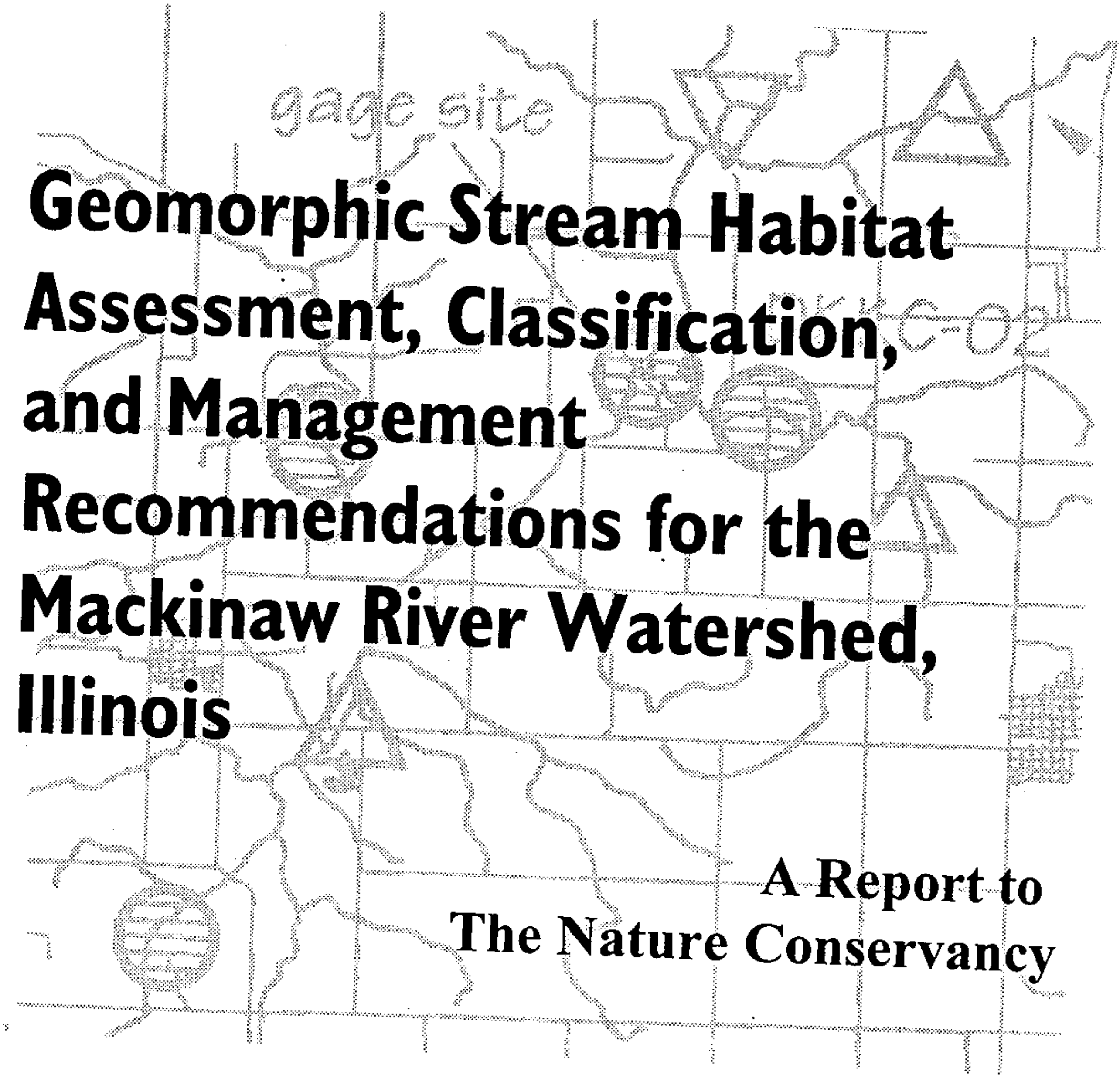

Geomorphic Stream Habitat Assessment, Classification, and Management Recommendations for the Mackinaw River Watershed, Illinois

A Report to
The Nature Conservancy

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Introduction

Scope and purpose of report.

This report presents data and analysis for a geomorphic process-based description of the Mackinaw River Watershed. The information presented here was gathered to guide management of aquatic ecosystems as part of a The Mackinaw River Project administered by The Nature Conservancy.

This report is part of a two-part series. The first part (Gough 1997) is a review of the literature on stream habitat assessment and classification. It also presents the methodology used to assess and classify stream habitat in this report. This report, along with Gough (1994), which is a general description of the watershed, should be considered companion documents to the report you are now reading. Gough (1994) covers basic geology and geomorphology of the Mackinaw Watershed, and cites studies and publications containing information on both physical and biological characteristics of the watershed.

This report is a concise presentation of data, analysis, and management recommendations. It is written for readers familiar with the documents mentioned above, especially Gough (1997), which includes details on geomorphic process and rationale for the methods used here.

This report presents data and analysis based on field measurements at 28 sites within the Mackinaw River basin. These sites are shown on Map 1 (Appendix B). Sites sampled, along with their drainage areas, are given in Figure 1. Based on this data and other information, reach-scale classifications for the Mackinaw Watershed are proposed. Best management practices (BMP's) and general management approaches for restoration and protection of aquatic ecosystems are offered based on these classifications.

Results

Watershed characteristics and management problems.

Water quality in parts of the Mackinaw River Watershed ranks among the best in Illinois, and the watershed has a number of reaches ranked as "unique aquatic resources" (Page et. al, 1992). This designation, the highest within Illinois' Biological Stream Classification system (BSC), has been given to parts of the Mackinaw River, Henline Creek, Walnut Creek and Panther Creek (Hite and Bertrand 1989). Many parts of the watershed have obviously degraded since European settlement, however. Others are threatened by further degradation or offer potential for improvement of habitat values. High quality reaches are always at risk for degradation and need protection.

The Nature Conservancy, in cooperation with private and government organizations and other stakeholders within the Mackinaw River Watershed, has identified key issues affecting both the quality of the Mackinaw River Ecosystem and the people who live in the watershed. The Watershed is dominated by row-crop agriculture (see Gough 1994, Retzer 1996a, and cited references) and conflicts exist between this intense landuse and the river ecosystem. In many cases, however, improved management of the Mackinaw River Watershed can benefit both agricultural landowners and the river ecosystem. Planning teams organized by The Nature Conservancy within the watershed have listed flooding, urban development, pollution, sedimentation, bank erosion, water quality, habitat loss, channelization, unstable channels, and citizen apathy as important issues (Retzer 1996a). With the exception of citizen apathy, these issues can be distilled into four categories: hydrologic regime, chemical water quality, sediment, channel stability, and habitat. More specifically, stakeholders are concerned about changes in the hydrologic regime that may increase flood frequency, water pollution, excess sediment, channel stability, and general degradation of aquatic habitat.

This report focuses on the geomorphic features and processes that move water, the substances dissolved in it, and sediment through the Mackinaw River Watershed. These features include river channels and their associated floodplains, which are integrators of many processes and events in the watersheds they drain and thus the primary focus of this study.

The data and analysis in this report directly address sediment, channel stability, and aquatic habitat. In this section, I will briefly address each of these river management issues and explain how the methods used in this study address them. A following section gives river segment classifications and management recommendations for the Mackinaw River Watershed.

Hydrology.

Aside from common soil and water conservation issues such as soil erosion, most Mackinaw River Watershed landowners are concerned with drainage and flooding. Much of the area of this basin is flat and was poorly drained when the first European settlers arrived. Since then, almost all such land has been drained using subsurface drains and ditching. Although this land is now relatively well drained, much of it is still subject to flooding. Henline Creek and upper Panther Creek are typical -- their upper watersheds are quite flat, and almost all headwaters channels have been artificially deepened and enlarged. Most of these channels are managed using periodic dredging and suppression of woody vegetation. Typically, ditched channels drain less than 100 km^2. Moving downstream, management of channels as ditches generally ends when they enter a larger channel or become too large for such management to be economically feasible, although other factors (such as political organization of drainage districts) are probably important. Transitions from ditches to natural channels are easily seen on topographic maps and aerial photographs as channels become sinuous and, usually, tree-lined. Most, perhaps all, drainage ditches in the watershed are fed by subsurface drainage tiles. Unfortunately, very little is known about the effects of artificial subsurface drainage on hydrology in midwestern watersheds.

Below ditched areas, channels in the Mackinaw Watershed are rarely subjected to such intense structural alteration until the river's floodplain becomes much larger and levees begin to appear. Extensive levee systems are first seen below the confluence of the Mackinaw

River and Panther Creek, and are fairly common below the Congerville gage site (see, for example, levees shown on the Mackinaw 7.5' topographic map). Channelization of the Mackinaw River does not again become common until drainage areas exceed 2100 km^2 (roughly where the Mackinaw River passes the City of Mackinaw). This transition can be clearly seen by comparing the Mackinaw and Hopedale 7.5' quad maps. The Mackinaw River has been extensively channelized for some distance up- and downstream of site DK-19 (where old Highway 121 and the present Interstate 274 cross the river). Although the effects of the extensive levee systems and channelization seen on this part of the river would be very difficult to quantify, it is likely that they profoundly alter the conveyance of floods large enough to be confined by the levees. The ditching and drainage done in the upper reaches of the watershed act to greatly increase the drainage efficiency -- rainfall is moved much more rapidly into channels than it would have been before the watershed was altered. This efficiency, while necessary for farming in some areas, increases the frequency of flooding in downstream areas. In general, ditching and drainage activities also greatly degrade aquatic habitat by creating wide, shallow, depositional channels that generally lack cover (especially woody cover) needed by many aquatic animals.

The Nature Conservancy has analyzed flow records for the Mackinaw River at the Congerville gage from 1945 to 1993, and concluded that changes in landuse within the watershed have caused a change in the rainfall-runoff relationship leading to increased flooding during that period (B. Richter and M. Mendelson memo, February 19, 1996, Retzer 1996b). Changes in drainage efficiency are not mentioned, but could account for changes in hydrologic response as well. Although the Mackinaw Basin is relatively well gaged (see list of gage sites in Gough 1994), this work remains the only effort to examine time trends in hydrologic response.

Stream channels within parts of the Mackinaw River Watershed show signs that increased flood frequency, duration, and magnitude have influenced stream channel morphology and habitat quality. Middle reaches of the Mackinaw between ditched regions and roughly DK-15 show a paucity of inchannel sedimentary features, primarily point bars, that indicates very efficient transport of sediment through these reaches. This is probably due to a combination of very stable, erosion resistant channels and relatively high stream power resulting from increased flood flows. Gage calibrations done at sites on the Mackinaw River, Money Creek, and Panther Creek show a strong relationship between channel morphology and flows with return intervals of 1.5 to 1.8 years, however, which indicates that these channels are morphologically balanced with present flow regimes. Channel bed and bank materials are relatively resistant to erosion, however, and this balance does not preclude effects on inchannel features such as bars.

Water quality.

This report discusses water quality only indirectly, as it is influenced by inchannel habitat within the basin. Other reports (see Retzer 1996a, Gough 1994, and Short et al. 1996) outline water quality conditions and influences within the Mackinaw River Basin. Retzer (1996b) offers a detailed discussion of water quality problems in the basin that makes use of the most recent water quality monitoring done by the Illinois EPA. Water quality in the ditched portions of the Mackinaw's drainage net is influenced by a lack of shading. Questions remain about suitable riparian vegetation for these channels, many of which were formerly wetlands and probably did not support riparian trees. Nevertheless, most of the water surface in these channels is unshaded in warm seasons, which leads to relatively high water temperatures and may cause dissolved oxygen problems because algae growth is uninhibited. The relatively wide, shallow channels created by ditching and maintained by dredging leave abundant substrate and shallow lowflow depths, which also encourages algae growth.

The improved drainage efficiency of the upper basin also may aggravate pollution problems. Subsurface agricultural drainage tends to effectively convey fertilizers to drainage channels, and nonpoint source pollution is greater when increases in drainage density occur (that is, when channel length per unit area increases). Drainage density and efficiency values commonly rise in urban areas and in poorly managed farm land. Rain and other precipitation that soaks into the ground or is temporarily stored before entering channels generally is less polluting than that flowing directly into a channel (for example, from a poorly managed farm field or parking lot).

Physical habitat and fluvial function.

Primary components of physical stream habitat include the water within a stream channel, cover, and the substrate on the channel bottom. During lowflows (and apart from chemical water quality), important characteristics of the water in a channel include velocity and depth. A reach of stream can also be characterized by the diversity in these characteristics. In general, a range of velocities and depths is considered important for a healthy ecosystem.

Woody debris is an important cover-forming element in this watershed, although overhead cover formed by grass rootmats and undercut banks is occasionally seen. Besides providing overhead cover and protection from predators, woody debris can be critical as substrate for invertebrate animals important to river ecosystems. At all sites sampled for this report, large woody debris was measured as outlined in Gough (1997). Figure 14 gives values for LWD index values for all sites sampled, as does Table A-1 (in Appendix A).

Channel bed substrates vary widely throughout the Mackinaw River watershed. Although a thin layer (usually <1 cm) of silty sediment covers beds in much of the basin, substrates range from clay to boulder-dominated sediments. Generally, the glacial till and glaciofluvial materials in the basin have been sorted and moved to leave streambeds that are dominated by gravel and cobble-sized materials. Bed substrates were recorded for all sample sites covered by this report, and have been measured for all IEPA sample sites within the basin as well (see Short 1988 and Short et al. 1996).

Sedimentation and stability.

Channel stability affects both aquatic habitat and riparian landowners. Farmers who work streamside fields are usually concerned with lateral stability of river channels because channel movement (usually seen and referred to as bank erosion) takes away prime agricultural land and usually leaves sandy, unfarmable sediments behind. Generally, the channels in the Mackinaw River Watershed are remarkably stable, however, with the exception of reaches below the Le Roy-Shelbyville Moraine, where the Mackinaw runs through sandy alluvium left behind by glacial drainage flowing through the Illinois River Valley. In these reaches, the Mackinaw River can be highly unstable. Figure 3 shows the history of lateral movement of a section of the Mackinaw River in this river segment.

River managers tend to focus on lateral channel movement, but rivers can show instability in the vertical dimension as well. Rivers subjected to channelization can show vertical instability. Increases in flood frequency and magnitude can also cause channels to downcut. This can result in higher, less stable banks, and lead to systemic channel widening and bank erosion. Generally, channels within the Mackinaw Watershed are vertically stabilized by cobbles and clay materials of glacial origin. Channels in the watershed tend to be vertically stable because modern flow regimes cannot effectively transport these materials. There is evidence throughout the watershed, however, that widespread channel downcutting has occurred in recent decades -- drops in grade are very commonly seen, for example through box culverts crossing small channels. Grade instability may also be seen as an overall increase in bed elevation resulting from systemic deposition in channels. Many of the artificial ditches in the Mackinaw River Watershed show such deposition, which is managed using periodic dredging.

River stability affects aquatic habitat quality as well. Although the influence of stability is poorly understood, it is clear that many river plants and animals are adapted to a certain amount of stability in habitat characteristics. In unstable reaches, substrates may shift with every flood, and lowflow depths are generally lower than in more stable reaches. Stable channels are typically narrower and deeper than artificially destabilized channels, and offer more shade and cover as well. Lateral channel movement (bank erosion) introduces sediment into stream channels.

Most reaches within the Mackinaw River Watershed are stabilized by bank and bed sediments that are very resistant to erosion, especially when protected by riparian vegetation. Bank sediments are typically dominated by clayey silt alluvium. The clay fraction in this material offers resistance to erosion but generally does not make hard enough to suppress plant roots. Generally, bank materials within the basin offer an excellent rooting medium, and are densely laced with the roots of riparian plants. This combination is highly resistant to erosion, and tends to form very stable banks.

Riparian forest loss.

The roots of riparian trees have a strong influence on bank stability in the Mackinaw Basin. River ecosystem health is directly influenced by the condition of riparian forests in other ways as well. Floodplain and riparian forests support terrestrial ecosystems that interact with adjacent aquatic systems. The floodplain forests along rivers provide shading, organic matter input, and contribute woody debris that is vital as cover and substrate. Large woody debris, especially entire trees, influence channel morphology by causing scour and deposition during floods. At low flows, these features increase diversity in substrate, depth, and current velocity, and create adjacent patches of differing habitat.

The above-ground parts of riparian trees influence channel morphology and fluvial process by offering hydraulic resistance to flood flows. By slowing flows over banks and floodplains, they encourage stability and deposition of sediment on these surfaces. Floodplain forests may also attenuate downstream flooding by slowing current velocities over floodplains.

At all sites sampled, riparian vegetation type was characterized as either woody or herbaceous. At each transect, the species and diameter (d.b.h., in m) of the largest tree within 1.0 W_{br} of transect endpoints was recorded, and the lower limit of permanent woody vegetation was noted for many transects. This elevation is generally controlled by fluvial process and is consistent throughout most reaches. This elevation can also be used as an indicator of bankfull, and indeed corresponded with bankfull for many, but not all, reaches sampled. Riparian vegetation characteristics can also be determined using aerial photos and the ground photos taken at each sample reach. Although forests are mapped on USGS 7.5' maps, many of the sheets covering the Mackinaw River Basin are were produced in the 1970's, and forest coverage has changed since then.

Connectivity to floodplains and flood refugia.

Floodplains are built by rivers and are a vital part of the fluvial system. Floodplains transport and store both water and sediment during overbank flows and are sources of ecologically important organic matter. On larger river systems, floodplains can become vital aquatic habitat during periods of long-term flooding (Junk et al. 1989).

The ditches of the upper Mackinaw Watershed do not have well developed floodplains, although some show signs of forming small channel "shelves" if they remain undredged for some time (see, for example, site TUR-01 on Turkey Creek). Although the land surrounding many ditches is periodically flooded, most ditches are sized so that the return interval of this flooding is much greater than that for bankfull flows on natural channels (see discussion on this type, and comparisons of sites on Henline Creek).

Most unleveed reaches of the Mackinaw River are well-connected to active floodplains. Most of these floodplains are used for row-crop agriculture. Where levees exist, the river channel is hydraulically disconnected from its floodplain, preventing storage of sediment and floodwater on these surfaces. During large floods, levees increase the river's efficiency in transporting water and sediment so that downstream reaches get more than their share. Unfortunately, it is very difficult to assess the exact influence of levees on downstream reaches. We can be reasonably sure, however, that downstream flooding is aggravated and that sediment that would have been stored on unleveed floodplains is sent downstream where it must be accounted for. The U.S. Army Corps of Engineers must frequently dredge excess sediment from the mouth of the Mackinaw. This problem is almost certainly aggravated by levees. At all sample sites, the connectivity between the river and floodplain was noted, and for at least two sites (DK-15 and DK-19) surveyed cross-sections include levees.

Hydraulic geometry, channel morphology.

Our understanding of hydraulic geometry is greatly improved by use of the bankfull flow concept in measuring and analyzing channel form and process (see Leopold 1994). Gage calibrations were performed at three sites on the Mackinaw Watershed to evaluate the presence and usefulness of bankfull indicators. These sites were PAN-01 on upper Panther Creek, MON-01 on Money Creek below Lake Bloomington, and DK-16 on the Mackinaw River near Congerville. All these sites are long-term USGS gage sites. For each site, gage records were used to develop return interval (r.i.) curves using an annual maximum series as recommended by Rosgen (pers. comm. 1995) and Leopold (1994). After this, rating curves for each gage were used to determine the elevations corresponding with stages for the 1.5-1.8 year flood. The long profile and cross section plots for MON-01, for example, show lines corresponding to the 1.5 and 1.8 year r.i. flood elevations. Figure 4a is a photograph of this site showing the bankfull elevation in relation to channel features and the lowest rooting elevation of riparian trees. Elevations tied to gage datum were determined in the field using gage survey notes provided by the Illinois District of the USGS.

Figure 5 shows W_{bf}, w:d ratio, and A_{bf} for the three gage sites plotted along with this data for all other sites in the basin. Figure 6 gives W_{bf} by site. Bankfull width for the three gage sites can be expressed by the least-squares line defined by:

$$W_{bf} = 0.7974\ A_d^{\ 0.5927} \qquad (1)$$

where A_d is drainage area in km^2. Adding data from all other sites the equation becomes:

$$W_{bf} = 2.1569\ A_d^{\ 0.3862} \qquad (2)$$

This second line plots somewhat higher than that for the three gages only, and is less steep. It also closely parallels that for data published by Dunne and Leopold (1978, data for Eastern United States, p. 614) which are also shown in Figure 5. The least squares line for equation 1 is strongly influenced by data from the Money Creek gage -- its W_{bf} lies well below the trend for sites with similar drainage areas.

At all three gage sites, bankfull elevations as determined from flow records closely corresponded with channel features. As the cross-sectional plots of these sites (Appendix A) show, a bank edge and floodplain were associated with bankfull at all three sites. The elevation of this floodplain was quite close to that of the 1.5 - 1.8 year r.i. flood. Since all three sites showed a well-expressed bank edge and floodplain at the bankfull elevation, this feature can probably be assumed to represent bankfull for the rest of the basin.

There are probably exceptions to this pattern. Rapidly downcutting channels may not properly express bankfull flow indicators. Site WAL-02 on Walnut Creek appears to have recently downcut, although it has what appears to be clear bankfull flow indicators. It does, however, have a terrace not seen at other sites which probably represents an older bankfull elevation (see cross sections, Appendix A). The Money Creek gage site (MON-01) is particularly interesting in this respect. According to the current landowner, the sample site was channelized some years ago. It has subsequently formed meanders and a clearly expressed channel shelf and bankfull floodplain that closely matches the appropriate return interval. Figure 4a is a photo of this site showing the bankfull elevation. This response is a strong indicator of the general validity of the bankfull flow concept and the tendency for channels to form floodplains at this elevation in this region. Rosgen's (pers. comm. at workshop, 1995) methods suggest that a bankfull indicator is usually found somewhat below the elevation of the highest bank edge at a site, but this tenet does not seem to hold for the Mackinaw River Watershed. Although flat-topped bars are sometimes found within channels, they are generally not correlated with other long-profile-parallel features and are usually at an elevation that is obviously much too low to define a channel capable of carrying bankfull discharges. Such a feature is indicated by the "false bankfull" note on the Panther Creek gage cross section (PAN-01 plot, Appendix A).

The correlation of bankfull flow indicators gained from these gage calibrations was used to determine bankfull channel dimensions at the remaining sample sites, excepting those that were artificially excavated. At these sites, including MER-05, MER-23, MER-16, MER-5, and TUR-01, dredge maintenance prevents the formation of a natural channel and associated bankfull indicators. Fluvial features that may represent bankfull channels were present, however, at TUR-01, MER-16, MER-23, and MER-18. These are indicated on the transect plots for these sites.

At sites showing bankfull indicators that were not clearly expressed, bankfull elevations for transects were estimated by adjusting the elevation for each transect so that the long-profile plot of bankfull elevation was parallel to that of the channel bed and water surface elevation line. For plots at these sites, the bankfull elevation value is shown just above the bankfull line (see, for example, the cross section plots for site DK-19).

Channel slope.

The slope (along the long profile) of a river reach strongly influences the velocity with which flow moves through it. Slope, hydraulic roughness, and channel cross-sectional dimensions are the primary variables determining current velocity and sediment transport capacity of a river reach. Channel slope is highly variable at the sub-reach scale at which riffles and pools are expressed. Generally, channel slope can be accurately determined by measuring water surface and bed elevations over a reach of 10 to $20W_{bf}$ in length.

Long profile plots of all sites sampled are given in Appendix A. Bed elevations were surveyed along the channel thalweg. Elevations were taken at intervals no greater than $1.0W_{bf}$, and usually at all significant breaks in slope. For reaches with very low slopes, supplementary elevation measurements were taken beyond the sample reach in order to increase the long-profile horizontal distance and increase the accuracy of slope measurement. Elevations were measured to the nearest 0.01m, horizontal distances were measured to the nearest 0.5 m. Long profile surveys were conducted with either an autolevel or laser level capable of this precision.

Generally, the low flow water surface provided a clear indication of slope. Few sites showed significant breaks in slope (see LMA-01 for an exception). Channel slope values are given on the long profile plots for all sites. In most cases, slopes were calculated using a least-squares line running through the low flow water surface elevation points.

Figure 7 shows channel slope plotted against drainage area for all sites. Most channel slopes are below 0.0015 m/m. Generally, there is only a very rough correlation between slope and drainage area. As Figure 7 shows, all sites draining more than 200 km^2 have slopes below 0.0015. There are no other apparent relationships between slope and drainage area. Figure 8, a long profile plot for the entire mainstem of the Mackinaw shows that there is no general trend in slope for the mainstem. Indeed, the mainstem slope consistently averages less than 0.00072 for most of the its length, showing only a slight increase in the river's upper reaches (Gough 1994). It is likely that the grade (or at least a strong control on grade) for the mainstem was formed by deposition of coarse materials and clay during glacial drainage and the current river regime is unable to further adjust grade.

Figure 9 gives slope by site name for all sites sampled. Only five sites, BUC-01, DKT-01, DKKC-02, MER-16, and WAL-02 show gradients of 0.0030 or higher. All these sites are strongly controlled by glaciofluvial materials -- cobbles and (except for DKT-01, which is subjected to backwater from the Mackinaw River) boulders appear in their beds, and all have bluff abutments in or near the sample site. Bluff abutment sites occur where channels cut into valley walls that typically hold till or glaciofluvial materials. These materials commonly contain cobble and boulder-sized particles that are introduced into the channel but not transported very far after being eroded. Such particles are called lag material. All these sites show high diversity in bed topography as a result of riffles formed by this lag material.

Stream power.

The relatively low slopes at all sample sites limit the energy available to erode channels and transport sediment. Specific stream power at bankfull (ω_{bf}) was computed for the three gage sites at which gage calibrations were done (See Gough 1997 for a discussion of specific stream power). Figure 10 shows ω_{bf} versus drainage area for these sites. Table 1 gives this information along with Q_{bf}, W_{bf}, and slope.

There are few published discussions of specific stream power variation by region, although it has been frequently mentioned as a meaningful metric for comparison of rivers (Nanson and Croke 1992, Marie Morisawa, pers. comm.) Nanson and Croke (1992), in a paper on floodplain classification, use specific stream power as a primary classification characteristic. In this paper, specific stream power between10 wm^{-2} and 300 wm^{-2} is classed as "medium." Probably, then most of the Mackinaw River Watershed sites sampled would fall into the low part of their medium range. This correlates well with observed sediment transport processes. D_{50} values of transported bed materials rarely exceeded 20mm at sample sites, and severe bank erosion and channel migration is quite rare.

Site	MON-01 Money Creek	PAN-01 Panther Creek	DK-16 Mackinaw River near Congerville
Slope, mm^{-1}	0.0020	0.0010	0.0010
A_{bf}, m^2	7.42	31.1	139.43
Q_{bf}, m^3s^{-1}	19.81	48.11	155.76
Specific stream power, wm^{-2}	45.2	25.26	36.4

Table 1. Slope, A_{bf}, Q_{bf}, and specific stream power (ω_{bf}) for gage calibration sites in the Mackinaw River Watershed.

Bank and bed materials.

Bed materials. Many workers analyze fluvial process concerning river bed materials using the assumption that surface bed materials are actively transported, at least with a return interval of several years. The channel assessment methods of Rosgen (e.g. Rosgen workshop pers. comm., 1995) and Newbury and Gaboury (1993), for example, employ pebble counts as primary metrics. While it is not clear that Rosgen or other workers use this metric as a index of bedload transport capacity, Newbury and Gaboury state plainly that they do, and estimate bed stability based on whether estimates of tractive force correspond with bed particle size (see Gough 1997 for a detailed discussion of this method).

Clearly, a significant portion of the largest streambed particles commonly found in the Mackinaw River Watershed are not transported by the present-day flow regime. At several sample sites large boulders appear in beds, and most sites are dominated by cobble-sized material. Typically, even small cobbles are clearly not moved -- one can pull these particles from the streambed and see that the upper and lower faces are differentially weathered from remaining in one position for at least several years. Figure 4 contains a photograph showing typical lag materials at site MER-20 on the Mackinaw River. The large particles seen in this photograph form a prominent riffle in this reach.

At each sample site, bed materials were described at transects and, sometimes, along the long profile survey. Bed materials are shown in the transect plots given in Appendix A. Although the sediment supply to most channels within the Mackinaw Watershed is clearly dominated by fine particles -- sand, silt and clay -- eroded from agricultural land, these materials do not dominate streambeds. Although the beds of many sample sites were covered by a very thin (less than 1 cm) of silt or sand, most beds were structurally dominated by gravels and cobbles. Some sites contained a significant fraction of sand as well, but silt dominated only a few sites, notably DK-21 and dredged sites. Dredged sites are in a constant state of disequilibrium -- their channels are generally oversized and prone to sediment deposition. Even so, bed materials at some ditch sites were dominated by larger (larger than sand) particles.

Generally, the dominance of relatively immobile bed materials means that channels within the Mackinaw Watershed are vertically stable and can be expected to remain so. While this is true of main channels, smaller high gradient streams may have sufficient slopes to transport large particles and adjust their grade. Cobble riffles are sometimes formed at the mouths of high gradient tributaries entering the main channel of the Middle Mackinaw, for example. Such small, relatively high gradient tributaries were not sampled as part of this study.

The materials found in many of the streambeds at sample sites are probably of glaciofluvial origin. Some materials are derived from tills excavated as channels erode the lower ends of steep valley walls (see slope discussion above). Generally, it appears that bed substrates are not a significant limiting factor in the Mackinaw except in ditched channels where beds are generally finer and much less stable. Sediment entering channels from eroding banks and agricultural land probably acts to degrade substrate habitat, however, by filling interstitial spaces and, in some cases, covering coarse particles. In general, however, the shifting, fines-dominated beds seen in some midwestern river systems are not typical of the Mackinaw Watershed.

Bank materials. Bank materials were described at all transects surveyed for this study. Most surficial materials in the basin are of glacial origin (excepting aeolian loess that covers parts of the basin), and at least four recessional moraines arch through the basin (see Gough 1994 and cited studies). Channels within the middle-to-lower watershed generally run through alluvium deposited well after glacial drainage. Most ditched channels run through heavy clay tills that are highly resistant to erosion. Farther down the watershed, bank materials can be highly variable, especially where channels abut valley walls. These walls can range from very well-consolidated clay till to almost pure sand (a prominent sand-dominated bluff appears below the DK-15 sample site). Generally, these bluffs are dominated by clays that hold gravel to boulder-sized particles, however. These bluffs are generally quite resistant to erosion, but may sometimes show slump failures after large floods.

Most streambanks formed of alluvium are dominated by clayey silt. Generally, this grades to poorly-sorted till material that contains more clay and also gravel to boulder sized particles, although the elevation of this interface varies widely throughout the basin and is not always clear because bank toes are often covered by displaced alluvium that is laced with plant roots. The appearance of tills at bank toes probably indicates incision of most channels after European settlement, but much more detailed work would be required to date this incision. The incision into till and glaciofluvial materials was halted by those materials, however, for most larger channels. Smaller, high gradient channels throughout the basin show signs of downcutting that is largely controlled by constructed drainage structures (e.g. box culverts) that are ubiquitous along section lines in the basin.

The roots of riparian vegetation formed dense networks in streambanks at almost every sample site in which alluvium formed channel banks. The clayey silt alluvium, although relatively resistant to erosion, appears to be soft enough to allow root penetration and forms a rich rooting medium. The combination of alluvium and plant roots is generally very resistant to erosion, at least by flows typical of this basin. This accounts for the remarkable lateral stability of most sampled reaches in the Mackinaw River Watershed.

Riparian vegetation.

Riparian vegetation type was recorded for all sites sampled as either herbaceous or woody, and notes on other characteristics of riparian vegetation and associated floodplains was recorded. This information can be seen on the transect plots in Appendix A and is available in digital data files. At all transects, the taxa (to genus level at least) and diameter (as d.b.h.) of the largest tree within 0.5 W_{bf} of transect endpoints was recorded. This information is also recorded in digital data files.

Mature riparian trees can be used to determine past channel stability. At many sites on the Mackinaw Watershed, mature trees are rooted very near the low flow water surface elevation along both banks, indicating lateral stability over a period of at least a few decades. An example of this condition is given in Figure 4, which shows a photo of site DK-20 on the Mackinaw River.

Most ditched channels within the watershed are kept almost completely free of woody vegetation. Conversely, most other channels are bordered by at least a thin band of trees. In the first decades for which aerial photographs are available for the basin -- from the late 1930's through the 1970's -- riparian forests were much less extensive in the Mackinaw Basin, probably as a result of the combined pressures of intensive row-crop agriculture and grazing. This pattern can also be seen by examining USGS 7.5' topographic maps of the Mackinaw River Watershed, many of which were first published in the 1970's. For example, comparison of the Secor 7.5' quad map, published in 1970, with recent aerial photographs shows much more extensive wooded areas both along the middle Mackinaw and lower Panther Creek. Relatively steep valley walls and the riparian areas of smaller tributaries show this same trend.

Row crop agriculture dominates the Mackinaw River Basin (see landuse data and discussion in Gough 1994). Wooded areas generally occurs in riparian areas and on valley walls and morainal topography where slopes are relatively steep. The areas between levees and river channels, and the levees themselves, are generally wooded as well (see, for example, leveed reaches on the Hopedale 7.5' quad map).

Many of the recently revegetated riparian areas (i.e. those allowed to regrow after grazing or farming pressure was removed in the 1960's and 1970's) are dominated by early successional species, most commonly silver maple (*Acer saccharinum*) that form relatively even-aged stands. This is especially true when riparian forests are very thin, often only one tree thick. Such thin riparian forests are commonly seen in the watershed. Older forests are much richer in terms of species diversity and age structure. Indeed, the history of most riparian areas can be easily determined by looking at this structure, which can be seen in many of the photos taken at sample sites.

The character of woody debris in channels is strongly influenced by the structure of adjacent and upstream riparian forests, depending on channel size and lateral channel migration. Young even-aged stands are not particularly effective in generating woody debris that is persistent in channels. Very large, old trees are typically more persistent as woody debris when they fall into stream channels -- either after dying or from bank erosion. Such debris can be seen at site DKB-01 on the West Branch of Panther Creek and at DKT-01 on Crooked Creek. These sites are both bordered by relatively old, structurally diverse riparian forests.

Classification of the Mackinaw River Watershed

Site selection, designation, sampling dates, and flow conditions during sampling.

Many of the sites selected for the geomorphic measurements presented here were on or very near sampling sites used for previous Illinois Environmental Protection Agency (IEPA) studies of the basin. At many of these sites, designated by alphanumeric codes beginning with "DK," biological measurements were taken by The Nature Conservancy, as reported in Retzer (1996b). Given the limitations of time and budget, sites were chosen to represent as many different segments of the Mackinaw and its tributaries as possible. Within some watersheds, notably Prairie Creek, Mud Creek, and the Little Mackinaw River, non-IEPA sites were chosen. These sites are designated by alphanumeric codes not beginning with DK. Sites chosen by Michael Retzer of The Nature Conservancy are denoted by MER- followed by two numbers. Those chosen by me use significant letters of the stream's name, usually the first three (e.g. PAN-01 for Panther Creek).

Based on general knowledge of the basin and consensus among conservation workers familiar with the Mackinaw Watershed, most of the sample sites were chosen to represent the best known habitat conditions within a given segment, or as "reference" sites to which degraded sites can be compared. Exceptions include DK-12, which lies above a channelized reach, WAL-01, which is partially grazed, and MER-18, which is also impacted by cattle.

