alluvium, but the efficacy of such treatments depends on concurrent reduction in upstream sediment sources.

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