Geomorphic field measurements were done from August, 1995 through July, 1996. Sampling dates for all sites are contained in digital data summaries and in the index for site photographs. The spring and early summer of 1996 were relatively wet, and several sites were sampled during times of high flow. For this reason, water surface elevations at some sites are significantly above typical lowflow conditions (see, for example, data for sites MON-01, BUC-01, and TUR-01). Digital data files for each site contain comments on stage, weather, and flow conditions during and preceding the sampling data. All field measurements were done by the author.

Classification characteristics

Drainage areas.

Drainage areas for all sample sites are given in Figure 1. Drainage areas for many other sites within the basin are available in the digital data files created during this process (see Appendix A). All but eight sample sites drained less than 500 km^2, seventeen of the sites drain less than 200 km^2. Drainage areas and other key classification characteristics are given in Table 2.

Table 2. The following four pages show classifications and key classification characteristics for the Mackinaw River Watershed, including drainage area, W_{bf}, bed and bank materials, ecosystem stresses, and riparian vegetation. Values for W_{bf} are not available for Type 1 sites because these reaches are dredged ditches.

Type/subtype	drain-age area, km^2	W_{bf}, m	channel slope	controlling bed materials	controlling bank materials	Typical vegetation	floodplain connection	stresses and landowner concerns	Sample sites
1. Low-slope headwaters	10-170	n/a	low, usually <0.001	clay to cobbles	clay	grass and rowcrops	limited by ditching and spoils levees	ditching and dredging, tile drains, lack of cover and natural riparian vegetation	MER-5, TUR-01, MER-16, MER-23
2. High-slope tributaries	<50	<5	generally > 0.008, as much as 0.010	not sampled, probably cobbles and boulders	not sampled	young to mature forest	not sampled	poor landuse, past clearing/grazing of riparian corridor	none
3. Low-slope tributaries	90-280	<20	0.0004 - 0.0048	cobbles - boulders	clayey-silt with tree roots	thin forest	usually natural	lateral instability, logjams, vulnerable riparian forests, poor water quality	LMA-01, MUD-01, PRA-01, WAL-01, DKKC-02, DKP-02, MON-01, DKKB-01, PAN-01
3c. Confluence reaches	90-280	<20	0.0004 - 0.0048	cobbles - boulders	clayey-silt with tree roots	mature, wide, riparian forest	usually natural	lateral instability, logjams, poor water quality	BUC-01, DKT-01, DKV-01,
3u. Urbanized reaches	90-280	<20	0.0004 - 0.0048	cobbles - boulders	clayey-silt with tree roots	variable	usually natural, but altered by channel incision	dumping, water quality, incision, alteration, channelization	WAL-02

Type/subtype	drain-age area, km^2	W_{bf}, m	channel slope	controlling bed materials	controlling bank materials	Typical vegetation	floodplain connection	stresses and landowner concerns	Sample sites
4. Upper Mackinaw River and lower Panther Creek	310-829	20-30	<0.0010	cobbles-boulders	clayey-silt with tree roots	thin to wide wooded corridor, sometimes with diverse age/species structure	natural	flooding, thin corridors, logjams, floodplain scour	DKK-02, DK-20
4b. bluff abutments	310-829	20-30	<0.0010, may be locally high where lag particles occur	cobbles-boulders	clayey-silt with tree roots	same as above, but wide and diverse forests more common	natural	flooding, logjams	MER-10
5. Middle Mackinaw River between Money Creek and Walnut Creek	1001-1755	27-45	<0.0009	cobbles-boulders	clayey-silt with tree roots	similar to type 4, but with generally thinner wooded corridor	natural, levees sometimes found	flooding, thin corridors, logjams, floodplain scour	DK-17

Type/subtype	drain-age area, km^2	W_{bf}, m	channel slope	controlling bed materials	controlling bank materials	Typical vegetation	floodplain connection	stresses and landowner concerns	Sample sites
5b. Bluff abutments	1001-1755	27-45	<0.0009	cobbles-boulders	clayey-silt with tree roots, clay till with lag cobbles	wide, diverse wooded corridor more common than for type 5	natural, levees sometimes found	flooding, thin corridors, logjams, floodplain scour	DK-17
6.Mackinaw River from Walnut Creek to Dillon Creek	1880-2600	45-55	<0.0006	cobbles-boulders	clayey-silt with tree roots	variable, row crops or single row of trees common	levees common	flooding, levee maintenance, bank erosion, water quality	DK-16, DK-15, MER-20
6b. bluff abutments	1880-2600	45-55	<0.0006, some-times locally higher	cobbles-boulders	clayey-silt with tree roots, clay till with lag cobbles	wide, diverse wooded corridor more common than for type 5	levees common	flooding, levee maintenance, bank erosion, water quality	see reach below DK-15

Type/subtype	drain-age area, km^2	W_{bf}, m	channel slope	controlling bed materials	controlling bank materials	Typical vegetation	floodplain connection	stresses and landowner concerns	Sample sites
6c. Channelized and/or leveed	1880-2600	45-55	<0.0006, some-times locally higher	cobbles-boulders	clayey-silt with tree roots, clay till with lag cobbles	wooded corridor often defined by levee tops, generally younger, less diverse	usually leveed	flooding, levee maintenance, bank erosion, water quality	DK-19
6m. Morainal traverse	2000-2600	45-55	<0.0006, some-times locally higher	cobbles-boulders	lag cobbles and boulders	wide, diverse wooded corridor more common than for type 5	levees less common, floodplain very narrow	flooding, slope failure	
7. Lower Mackinaw River	2680-2921	55 - 70	<0.0006, some-times locally higher	cobbles-boulders	variable -- clayey-silt with tree roots, oxbow fill sediments, and sandy alluvium	highly variable --rowcrops, young willows on large bars, mature forest	variable, levees common	flooding, floodplain scour and sedimentation, severe bank erosion	DK-12

Channel morphology.

Downstream hydraulic geometry within the basin generally showed expected patterns, but high variability for sites draining less than about 200 km^2. Figure 5 shows W_{bf}, A_{bf}, and w:d ratios versus drainage area for all sites sampled. No drainage area range was sampled sufficiently to perform meaningful statistical analyses, particularly in the lower watershed, but some trends are apparent. Trends for W_{bf} were discussed in the previous section. Values for W_{bf} at sites draining less than 200 km^2 range from about 9 m to almost 20 m, with no apparent increase within this range. Values for A_{bf} also showed high variability for sites draining less than 200 km^2.

Generally, however, the width:depth ratio remains remarkably stable, ranging between 8 and 17 (with a few exceptions). The w:d ratio climbs above 20 for the two lowest sample sites, however (DK-19 and DK-12). Site DK-19, which drains 2516 km^2, is impacted by channelization -- the entire reach was channelized sometime prior to 1970. Site DK-12 lies on the old Illinois River floodplain. Its banks are largely composed of erodable sand-dominated materials, and it is impacted by upstream influences and a long channelized reach beginning just below the sample reach.

Values for w:d ratio cluster closely between 9 and 12 for sites draining from 90 to 200 km^2 (see Figure 11). The five sites draining less than 90 km^2 had widely varying w:d values -- from 7.08 for DKT-01 on Crooked Creek to 15.15 for LMA-01 on the Little Mackinaw River. From the data available, then, it appears that w:d ratio is a good diagnostic measure for reaches draining between about 90 and 2500 km^2. For these segments, w:d ratios range between 8.4 and 14.75. As Figure 11 shows, two sites, MER-18 and MER-10, lie at the top of this range. MER-18 is impacted by cattle grazing and MER-10 is a bluff abutment site strongly controlled in the vertical dimension by lag particles, which likely explains its w:d ratio.

Since w:d ratio showed a relative constancy for most sample sites, it follows that bankfull channel mean depth (d_{mean}) should show variability similar to that of bankfull width. Bankfull channel mean depth is calculated for all transects using the formula $d_{mean} = A_{bf} / W_{bf}$. Maximum bankfull depth (d_{max}) showed the most variability of any channel morphology measurement. Values for both are plotted against drainage area in Figure 12. Maximum bankfull depth is defined here as the maximum distance from bankfull elevation to the streambed for all transects within a reach, and is recommended as an assessment metric by Rosgen (pers. comm., workshop, 1995). Values for d_{mean} are variable at the reach, segment and watershed scale, but generally increase in a downstream direction. Values for d_{max} do so as well, but may be strongly influenced by local geologic control or hydraulic controls such as the presence of large woody debris that creates scour holes. Such features were generally avoided as transect sites, however, so maximum depths within transect reaches probably exceed the d_{max} values given here.

While d_{mean} values are important as a component of the w:d ratio, d_{max} values can be valuable as an indication of channel characteristics influencing manageability. Values for d_{max} can also indicate the tendency for channels to be laterally unstable. All other things being equal, banks that are higher tend to be both more prone to erosion and more difficult to revegetate.

Sinuosity.

At each sample site, a river segment including the sample site and of generally similar sinuosity was chosen for measurement. Sinuosity was measured from recent (1988 or later) 1:40,000 aerial photographs, and is given in Figure 13. Sinuosity generally ranged between 1.10 and 1.26, values considered low for meandering rivers (Rosgen, pers. comm. and unpublished workshop materials, 1995). A few sites -- DK-21, MER-20, and DK-12 --had sinuosity values above 1.40. Sinuosity varies widely throughout the basin, often over a scale of a few reach-lengths. Tributaries to the Mackinaw commonly show a sharp increase in sinuosity as they enter confluence zones. This occurs as the Mackinaw River confluences of Henline Creek and Buck Creek on the Cooksville and Lexington 7.5' maps, respectively.

I was able to find no apparent trends in sinuosity, except perhaps a slight increase in sinuosity with increasing drainage area. This trend would perhaps be clearer had not DK-19 been channelized. This site was highly sinuous prior to its pre-1970 straightening -- former meanders can be clearly seen on maps and aerial photographs. Aside from ditches (which generally are straight, and thus have a sinuosity of 1.00), sinuosity was not influenced by channelization for other sites. Sinuosity is an important classification characteristic in the Rosgen System, and is discussed with respect to that system below.

Bank and bed materials.

Although bank and bed materials are remarkably similar for most of the sampled sites, these characteristics can be important for classification and assessment, especially for river systems in which bank and bed material characteristics are more variable. As discussed earlier in this report, bed materials at all sample sites probably act as strong vertical controls on channel form -- most river segments within the basin are probably vertically stable. I am aware of only one case of active headcutting, reported on Dillon Creek just west of the City of Dillon (pers. comm., Don Roseboom, Illinois State Water Survey). Bed materials vary little over segment scales in this watershed. At the smaller reach scale, however, bed materials may be influenced by local geologic and landscape controls. Bluff abutment reaches tend to be dominated by large lag particles -- cobbles and boulders -- left behind as the bluff is eroded. These sites, including MER-10 and LMA-01 can have high slopes and high w:d ratios. Sometimes steep, riffle dominated reaches appear at bluff abutment sites. Such a reach lies immediately downstream of site DK-15. These sites may be very ecologically important because parts of the mainstem of the Mackinaw River generally lack riffle habitat. No riffle occurs for at least 1.0 km upstream of the DK-15 bluff abutment site, for example, perhaps because bed sediments from bluff abutment sites act as strong grade-controls that form extensive upstream pools, which, in this case, includes the entire DK-15 sample reach.

I found almost no correlation between drainage area or channel size and bed materials. Although bed coverage by finer materials, including sand and gravel, varied by site, at least cobble-sized particles appeared at every site (bed materials are shown on transect plots, Appendix A). Channel management does appear to affect the quality of substrate habitat in at least one case -- recently dredged channels tend to have finer bed materials that are generally poorly consolidated. This response is predictable, given the depositional nature of these artificially maintained channels.

Riparian vegetation.

Riparian vegetation is strongly influenced by row-crop agriculture in the Mackinaw River Watershed. Most of the floodplain area within the basin is used for farming. Riparian forests exist where land is unsuitable for agriculture or landowners have chosen to manage for at least a thin riparian forest (here *wide* and *thin* apply to thickness of the forest in a direction perpendicular to the channel's flow). For these reasons, riparian vegetation structure at sample sites falls roughly into at least seven categories, including:

--herbaceous vegetation, usually grasses, only at ditched sites and sites grazed, farmed or mowed to the channel margin
--wide, sometimes older, diverse, riparian forests at confluence reaches
--thin (sometimes only one tree thick) bands of riparian trees between channels and row-cropped fields
--riparian forest on steep, unfarmable bluffs bordering the river channel
--relatively wide riparian forests between main channel levees and the river channel, common in lower reaches of the Mackinaw River
--riparian forests, generally wide and diverse, at farmable sites where landowners have chosen to manage for forest habitat
--riparian forests, generally wide and diverse, within narrow and/or steep tributary valleys generally unsuitable for rowcrop farming

Most of these types can be seen on the Mackinaw 7.5' quad map in the area around site DK-15. A typical confluence area (site DKV-01 and the reach between it and the Mackinaw River on Henline Creek) and ditched channels can be seen on the Cooksville 7.5' quad map and recent vertical aerial photographs of this area. Photographs of riparian forests along three stream reaches are given in Figure 4.

Management and local controls.

Local controls include river characteristics that may vary at the reach scale to alter channel morphology and habitat values. These include channel and floodplain management, local changes in bed and materials, and changes in hydraulics, geology, or riparian landscape characteristics determined by a reach's location on a floodplain or within the drainage net. Examples of the last condition include reaches or sub-reaches in which the channel runs alongside a steep valley wall and confluence sites where two channels join. Common human impacts on channels within the Mackinaw River Watershed include:

--channelization, ditching and dredging
--suppression of riparian trees
--bridges and pipeline crossings
--livestock grazing
--levees
--bank armoring for erosion control, commonly with broken concrete slab material in this watershed
--beaver dams

It is common for beaver to build small dams in the upper portions of the watershed. A rather large dam that affected several hundred meters of low-flow water surface level appeared below site PAN-01 on Panther Creek during this study.

Confluence-affected reaches are common on the Mackinaw Watershed. Some of the most biologically diverse sites are confluence sites, including site DKV-01 on Henline Creek. This is probably due in part to the connection such sites have with the mainstem of the Mackinaw, which provides a migration route to permanent wetted habitat (see Osborne and Wiley 1992, in which this effect is discussed for the Mackinaw and other watersheds in Illinois). These sites are also subjected to backwater during times of flood, especially when a smaller tributary joins the Mackinaw River, which may rise 3 or more meters in elevation during a flood, drowning the lower reaches of the tributary. Probably because of frequent flooding, confluence sites also tend to be managed as forestland by landowners, further enhancing their ecological value and inputs of large woody debris.

Site DKT-01, on Crooked Creek, is the most profoundly influenced confluence site sampled. Although several other sites, including DKV-01 on Henline Creek and BUC-01 on Buck Creek, are near enough to the Mackinaw River to be influenced by it, the Crooked Creek site's downstream end is less than 100 m from the Mackinaw River's channel, and most of the sample reach lies in the Mackinaw's floodplain. Such reaches are heavily influenced by backwater effects, and the large volume of woody debris in this reach is probably due in part to this effect. This reach also shows a very low w:d ratio of 7.08 at least in part because the reach runs in the Mackinaw River's floodplain. The elevation of this floodplain is controlled by the processes in the larger Mackinaw River. As Crooked Creek cuts through this floodplain, its channel depth must match that of the Mackinaw's (to properly meet its grade), while its bankfull width value remains relatively unchanged, resulting in a low width:depth ratio.

Application of the Rosgen system.

Rosgen's stream classification is discussed in detail by Rosgen (1996) and Gough (1997). Few of the reaches measured for this study clearly fit into this system. All are single thread channels (although some anastomosing channels existed on the Watershed in decades past -- see Figure 3) and classify as "slightly entrenched." Entrenchment values for all channels were much greater than 2.2, with the exception of the incised channel at site WAL-02 on Walnut Creek, which has an entrenchment ratio of 2.7 or less (this site has obviously undergone recent adjustment, and bankfull indicators were not clear). These characteristics clearly place these channels into the E or C categories. Width:depth ratios, the next classification characteristic, are generally compatible with these two types. Those with "very low" w:d ratios (<12) fall into the classification branch leading to E-type channels, those with "moderate to high" w:d ratios >12 fall into the C category. Both these categories require high (>1.4) or very high (>1.5) sinuosity, however. Only two sites, MER-20 (at 1.45) and DK-12 (at 1.44) have sinuosity values between 1.4 and 1.5, and only DK-21, with a sinuosity of 1.59, exceeds the 1.5 breakpoint. Thus DK-12 would fall into the E type, and sites DK-21 and MER-20 would fit into the C type. All three sites have gravel beds in which cobbles and boulders also appear (and probably control grade, especially at sites DK-12 and MER-20).

Rosgen's system does allow for interpretation and loosening of classification characteristic value ranges, at least according to unpublished workshop materials from a 1995 session I attended. If the sinuosity value breakpoint between C and E channels is lowered from >1.4 to >1.2, then most sites in the Mackinaw Watershed would classify as C channels.

The Rosgen classification for a reach is heavily influenced by the entrenchment ratio value. It appears that many midwestern streams, especially those in glaciated regions, have very high entrenchment values, e.g. the "flood prone" areas include the entire valley flat. At site DKKC-02 on the East Branch of Panther Creek, the entire valley flat was surveyed, along with high water marks from a recent flood that clearly show the entire valley to be flood prone. At this site, the entrenchment ratio exceeds a value of eight. While geologically older fluvial landscapes (i.e. unglaciated or uplifted) often show terrace sets that lead to lower entrenchment values, my experience and that of colleagues (e.g. John Fantz, Missouri Department of Conservation, pers. comm.) indicate that these features are poorly expressed or nonexistent in many midwestern channels. Thus Rosgen's system classifies all such single-thread channels (i.e. those that are "slightly entrenched, with values >2.0) as either E or C channels.

Mackinaw River Watershed segment types.

In the following section, channels within the Mackinaw River Watershed are classified according to methods and rationale outlined in Gough (1997). This ordering is necessarily descriptive because channels within the watershed share a remarkable number of features, and some primary geomorphic characteristics such as channel slope do not vary systemically in the basin.

As described in Gough (1997), classification systems should be applicable to broad regions, but should be adaptable to the goals of the projects for which they are used. This classification is done primarily to enable protection and restoration of the Mackinaw River Ecosystem. It is also adapted to goals of The Nature Conservancy's Mackinaw River Project. This project is aimed at holistic watershed planning and management -- it is organized to not only manage the watershed for ecological goals but also those of stakeholders, primarily farmers, who live in the watershed. Because the Mackinaw River Project includes stakeholders in all steps of decision-making processes, this classification system is designed to address concerns of a wide array of interests, and present information in ways that are meaningful to them.

This section also offers best management practices (BMP's) for each river segment type. Stream types are organized in order of increasing drainage area (and, generally, channel size), which is the most significant classification characteristic for channels within this watershed. Other primary classification characteristics are drainage net position (particularly for confluence sites), local geologic control, and local management.

Type 1
Low-slope headwaters streams

General description.

Upland streams draining areas of low slope either on top of or between moraines. Representative sites include MER-5 on Henline Creek, site TUR-01 on Turkey Creek, and MER-16 and MER-23 on the upper Mackinaw River. Segments of this type are easily identified from maps and aerial photographs by their lack of riparian forests and straightness. Much of the landscape on which these channels occur was very poorly drained before European settlement. Nearly all of these channels have been ditched and are fed by tile drain systems. Most do not have natural floodplains. A majority of the headwaters streams in the basin fit this type, excepting the high slope tributaries type listed below.

Drainage areas.

Ditched channels generally drain < 170 km^2, and usually <100 km^2. Management as ditches tends to end when drainage area becomes too large or topography prohibits it, as when channels enter floodprone confluence sites.

Channel morphology, process, and composition.

Ditched channels are generally maintained to be much larger than natural channels draining similar areas might be. Compare, for example, cross-section plots for sites MER-5 and DKV-01 on Henline Creek. Channel geometry analyses here do not include these sites because bankfull channel determinations could not be made. Dredging generally prohibits the formation of a bankfull channel or floodplain, although some channels display such features if they remain undredged for some time. See cross-sections for site TUR-01, for example. Reaches within this segment type are almost universally depositional in nature because their channels are generally oversized and fed by sediment eroded from row crop fields. Most appear to have been managed as grass-bordered ditches since they were first built, and most appear to be horizontally stable because bank materials are generally quite resistant to erosion. Although larger ditches appear to be resistant to downcutting, evidence abounds in the basin of downcutting of very small drainage ditches (i.e. those roughly less than 3 m wide). This downcutting may have been a response to dredging and general disturbances to grade caused by ditching and ditch management. Most of this downcutting is controlled by drainage structures such as box culverts, however.

Bed materials vary, but tend to include cobble and even boulder-sized materials that act as strong vertical controls. Recently dredged sites can be dominated by very loose sand, silt, and fine gravels that rapidly replaced dredged material. Bank materials tend to be clay-dominated tills and clayey wetland soils which are highly resistant to erosion, and serious bank erosion appears to be rare.

Slope and sinuosity.

Slopes are generally quite low, <0.001, although some sites show high slopes for drainage ditches, which, in glaciated regions, have slopes of <0.0004 or less. Generally, these ditches are straight with only occasional artificial bends. Lowflow channels in ditches not dredged for some time can show regular meandering within the ditch boundaries, however.

Riparian vegetation and large woody debris.

Generally ditches are kept almost completely free of woody vegetation and are bordered only by introduced grasses. Ditch banks are, however, generally inviting to woody species (although their clayey nature may discourage some species). At most sample sites, ditch banks did not appear to be excessively dry in the summer months. Most ditches are bordered by levee-like accumulations of dredge spoils and are farmed to within a few meters of the channel (see cross-section plots). Dredge spoils are commonly dominated by sand, but contain gravel and cobble-sized particles. Ditched reaches generally lack both local and upstream sources of woody debris and are almost universally free of any woody cover.

Floodplain connection.

Ditches generally have no natural floodplain.

Management concerns.

Ditches are seen by the many of landowners as biologically sterile drainage structures, although many harbor significant aquatic ecosystems. Landowners are concerned with dredging and vegetation removal to reduce roughness and keeping channels large to pass floodwaters as effectively as possible. Ditches do this well, and probably contribute significantly to downstream flooding within the Mackinaw River Watershed.

Subtypes and variations.

Within this drainage area range there are many small drainages in areas of higher relief that are not ditched. These are discussed in the following type description. Some ditches appear to be dredged much less frequently than others. These probably have higher habitat values than more frequently dredged channels. These ditches have better expressed pool-riffle structure, more stable and generally larger substrate, and some overhead cover in the form of slightly undercut channel shelves (see TUR-01).

Type 2
High-slope tributaries

General description.

This type was not directly measured for this study. These channels drain relatively high relief watersheds associated with the main channel of the Mackinaw River, Panther Creek, or morainal features. Examples of these small drainages can be seen in abundance in association with the Eureka Moraine in the area around the confluence of the Mackinaw River and Panther Creek on the Secor 7.5' quad map. They are also common in association with the Bloomington Moraine farther down the watershed, as seen on the Mackinaw 7.5' quad map. The Red River, a tributary to the lower Mackinaw River, stands out as a larger example of this type. This watershed was not assessed for this study, but may have erosion problems associated with poor land use and relatively high relief.

Drainage areas.

Drainage areas are small, generally <50 km^2, often <5 km^2.

Channel morphology process, and composition.

These sites were not sampled, but can be seen entering main channels in areas of relatively high relief, where they often leave deposits of rather course material, sometime cobbles-sized particles. These deposits may be important as riffle-forming structures, especially on the main channel of the Mackinaw River in the two areas mentioned above. Slopes may be quite high.

Slope and sinuosity. The lower Red River's slope approaches 0.009 and smaller tributaries along the Mackinaw's main channel near site DK-17 exceed 0.010 (from 7.5' maps). Sinuosities were not measured for this type.

Riparian vegetation type and management.

The watersheds and riparian areas of these channels have generally been allowed to recover from grazing pressure over the last few decades. There is some concern that the relatively high slopes of these watersheds generate high sediment loads under closed-canopy forest cover than under more savanna-like cover that probably existed prior to European settlement (Roger Anderson and Don Roseboom, pers. comm.). Again, research is lacking, but ongoing work in other watersheds by Don Roseboom of the Illinois State Water Survey may shed some light on this problem.

Management concerns, floodplain connection, and subtypes.

These channels and their watersheds should be further examined for potential erosion problems and signs of delivery of excess fine sediment to main channels. The riparian areas of some of these channels may represent important riparian wildlife habitat, particularly because they are connected to the riparian corridor of the Mackinaw River. Floodplain connection and subtypes were not determined for this type.

Types 3, 3a (confluence sites), and 3u (urban-influenced) Low-slope tributaries.

General description.

Tributaries to the Mackinaw River, a short section of the Mackinaw River above Henline Creek, and Panther Creek draining from 90 km^2 to about 280 km^2. These channels are primarily classified by drainage area and watershed relief. Watershed relief and channel slopes, which range from 0.0004 to 0.0048, are relatively low. The upper reaches of most of these watersheds are ditched.

Representative sites include site DKV-01 on Henline Creek, DKT-01 on Crooked Creek, DKP-02 and MON-01 on Money Creek, BUC-01 on Buck Creek, WAL-01 and WAL-02 on Walnut Creek, MUD-01 on Mud Creek, PRA-01 on Prairie Creek, DKKB-01 West Branch of Panther Creek, DKKC-02 the East Branch of Panther Creek, PAN-01 on Panther Creek, DK-21 on the upper Mackinaw River, and LMA-01on the Little Mackinaw River.

Most of these channels have shown regrowth of riparian trees following periods of intensive riparian landuse (usually grazing) in the 1960's and 1970's. Some of the lower reaches of these channels were channelized (e.g. site MON-01 on Money Creek, and MUD-01 on Mud Creek), but most have recovered from this management and are not actively manipulated. These channels have generally shown remarkable lateral stability over the period for which aerial photographs are available.

Drainage areas.

At their mouths, these channels drain from about 90 km^2 to about 280 km^2. Most sample sites on these tributaries drain considerably less than 160 km^2, however.

Channel morphology, process, and composition.

Bankfull width for these channels is generally < 20 m. Width: depth ratios for sample sites within this type range from about 8 to 13, and generally are less than 12.5 as shown in Figure 11. D_{max} values are generally < 1.75 m and d_{mean} values < 1.5 m. Bankfull indicators were generally strongly expressed at these sites. Bluff abutments occur on these tributaries and represent strong local controls on channel morphology and process.

Bed materials are dominated by gravels, but beds at all these sites held cobbles and sometimes boulders, indicating strong vertical control. Sometimes fresh deposits of sand occur. Although some sites contained strongly expressed inchannel sedimentary features (point and midchannel bars), others, such as PAN-01 and DKKB-01 showed few bars or only low bars composed of very coarse material that is probably immobile. The site photos clearly show these differences for most sites.

Bank materials ranged from clayey tills to clayey silt alluvium. Sandy alluvium appeared in channel shelves at some sites (see, for example, PRA-01, transects 8 and 9). The bank materials within this type generally combined with riparian vegetation to form very erosion-resistant channel margins, making these channels quite laterally stable when well-vegetated.

Slope and sinuosity.

Slopes vary widely, with no discernable pattern related to drainage area. Watershed relief and channel slopes, which range from 0.0004 to 0.0048, are relatively low. Sinuosity for these sites is generally low, ranging from 1.10 to 1.30.

Riparian vegetation and large woody debris.

These sites are usually bordered by at least a thin band of trees. Some sites showed a mixed-age, taxonomically diverse riparian forests (e.g. DKKB-01 on the West Branch of Panther Creek). Others, PAN-01 on Panther Creek, for example, show wide, unmanaged stands of even aged trees as a result of being "let go," in the 1970's or early 1980's. In most cases, the lowest elevation of riparian trees approaches the low water elevation (see transects and site slides for BUC-01 on Buck Creek, for example).

Large woody debris index values (see Figure 14) were generally highest for this type. These channels are small enough for logjams to occur, although this accounted for a high woody debris value at only DKT-01 on Crooked Creek (which is also a confluence site). This site also shows how the potential for woody debris cover is high when old growth trees are present near the channel.

Floodplain connection.

These sites are generally well-connected to wide, active floodplains. Small natural levees are sometimes present.

Management concerns..

Although landowners are sometimes concerned with bank erosion, as evidenced by riprapping of banks (almost always with broken concrete slab material) at some sample sites, lateral erosion problems are probably more perceived than real. Landowners are likely concerned with flooding at these sites, but the best solution for this is improved upstream water management. Logjams may be a problem at these sites, but appear to be rare because very large trees are either lacking or are not moveable by these channels -- flow regimes lack the capacity to transport large trees any significant distance, precluding formation of large jams. Urban influenced segments include Prairie Creek, whose upper reaches are dominated by the City of Morton, and lower Walnut Creek below Eureka. These segments suffer from typical water quality problems (see Retzer 1996b) and from increases in flood magnitude and frequency.

Riparian forests often provide nearly complete shading of these narrow channels -- the canopy closes over some sites (e.g. DKV-01 on Henline Creek, DKT-01 on Crooked

Creek). These sites generally contain high quality habitat, and rank among the highest in Illinois in the Illinois BSC classification (see also Retzer 1996b).

Many of these segments are impacted by poor water quality (see Retzer 1996b), and by heavy sediment and water loads from ditched agricultural land in their upper watersheds. Their relatively small, erosion-resistant channels appear to very effectively move fine sediment (sand and silt) through these segments during floods, however.

Subtypes and variations.

Confluence sites (type 3a) form a significant subtype. Site DKT-01 on Crooked Creek is the most profoundly influenced confluence site. As tributaries of this type grade into the Mackinaw River or Panther Creek valleys they become more sinuous and riparian forests become wider and more diverse. This likely occurs because these areas are more floodprone and difficult to farm (as related by at least one landowner). These areas may also be subject to heavy floodplain deposition -- the floodplain around the confluence site at PAN-01, where the East Branch of Panther Creek enters Panther Creek shows signs of significant deposition in the form of "telephone pole" trees and buried fencepoles.

Urban influenced segments (type 3u) are influenced by poor water quality, mostly from wastewater, but perhaps from urban non-point sources as well (see Retzer 1996b). These channels also signs of increased flood magnitude and frequency, especially lower Walnut Creek, which shows clear signs of recent incision, but is probably now vertically stable. Bank erosion may be a serious problem in this segment, however, is channel width and slope continues to adjust.

Types 4 and 4b (bluff abutment sites)
Upper Mackinaw River and lower Panther Creek

General description.

Mackinaw River above its confluence with Money Creek and Panther Creek from the entry of its West Branch to its confluence with the Mackinaw River. Representative sites include DKK-02 on Panther Creek and DK-20 and MER-10 on the Mackinaw River. Channel size and lowflows become large enough to provide significant year-round aquatic habitat and often wide wooded river corridors, but still small enough that channels are well-shaded, especially at bluff sites. Channels are generally very stable laterally and not significantly affected by direct channel alteration (e.g. channelization). Historical photos show signs of instability at some lower Panther Creek sites (and possible channelization), but most reaches remained remarkably stable despite widespread removal of riparian trees (which have now mostly regrown). Sites DK-20 and MER-10 on the Mackinaw River and DKK-02 on Panther Creek lie within this segment.

Drainage areas.

On Panther Creek, drainage area ranges from 310 km^2 on below the mouth of the West Branch to 441.7 km^2 at its confluence with the Mackinaw River. This segment of the Mackinaw River drains from about 390 km^2 below the mouth of Henline Creek to 829 km^2 above its junction with Sixmile Creek.

Channel morphology, process and composition.

Bankfull widths are generally between 20 and 30 m, and d_{mean} values run from 2.0 to 2.2 m. Width: depth ratios remain rather low for this type -- both DKK-02 and DK-20 have values below 11. Site MER-10 is rather high at 14.75, but it is a bluff abutment site and these typically show higher w:d ratios. Bank materials are dominated by clayey silt alluvium that is almost always densely penetrated by the roots of riparian trees and other plants. Bed materials become finer in this segment, but cobbles and boulders are still present and act as vertical control. Local controls include tributary entries and bluff abutments that often contain dense clay tills and cobble to boulder-sized rocks that form lag deposits and riffles. Site MER-10 is a notable bluff abutment site.

Slope and sinuosity.

Channel slopes at sample sites are rather low, all lie below 0.0010. Although bluff abutment sites can be dominated by riffles, MER-10 has a slope of only 0.0003. Sinuosity for these sites is generally low, ranging from 1.08 to 1.24.

Riparian vegetation and large woody debris.

This segment type generally runs through narrow, sometimes steep walled valleys. Because floodplains are not always suitable for farming, wide, diverse riparian forests can be found in this type. These forests often extend up bluffs to the valley margins. This can be seen on the Lexington and Greatly 7.5' quad maps (note that both these maps were compiled from 1975 aerials). Riparian trees often appear well-within the bankfull channel, sometimes to the lowflow water's edge (Figure 4 gives a photo of site DK-20; see also cross-sections for this site). Values for large woody cover can be high in these reaches.

Floodplain connection.

Reaches within this segment are generally connected to a broad, active floodplain at just above the bankfull level. I found no levees within this segment. Small natural levees are sometimes seen.

Management concerns.

As with most other types, some concern over flooding of farmland exists in these segments, but many farmers seem to accept this as a necessary, natural process. Serious bank erosion appears to be rare. These reaches are probably affected by increased flood frequency and magnitude, as evidenced by a lack of prominent bars -- it appears that these channels have strong margins that are not erodable and thus very effectively move sediment downstream. This may lead to a lack of inchannel diversity in bedform and hydraulic habitat, however. Channels within this segment are able to transport whole trees, and large logjams form within this type. They do not appear to be common, but are a concern to landowners because they cause localized bank erosion (this occurred at the upper end of the DK-20 sample reach).

Subtypes and variations.

Bluff abutment (type 4b) sites occur in this segment. Site MER-10 lies within such a reach.

Types 5 and 5b (bluff abutment site)
Middle Mackinaw between Money Creek and Walnut Creek

General description.

The Mackinaw River from below the mouth of Money Creek to its confluence with Walnut Creek. Site DK-17 lies within this segment. Four major tributaries, Money Creek, Denman Creek, Sixmile Creek, and Panther Creek enter this reach and define subsegments. Both Money Creek and Sixmile Creek hold major reservoirs that influence flood routing and water quality in this segment. Although the Mackinaw River's floodplain does not expand much in this segment, valley relief almost doubles as the valley cuts through the Eureka Moraine, and many small, steep tributaries enter the river along the lower end of this segment, where site DK-17 lies. The Gridley, El Paso, and Secor 7.5' maps cover this segment.

The Panther Creek to Walnut Creek subsegment covers only about 5 km^2 between these two confluences. The entry of Panther Creek raises the Mackinaw's drainage area from about 1275 km^2 to 1717 km^2. Although Panther Creek significantly raises the Mackinaw's drainage area, there appear to be no significant effects on channel morphology and process beyond the expected increase in channel size. Floodplain width remains little changed until the entry of Walnut Creek, which defines the beginning of the next segment.

As with most of the channels in the basin, this segment has generally shown lateral stability during the period for which aerial photographs are available (since the late 1930's) despite periods of widespread riparian forest elimination.

Drainage areas.

Drainage areas range from 1001 km^2 below the mouth of Money Creek to approximately 1755 km^2 above the mouth of Walnut Creek. Money Creek contributes 111 km^2 drainage area, Panther Creek contributes 442 km^2, and Sixmile Creek contributes 172 km^2 to this segment.

Channel morphology, process, and composition.

At site DK-17, the only sample site within this segment, W_{bf} averages 29.7 m, d_{mean} averages 2.39 m, and w:d ratio is 12.9. D_{max} for this sample reach is 3.03 m. At this site, bank alluvium becomes sandier than that in upstream segments, but remains well stabilized by riparian vegetation. Sand dominates the bed surface, but gravel and cobble riffles are present. Steep, high valley walls make bluff abutment sites are common in this segment.

Slope and sinuosity.

Slope at DK-17 drops to 0.0009 and remains below this value for all downstream sample sites on the Mackinaw River. Sinuosity, at 1.25, is above average for the basin.

Riparian vegetation and large woody debris.

At points along this segment, mature trees are still found well within the bankfull channel, but not as commonly as in the preceding segment. Wide riparian forest border the river at points along and near bluff abutment sites (see reaches upstream and downstream of site DK-17 on the Secor 7.5' quad). The floodplain becomes wider, however, and rowcrop agriculture along the river is common. At many points, only a single row of trees borders the river, and these are sometimes even-aged stands. Large woody debris index values are above average for the basin.

Floodplain connection.

Although a few levees appear in this segment, floodplains are generally unobstructed and hydraulically active.

Management concerns.

Landowner concerns and habitat issues are essentially the same as for type 4 channels, except that conflicts between riparian forests and rowcrop agriculture are probably more common. Logjams also appear to be less of a concern because the Mackinaw's channel becomes large enough to accommodate even very large trees without becoming completely blocked. The numerous small, steep, Type 2 tributaries entering the Mackinaw create coarse gravel and cobble riffles that may be biologically important. The diverse topography and riparian forests along the high valley walls create important riparian forest habitat.

Subtypes.

Type 5b includes bluff abutment sites, which are numerous in this segment.

Types 6, 6b (bluff abutment), 6c (channelized and/or leveed), 6m (moraine traverse reaches)
Mackinaw River from Walnut Creek to Dillon Creek

General description.

This segment begins with the confluence of Walnut Creek with the Mackinaw River. Sample sites DK-16 (the Congerville gage site), DK-15, MER-20, and DK-19 lie in this segment. The entry of Panther Creek only 5 km upstream of this point raises the Mackinaw's drainage area from about 1275 km^2 to 1717 km^2. The entry of Walnut Creek raises the drainage area to more than 1880 km^2. Thus, from above the mouth of Panther to below the mouth of Walnut Creek, the Mackinaw River's drainage area increases more than 67 percent. This increase in discharge and, probably, change in topography and geology as the Mackinaw's valley ends its traverse of the Eureka Moraine, results in a profound change in the river and its valley. The width of the Mackinaw's valley increases from 200-300 m above Walnut Creek to an average of about 1000 m. Very large floodplain farm fields become common, as do levees. The Mackinaw's pattern becomes more sinuous, but still obviously controlled by local geology at bluff abutment sites, and still irregular (see the Mackinaw 7.5' quad). This segment includes the Mackinaw River's traverse of the Le Roy - Shelbyville Moraine. The lower end of this traverse is roughly defined by the entry of Dillon Creek from the north.

This type generally shows lateral stability over the period of record for aerial photographs, although some short sections (e.g. the two loops just north of Maraldo Lake) show considerable lateral movement. Most of the tributaries mentioned below were sampled as well.

Drainage areas.

From 1880 km^2 below the mouth of Walnut Creek to about 2600 km^2 above Dillon Creek. Major tributaries include Walnut Creek (draining about 178 km^2), Rock Creek (116.0 km^2), Prairie Creek (61.2 km^2), Mud Creek (118.0 km^2), and the Little Mackinaw River (143.7 km^2).

Channel morphology, process and composition.

Sites DK-15, DK-16, and MER-20 are very similar in both bankfull width, which averages about 42 m for the three, and w:d ratio, which averages about 13.5.

Bed and bank materials become more variable within this segment. Silty alluvium remains dominant in banks, but the fraction of clay is somewhat reduced. At at least one site (the loops above Maraldo Lake mentioned above) channel stability is reduced by lenses of sandy material at the bank toe. This does not appear common, but may be a primary cause of local instability. The roots of riparian trees remain a common and important constituent of bank materials. High, steep bluffs are formed at some bluff abutment reaches. Such a bluff can be seen just below site DK-15. At this site, the bluff is over 19 m high. Much of the material in the bluff is sand, but it also introduces cobble and boulder lag material into the channel, which forms a very steep and swift (but short) riffle system just below the bluff. At site MER-20, a prominent riffle and deep scour hole are formed by large lag particles (including boulders) not associated with a bluff. A photo of his riffle is shown in Figure 4. This riffle results in the rather high slope of 0.0010 for this segment. It is possible that such drops in grade account for much of the overall drop in elevation through this reach. These sites are certainly important habitat elements in segments that may otherwise be quite flat and pool-dominated (as is site DK-15).

Surface bed materials are generally dominated by sand and gravel, although coarse gravel and cobble substrates are abundant, especially where lag materials occur. The very localized lag deposits at site MER-20 and below site DK-15 clearly show that the river is unable to transport materials larger than coarse gravel. Natural levees are common, and are generally formed of sand-dominated material. On no part of the river did I find evidence of particles larger than sand being moved onto floodplains.

It is in this segment that large, well expressed point and midchannel bars first become frequent. These are most obvious on vertical aerial photographs. Bars formed by modern sediment transport have D_{50} values of 17 mm or less, however. Midchannel and lag material bars (such as those seen at MER-20) can contain much larger particles.

Slope and sinuosity.

Overall, the river's gradient is relatively unchanged from the previous segment, and averages roughly 0.0006 for the entire segment. Sinuosity increases somewhat, to above 1.2 for most sites. Sinuosity around site MER-20 is 1.45.

Riparian vegetation and large woody debris.

Riparian vegetation varies widely. At many sites within this reach, row-cropped farm fields run to the channel edge. More typically, at least a single row of riparian trees exist, although these are often even-aged silver maple (as on the left bank of site MER-20). Tree rooting elevations vary. Although mature trees can still be found well below bankfull elevations, the rooting elevation is higher than for upstream reaches (compare cross-sections for DK-16 and MER-20, for example). At many leveed reaches, the levee top defines the margin between woody vegetation and row-cropped fields (see many examples on the Hopedale 7.5' quad map) -- levees are generally set back from the river a short distance (typically >20 m) and the floodplain between levees and the channel is unfarmed.

Taxonomically diverse old growth forests occur at some bluff abutment sites. An example can be seen the segment traversing the LeRoy-Shelbyville Moraine (type 6m) on the high (over 30 m) left-bank bluff in the northeast corner of section 20, Dillon township (center of Delavan North 7.5' quad map). The mature trees that enter channels from these forests provide a source of woody debris, and large woody debris index values can be high in this segment. Although high water precluded quantitative sampling of LWD at DK-16, it many large snags appeared in the lowflow channel there. LWD index values (Figure 14) are below the basin average for sites DK-16, MER-20, and DK-19, but this may be due to channel size.

The values are normalized by the horizontal area of the reach at bankfull (i.e. the product of reach length and bankfull width), and larger channels, even though healthy, should probably be expected to show somewhat lower values, especially when they are large enough to preclude formation of logjams.

Floodplain connection.

The majority of reaches within this segment are hydraulically disconnected from floodplains by levees. Channel cross sections that included levees were run for sites DK-15 and DK-19. I found a levee along the right bank of site MER-20, but it had failed at least one point and was obviously no longer maintained (and the land it was built to protect allowed to regrow in trees). Levees can be seen on 7.5' quad maps (which are, remember, generally compiled from 20 year-old data) about where Rock Creek enters the Mackinaw (see Mackinaw 7.5' quad) and are ubiquitous along river reaches shown on the Hopedale 7.5' quad.

It appears that significant sediment deposition has occurred on the floodplain surfaces within levees, leading to a significant drop in elevation between the riverward floodplain and the farmed floodplain protected by the levee. At transect 9.5 on site DK-19, this difference is 0.73 m. Signs of this deposition, including fresh sediment and "telephone pole" trees, can be commonly seen on floodplain fragments between levees and the river channel. On unleveed reaches (e.g. the right bank of site MER-20), natural levees are common.

Management concerns.

Levee management is an ongoing problem for most floodplain landowners in this segment. The buildup of sediment on the riverward sides of these levees causes ever higher stages for large floods, and both increases the threat to levees and causes failures to be more damaging when they occur. Levees are typically built and maintained by individual landowners, apparently without consideration for integrated management with other landowners or other river management issues. Floodplain fields along this segment can be very large, and flooding is a primary concern of landowners.

Although some reaches along this segment show signs of serious lateral migration and losses from bank erosion, these problems are less common that generally seen on a river of this size, and tend to be localized. Although the Mackinaw's channel becomes very large in this segment, many reaches are effectively stabilized by tree roots. Often trees are not as effective on rivers of this size. Aside from habitat issues, trees remain an important factor in protecting land values by controlling bank erosion.

The first major channelization on the Mackinaw River (aside from upland ditches) occurs within this segment. About 6 km (of post channelization length) of the Mackinaw River on either side of the Highway 121 bridge were straightened sometime prior to 1970. Much of this reach was subsequently leveed. It is obvious even from the 7.5' map covering this reach that the river was quite sinuous throughout this reach. Although some return to meandering has occurred, the river was significantly shortened. Sample site DK-19 lies within the channelized reach, below the highway bridge. The very high (21.7) w:d ratio for this reach is probably due to instability following channelization.

Water quality degrades in this segment of the Mackinaw. At least two tributaries, the Little Mackinaw River and Mud Creek, contribute water that is commonly polluted with municipal wastewater (see Retzer 1996a and 1996b).

Trends in river biota for this segment are discussed in Retzer (1996b). Although it is clear that certain indicator species become less common in this segment, it is not clear whether this is due to physical habitat degradation (e.g. domination of beds by sand) or water quality degradation. It is clear that improvements in habitat quality are possible, especially in riparian habitat quality.

Subtypes and variations.

The Mackinaw changes character somewhat in its rather short (about 4 km) traverse of the LeRoy-Shelbyville Moraine (type 6m). Within this reach it appears that resistant glaciofluvial deposits cause a very narrow floodplain and local topography results in high, wooded bluffs that are probably unique within the watershed. This entire reach is visible on the Delavan North 7.5' quad map.

Type 7
Lower Mackinaw River

General description.

The lower Mackinaw River, from the LeRoy-Shelbyville Moraine to its confluence with the Illinois River. After traversing the LeRoy-Shelbyville Moraine, the Mackinaw River enters a former floodplain of the Illinois River that is dominated by glaciofluvial sediments. This transition corresponds roughly with the border between the Delavan North and South Pekin 7.5' quad maps. Bank materials become variable, but are dominated by highly erodable sand. This segment is subjected to increased water and sediment loads from upstream channel management. Weaker bank materials and increased flows result in a dramatic decrease in lateral stability for this segment, as shown in Figure 3. Much of the lower section of this segment (over 5 km) has been channelized as well. Sample site DK-12 lies just above the channelized reach.

Drainage areas.

Drainage area ranges from about 2680 km^2 below the mouth of Dillon Creek to about 2900 km^2 at the Mackinaw River's mouth.

Channel morphology, process, and composition.

Variable bank materials in this segment make channel morphology quite variable. In general, however, bankfull widths and width:depth ratios increase sharply for this segment (see Figures 5, 6, and 11). Bankfull width averages 63.2 m at DK-12, and w:d ratio is 32.1.

Bank materials vary at DK-12, from clayey silt alluvium to glaciofluvial materials that are composed primarily of sand. These sandy banks are highly erodable. Bed materials at this site are dominated by clay and cobbles. This site has a relatively high gradient of 0.001, and an almost constant drop in water surface elevation (see long profile plot) probably because it lies just upstream of a long (>5 km) channelized reach. These coarse materials appear to have acted as grade controls. Generally, it appears that cutbanks within this reach become high enough to limit the effectiveness of riparian trees in controlling channel movement, although they remain an important influence. The well-drained sandy alluvium probably limits growth of wet-site woody species as well. Stands of willows can be seen, however, on the point bars that form opposite migrating cutbanks (e.g. at the bends above Wagonseller Bridge, shown in Figure 3).

It appears that clayey alluvium may act as a control on lateral movement in some reaches, although further reconnaissance should be done to confirm this. Bridges are the only other apparent local controls in this segment.

Site DK-12 is one of the few in the basin to show two clear sets of terraces. A lower terrace appears to form the bankfull channel. A broad floodplain lies about 2 m above this surface (see transect 5 plot). This entrenchment is probably the result of downcutting following the extensive channelization of the Mackinaw River from just below this site to its confluence with the Illinois River.

Slope and sinuosity.

Site DK-12 has a relatively high gradient of 0.001. The Mackinaw River's long profile plot (Figure 8) does not display the concave-up shape seen in many river basins, i.e. the lower Mackinaw's gradient does not significantly fall below that of the middle sections of the river. Sinuosity at site DK-12 is 1.44 -- higher than that for most other sites. Generally, the weaker bank materials and increased lateral migration of the lower river results in higher sinuosity values.

Riparian vegetation and large woody debris.

Wide riparian forests appear in this type only where rapid lateral migration has rendered land unfarmable (see Figure 3). These stands are generally young and composed of disturbance-adapted riparian species. The channelized reach below site DK-12 has a thin riparian corridor delineated by levee tops that are very close to the channel along much of this reach. Some trees grow into the bankfull channel at site DK-12 (see transect plots), but these are usually only young willows (*Salix spp)*.

The 1939 aerial photographs of the reach above Wagonseller Road (Highway 1250E, Figure 3) show an anastomosed channel associated with a wide floodplain forest. Incision of the Mackinaw's channel since that time has probably altered the water table in this area so that such wide floodplain forests and wetlands cannot exist.

LWD index values are rather low for this segment, but very large trees with associated inchannel habitat patches are not unusual.

Floodplain connection.

Channel-floodplain connection is influenced by channel incision and by levees in this segment. Much of the channel below site DK-12 is leveed. Although incision generally reduces the frequency of floodplain inundation, flood frequency and magnitude may have increased as a result of upstream channel management and landuse (see Retzer 1996a). Over the past decade, the highest floodplain surfaces within this segment have been flooded several times.

Management concerns.

More than any other segment in this watershed, this segment is plagued by extreme lateral instability. The very large channel size and high cutbanks (left after channel incision) make bank stabilization using vegetation difficult and perhaps impossible, and structural stabilization would be extremely expensive. The floodplain within this segment is subject to frequent flooding of long duration. Aside from channel stability, this is a primary concern of landowners.

Inchannel habitat at site DK-12 is characterized by rather high current velocity and coarse substrates, which is unusual for a big-river site. Since this segment is an integrator of water quality and hydrology for the entire watershed, the stresses imposed from above are many. Most segments of the Mackinaw River leading to this one transport sediment very efficiently, and some of the bank erosion seen within this segment is probably due in part to excess sediment loading of this segment.

Classification of aquatic biota

Ongoing work by Mike Retzer of The Nature Conservancy shows fairly strong correlations between "physical" types proposed in this report and river fishes (undated memo, November, 1996). It appears that a biotic classification based on fish species presence and absence fits the physical classification system described here. Fish distribution is strongly correlated with both drainage area and position in the drainage network, especially at sites where Type 3 channels meet the Mackinaw mainstem (e.g. DKV-01 on Henline Creek).

Table 3 gives Retzer's preliminary results (his work is not yet published). In this table, physical types are designated by a number. Biotic types are designated by the letters A through E based on fish species presence/absence. (Note that the biotic classifications should not be confused with physical subtypes e.g., 3u, in which the "u" designates urban-influenced reaches). Retzer's classification is based on analysis of fish sampling data using Phylogenetic Analysis Using Parsimony (PAUP), constrained by the physical classifications (M. Retzer, pers. comm. 1997).

As Table 3 shows, distribution of many fish species is correlated with drainage size. The distributions of many fishes end as stream size decreases. Types 6 and 7, at the lower end of the Mackinaw Watershed, have no species absent. Moving upstream to type 5 (biotic type B), several species present in types 6 and 7 become absent, and dominant species change. This pattern continues as drainage area becomes smaller through Type 4.

No strong differences in fish distribution were detected between Types 1 and 3, and these segments are both assigned to Biotic Type D (M. Retzer, pers. comm. 1997). This may be due in part to limited fish data, particularly from Type 1 streams. A reduction in the importance of drainage area is not surprising because classification of reaches as physical types 1 or 3 is more strongly influenced by channel morphology (and management) than by drainage area.

Physical types	Biotic type	Representative sites	Species present	Species absent	Dominant species
6 and 7	A	DK-12, 19, 15, 16	highfin carpsucker (*Carpoides velifer*), sauger (*Stizostedion canadense*), silver chub (*Macrhybopsis storeiana*), walleye (*Stizostedion vitreum*)	none	sand shiner (*Notropis ludibundus*), red shiner (*Cyprinella lutrensis*), river carpsucker (*Carpiodes carpio*), shorthead redhorse (*Moxostoma macrolepidotum*)
5	B	DK-17	channel catfish (*Ictalurus punctatus*), smallmouth buffalo (*Ictiobus bubalus*), goldeye (*Hiodon alosoides*), drum (*Aplodinotus grunniens*), shortnose gar (*Lepisosteus platostomus*), river carpsucker (*Carpiodes carpio*)	same as those present for physical types 6 and 7	longear sunfish (*Lepomis megalotis*), stoneroller (*Campostoma anomalum*), golden redhorse (*Moxostoma erythrurum*), gizzard shad (*Dorosoma cepedianum*), smallmouth buffalo (*Ictiobus bubalus*)
4	C	DK-21, DKK-02, DK-20, MER-10	gizzard shad (*Dorosoma cepedianum*), quillback (*Carpiodes cyprinus*), silver redhorse (*Moxostoma anisurum*), northern hogsucker (*Hypentelium nigricans*), shorthead redhorse (*Moxostoma macrolepidotum*), carp (*Cyprinus carpio*)	same as those present for physical types 5, 6 and 7	striped shiner (*Luxilus chrysocephalus*), stoneroller (*Campostoma anomalum*), red shiner (*Cyprinella lutrensis*), stoneroller (*Campostoma anomalum*)
1 and 3	D	Crooked Ck., Buck Ck., MON-01, DKV-01, DKP-02, E. Br. Panther Ck., PAN-01, WAL-02, W. Br. Panther Ck., MER-5	redfin shiner (*Lythrurus umbratilis*)	same as present for physical types 4,5,6,7	bluntnose shiner (*Notropis simus*), redfin shiner (*Lythrurus umbratilis*), striped shiner (*Luxilus chrysocephalus*), red shiner (*Cyprinella lutrensis*), stoneroller (*Campostoma anomalum*)
2	E	Red River	blacknose dace (*Rhinichthys atratulus*), southern redbelly dace (*Phoxinus erythrogaster*)	same as present for physical types 4,5,6,7	blacknose dace (*Rhinichthys atratulus*), southern redbelly dace (*Phoxinus erythrogaster*)

Table 3. Fish distributions by physical type in the Mackinaw Watershed, from preliminary work by Retzer (pers. comm. 1997).

Management recommendations

This section outlines management recommendations for the Mackinaw River Watershed. These recommendations include best management practices (bmp's) for the segment and reach classifications previously outlined.

Holistic watershed management is discussed in Gough (1997). As noted in this report and recently in Frissell and Bayles (1996), watershed-scale ecosystem protection and restoration remains difficult because river ecosystems are complex and we have no good models with which to predict response to changes caused by our restoration efforts. There is no published list of methods or bmp's that is all-inclusive, and many practices are designed to meet only a single goals, e.g. creation of habitat or control of channel stability (usually bank erosion). Most restoration or protection methods applicable to midwestern rivers remain experimental because even those that have been widely used have not been adequately monitored. In general, it is best to choose management approaches that provide both high cost:benefit ratios and multiple benefits. Reestablishment of riparian forestland stands as a good example of such an approach. This can often be done by simply removing stresses that prevent tree growth (e.g., grazing pressure or farming). Benefits include increased floodplain and riparian habitat values, channel stability, water quality, and inputs of wood that form instream cover.

The word *restoration* implies a return to a previously existing state. We have little data on presettlement conditions for most midwestern watersheds, including the Mackinaw River's. Much of the upland areas of the Mackinaw Watershed have probably been changed beyond restorability by intensive ditching -- in any case, the very high agricultural value of this land makes large-scale restoration to presettlement conditions economically and socially impossible. It is quite possible, however, to greatly increase ecological health of streams in these areas.

Most restoration and protection efforts in this watershed will take place with cooperation and guidance from private landowners, mostly farmers, who control most of the land in the basin. Concerns of these landowners are outlined in the previous classification section. In some cases environmental protection and restoration conflict with the goals of farmers. Often, however, these goals are not as disparate as they may seem. Restoration of riparian woodlands, for example, can benefit farmers by reducing debris washed into floodplain fields and by stabilizing stream channels that might otherwise erode agricultural land. It is possible that better management of upland drainage ditches in the Mackinaw River Watershed can not only increase ecological health but also greatly reduce both the cost of maintaining these channels and downstream flooding.

Manageability.

We must approach management of river ecosystems with an understanding of how these systems work and how we can influence them. The history of river management is filled with examples of society's failure to appreciate the difficulties in effectively changing river function and structure. The work reported here is largely aimed at understanding the fundamental morphology and function of the Mackinaw River Watershed to plan its management.

The most effective and efficient river management projects are carefully planned to achieve the most benefit for the least cost. This is best done when relatively small changes (and expenditures) result in significant improvements in both ecosystem health and economic value to landowners. To understand and plan river management, we must understand the possible states of a river system. The approaches recommended here are based on an estimation of possible states gained by measuring channel morphology and indicators of fluvial process in the Mackinaw River Watershed. In many cases, possible states can be estimated by comparing river reach characteristics. For this reason, many of the sample sites chosen were reference sites -- they are considered to be relatively ecologically healthy and thus represent the best possible state of a reach with given geomorphic characteristics.

The manageability of river form and process varies widely depending on the characteristics or process to be managed and the nature of the river system. Most of the Mackinaw River Watershed's channels are inherently stable; for example, making management for stability relatively easy. The lower Mackinaw River, however, with sand-dominated bank materials and impacts from increased flood peaks and sediment loads, contrasts with the rest of the basin. Managing this segment for stability would be very expensive.

For a given river reach, certain characteristics can be reasonably managed at the reach scale. Others must be influenced at a larger spatial (and perhaps temporal) scale. At the reach scale, we cannot influence the water and sediment load carried by a channel. This characteristic is not locally manageable. When banks are armored with riprap, however, the erodability of channel banks is reduced at the local scale, which may stabilize a channel subjected to increased flooding from an altered watershed. Riparian vegetation is relatively easy to manage at the local scale. Bed materials and channel slope are generally unmanageable at any scale although changes in other characteristics may greatly alter the distribution of bed materials and diversity in channel depth.

Site assessment.

The methods outlined in Gough (1997) for assessment of river form and process at the reach scale can be used to compare reaches to reference conditions and to assess sites for restoration projects. Given the drainage area for a site, channel dimensions should fall within a range of values. If deviations occur, they should be explained by local conditions. Reaches devegetated by grazing, for example, often show relatively high width:depth ratios. Cattle exclusion and restoration of riparian trees can be expected to result in a decreased width:depth ratio. Failing explanation of deviations at the reach scale, impacts outside a given reach should be considered.

Data on fundamental channel characteristics are essential for the design of some restoration projects. Changes in ditch management, for example, can be made only after assessing the influence (through hydraulic analysis) of channel alterations on the capacity of these channels to convey floods. The influence of restoration projects on habitat quality cannot be measured without basic pre-project surveys of channel characteristics.

Certain geomorphic features are powerful diagnostic tools. The presence of mature trees along both banks of a channel at elevations near the channel bed indicates long-term lateral stability for a reach (see Figure 4). Woody vegetation on point bars can also indicate rates of lateral movement. Although steep, unvegetated cutbanks are often taken as indicators of erosion, a much more reliable indicator of lateral movement is the condition of the point bar opposite such a bank. Unusually large, unvegetated point bars can indicate relatively rapid lateral channel movement.

As managers gain experience and data in a given watershed, certain channel and watershed characteristics emerge as critical influences. In watersheds with relatively erodable bank materials, riparian vegetation condition may strongly influence channel form. In the Mackinaw Watershed, drainage area and position in the drainage network strongly influence channel morphology and habitat quality. Aside from these systemic variables, landowner management at the reach scale varies widely and is a primary influence on habitat quality.

Although sites can be assessed for ecological health and management planning at the reach scale, assessments should take into account influences from segment and watershed scale processes, especially water quality and hydrologic regime. Although rare in this watershed, vertical instability must always be assessed and understood before reach-scale management is planned. Vertical (or grade) changes in channels are often triggered by influences outside a given reach (e.g. downstream channelization), and thus require an informed and sometimes sophisticated assessment approach.

Best management practice goals and application strategy.

In planning restoration, it is important to consider the influence of a project outside the reach, segment, or watershed for which it is being considered. This is strongly influenced by the reach's classification and position in the drainage network. Reach scale projects on large (e.g. Type 5, 6, or 7) channels may have little downstream influence. Restoration of a reach within a Type 1 channel, however, may significantly improve water quality within that channel's watershed and at a key downstream confluence site. Generally, larger channels are more difficult to manage because they are subjected to a much wider array of influences than small channels such as Types 1, 2, and 3. This is especially true of water quality influences. Types 7 and 8 on the Mackinaw Basin are influenced by a large number of point and nonpoint sources of pollution. Although sometimes difficult to apply, a "top down" approach to watershed management is generally best, especially with respect to water quality.

Smaller channels are generally much easier to effectively alter. Project costs are less, and results generally easier to assess. In the Mackinaw River Watershed the mosaic of private ownership may mean that several landowners control a Type 6 or 7 reach, while it is not common for several reaches (of $20W_{bf}$) to be controlled by a single landowner in other types, especially for Types 1, 2, and 3.

Protection and prevention practices.

Certain reaches within his watershed are of obviously high ecological value, especially within segment Types 3, 4 and 5. These reaches also represent areas of very high aesthetic and recreational value, especially within Types 4 and 5. Most of these sites do not need local changes in management, although they remain influenced by upstream channel and land management. They are also at risk of degradation due to local changes in management. Although restoration and protection programs often focus on altering degraded reaches, it is critically important to protect such high quality reaches from degradation. Protection is especially cost-effective, since it may require only monitoring and landowner education. Specific protection and prevention measures include:

--Elimination of dredging (or reduction in frequency) for Type 1 channels.

--Prevention of downstream extension of dredged ditches into "natural" channels, especially confluence (Type c) sites.

--Protection of riparian forests at confluence sites, especially those that join the Mackinaw River mainstem in Types 3, 4 and 5.

--Protection of riparian forests and natural channel morphology (e.g., prevention of channelization) in Types 4 and 5. This includes high quality riparian areas managed by the Parklands Foundation and private landowners.

--Protection of high-quality *floodplain* forests in these areas.

--Continued cattle exclusion from areas not now grazed (primarily through education and awareness programs).

--Prevention of point-source pollution from dumping and burning in riparian areas, especially of potentially toxic materials like chemical containers and tires. Most sample sites contained inert debris like car parts and large appliances, indicating a history of dumping in channels.

--Prevention of levee building and channelization, especially in unchannelized/unleveed reaches in Types 5, 6, and 7.

Riparian forest management.

In the Mackinaw Watershed, as in many midwestern watersheds, improved management of riparian and floodplain forests represents a very promising, cost-effective means of improving ecological, recreational, and economic values. Goals for riparian forest management include expansion of forested area width; improvement of existing forest age and species diversity; and establishment of riparian forests in areas where none now exist.

Moving downstream along many Type 1 and 3 channels, riparian forests do not usually become common until these channels near the mainstem of the Mackinaw River or Panther Creek. Examples include Henline Creek, Buck Creek, and the East Branch of Panther Creek. On such channels, an upstream expansion of riparian forests would provide many water quality and stream habitat benefits. Aside from benefits to the aquatic ecosystem, widening of riparian corridors would greatly improve connectivity between riparian and floodplain habitats by providing adequate travel corridors for terrestrial animals. This expansion would be especially valuable when coupled with two-stage channel management for Type 1 streams (discussed below).

Opportunities for widening of riparian forests exist along almost all segment types within the basin. This widening would be particularly valuable in these cases:

--Along Type 3, 4, and 5 channels where the wooded corridor is a single row of trees and of essentially one age class and species, leaving it subject to severe degradation as trees approach the end of their lifespans. Thinness also leaves sections of the forest prone to elimination from even minor local bank erosion due to causes like beaver dams or small log jams.

--Along all types where the river's meander belt greatly exceeds the width of the riparian forest. In this case, natural meander migration can eliminate riparian forests and leave banks unvegetated. Type 6 reaches are particularly vulnerable.

Where riparian forest width is adequate, opportunities exist for improvement in age diversity, diversity in species, and absolute age (and thus size) of trees. It is probable that large woody debris was much more common in streams within this basin prior to European settlement. Many tree species native to this region become very large if allowed to reach maturity, and such trees would create significant aquatic habitat after falling into stream channels. It is now uncommon to see trees much larger than about 0.45 m d.b.h. in stream channels. Managing forest stands for greater absolute age and size (a long-term goal, of course) should greatly improve the abundance and quality of woody cover in channels. This would obviously benefit terrestrial riparian wildlife as well.

Riparian forest structure varies greatly in the Mackinaw Watershed. There are many reaches, however, where stands are of essentially one species and age. There is little data on specific relationships between aquatic habitat quality and riparian stand structure, but it is likely that improvements in diversity of riparian and floodplain forests would benefit aquatic habitat. Again, benefits to riparian wildlife are obvious.

Ditch (Type 1) management.

Type 1 channels drain a significant part of the Mackinaw River Watershed -- probably greater than 30%. Changes in management of these channels may represent the greatest opportunity for improved aquatic habitat conditions in this watershed. These channels undoubtedly play a role in downstream flooding and pollution problems because they are very efficient in moving water and sediment and have been disconnected from floodplain areas that could provide storage. Many of these ditched channels have flows of sufficient quality and quantity to support significant aquatic ecosystems, but lack critical habitat elements, particularly diversity in bed topography and woody cover. Further, many ditches are frequently dredged. While this dredging may be needed in some areas, it appears that much of the dredging is unnecessary, or at least its frequency is much greater than is required to maintain hydraulic capacity. In some midwestern drainage channels, dredging is required to maintain bed depth, which is necessary to keep drain tile outlets clear. Most tile outlets I observed on the Mackinaw Watershed enter channels at elevations greater than 1 m above the bed, however, and are in little danger of blockage by sediment deposition.

Unfortunately, there are no models for improved ditch management in the midwestern United States. Some states have begun small pilot programs and inquiries, but the idea of improving ditches or better managing them for ecological values is still very new.

Most ditches on the Mackinaw are maintained as trapezoidal channels similar to that shown in Figure 15. Cross-section plots for sites MER-05, MER-16, MER-23, and TUR-01 show this condition. These channels are morphologically unstable and tend to fill with sediment for two reasons -- first, for reasons that are still unclear, stream channels almost never form straight lines. Some meandering is natural and unavoidable. Most ditches in the Mackinaw show signs of slight meandering within the ditch boundaries if left undredged for more than a year or two. Second, most larger ditches are greatly oversized. Comparison of sites DKV-01 and MER-05 on Henline Creek, for example, shows that the cross-sectional area of MER-05 is much greater than that of the natural channel below it, even though hydraulic roughness at MER-05 is much less. This maintenance of a large cross section requires frequent dredging because the "natural" channel that might exist at these sites is considerably smaller and of a different shape. Thus we see a tendency for deposition in of these channels. It appears that many of these ditches, unlike those in many other glaciated midwestern watersheds (especially those lying in areas that were glacial lakes), have rather high slopes, which means they do not need such large cross-sections to adequately convey floods. There also appears to be a widespread perception that dredging lowers the frequency of out-of-bank flooding in these channels. While this is probably true for some, I believe it the effectiveness of dredging on flood carrying capacity is greatly overrated for most Type 1 channels in this watershed.

Figure 15 shows a possible alternative condition for these ditches. Changes include presence of a channel "shelf" or floodplain at approximately the bankfull flow elevation, woody cover associated with this shelf, and trees and/or a combination of native grasses on the shelf and at least one sideslope of the channel. The possible benefits of these changes are many:

--A slight slowing of average current velocity that could attenuate downstream flooding problems without causing local flooding.

--Greater absolute channel depth that may actually improve drainage conditions for the surrounding farmland, especially if tile outlets are near the bed.

--Possible elimination of dredging and its associated costs, because a narrower, more stable lowflow channel would more effectively convey sediment.

--Creation of a small vegetated channel shelf would provide some sediment storage capacity and would also provide a buffer and processing area for pollutants, especially excess nutrients associated with agricultural fertilizers.

--Shading of the lowflow channel that could reduce problems with algae (and associated dissolved oxygen problems) and reduce summer water temperatures. This benefit may occur even without trees, if the lowflow channel is maintained in a narrower, deeper form that is at least partially shaded by grasses.

--Addition of woody cover that is now completely absent in these channels.

--Greatly enhanced aesthetics for what are now generally seen as rather ugly channels.

--Creation of riparian habitat and terrestrial wildlife travel corridors that are connected with high-quality confluence sites (Type 3c reaches in particular).

Some elements of this scheme are optional or already exist. Many channels in the basin have naturally formed the channel shelf shown in Figure 15. This can be seen in the cross sections for TUR-01, for example (compare this site to BUC-01, an unditched site of similar drainage area). While trees provide obvious benefits, there may be considerable resistance to their use because they may raise hydraulic roughness in these reaches. Use of native grasses in these channels (as opposed to the introduced species now seen) would improve habitat conditions. To my knowledge, this method has not been tried in the midwestern United States, although it is used in Europe (see Purseglove 1987). Williams and Swanson (1989), working in urban areas, have shown that allowing trees to grow on the banks of channelized ditches actually eliminated maintenance needs as trees matured and shaded out vegetation within the channel that had previously been controlled by frequent mechanical removal (as is the case for most ditches in the Mackinaw Watershed).

The channel geometry data gathered in this study provide critical information needed to design improved channels. Bed and bank materials are generally homogenous among these sites and slopes fall within a fairly narrow range of values. This appears to be true even between the Type 1 ditched sites and the Type 3 sites they generally feed, meaning that the Type 3 cross-sections provide reasonable design parameters. The cross-section and slope data gathered for the Type 1 sites surveyed is sufficient to perform the simple hydraulic analysis needed to determine if changes in cross-sectional morphology and hydraulic roughness will indeed influence flood elevations (which will be a primary concern of landowners).

Flooding and water quality.

Although flooding is a primary concern of landowners in the Mackinaw River Watershed, do not have enough information to determine specific causes and approaches to flood reduction. It is likely that the extensive changes in drainage efficiency caused by universal ditching of upland areas aggravates flooding, but we cannot know by how much without much further research. It is also likely that the extensive levees seen along Type 6 reaches increases flood magnitude and frequency in the lower reaches of this type and in the lower Mackinaw (Type 7). The shape of the Mackinaw River Watershed may also aggravate flooding within Type 6 reaches as well. The Mackinaw River, Panther Creek, and Walnut Creek come together roughly in the center of the watershed in a radial pattern, meaning that flood peaks from intense storms in these highly impacted watersheds would arrive in this part of the Mackinaw at roughly the same time -- the entry of Panther and Walnut Creeks increases the Mackinaw's drainage area by 67 percent along a river distance of only a few kilometers.

Although data are insufficient to draw firm conclusions, there is some evidence that increased flood magnitude and frequency has altered Type 3, 4 and 5 channels on the Mackinaw Watershed. As noted in discussions of these types, point and midchannel bars are relatively rare in these types. This may be due to increased flooding, indicating upland causes, aggravated by ditching. In many fluvial systems, these channels (i.e. Types 3, 4, and 5) would be enlarged by this change in the hydrologic regime, but channels in these types are generally very resistant to erosion. Channel incision after European settlement may contributed to this condition.

Richter and Mendelson of The Nature Conservancy (memo dated February 19, 1996) have concluded that upland landuse changes have lead to increased flooding since the late 1960's, but have not speculated on the nature of these landuse changes. As with other possible causes of increased flooding, it is very difficult to determine the specific effects of landuse on flooding. Better soil and water conservation measures, especially use of minimum-till and no-till methods on the agricultural land that dominates this watershed will reduce flooding and other impacts on aquatic habitat, but exact effects cannot be predicted, except perhaps for very small watersheds.

Many Type 1 channels in the Mackinaw River Watershed are fed by small ditches that run along ubiquitous section-line roads. In general, these ditches become steep, eroding gullies as they enter larger channels, and in some cases represent significant sources of sediment pollution, especially since most of them drain agricultural land and are not protected by buffer strips or other structures. Better management of these ditches (through water control structures and vertical stabilization) may represent an opportunity for better control of both flooding and sediment pollution.

Management of urban influences.

As with flooding, the problems associated with urbanization in the watershed are very difficult to assess. It appears that Walnut Creek has been negatively affected by urban development in and around the City of Eureka. Reaches within the city show signs of serious abuse, including channelization (along the golf course west of town) and dumping of trash and construction debris in the channel (particularly as the channel passes the wastewater treatment plant at the southwest border of Eureka). Site WAL-02 is the only sample site showing clear signs of recent channel incision, which has led to the generation of a large quantity of sediment.

The upper reaches of Mud Creek are dominated by the City of Morton. Retzer (1996b) has documented severe water quality problems associated with this area and other urbanized watersheds. In general, it appears that the water quality problems associated with urban areas far outweigh the morphological changes caused by altered hydrology in these watersheds, meaning that pollution should be addressed before physical habitat management is considered.

Channel stability.

Most riparian landowners in the Mackinaw River Watershed are concerned with channel stability, usually with lateral stability. Although the process of channel migration is usually seen and referred to as "bank erosion," it is actually more complex process involving the entire channel. As cutbanks erode, a point bar usually builds opposite the eroding bank. Although banks are eroded, the net sediment exported from such a reach may be zero because the erosion is balanced by sediment deposition on the opposite bar. This distinction is critical in diagnosing the importance of channel stability at a given site. If both banks along a reach are eroding, the channel is generally vertically unstable as well. This is usually caused by a systemic problem, e.g. channelization downstream of the site or an increase in flood frequency or magnitude. Such systemic influences must usually be addressed at the source of the problem, not at the reach scale.

Perceptions of the nature and significance of bank erosion problems are commonly clouded by two misconceptions: that *all* channel movement is bad, and that high, bare cutbanks always indicate erosion. Channel movement is best diagnosed by observing the reach as part of a segment. It is common to see short sections of stream that are unstable because of unusual local conditions, including changes in bank material and removal of riparian vegetation. Other causes include logjams and structures such as bridges. Generally, the erosion caused by these structures is minor when looked at from a segment-scale perspective, and should be addressed accordingly.

Assessment of bare cutbanks should include observations of historical aerial photographs (if possible), channel geometry, and indicators of fluvial process per the methods outlined in this report and in Gough (1997). In particular, observations of the bank or bar opposite a suspected bank erosion site should give a general indication of the rate of erosion and its significance. Along Type 1, 3, 4, and 5 channels, severe lateral erosion is quite rare in this watershed. Type 2 channels were not assessed for this problem. Lateral channel movement becomes more common in Type 6 channels, and is very common in Type 7 reaches.

Control of channel migration in Type 6 and 7 channels is probably impractical, however -- these segments are impacted by increased flooding, sediment loads, and severe alteration of the floodplain-channel connection. These channels are also very large, meaning that an erosion control project covering even one meander bend will have a minimum cost approaching $10,000. Chances of catastrophic project failure also tend to be higher at such sites. Bank erosion at these sites is best addressed by methodic, long-term changes in watershed landuse and in management of smaller channels.

Lateral channel stability is generally best addressed by maintaining healthy, wide, riparian forests along channels, especially within this watershed, where most channels are very effectively stabilized by trees. Other structural means of erosion control include so-called *biotechnical* means that make use of tree plantings, and "hard" methods that use construction materials such as quarried stone or concrete.

Along many reaches within this watershed, landowners have stabilized banks using riprap composed of broken concrete slab material (generally waste material from road reconstruction). Generally, these efforts are successful and do not appear to be environmentally damaging (although they are not very aesthetically appealing), especially where landowners have allowed natural trees to grow through the riprap. Such an example occurs in and upstream of site DK-15. In other cases, landowners have attempted to use old cars and other junk to stabilize banks. This method is generally unsuccessful, and can be a source of pollution if batteries, engines, transmissions, etc. remain in the cars or farm equipment. It appears, though, that channel migration at most of these sites could be effectively controlled by using willow pole plantings, tree revetments, or other means of reestablishing riparian trees. Design and suitability of such methods should make use of the data contained in this report by comparing proposed project reaches with nearby reference reaches, which are usually stabilized by trees.

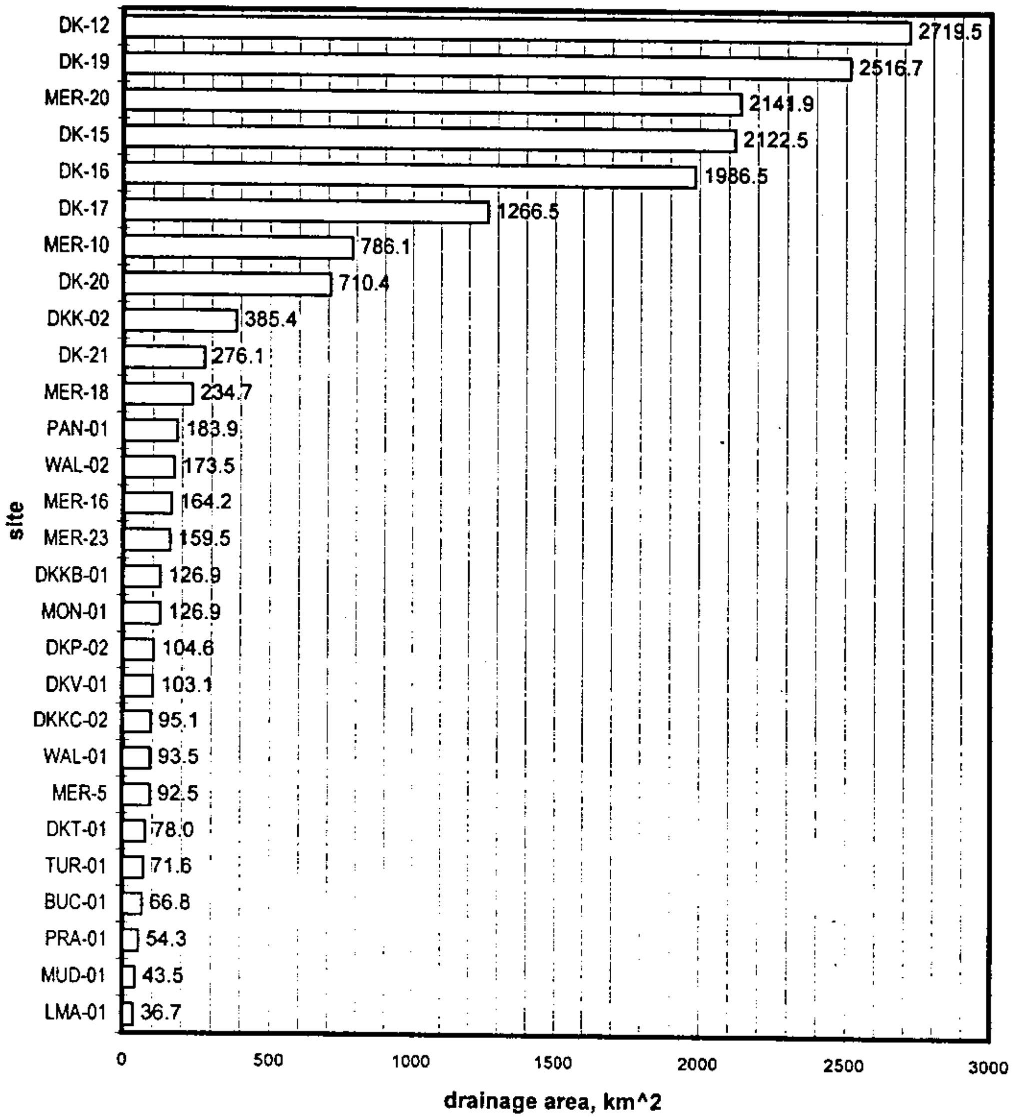


Figure 1. Drainage area by site name for sites in the Mackinaw River Watershed.

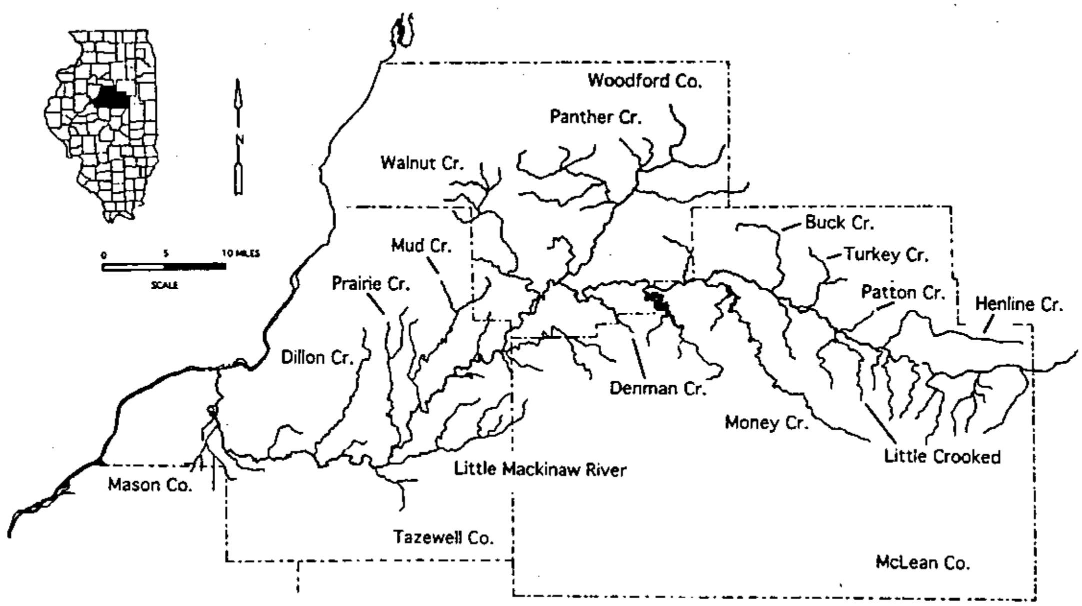


Figure 2. Map of the Mackinaw River Watershed showing major tributaries and location within central Illinois.

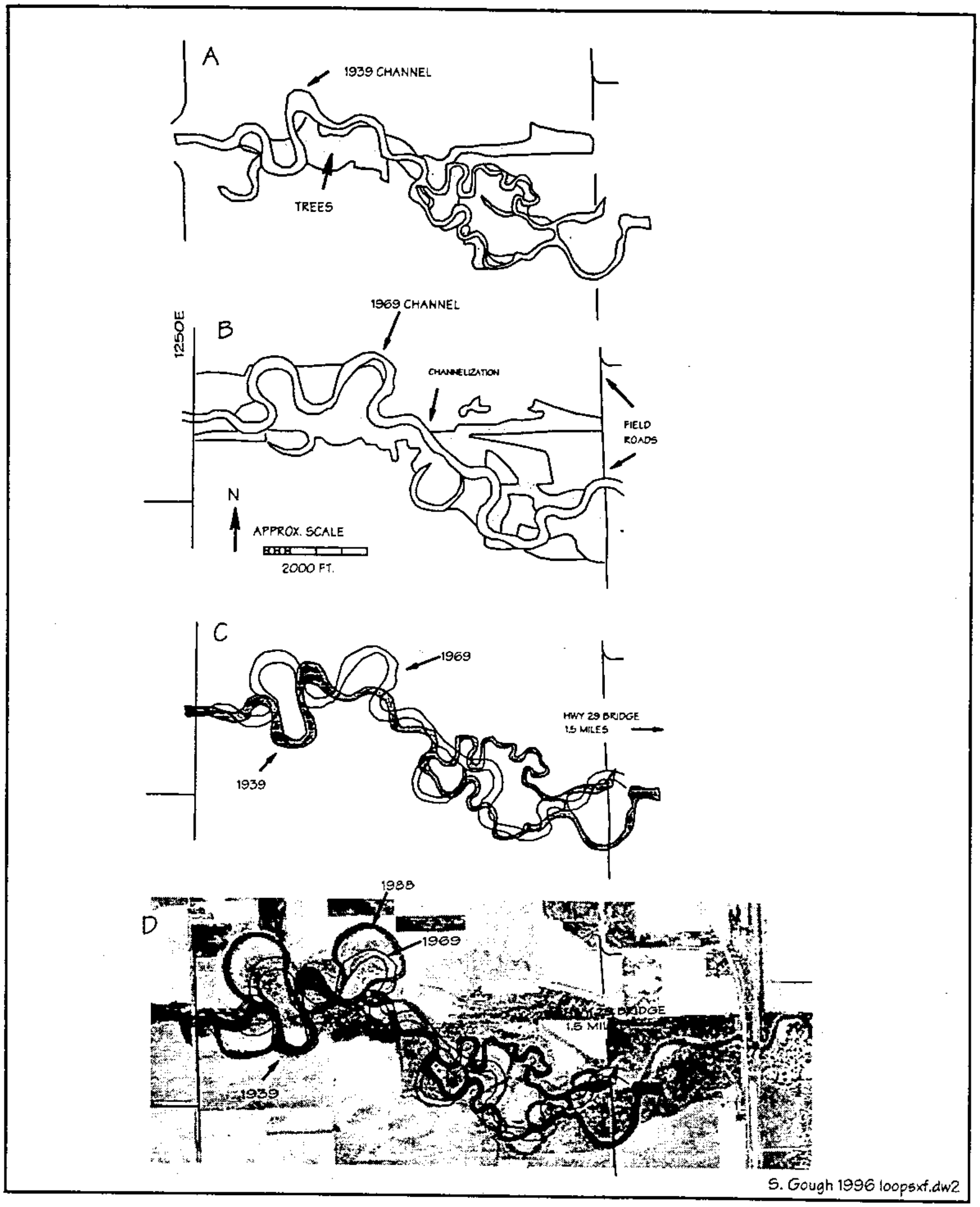


Figure 3. Changes in the Mackinaw River above Highway 1250E, Tazewell County, Illinois from 1939 to 1988. From USDA aerial photographs. (A) the 1939 channel and wooded areas, (B) the 1969 channel and wooded areas, (C) the 1939 and 1969 channels superimposed, and (D) the 1939 and 1969 channels overlain on a 1988 aerial photograph. This section of the Mackinaw River is migrating laterally through highly erodable sand-dominated bank materials and is impacted by channelization and other flood control measures.

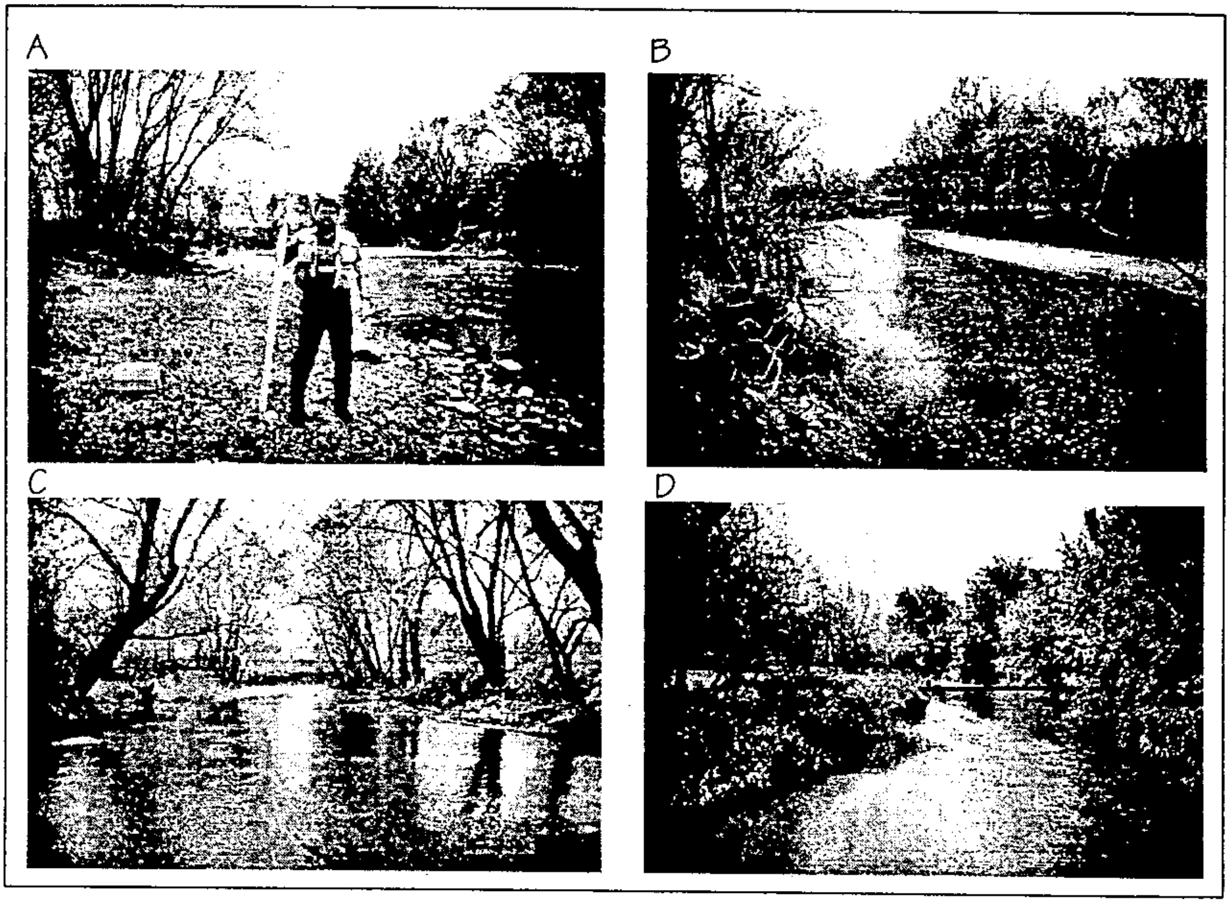
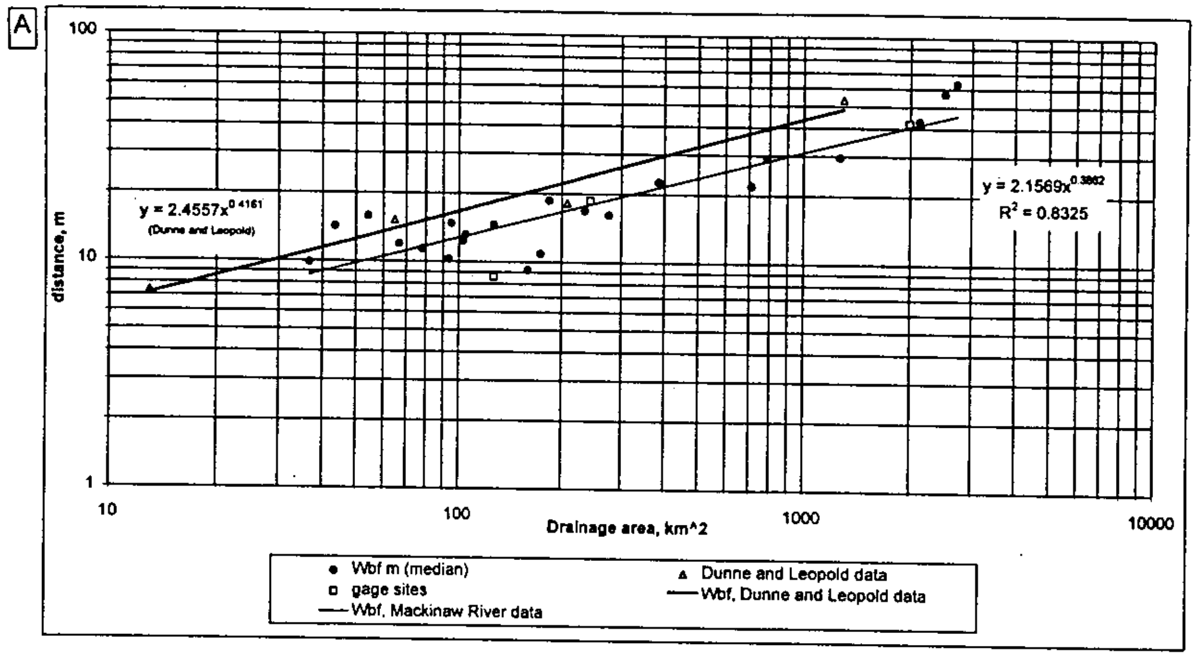


Figure 4. (A) The author at site MER-20 on the Mackinaw River, showing large lag materials that form a prominent riffle. (B) MER-20 just downstream of this riffle, showing a small point bar and the lower limit of woody vegetation for this site. (C) Site DK-20 showing mature trees rooted near the lowflow water surface along both banks and the thin riparian forest typical of many reaches in the watershed. (D) The Money Creek gage calibration site (MON-01) showing a channel shelf at left. The thin line shows bankfull elevation (from gage data). Note the correspondence between this elevation and both the channel shelf and the lower limit of woody vegetation at the left. This view is upstream, all others face downstream.



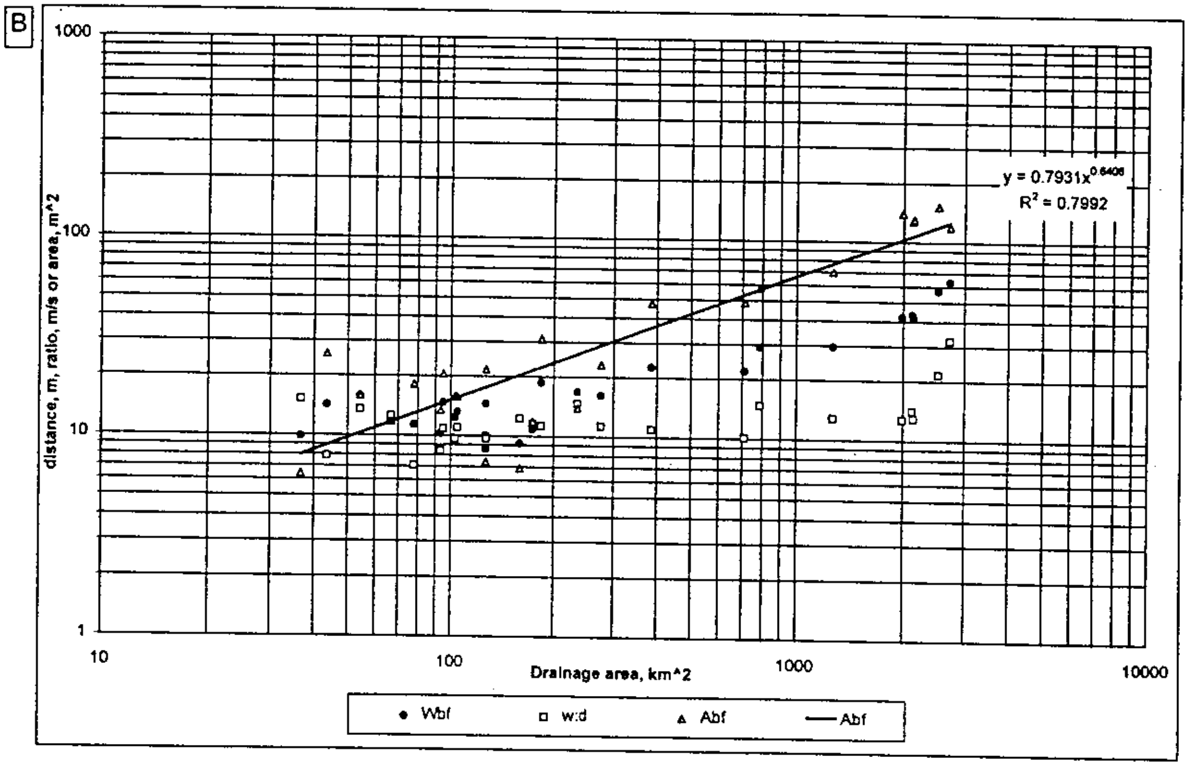


Figure 5. (A) Bankfull width plotted against drainage area for all Mackinaw Watershed sample sites. Data points are median values for all transects at a sample site. This figure also shows data from Dunne and Leopold (1978, p. 615, for "eastern United States" channels). (B) Bankfull width, w:d ratio, and bankfull area for all sites.

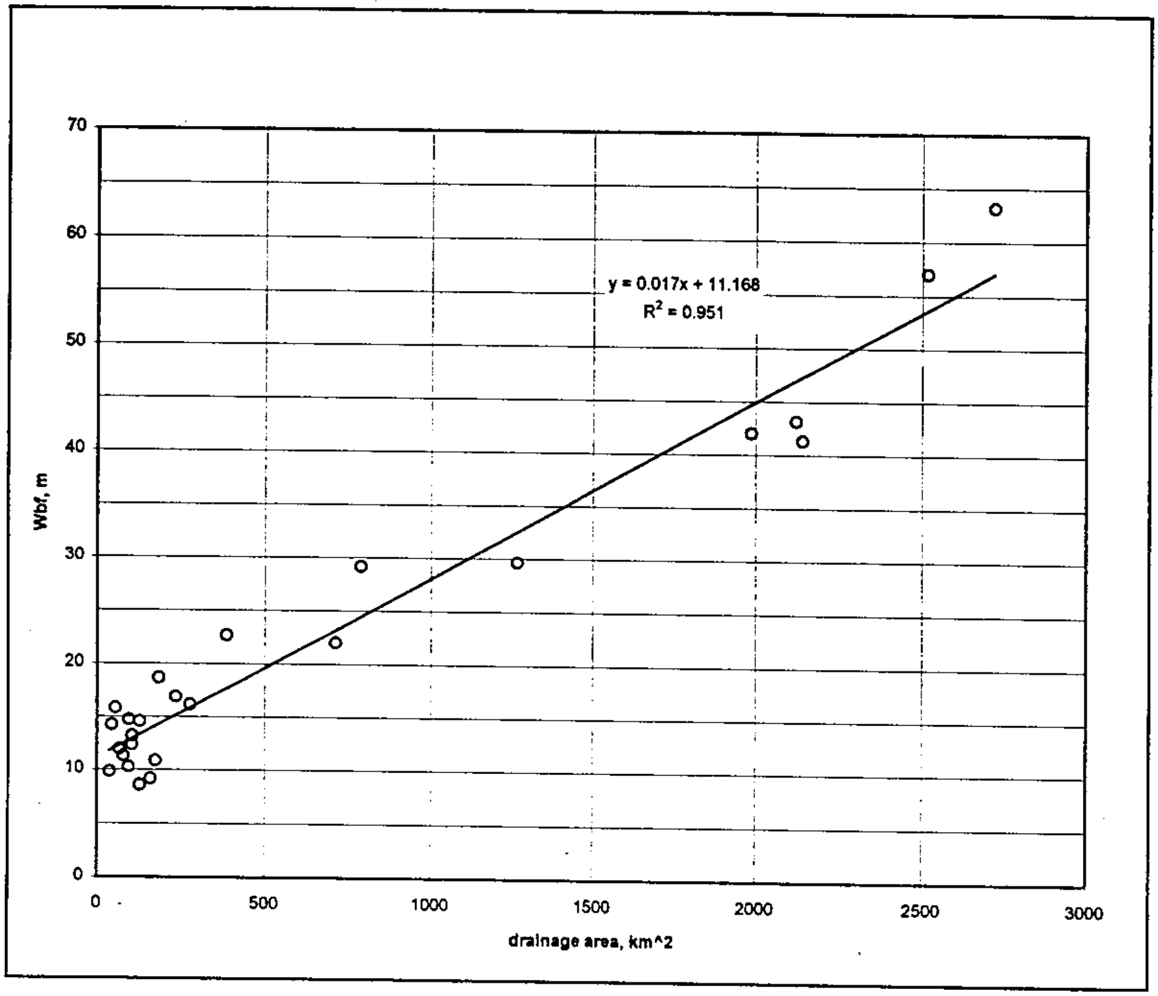


Figure 6. Bankfull width plotted against drainage area for all sites sampled.

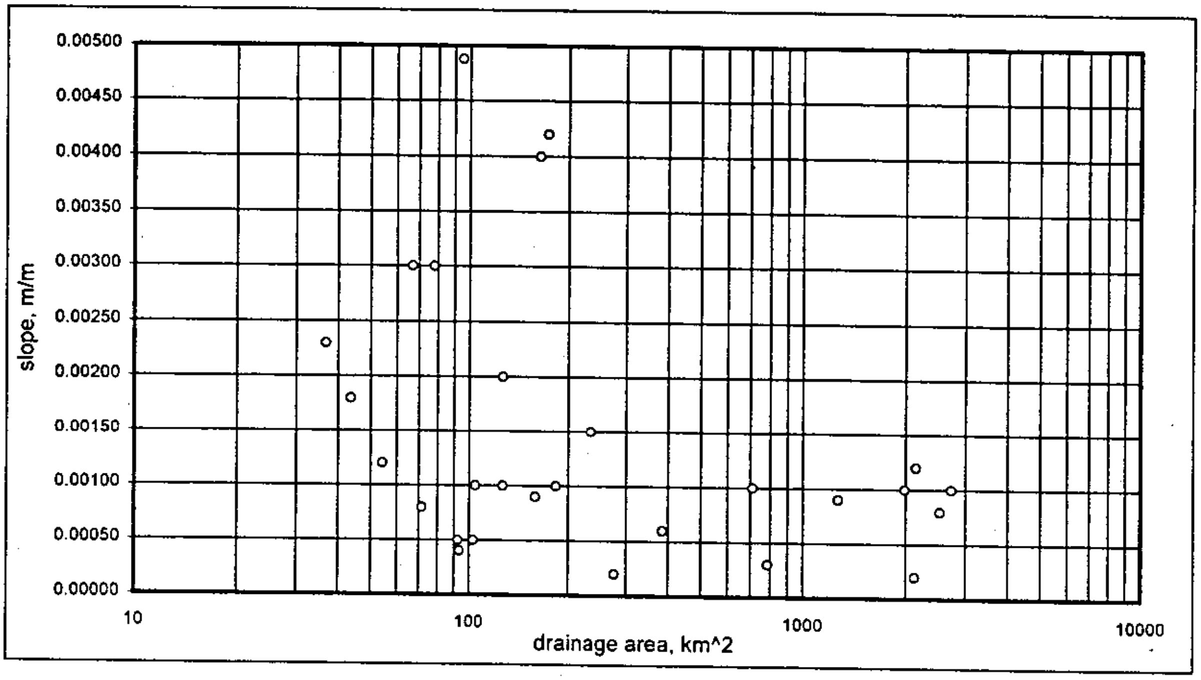


Figure 7. Channel slope plotted against drainage area for all sites sampled.

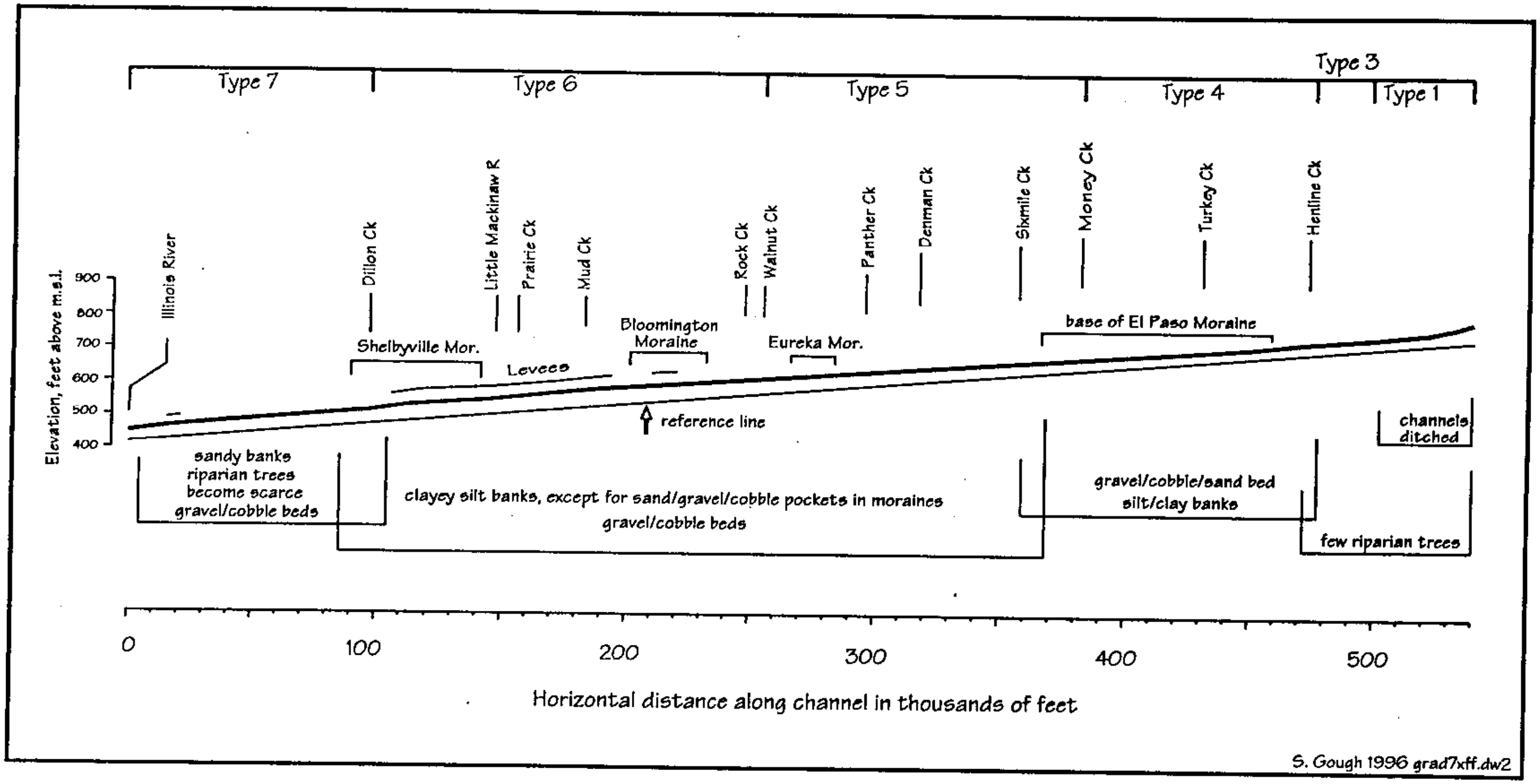


Figure 8. Long profile plot of the Mackinaw River main channel, compiled from USGS 1:250,000 maps, showing major fluvial features, tributary entries, and physical classifications. The straight reference line drawn below the plot shows the relative homogeneity in slope.

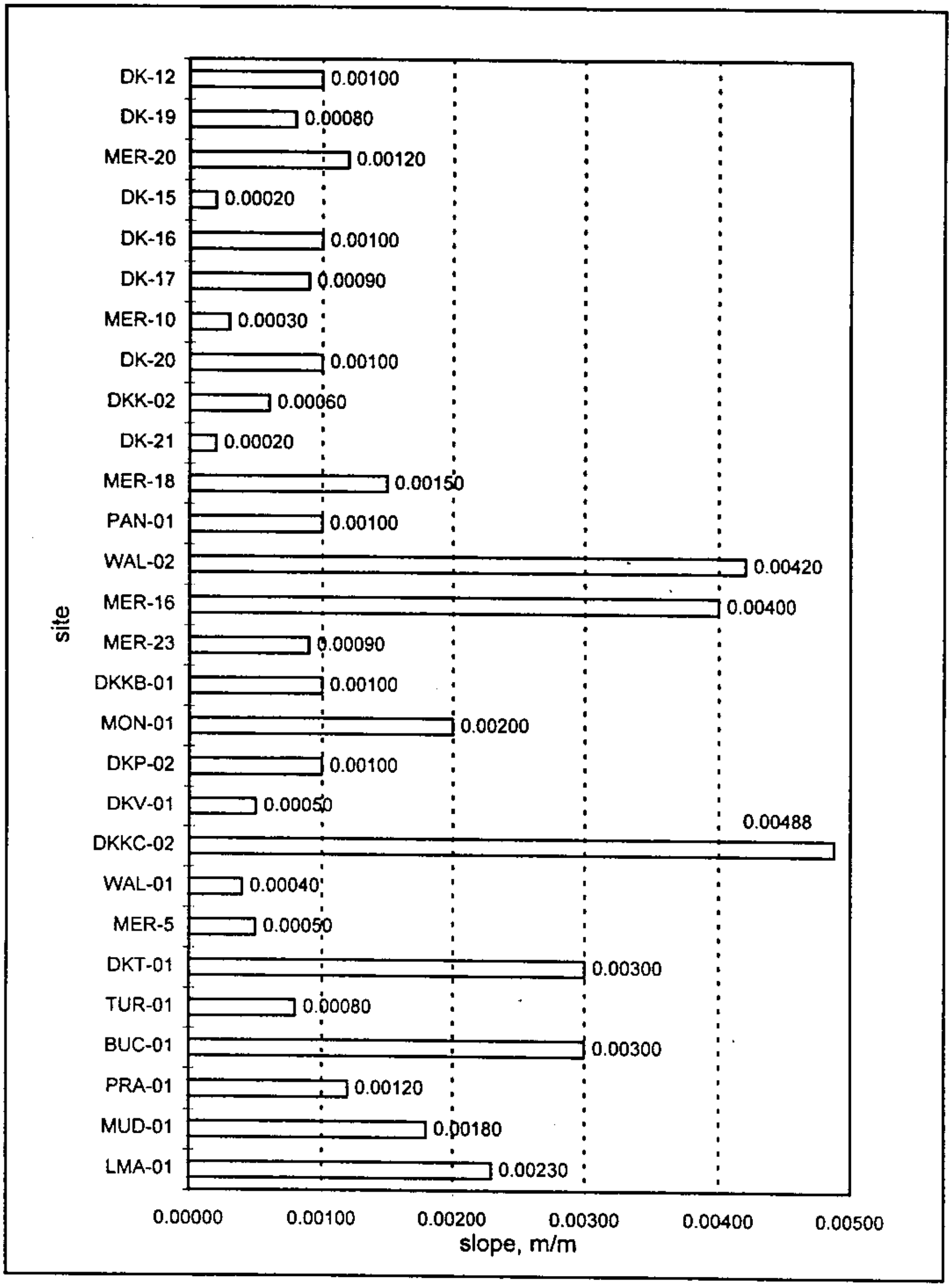


Figure 9. Channel slope by site name for all sites sampled. Site names are in order of increasing drainage area from bottom to top.

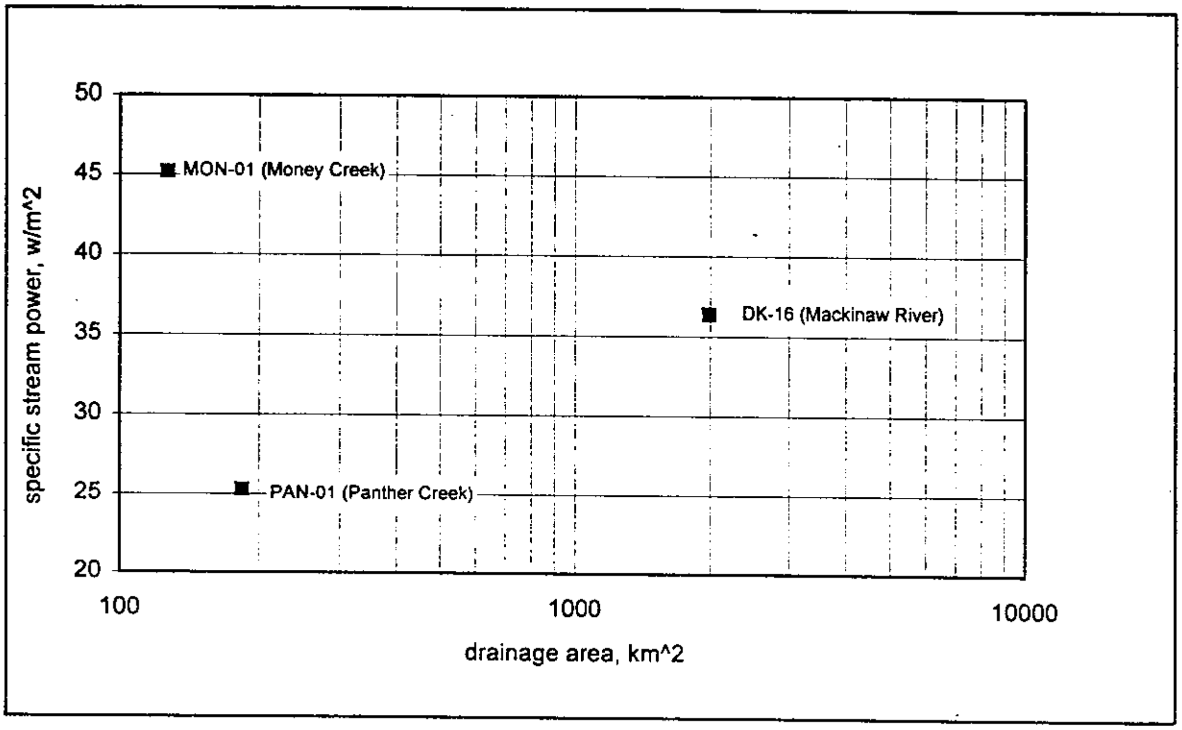


Figure 10. Specific stream power plotted against drainage area for the three gage calibration sites.

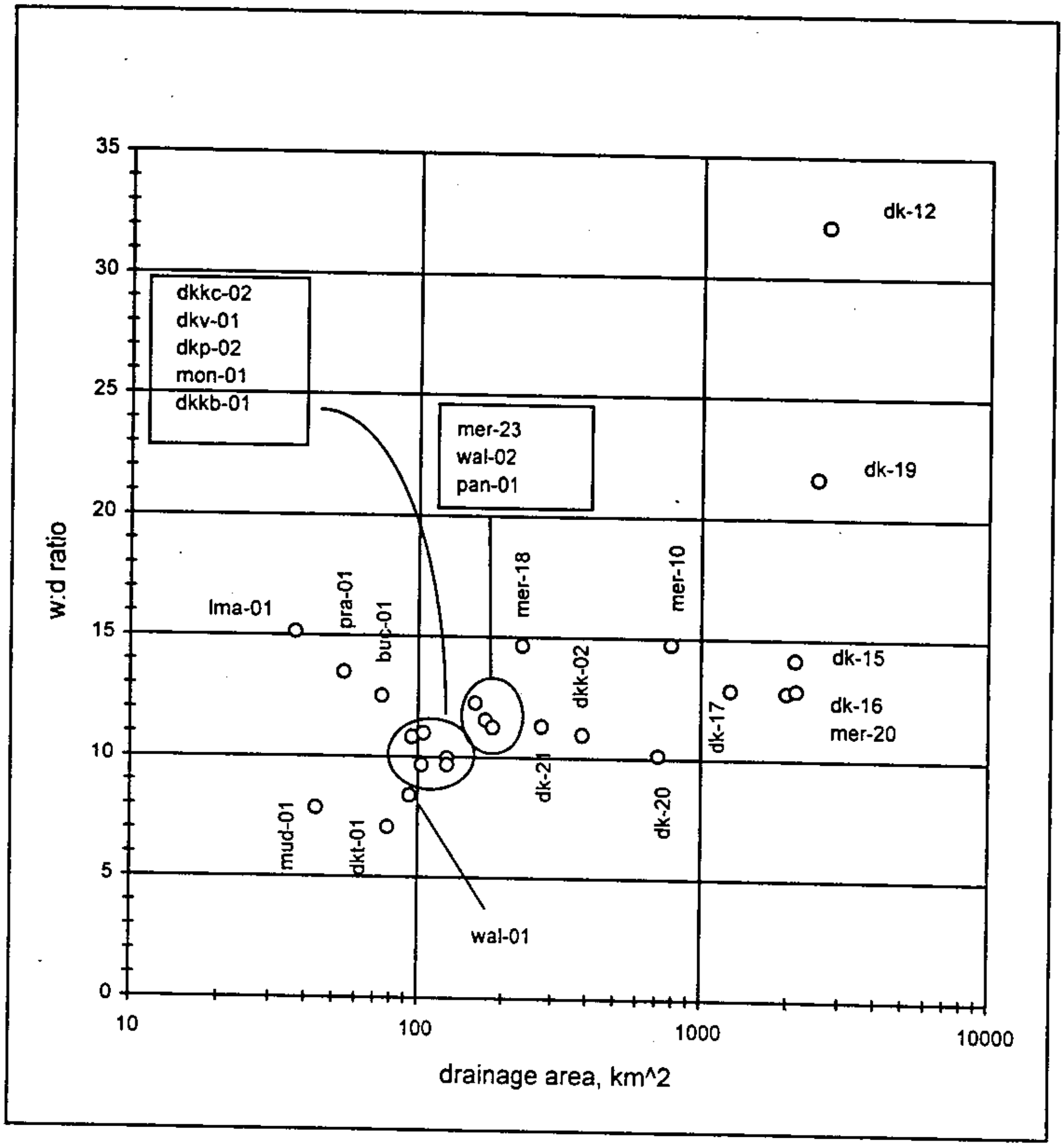


Figure 11. Bankfull width:depth ratio plotted against drainage area for all sample sites.

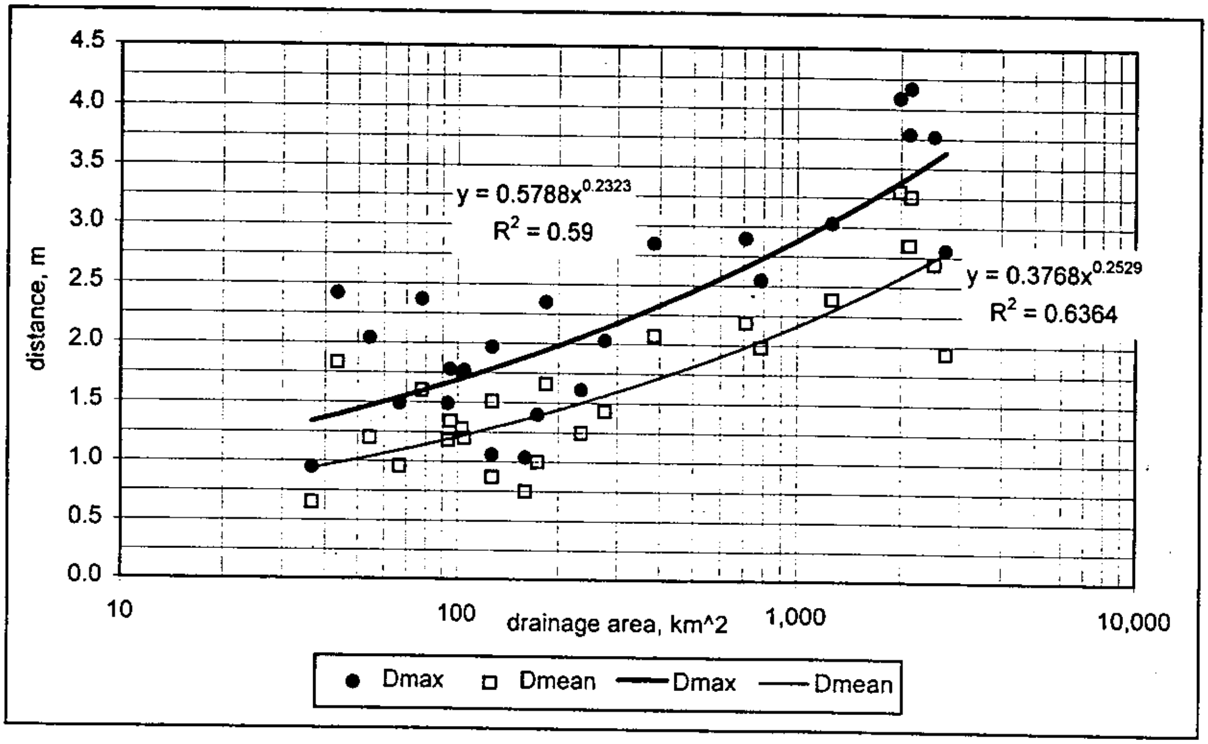


Figure 12. Maximum bankfull depth (D_{max}) and mean bankfull depth (D_{mean}) for all sites.

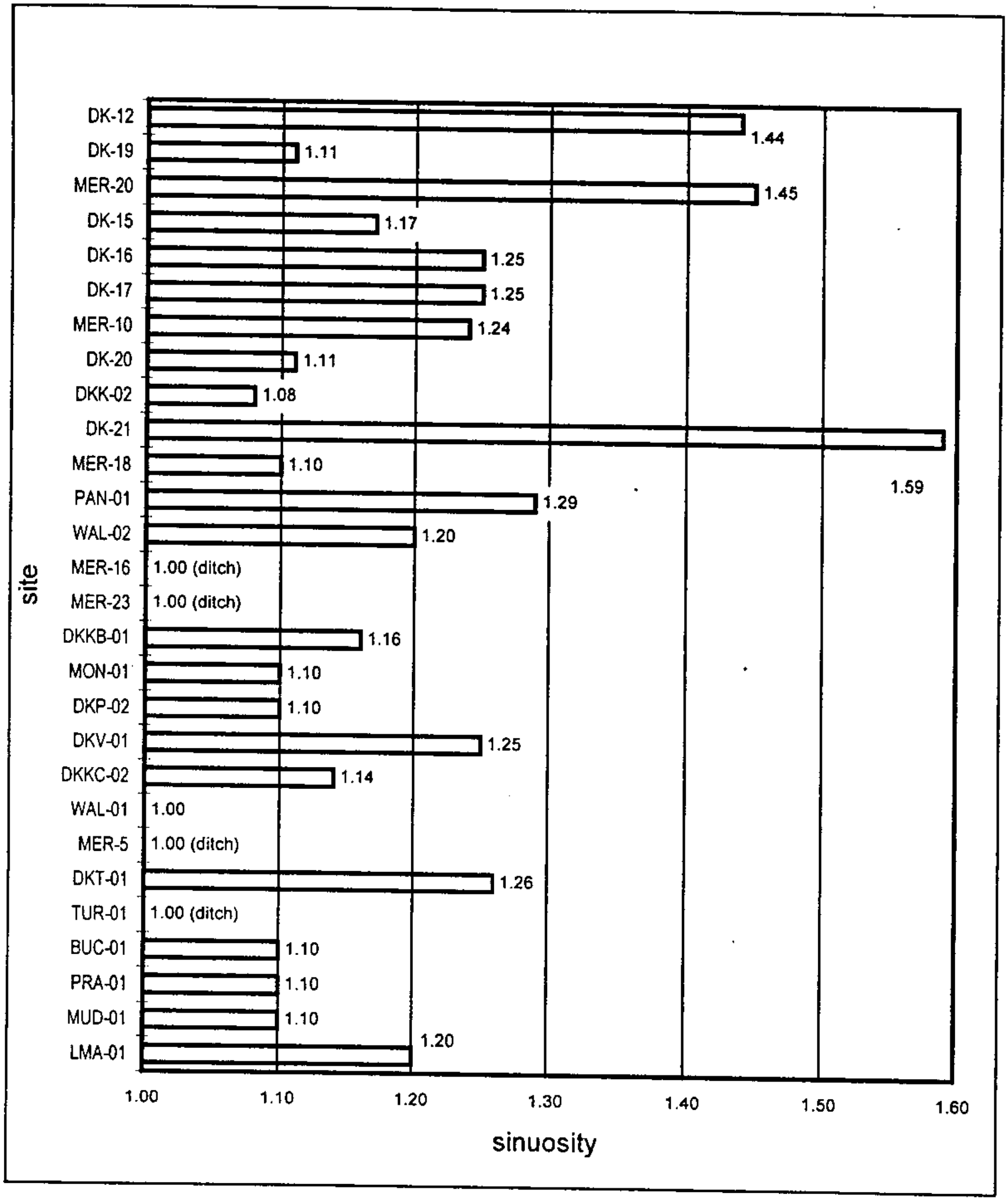


Figure 13. Sinuosity by site name for all sites. Sites are ordered by increasing drainage area from bottom to top.

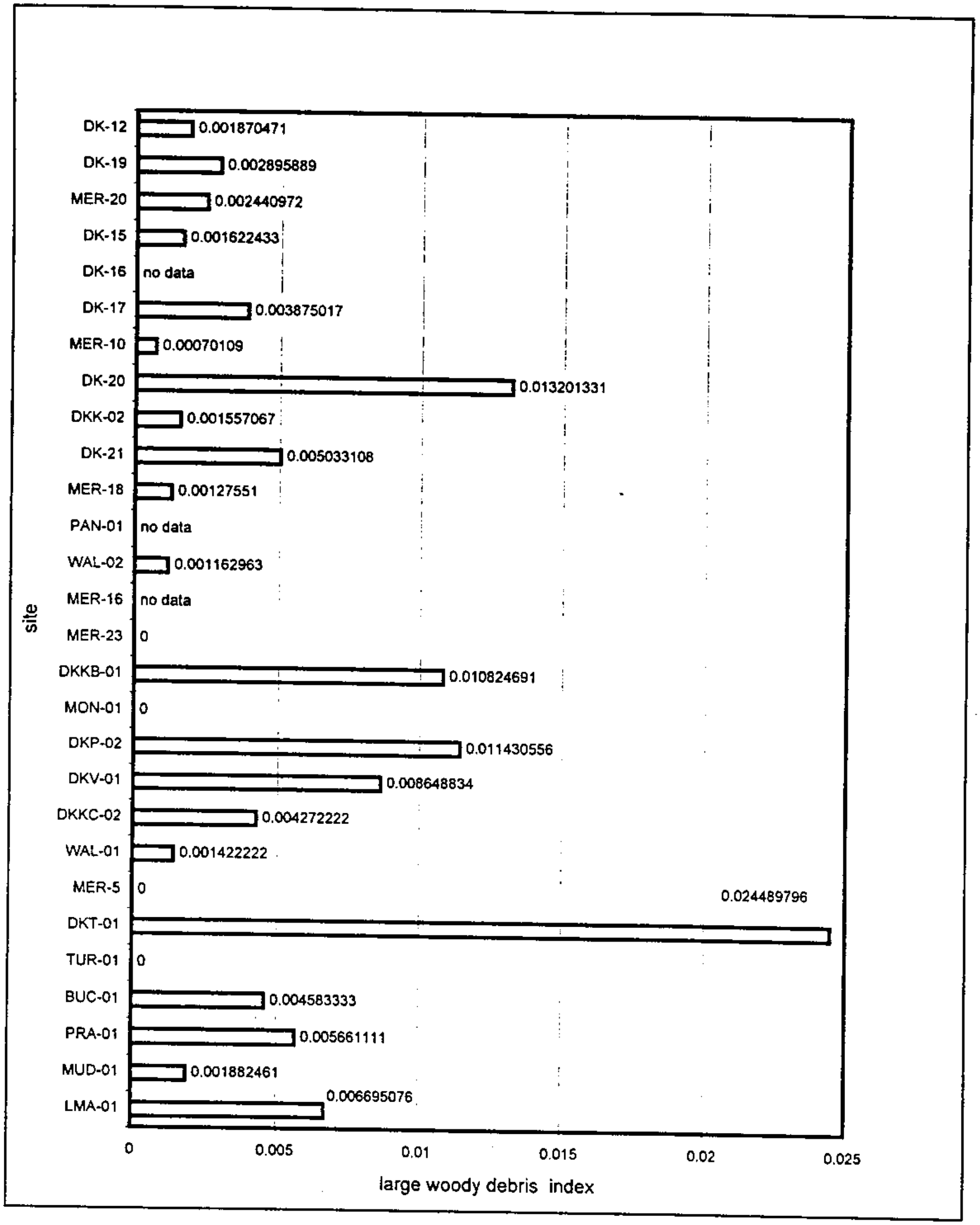


Figure 14. Large woody debris (LWD) index values by site name. The LWD index is the summed product of length and diameter of all LWD pieces in the sample reach divided by the reach's total bankfull planform area.

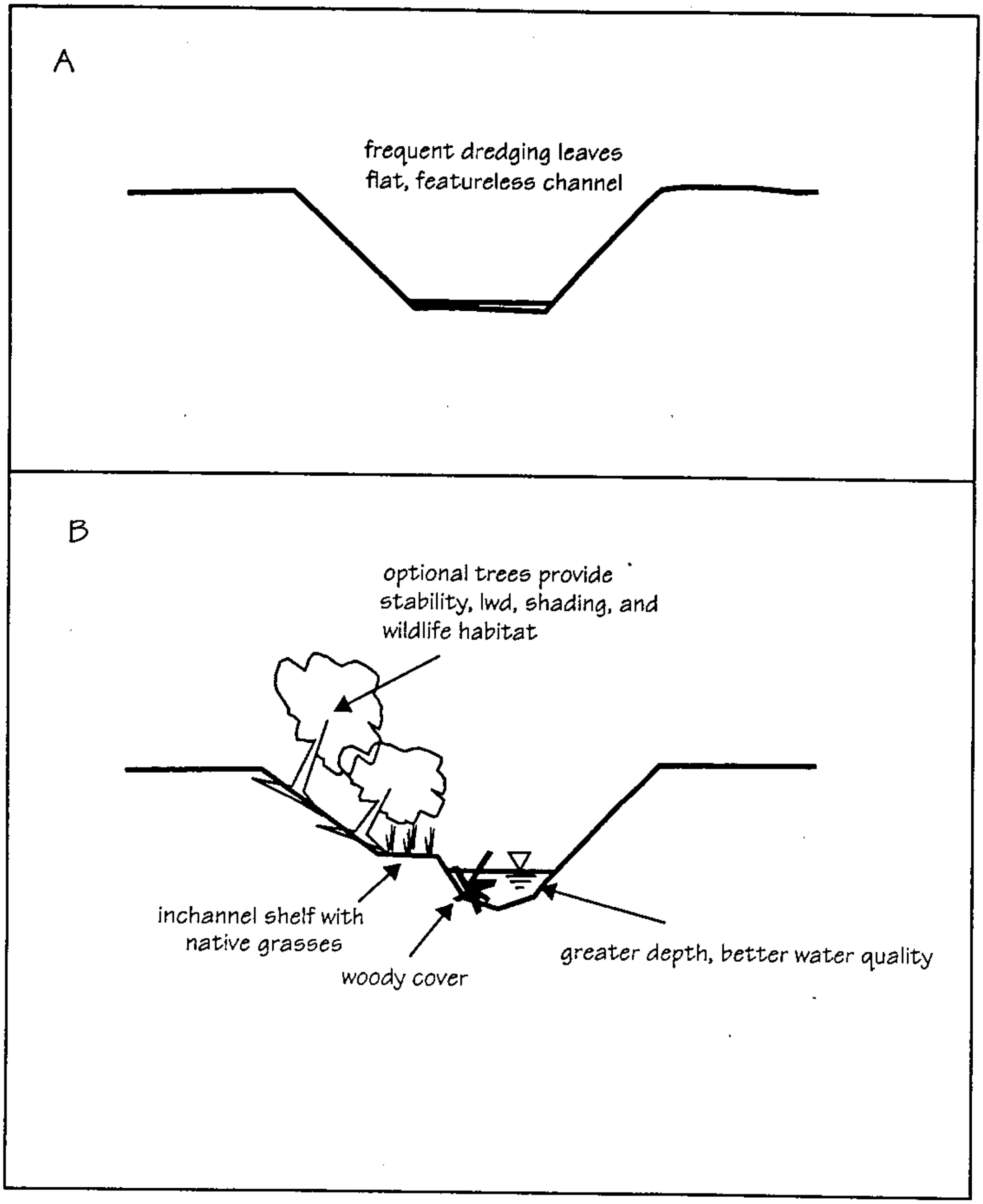


Figure 15. (A) Typical ditch (Type 1) channel in the upper Mackinaw River Watershed. Frequently dredged ditches are oversized with relatively flat beds that have very low mean lowflow depths and no cover. (B) Alternative management for these ditches. When channel slope is adequate, such a channel could still pass flood flows while providing vastly improved aquatic and riparian habitat. Water quality would also be improved by greater mean depth and shading, which would reduce warm weather water temperatures and algae growth.

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Appendix A

Site photos.

Reference photographs were taken of all reaches sampled for this study. Field notes and an index record the exact location (with respect to long profile and transect surveys and benchmarks) of all photographs (see digital data, below). Sets of these slides are retained by The Nature Conservancy and by the author.

Digital data.

Digital data delivered to The Nature Conservancy includes:

--Numerical data for all long profile surveys and cross sections in Excel (*.xls) format. Spreadsheet files also include field note information as described in Gough (1997) and survey control data required to reproduce surveys for monitoring purposes.

--A spreadsheet file indexing all site photographs. The index includes some description, and also sample/photo dates and gives location of photographs with respect to long profile and transect stationing.

--A graphs and charts produced in Excel format.

--A WordPerfect file containing a glossary of all abbreviations used in my field notes and on figures (Also given here in Appendix C).

Raw data.

Table A-1 (following two pages) contains much of the channel geometry data and drainage areas for all sampled sites. Where the word "median" appears, values given are the median values for all transects surveyed at a sample site.

Long profile plots.

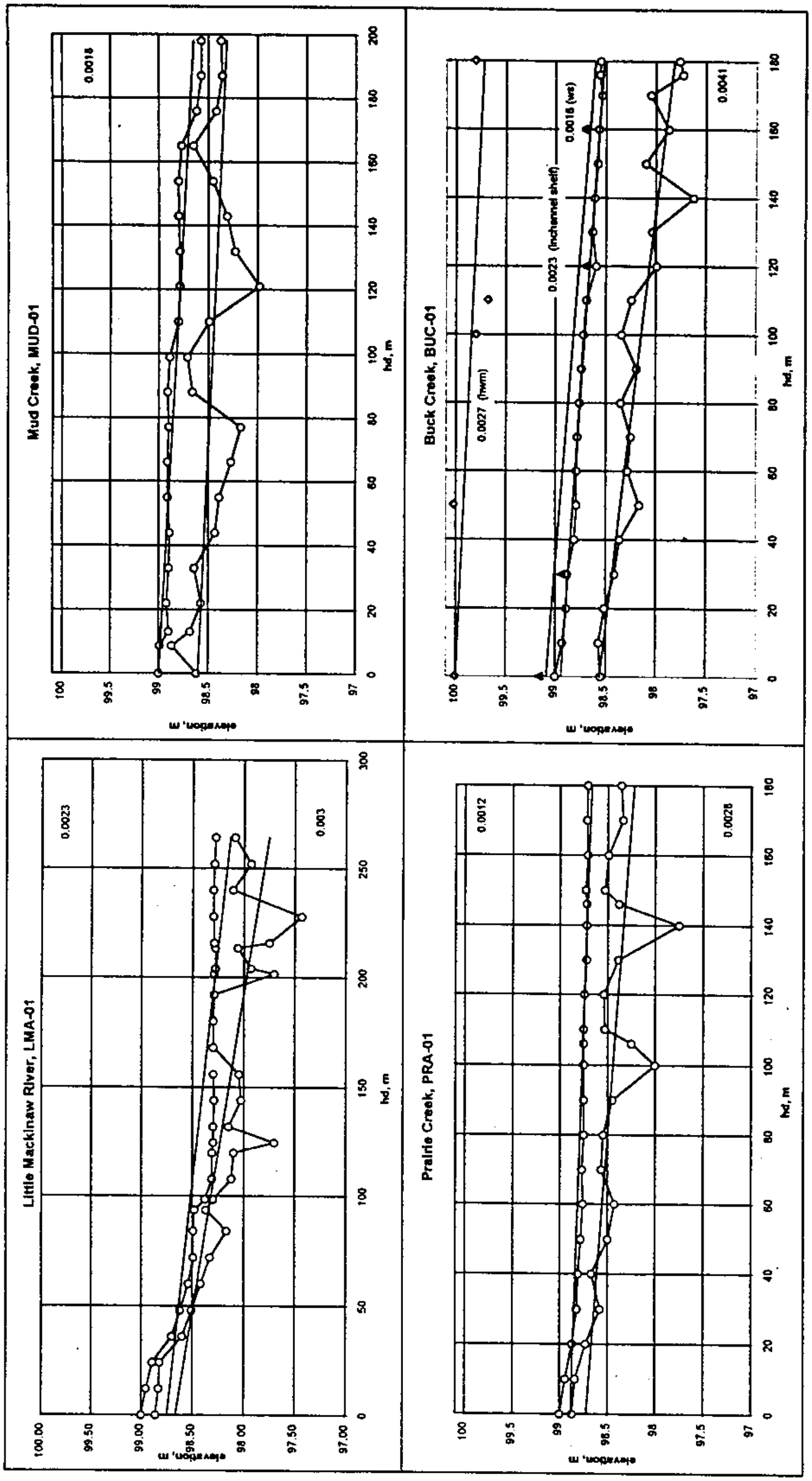
Graphs of long profile survey data follow. Site name is given at the top of each plot. Circles indicate all elevation points. Channel slope was determined by a least squares line through water surface elevations and is given in the upper right corner of each plot. Values shown in the lower right corner of plots are for least squares lines through bed elevation data. These are not shown for all plots.

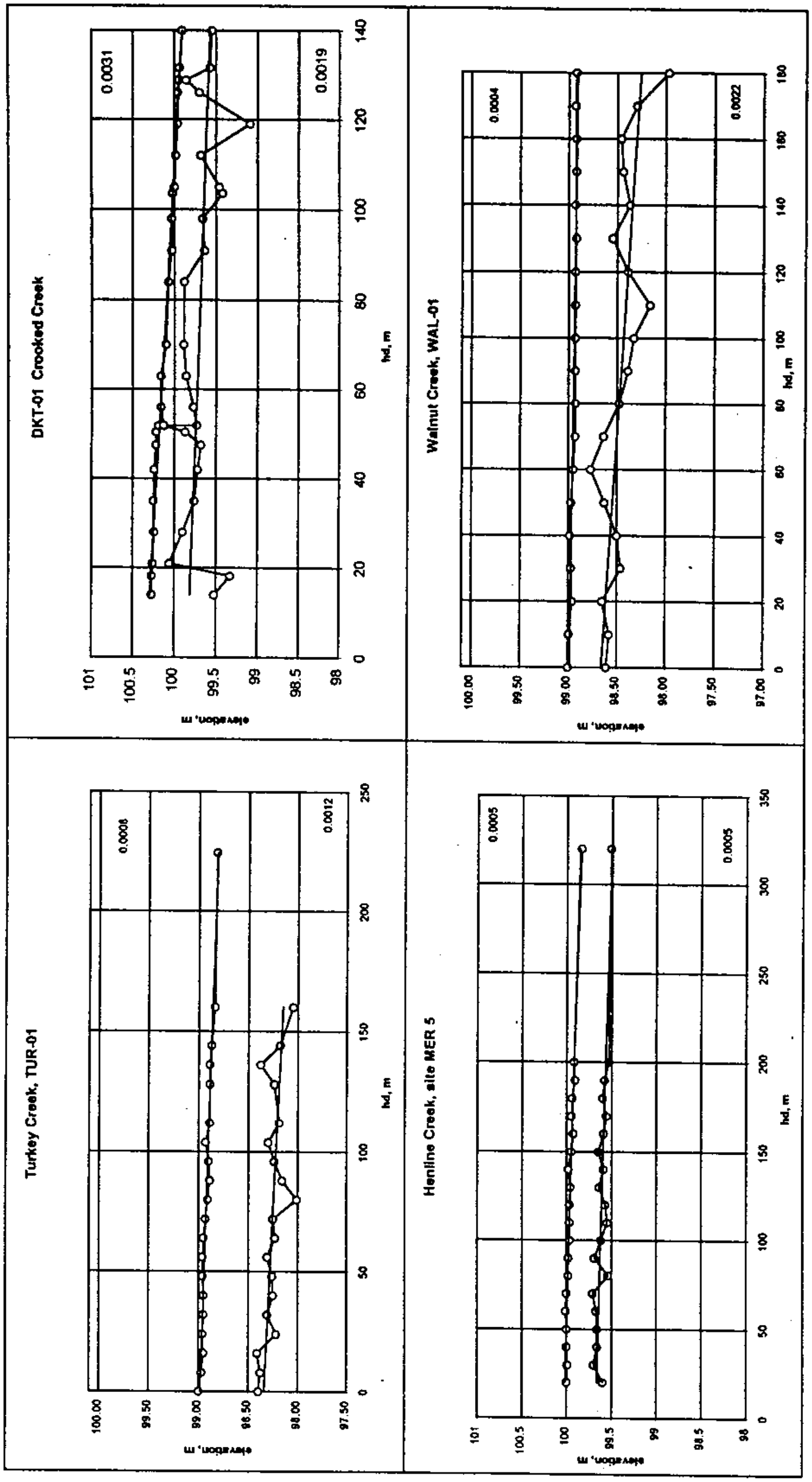
Channel cross section (or transect) plots.

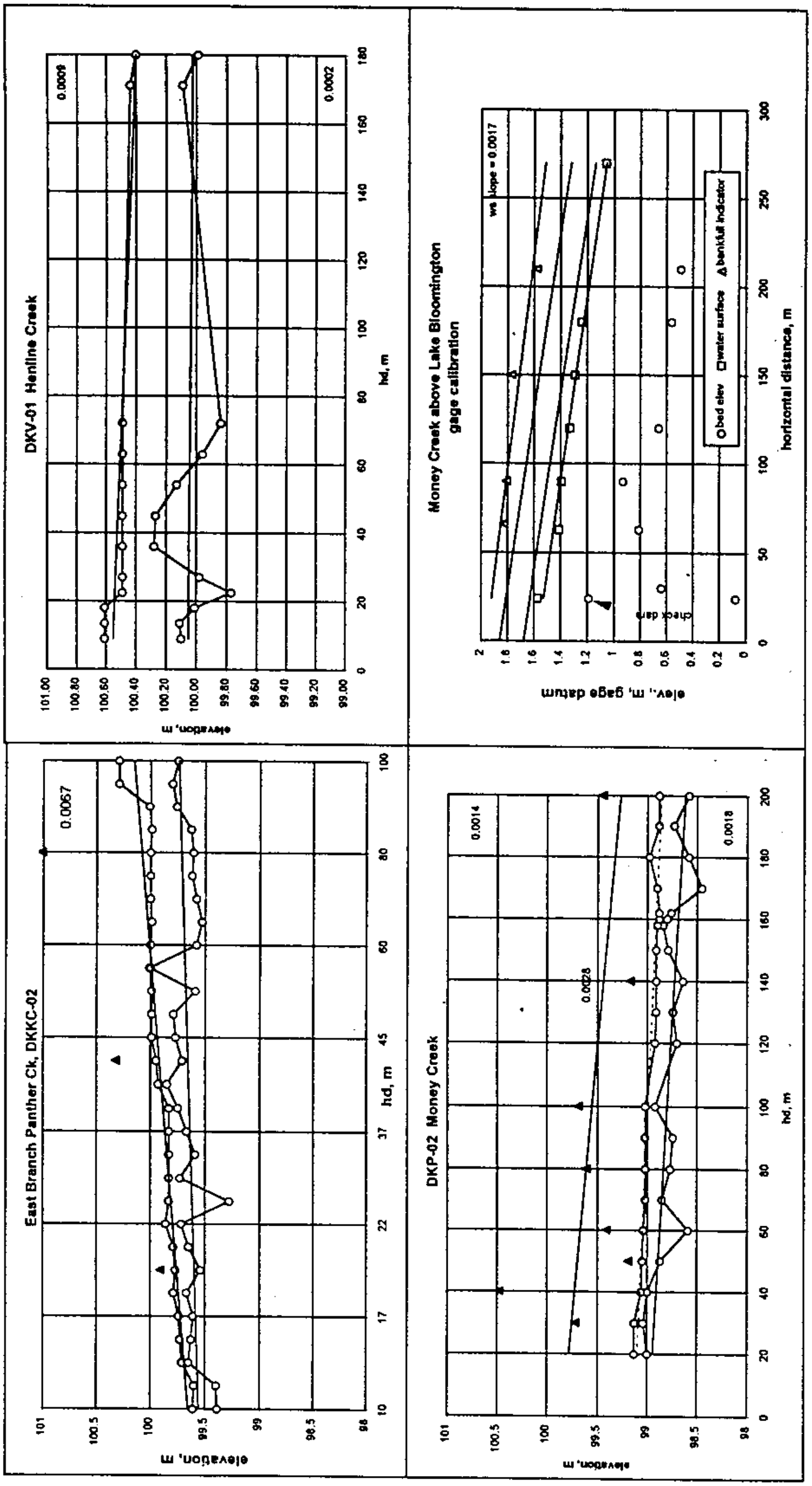
Graphs of channel cross section surveys follow. Definitions for abbreviations used on these plots and in field notes are given in Appendix C.

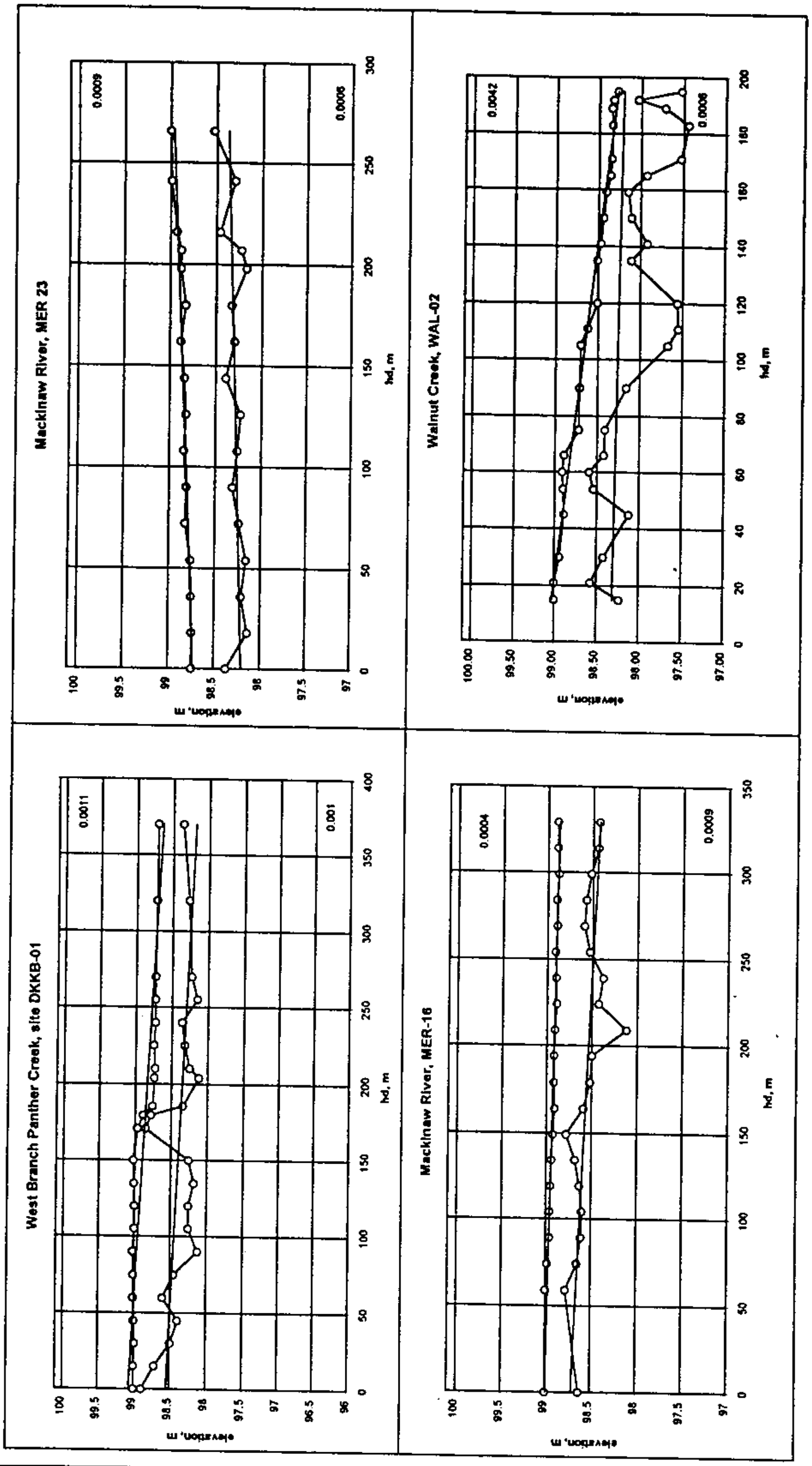
Stream name	Little Mackinaw River	Mud Creek	Prairie Creek	Buck Creek	Turkey Creek	Crooked Creek	Henline Creek	Walnut Creek	E. Br. Panther Creek	Henline Creek	Money Creek	Money Creek	W. Br. Panther Creek	Mackinaw River
Code	LMA-01	MUD-01	PRA-01	BUC-01	TUR-01	DKT-01	MER-5	WAL-01	DKKC-02	(MER_4)	DKP-02	MON-01	DKKB-01	MER-23
slope m/m	0.0023	0.0018	0.0012	0.003	0.0008	0.003	0.0005	0.0004	0.0122	0.0005	0.001	0.002	0.001	0.0009
slope, ft/mi	12.14	9.50	6.34	15.84	4.22	15.84	2.64	2.11	64.42	2.64	5.28	10.56	5.28	4.75
sinuosity	1.20	1.10	1.10	1.10	1.00	1.26	1.00	1.00	1.14	1.25	1.10	1.10	1.16	1.00
Wbf m (median)	9.84	14.23	15.82	11.95	n/a	11.33	n/a	10.27	14.71	12.38	13.2	8.6	14.57	9.2
Abf m^2 (median)	6.4	25.76	15.84	11.75	n/a	18.15	n/a	13.46	20.55	15.86	15.7	7.42	21.75	6.89
Dmean m (median)	0.65	1.83	1.2	0.96	n/a	1.6	n/a	1.18	1.34	1.28	1.2	0.87	1.51	0.75
w:d (median)	15.15	7.86	13.49	12.52	n/a	7.08	n/a	8.41	10.85	9.67	11.00	9.97	9.69	12.27
Dmax m (median)	0.95	2.42	2.04	1.49	n/a	2.37	n/a	1.49	1.78	1.74	1.77	1.06	1.97	1.04
entrenchment ratio	>2.2	>2..2	>2.2	>2.2	ditch	>2.2	>2.2	>2.2	>2.2	>2.2	>2.2	>2.2	>2.2	ditch
drainage area ac	9070	10758.4	13424	16512	17693	19264	22848	23104	23488	25472	25856	27840	31360	39424
drainage area mi^2	14.2	16.8	21.0	25.8	27.6	30.1	35.7	36.1	36.7	39.8	40.4	43.5	49.0	61.6
drainage area km^2	36.7	43.5	54.3	66.8	71.6	78.0	92.5	93.5	95.1	103.1	104.6	126.9	126.9	159.5
lwd index	0.006695	0.001882	0.005661	0.004583	0	0.02449	0	0.001422	0.004272	0.008649	0.011431	nd	0.010825	0
d50 mm	nd	nd	30	8	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
BHmax, m	3.84	3.07	2.10	1.56	na	2.39	na	2.34	2.02	3.27	1.91	1.47	2.53	2.98
tractive force Dmax kg/m^2	2.185	4.356	2.448	4.47	nd	7.11	nd	0.596	21.716	0.87	1.77	2.12	1.97	0.936
tractive force Dmean kg/m^2	1.495	3.294	1.44	2.88	nd	4.8	nd	0.472	16.348	0.64	1.2	1.74	1.51	0.675
incipient diameter, mm, using Dmean	14.95	32.94	14.4	28.8	nd	48	nd	4.72	163.48	6.4	12	17.4	15.1	6.75

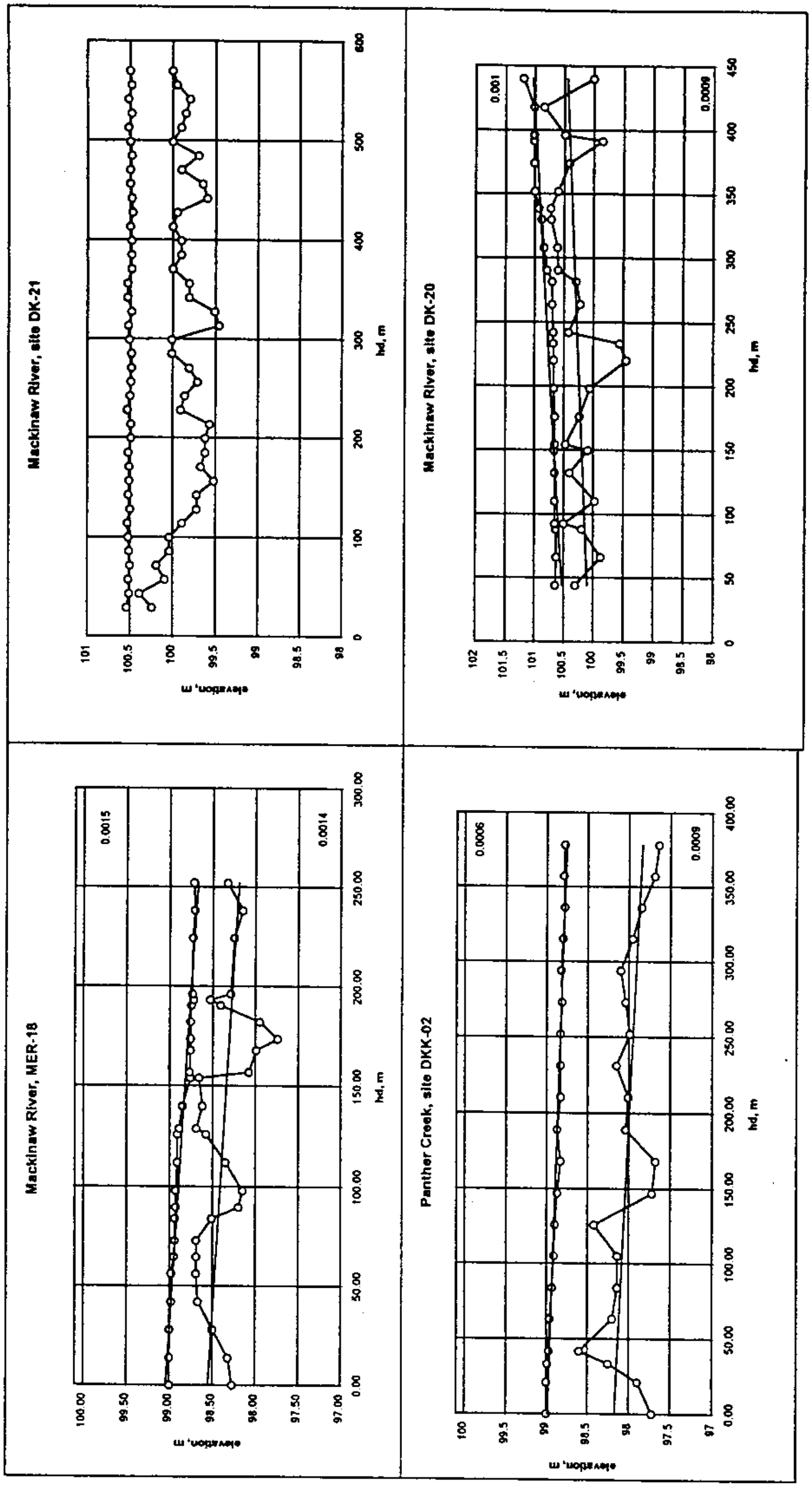
Stream name	Mackinaw River	Walnut Creek	Panther Creek	Mackinaw River	Mackinaw River	Panther Creek	Mackinaw River	Mackinaw River	Mackinaw River	Mackinaw River	Mackinaw River	Mackinaw River	Mackinaw River	Mackinaw River
Code	MER-16	WAL-02	PAN-01	MER-18	DK-21	DKK-02	DK-20	MER-10	DK-17	DK-16	DK-15	MER-20	DK-19	DK-12
slope m/m	0.004	0.0042	0.001	0.0015	0.0002	0.0006	0.001	0.0003	0.0009	0.001	0.0002	0.0012	0.0008	0.001
slope, ft/mi	21.12	22.18	5.28	7.92	1.06	3.17	5.28	1.58	4.75	5.28	1.06	6.34	4.22	5.28
sinuosity	1.00	1.20	1.29	1.10	1.59	1.08	1.11	1.24	1.25	1.25	1.17	1.45	1.11	1.44
Wbf m (median)	n/a	10.87	18.7	16.9	16.2	22.71	22.05	29.2	29.66	42.01	43.15	41.32	56.99	63.21
Abf m^2 (median)	n/a	11.88	31.1	13.9	23.14	47.37	48.55	57.8	69.99	139.43	127.14	130.57	151.47	119.33
Dmean m (median)	n/a	1	1.66	1.25	1.43	2.07	2.19	1.98	2.39	3.3	2.85	3.26	2.69	1.94
w:d (median)	n/a	11.56	11.27	14.65	11.33	10.99	10.15	14.75	12.89	12.79	14.17	12.90	21.67	32.14
Dmax m (median)	n/a	1.4	2.35	1.61	2.03	2.85	2.9	2.55	3.03	4.09	3.79	4.17	3.77	2.81
entrenchment ratio	ditch	>2.2	>2.2	>2.2	>2.2	>2.2	>2.2	>2.2	>2.2	>2.2	>2.2	>2.2	>2.2	>2.2
drainage area ac	40562	42880	45440	57991	68224	95232	175552	194240	312960	490880	524480	529280	621888	672000
drainage area mi^2	63.4	67.0	71.0	90.6	106.6	148.8	274.3	303.5	489.0	767.0	819.5	827.0	971.7	1050.0
drainage area km^2	164.2	173.5	183.9	234.7	276.1	385.4	710.4	786.1	1266.5	1986.5	2122.5	2141.9	2516.7	2719.5
lwd index	0	0.001163	nd	0.001276	0.005033	0.001557	0.013201	0.000701	0.003875	nd	0.001622	0.002441	0.002896	0.00187
d50 mm	nd	24.5	nd	nd	3	nd	nd	nd	25	nd	nd	13	17	10
BHmax, m	na	2.98	2.00	2.15	1.96	3.66	3.58	2.67	3.69	5.87	4.15	3.94	4.34	3.57
tractive force Dmax kg/m^2	nd	5.88	2.35	2.415	0.406	1.71	2.9	0.765	2.727	4.09	0.758	5.004	3.016	2.81
tractive force Dmean kg/m^2	nd	4.2	1.66	2.97	0.286	1.242	2.19	0.594	2.151	3.3	0.57	3.912	2.152	1.94
incipient diameter, mm, using Dmean	nd	42	16.6	29.7	2.86	12.42	21.9	5.94	21.51	33	5.7	39.12	21.52	19.4


Mud Creek, MUD-01
0.0018
Buck Creek, BUC-01
0.0027 (fwm)
0.0023 (inchannel shelf)
0.0018 (ws)
0.0041
Little Mackinaw River, LMA-01
0.0023
0.003
Prairie Creek, PRA-01
0.0012
0.0028
elevation, m
hd, m

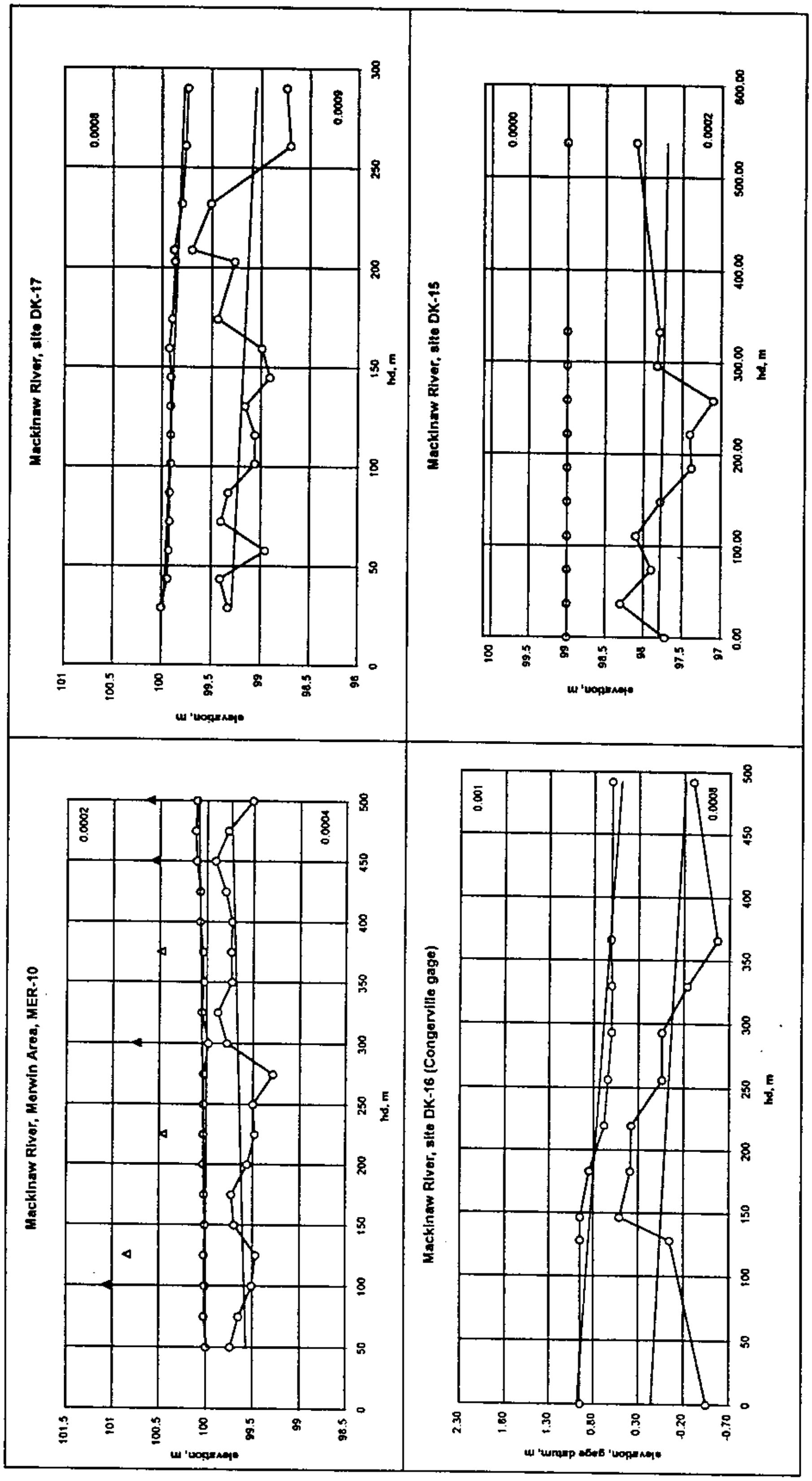

DKT-01 Crooked Creek
0.0031
0.0019
elevation, m
hd, m
Walnut Creek, WAL-01
0.0004
0.0022
elevation, m
hd, m
Turkey Creek, TUR-01
0.0008
0.0012
elevation, m
hd, m
Henline Creek, site MER 5
0.0005
0.0005
elevation, m
hd, m

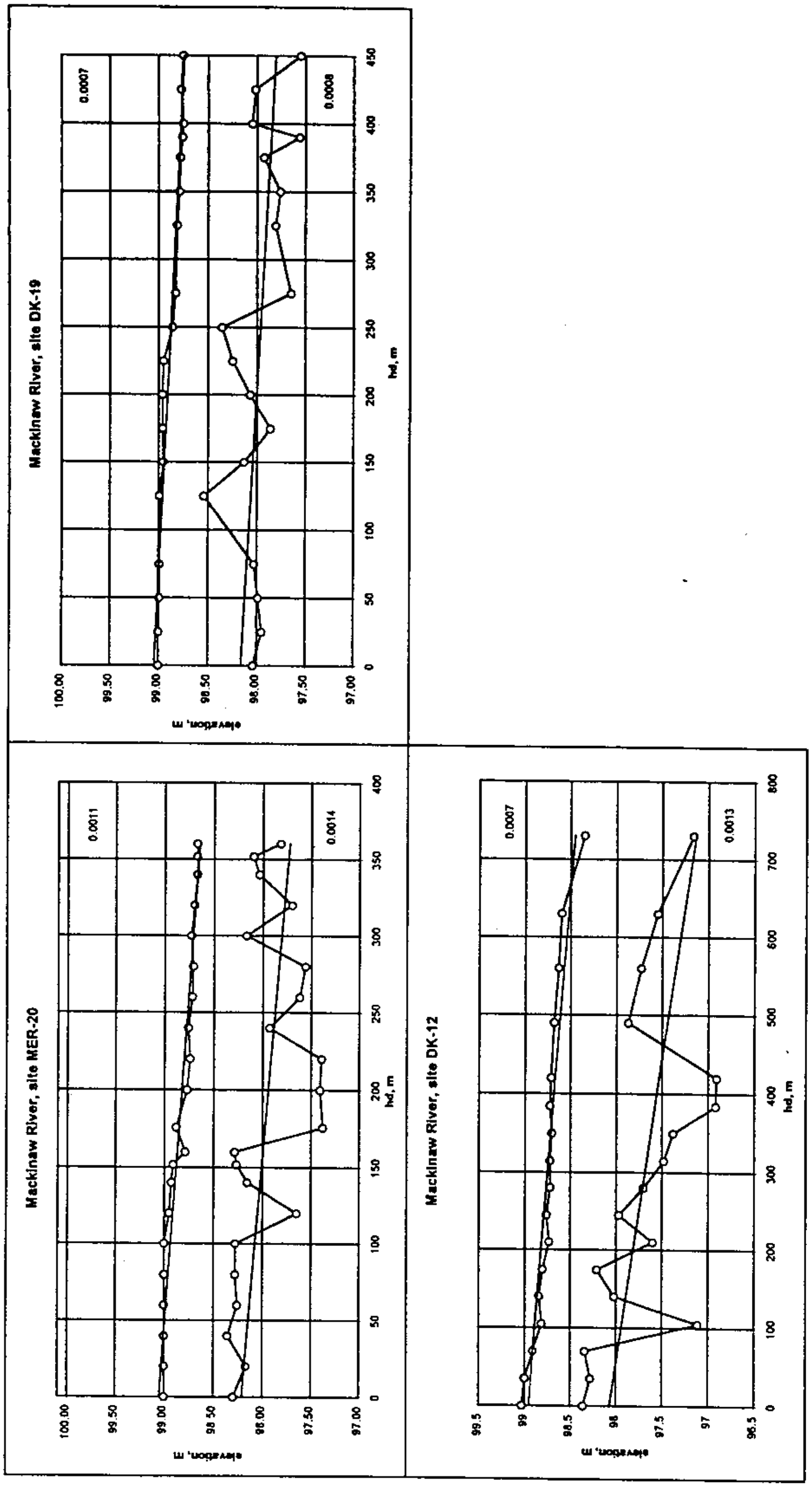

DKV-01 Henline Creek
0.0009
0.0002
elevation, m
hd, m
East Branch Panther Ck, DKKC-02
0.0067
elevation, m
hd, m
Money Creek above Lake Bloomington gage calibration
ws slope = 0.0017
check dam
elev., m, gage datum
horizontal distance, m
bed elev
water surface
bankfull indicator
DKP-02 Money Creek
0.0014
0.0028
0.0018
elevation, m
hd, m


Mackinaw River, MER 23
0.0009
0.0006
Walnut Creek, WAL-02
0.0042
0.0006
West Branch Panther Creek, site DKKB-01
0.0011
0.001
Mackinaw River, MER-16
0.0004
0.0009
elevation, m
hd, m

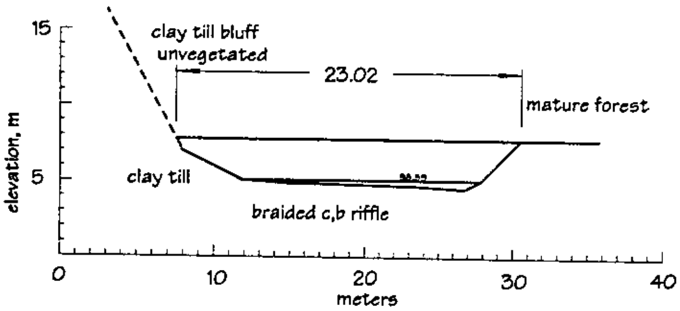


Mackinaw River, site DK-21
elevation, m
hd, m
Mackinaw River, site DK-20
0.001
0.0009
elevation, m
hd, m
Mackinaw River, MER-18
0.0015
0.0014
elevation, m
hd, m
Panther Creek, site DKK-02
0.0006
0.0009
elevation, m
hd, m

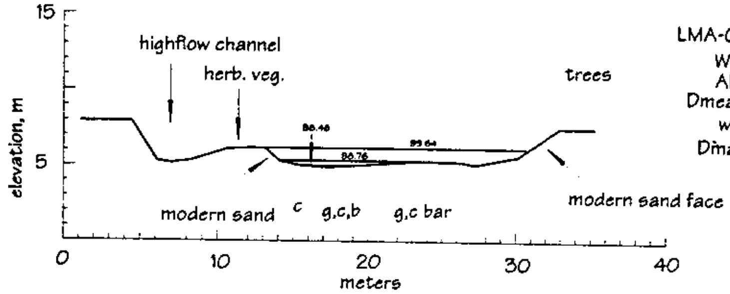

Mackinaw River, site DK-17
elevation, m
hd, m
0.0008
0.0009
Mackinaw River, site DK-15
elevation, m
hd, m
0.0000
0.0002
Mackinaw River, Merwin Area, MER-10
elevation, m
hd, m
0.0002
0.0004
Mackinaw River, site DK-16 (Congerville gage)
elevation, gage datum, m
hd, m
0.001
0.0008


Mackinaw River, site DK-19
0.0007
0.0008
elevation, m
hd, m
Mackinaw River, site MER-20
0.0011
0.0014
elevation, m
hd, m
Mackinaw River, site DK-12
0.0007
0.0013
elevation, m
hd, m

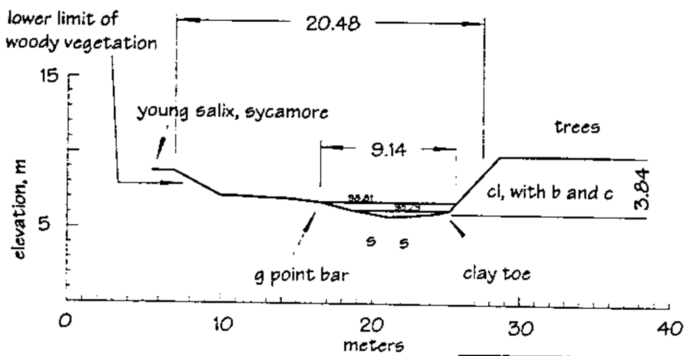
Little Mackinaw River, LMA-01



LMA-01, transect 2.1
Wbf = 23.02
Abf = 58.61
Dmean = 2.54
w:d = 9.06
Dmax = 3.24

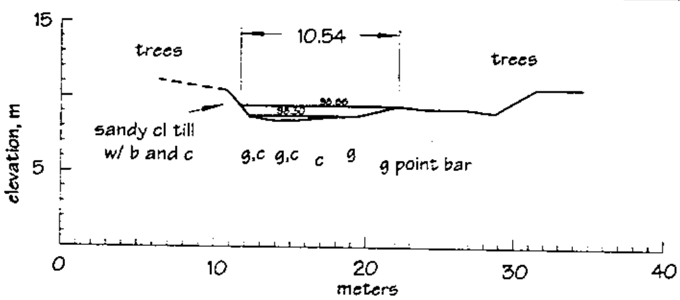


LMA-01, transect 4.9
Wbf = ?
Abf = ?
Dmean = ?
w:d = ?
Dmax = ?



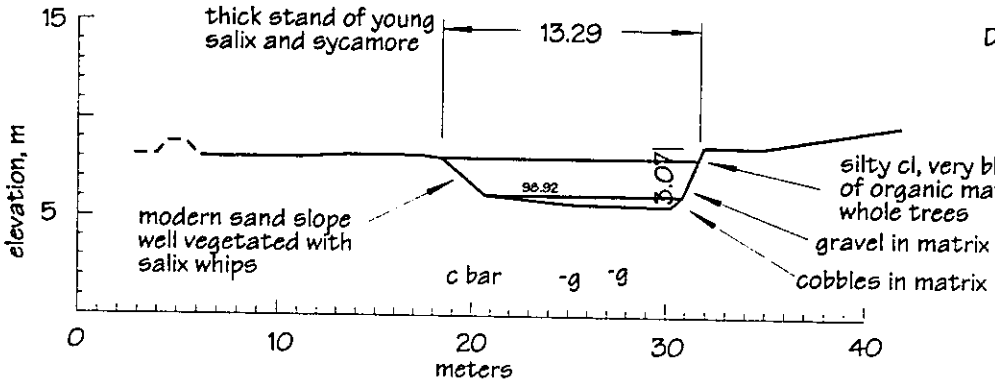
LMA-01, transect 9.0
Wbf = 9.14
Abf = 5.70
Dmean = 0.62
w:d = 14.74
Dmax = 0.93
BHmax = 3.84

Note: Bankfull elevations not clear for this reach, most likely because of strong control by clay till and lag particles (boulders and cobbles).



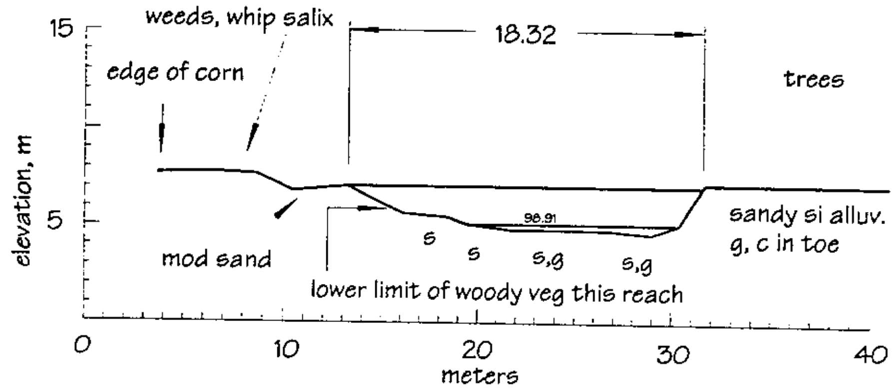
LMA-01, transect 11.2
Wbf = 10.54
Abf = 7.10
Dmean = 0.673
w:d = 15.66
Dmax = 0.98

Mud Creek, site MUD-01



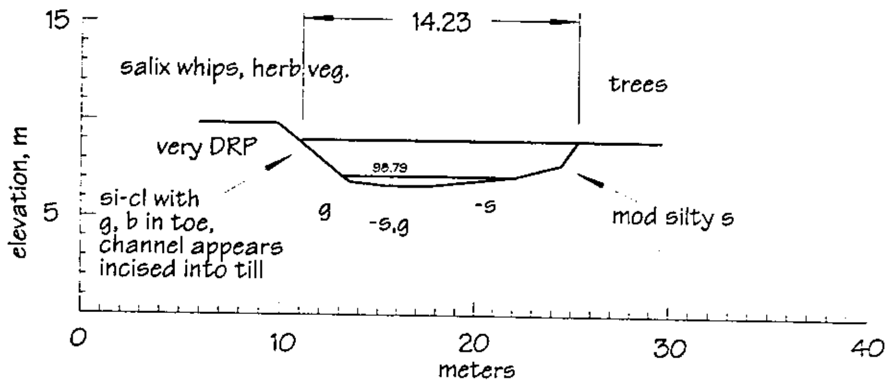
MUD-01, transect 3.4

Wbf =	13.29
Abf =	25.58
Dmean =	1.92
w:d =	6.92
Dmax =	2.42
BHmax =	3.07



MUD-01, transect 5.1

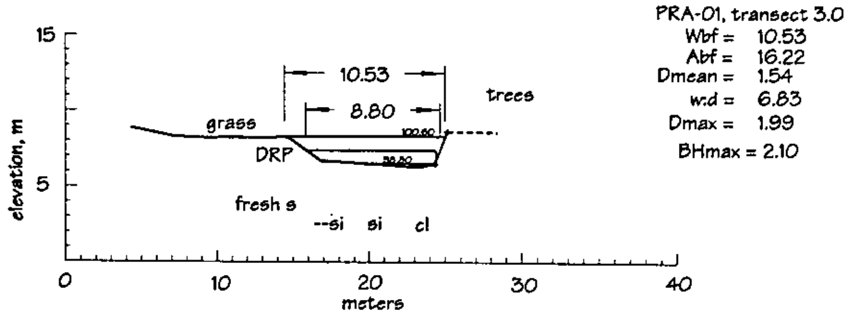
Wbf =	18.32
Abf =	33.51
Dmean =	1.83
w:d =	10.01
Dmax =	2.47

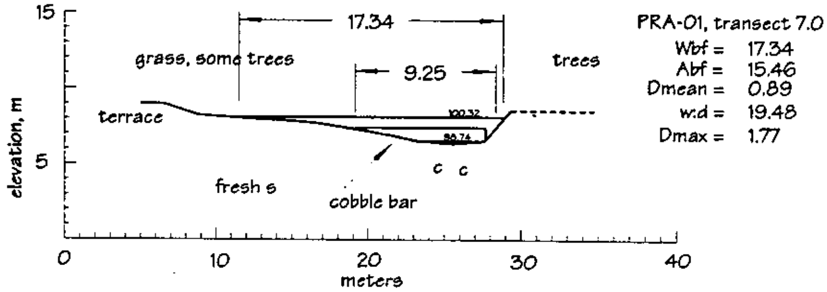


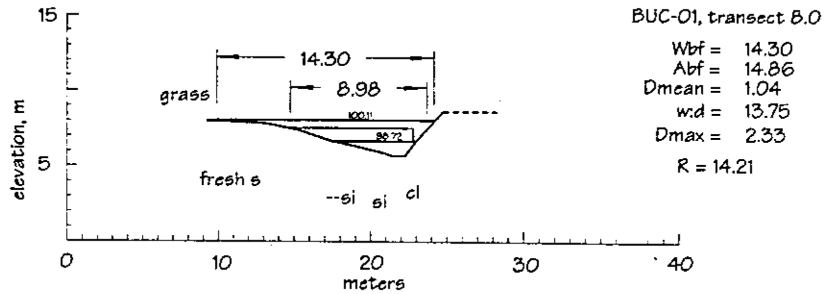
MUD-01, transect 7.0

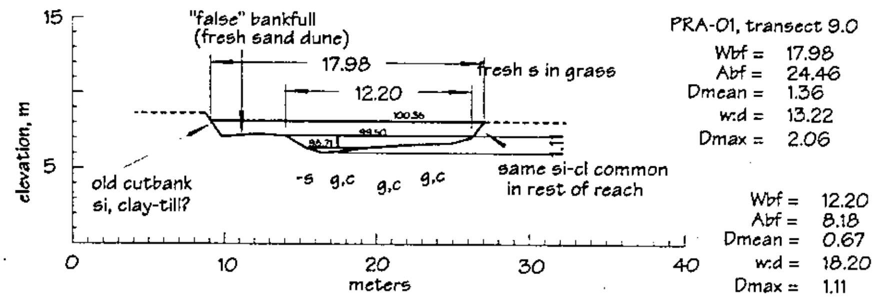
Wbf =	14.23
Abf =	25.76
Dmean =	1.81
w:d =	7.86
Dmax =	2.36

Prairie Creek, site PRA-01

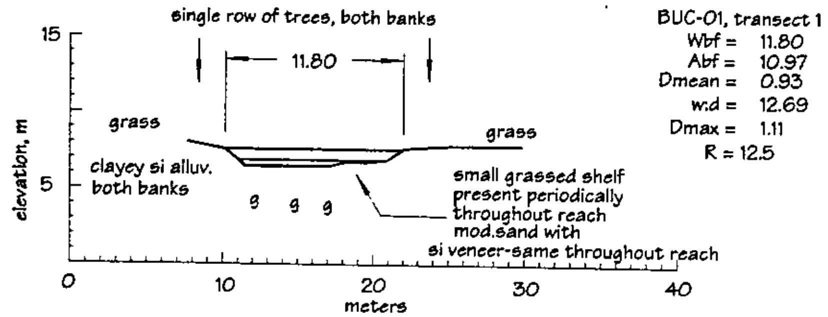


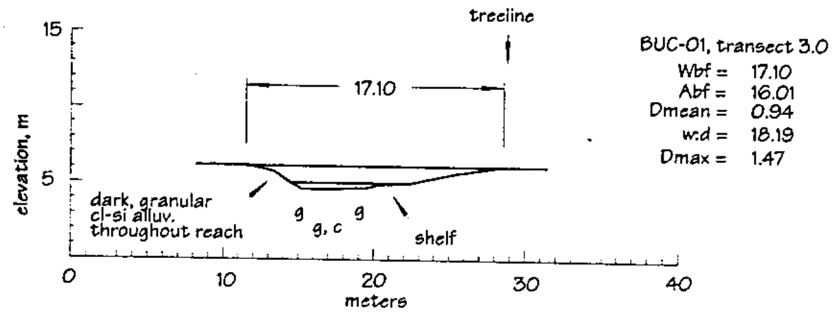


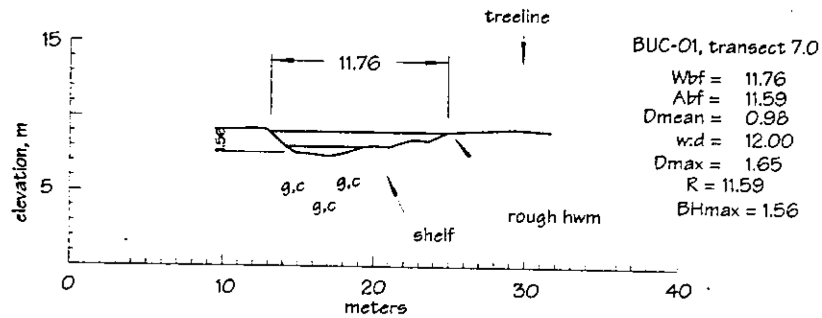


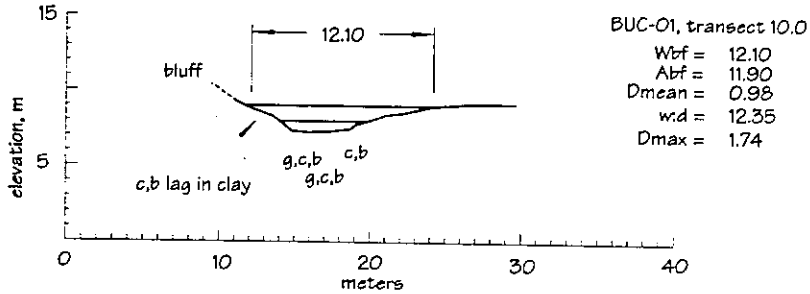


Buck Creek, site BUC-01

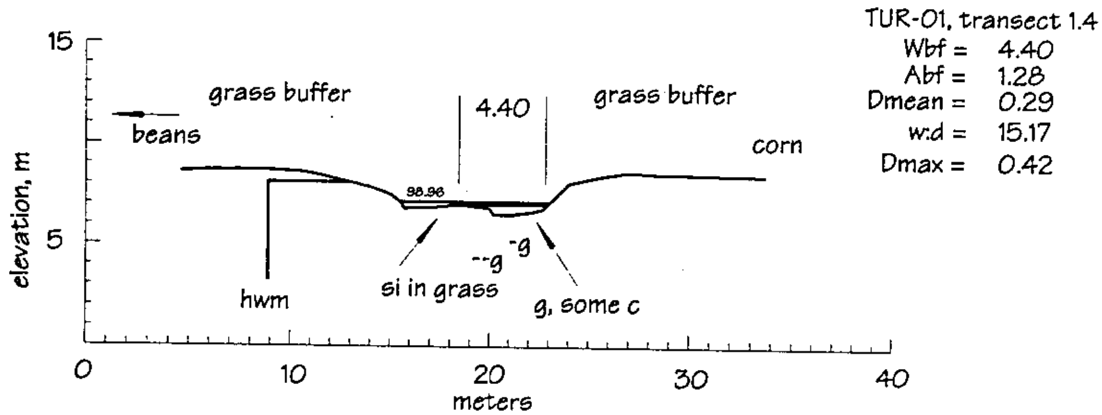


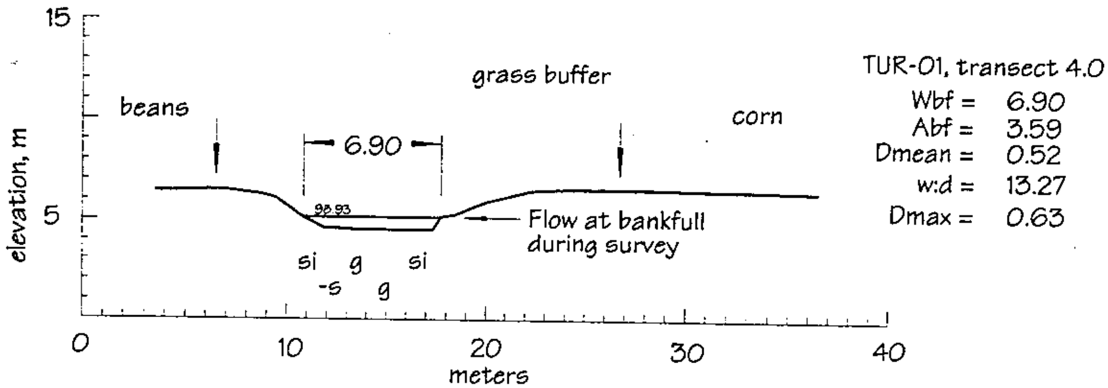


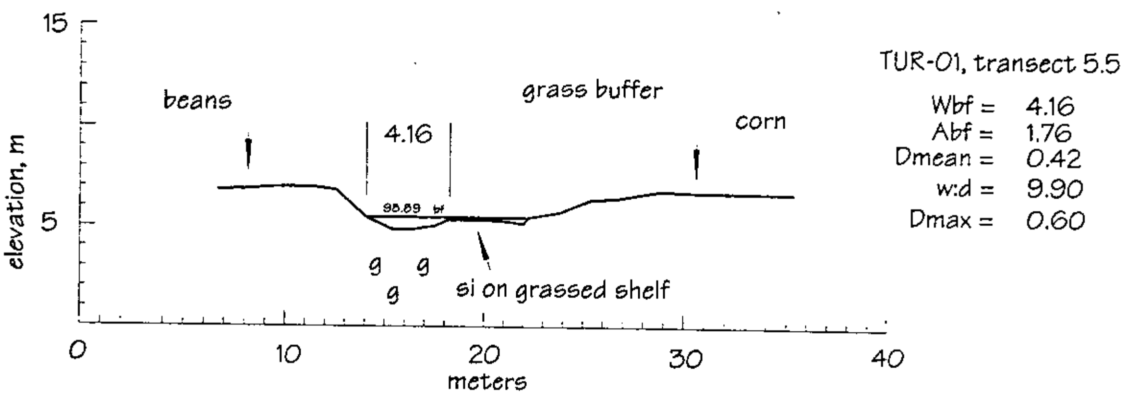




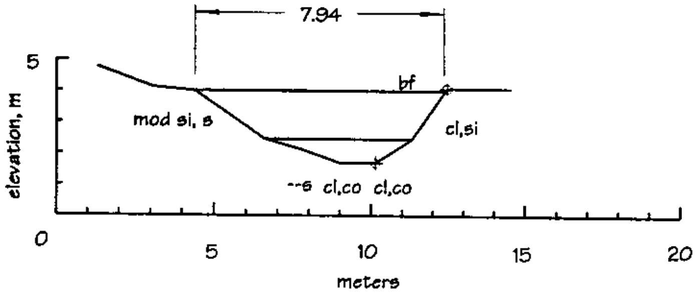
Turkey Creek, site TUR-01



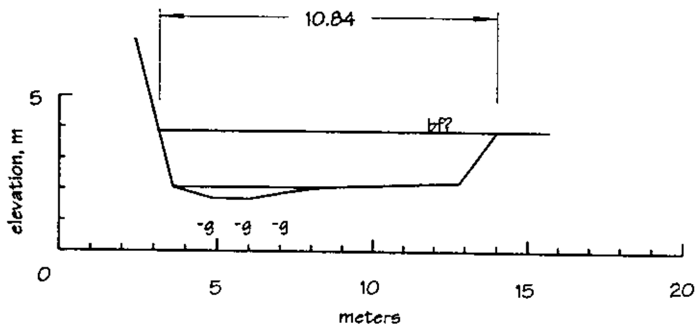




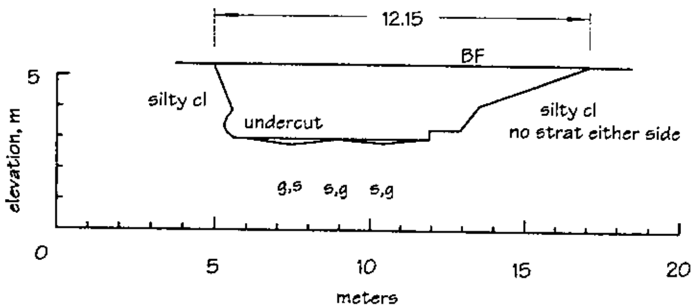
Crooked Creek, site DKT-01



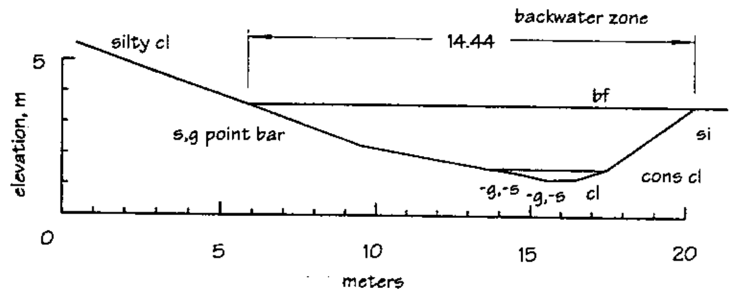
DKT-01, transect 1
Wbf = 7.94
Abf = 11.92
Dmean = 1.50
w:d = 5.3
Dmax = 2.3
BHmax = 2.39



DKT-01, transect 2
Wbf = 10.84
Abf = 18.64
Dmean = 1.72
w:d = 6.3
Dmax = 2.19

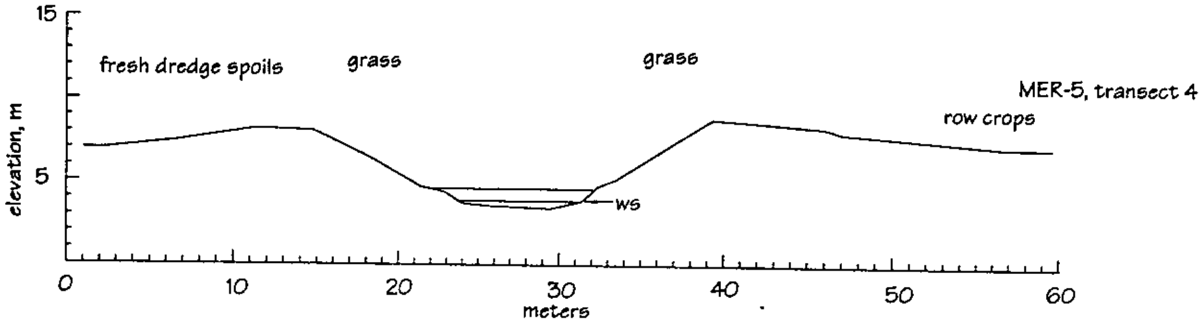


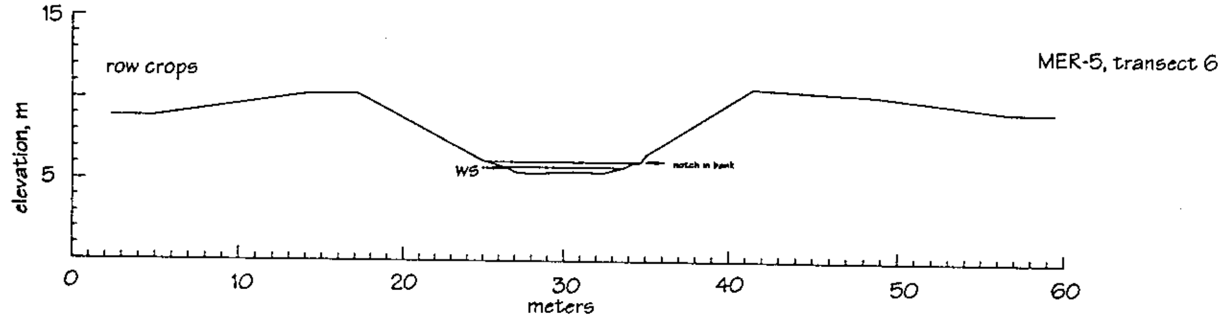
DKT-01, transect 5
Wbf = 12.15
Abf = 21.87
Dmean = 1.8
w:d = 6.75
Dmax = 2.60

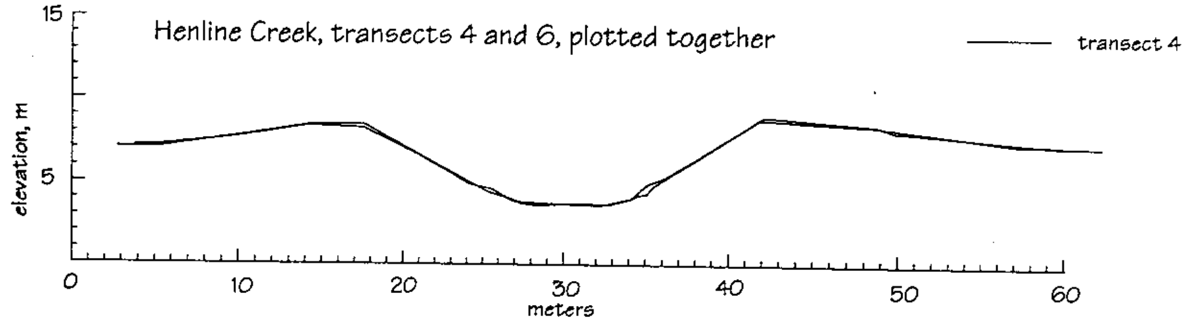


DKT-01, transect 10
Wbf = 14.44
Abf = 20.19
Dmean = 1.40
w:d = 10.3
Dmax = 2.41

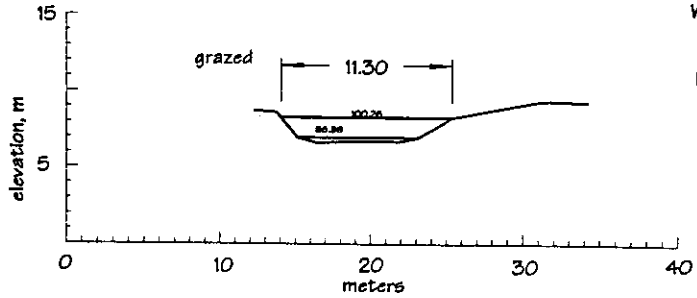
Henline Creek, site MER-5





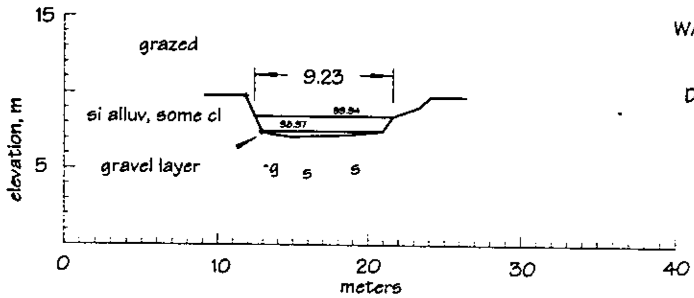


Walnut Creek, site WAL-01

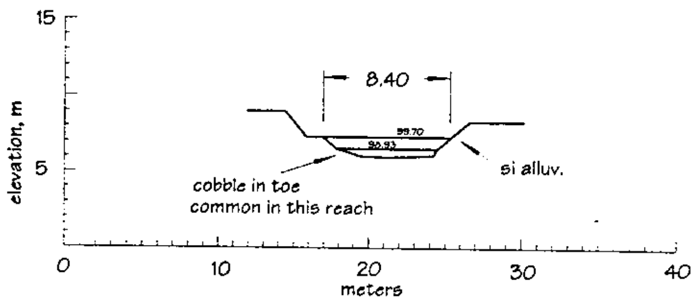


WAL-01, transect 2.0
Wbf = 11.30
Abf = 14.59
Dmean = 1.29
w:d = 8.76
Dmax = 1.65

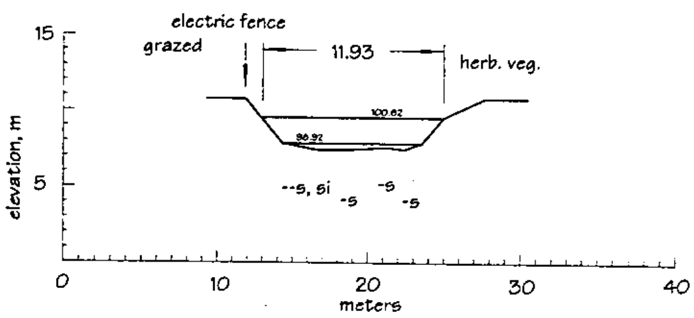
This reach is affected by cattle grazing and, probably, incision. Bankfull indicators are not clear.



WAL-01, transect 3.7
Wbf = 9.23
Abf = 9.87
Dmean = 1.07
w:d = 8.63
Dmax = 1.33
BHmax = 2.34

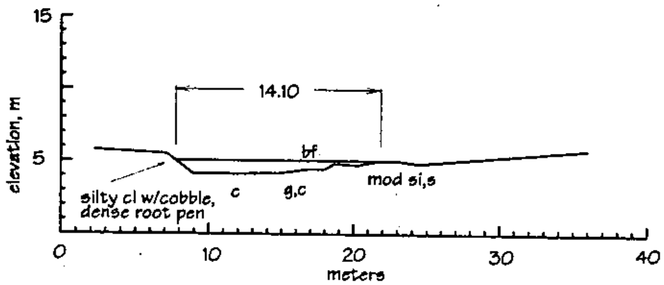


WAL-01, transect 8.0
Wbf = 8.40
Abf = 8.61
Dmean = 1.02
w:d = 8.23
Dmax = 1.32
Ent. Ratio = >2.2



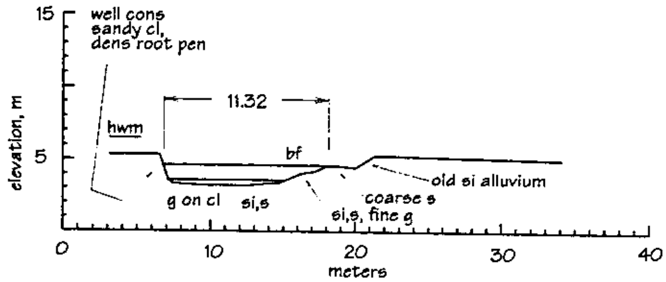
WAL-01, transect 9.0
Wbf = 11.93
Abf = 20.75
Dmean = 1.74
w:d = 6.87
Dmax = 2.10

East Branch Panther Creek, site DKKC-02



DKKC-02, transect 4

Wbf = 14.1
Abf = 8.78
Dmean = 0.62
w:d = 22.7
Dmax = 0.92

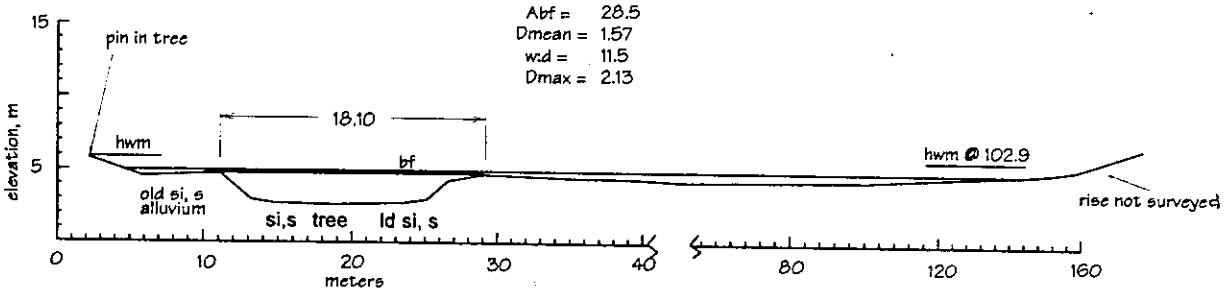


DKKC-02, transect 5

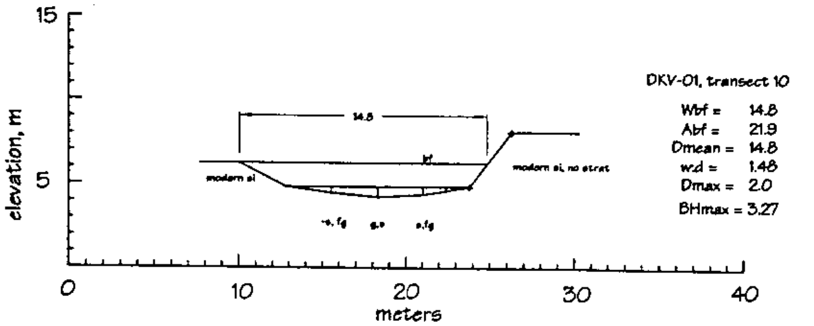
Wbf = 11.32
Abf = 12.6
Dmean = 1.11
w:d = 10.2
Dmax = 1.44

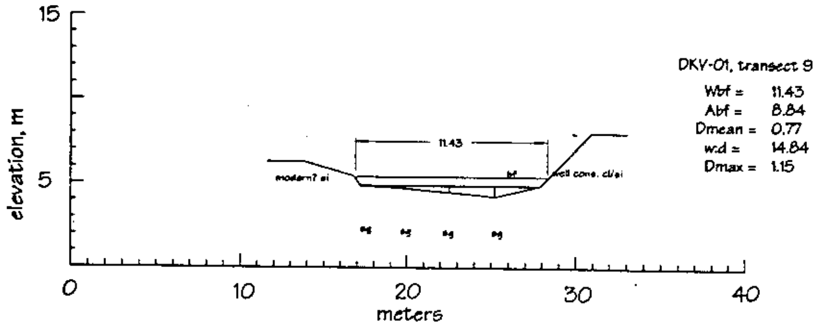
DKKC-02, transect 6.5

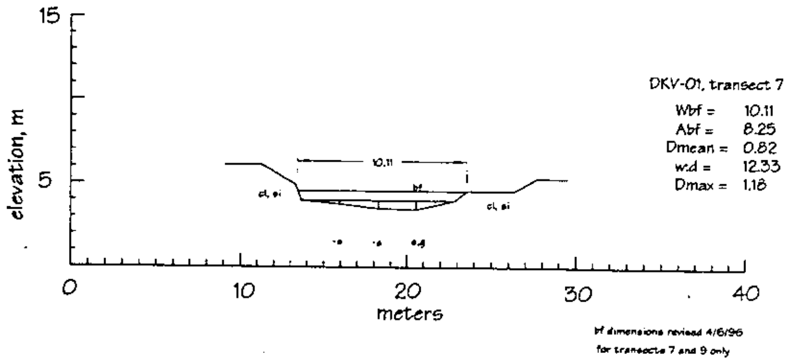
Wbf = 18.10
Abf = 28.5
Dmean = 1.57
w:d = 11.5
Dmax = 2.13

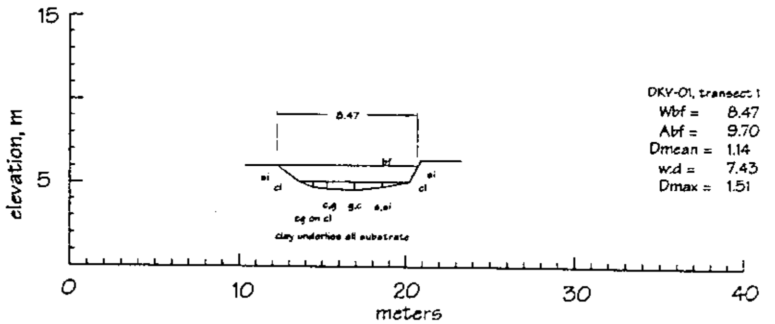


Henline Creek, site DKV-01

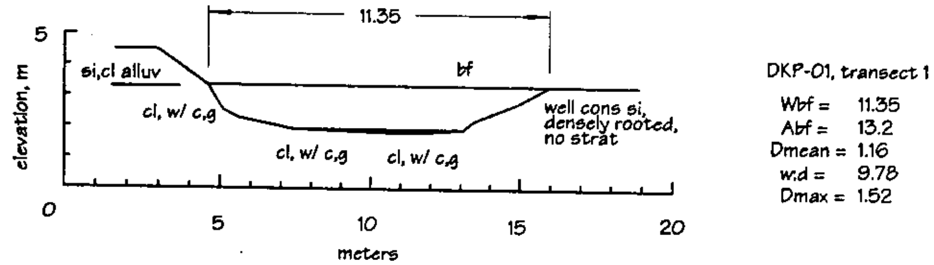


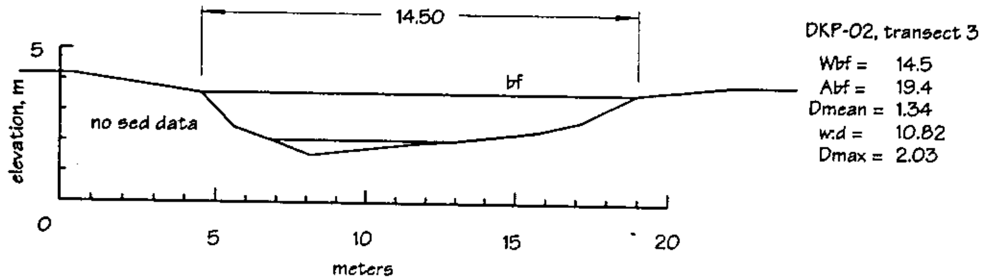


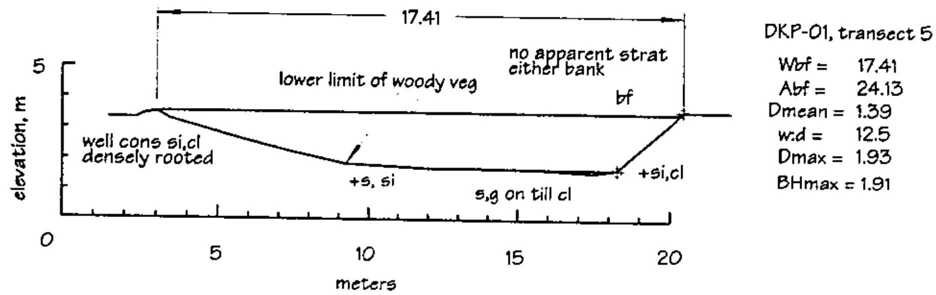


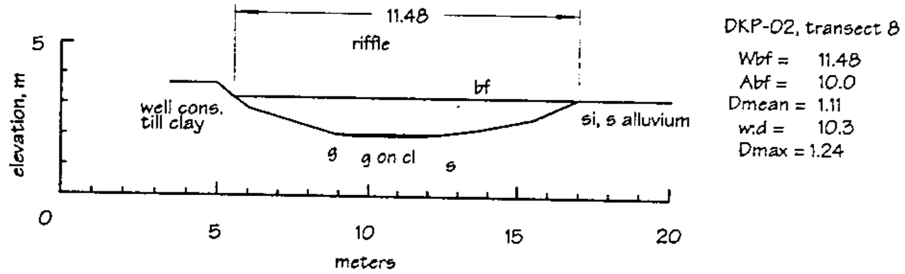


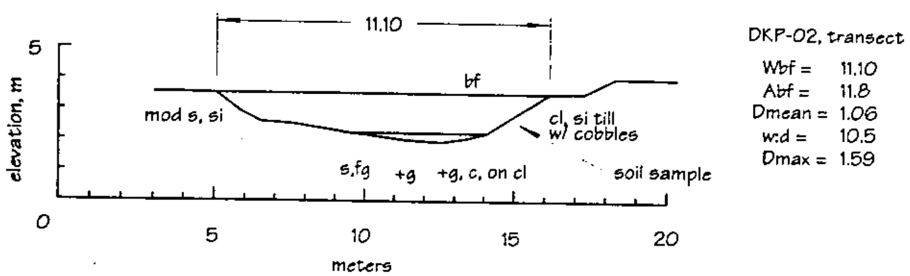
Money Creek, site DKP-02



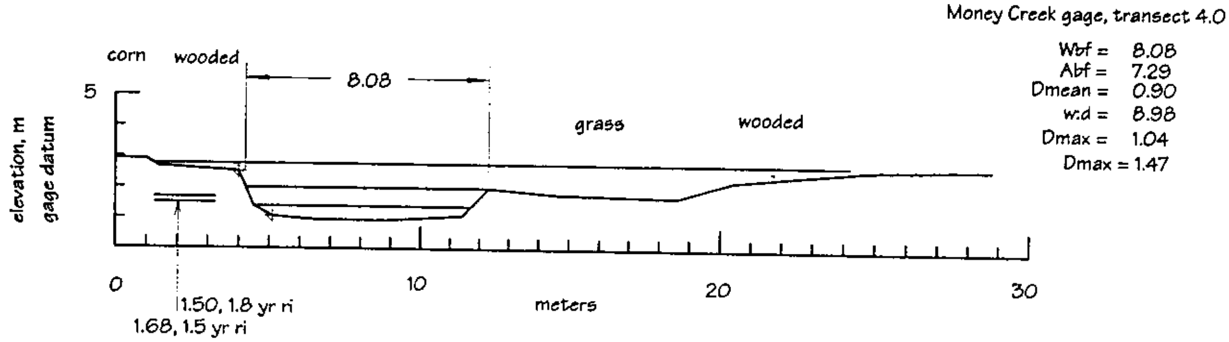




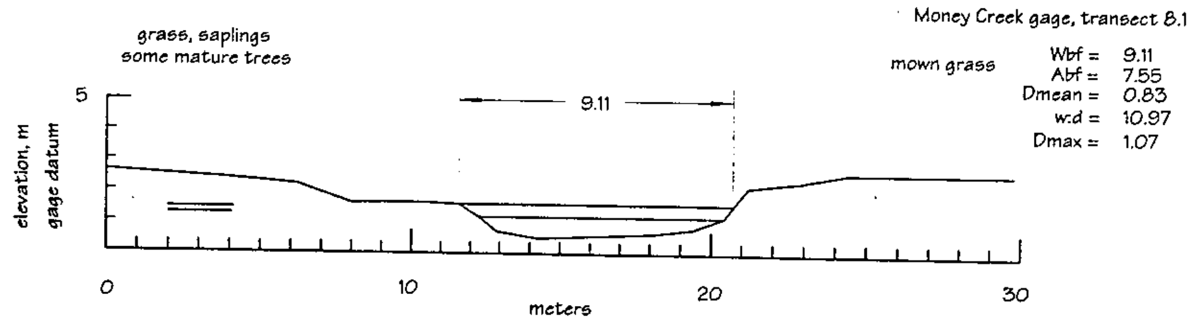




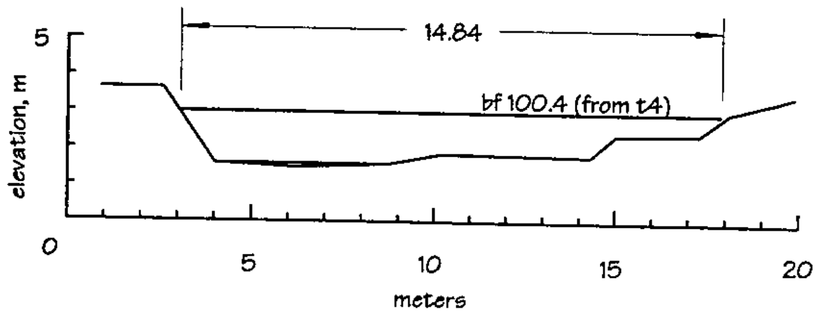
Money Creek above Lake Bloomington
site MON-01
gage calibration



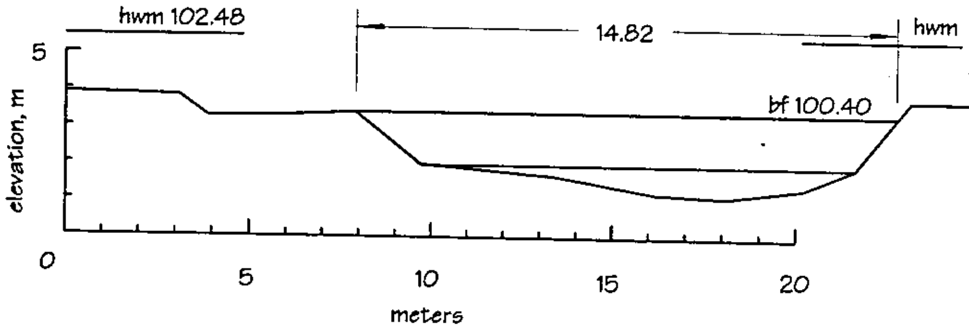
Double lines at left of each transect are 1.5 and 1.8 yr flood elevations.



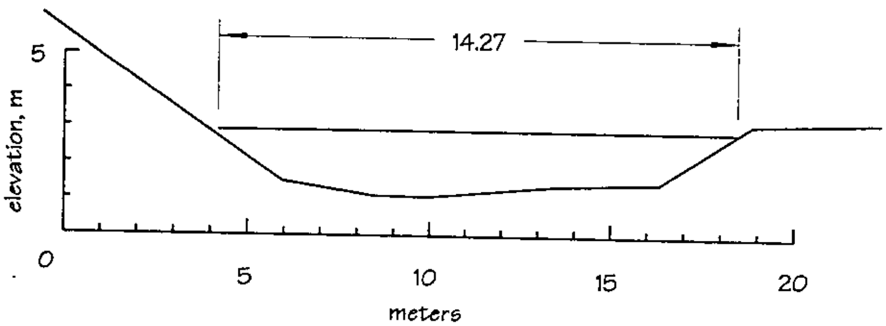
West Branch Panther Creek, DKKB-01



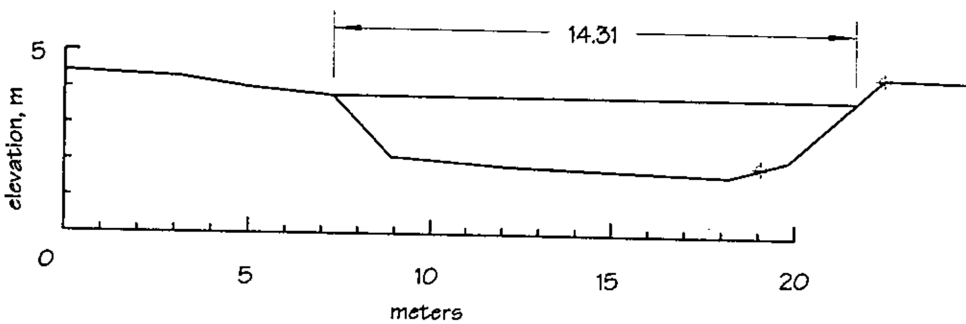
DKKB-01, transect 1
Wbf = 14.84
Abf = 16.56
Dmean = 1.12
w:d = 13.25
Dmax = 1.51



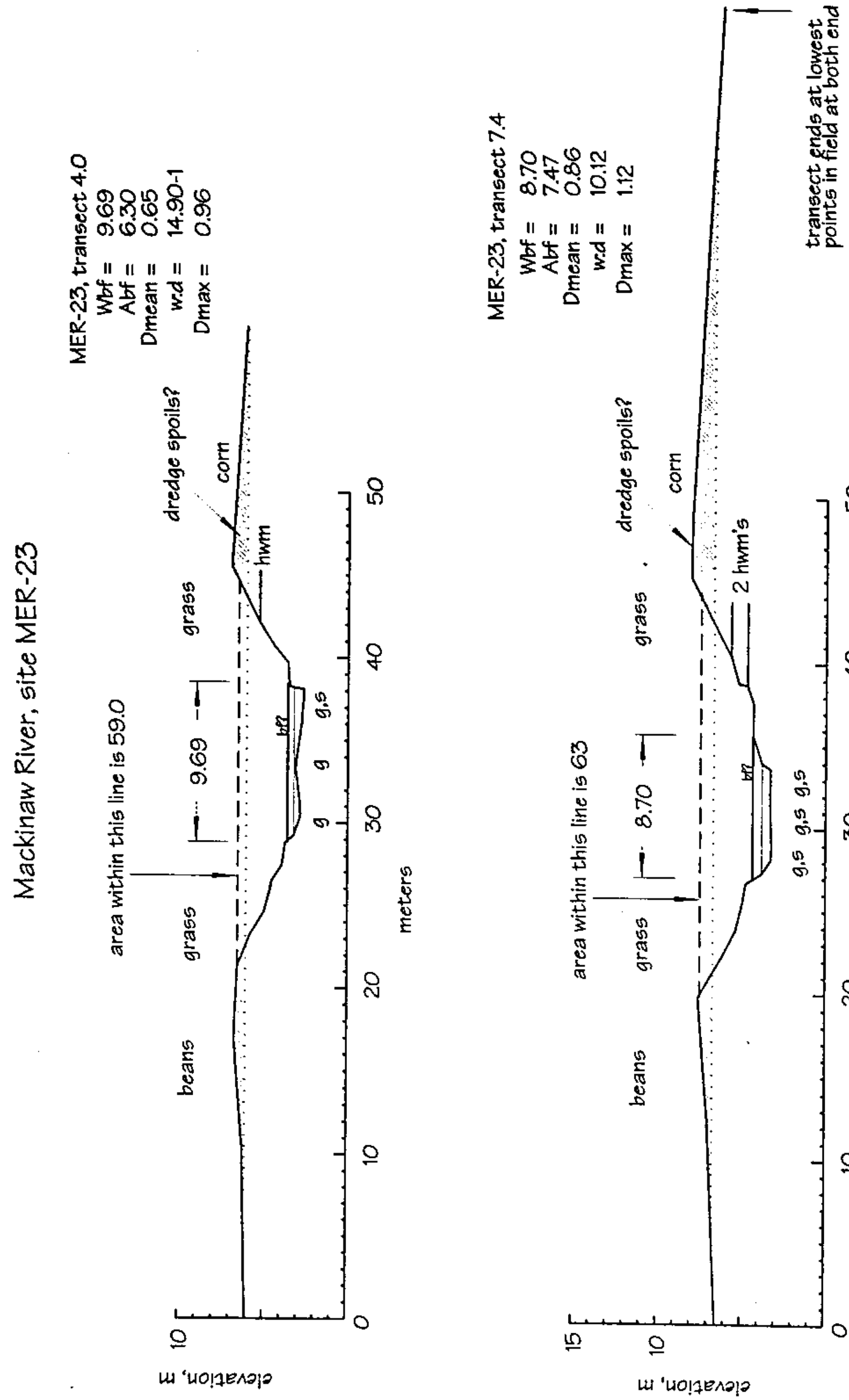
DKKB-01, transect 4
Wbf = 14.82
Abf = 24.55
Dmean = 1.66
w:d = 8.93
Dmax = 2.29



DKKB-01, transect 6
Wbf = 14.24
Abf = 19.44
Dmean = 1.36
w:d = 10.47
Dmax = 1.79

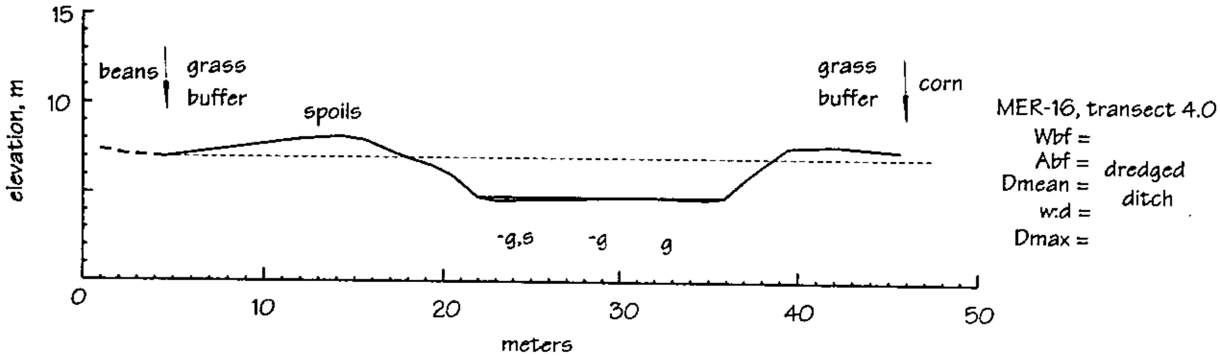


DKKB-01, transect 8.
Wbf = 14.31
Abf = 24.06
Dmean = 1.68
w:d = 8.5
Dmax = 2.14
BHmax = 2.53



Mackinaw River, site MER-23
MER-23, transect 4.0
Wbf = 9.69
Abf = 6.30
Dmean = 0.65
w:d = 14.90-1
Dmax = 0.96
area within this line is 59.0
9.69
beans
grass
grass
dredge spoils?
corn
hwm
elevation, m
meters
MER-23, transect 7.4
Wbf = 8.70
Abf = 7.47
Dmean = 0.86
w:d = 10.12
Dmax = 1.12
area within this line is 63
8.70
2 hwm's
transect ends at lowest points in field at both end

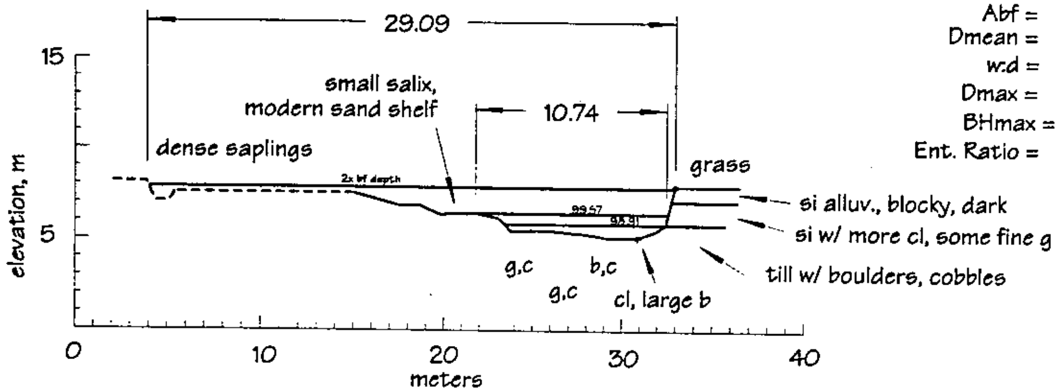
Mackinaw River, site MER-16

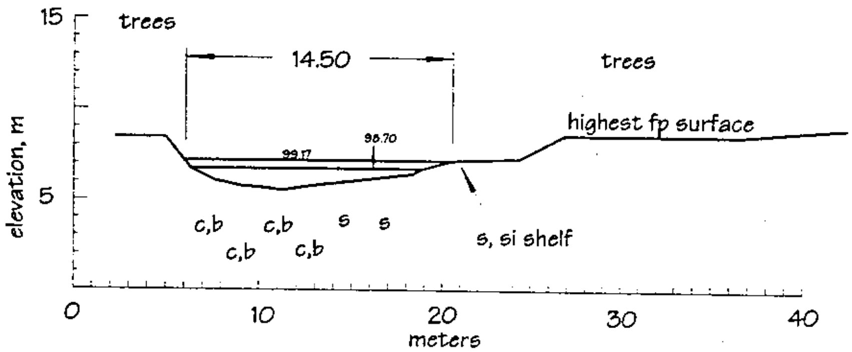


Walnut Creek, site WAL-02

WAL-02, transect 2.1

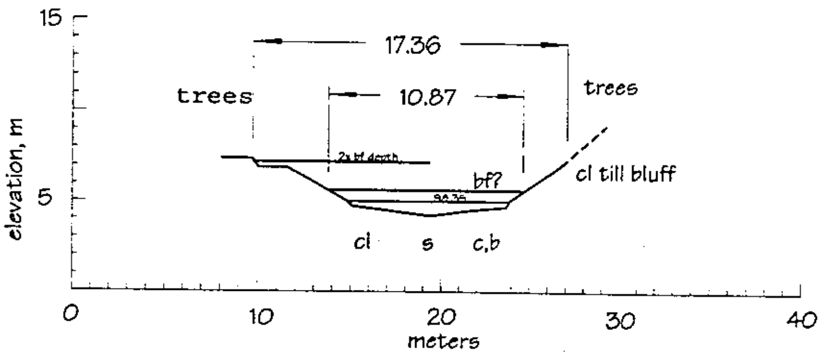
Wbf = 10.74
Abf = 9.98
Dmean = 0.93
w:d = 11.55
Dmax = 1.32
BHmax = 2.98
Ent. Ratio = 2.71





WAL--02, transect 4.0

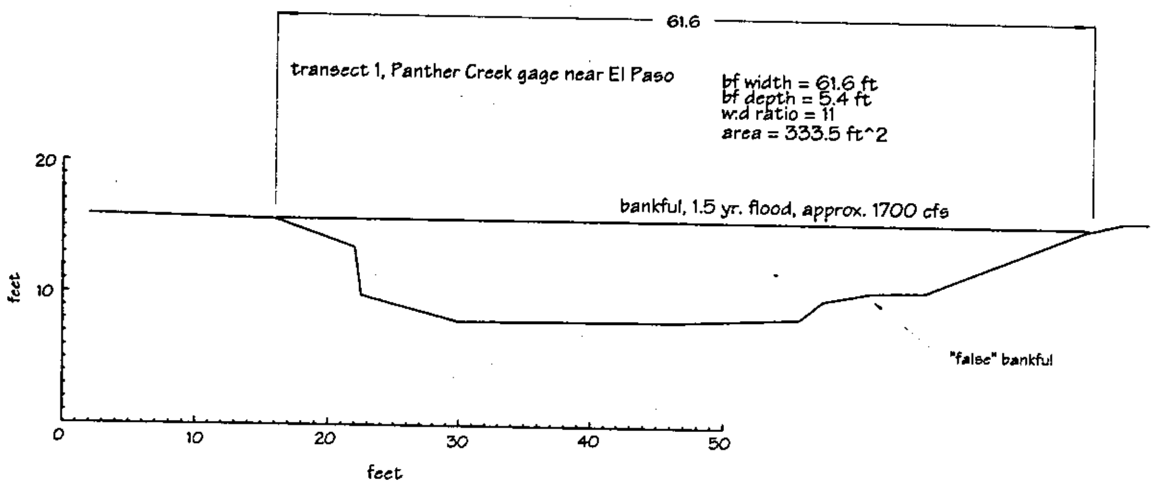
Wbf = 14.50
Abf = 14.75
Dmean = 1.02
w:d = 14.21
Dmax = 1.63
Ent. Ratio = >>2.2



WAL-02, transect 6.8

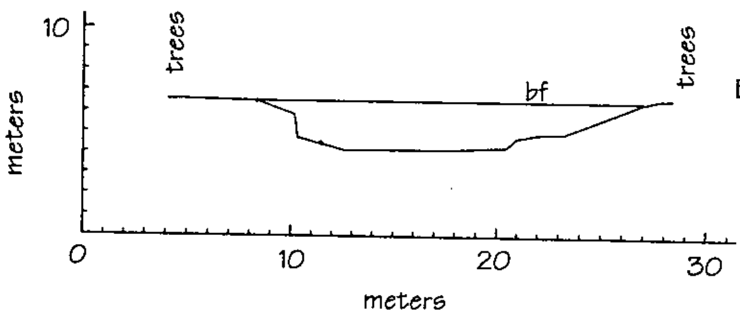
Wbf = 10.87
Abf = 10.90
Dmean = 1.00
w:d = 10.87
Dmax = 1.33
Ent. Ratio = 1.60

Panther Creek Gage, Site PAN-01
gage calibration



Panther Ck gage, transect 1

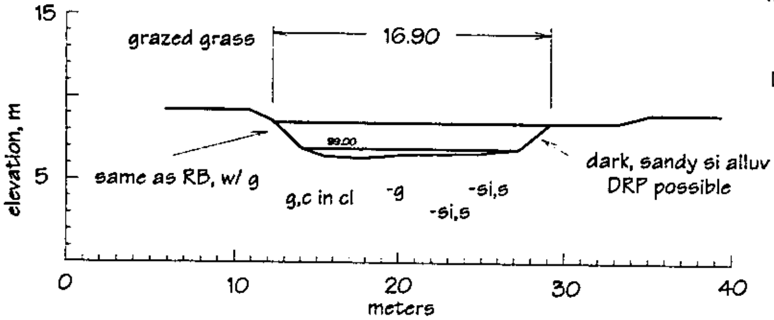
Wbf = 18.7
Abf = 31.1
Dmean = 1.66
w:d = 11.27
Dmax = 2.35
BHmax = 2.00



Mackinaw River, MER-18

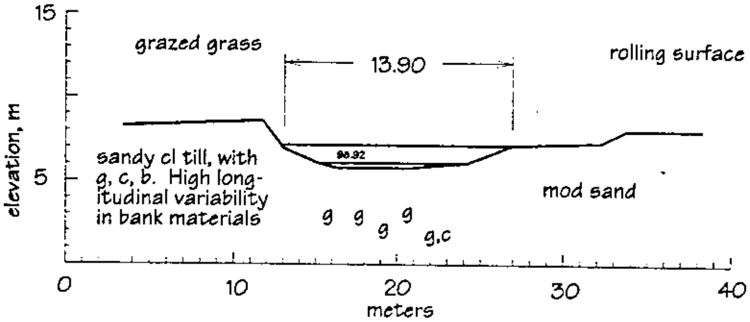
MER-18, transect 2.0

Wbf = 16.90
Abf = 28.15
Dmean = 1.66
w:d = 10.18
Dmax = 2.10



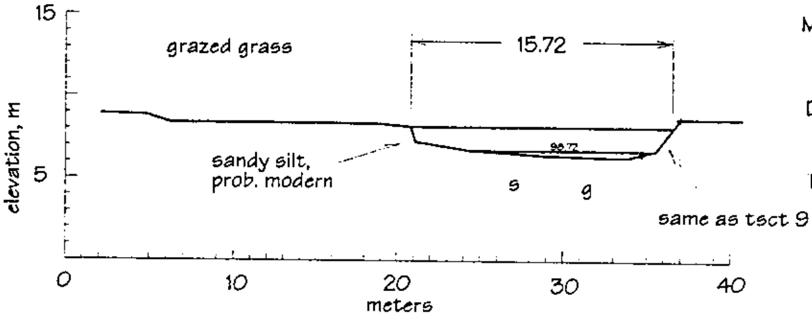
MER-18, transect 3.7

Wbf = 13.90
Abf = 14.32
Dmean = 1.03
w:d = 13.49
Dmax = 1.33



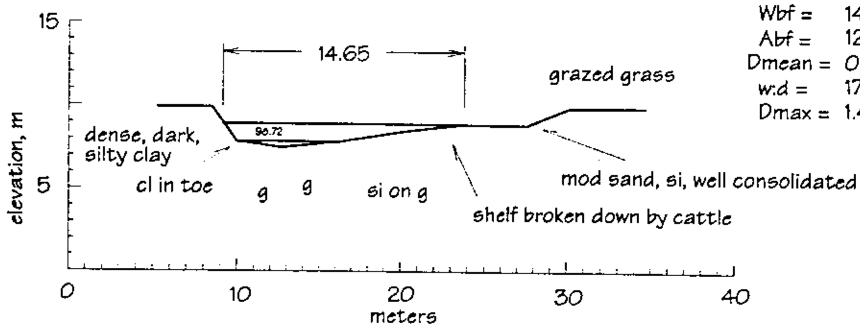
MER-18, transect 8.0

Wbf = 15.72
Abf = 23.18
Dmean = 1.47
w:d = 10.69
Dmax = 1.80
BHmax = 2.15

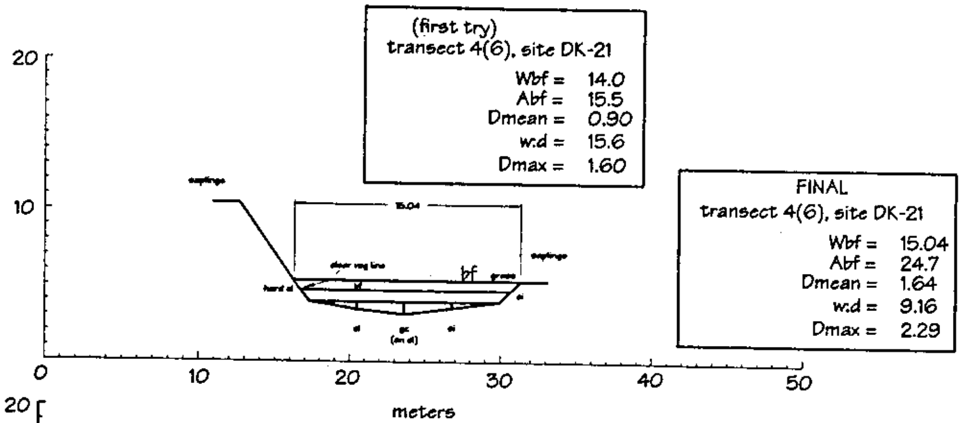


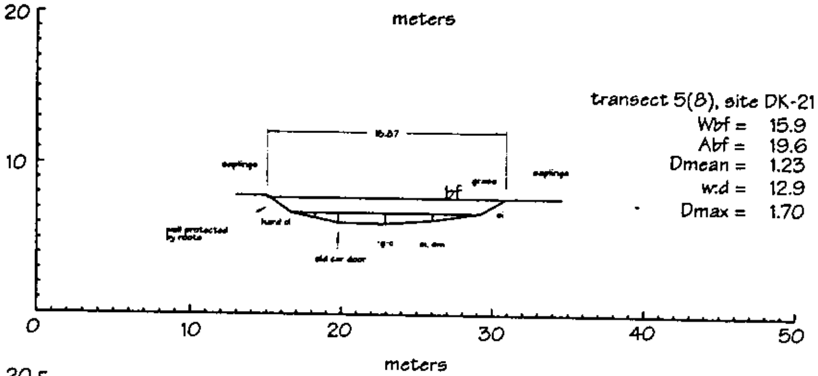
MER-18, transect 9.0

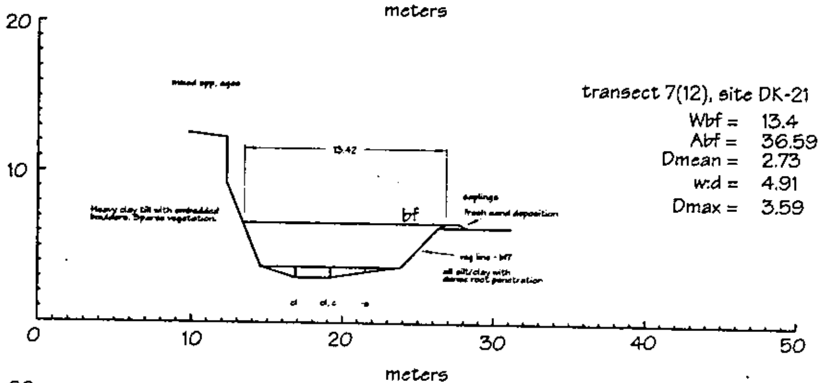
Wbf = 14.65
Abf = 12.05
Dmean = 0.82
w:d = 17.86
Dmax = 1.42

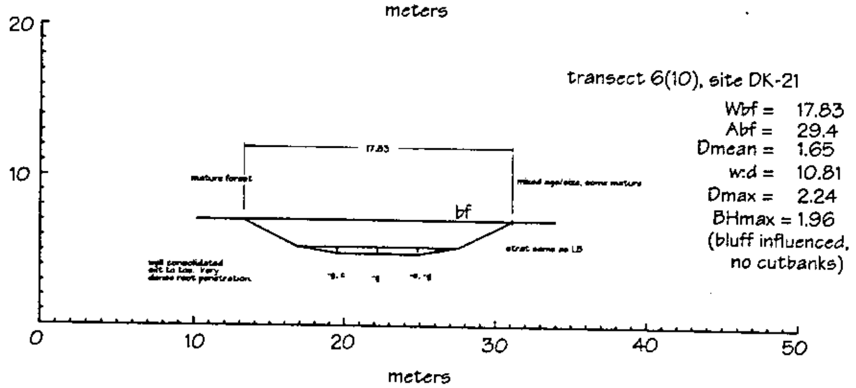


Mackinaw River, site DK-21

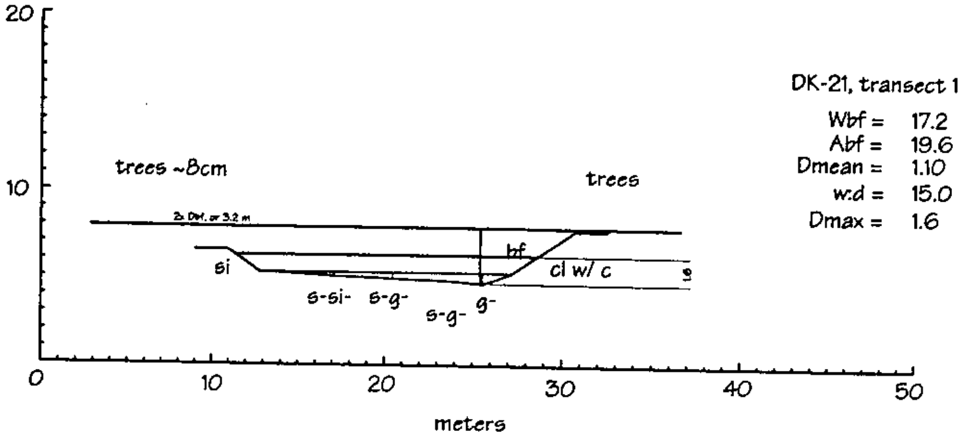


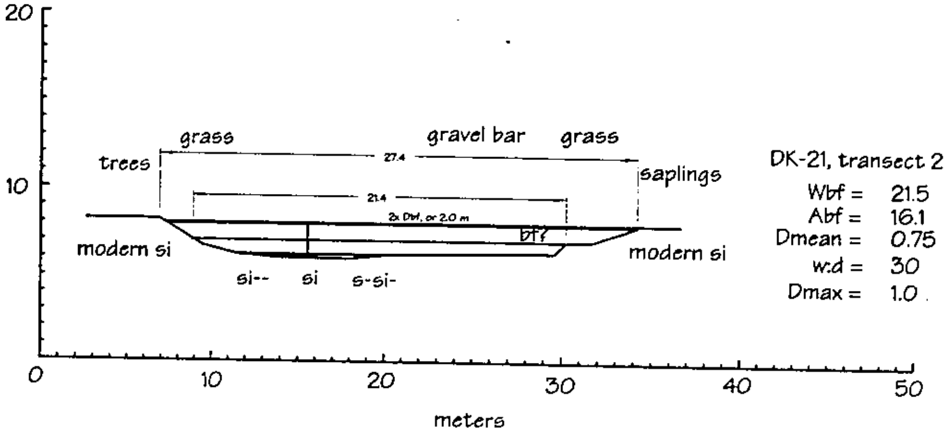


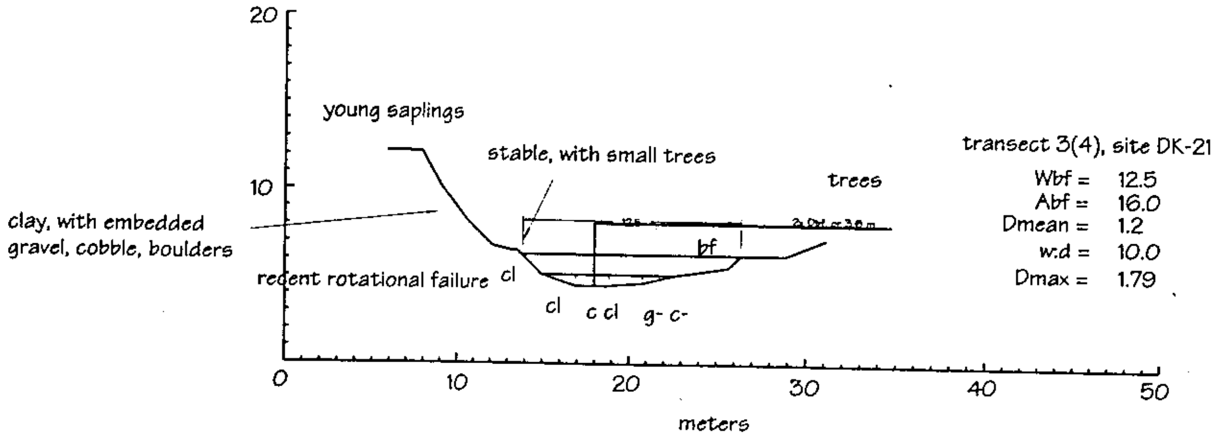




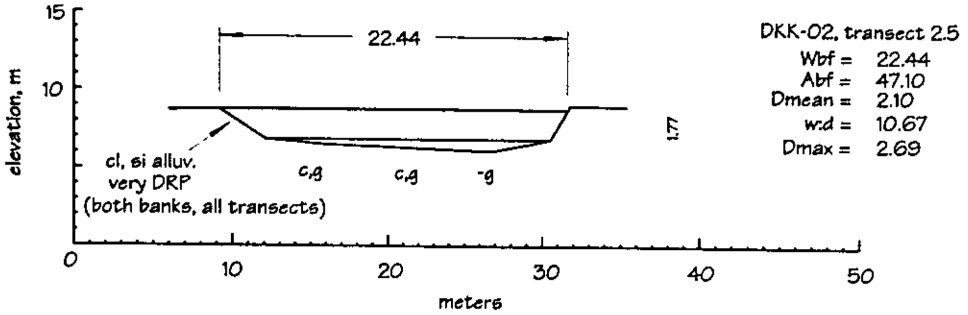
Mackinaw River, site DK-21

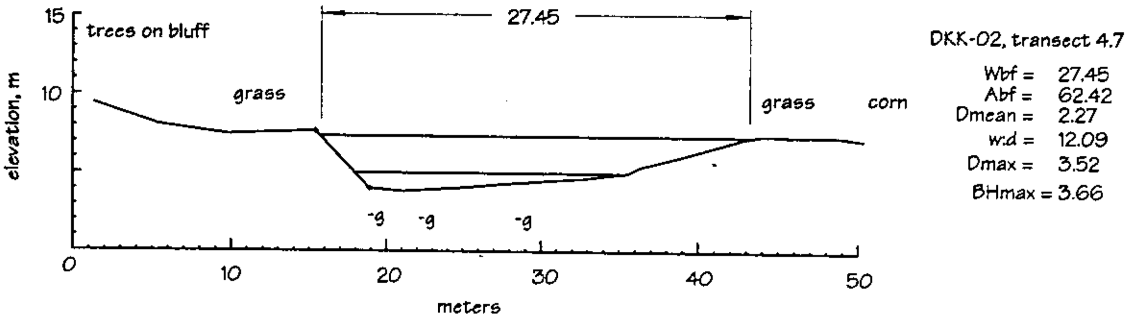


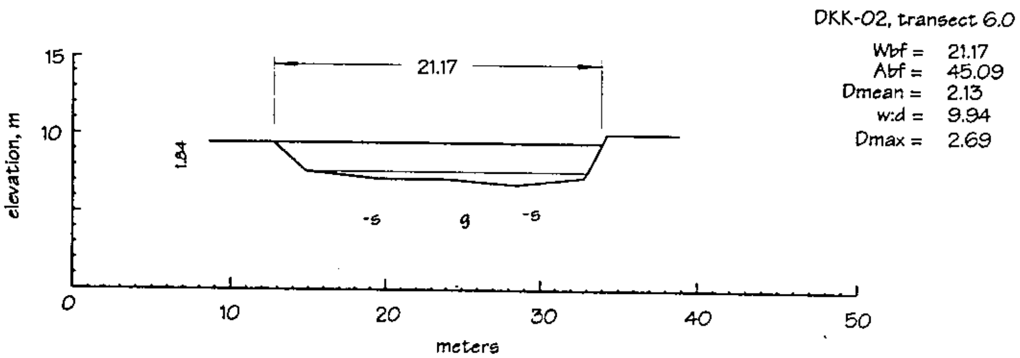


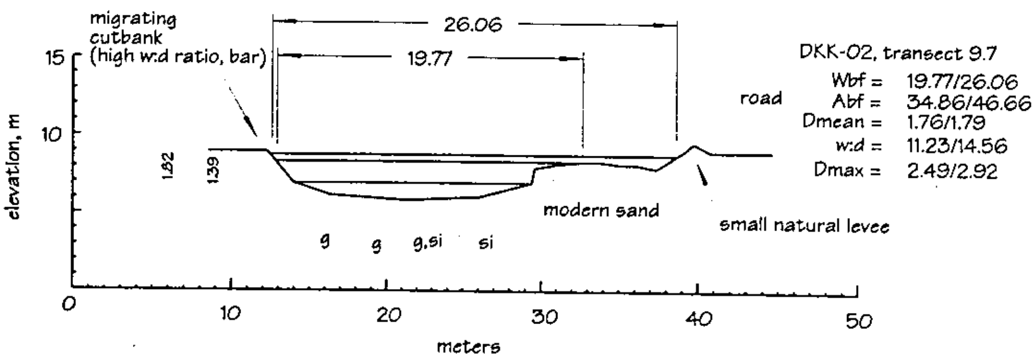


Panther Creek, site DKK-02

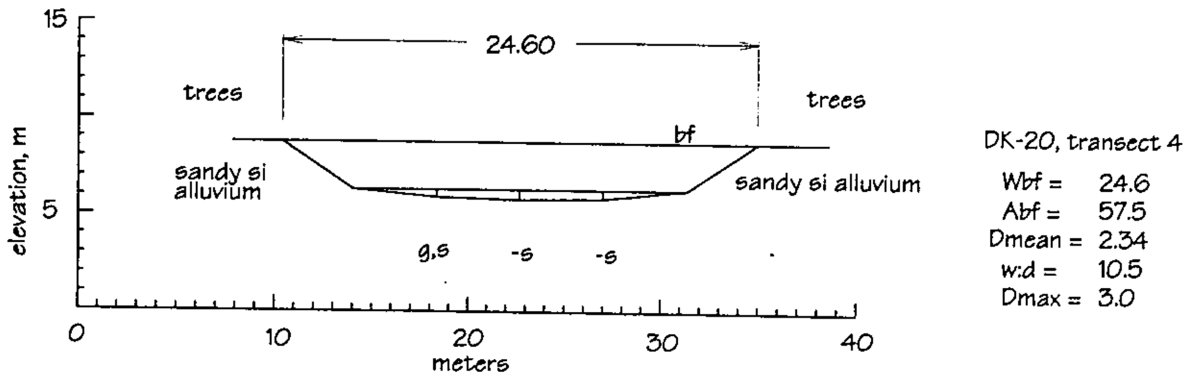


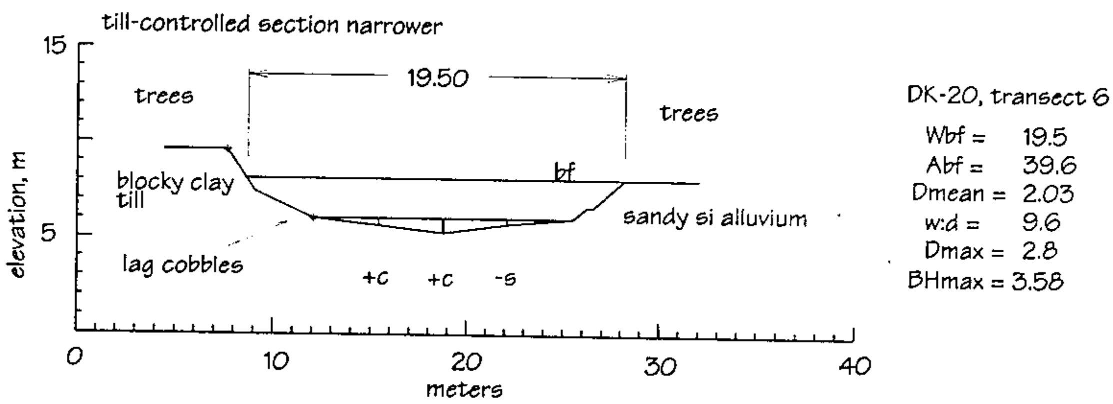




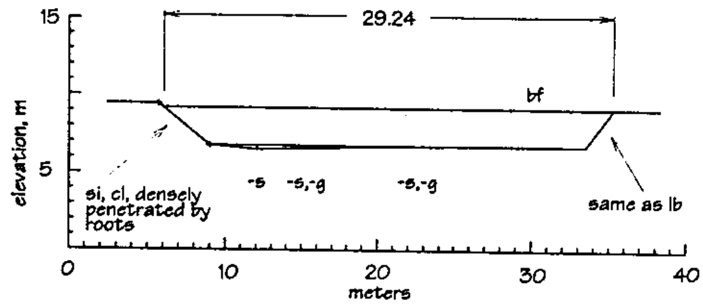


Mackinaw River, site DK-20

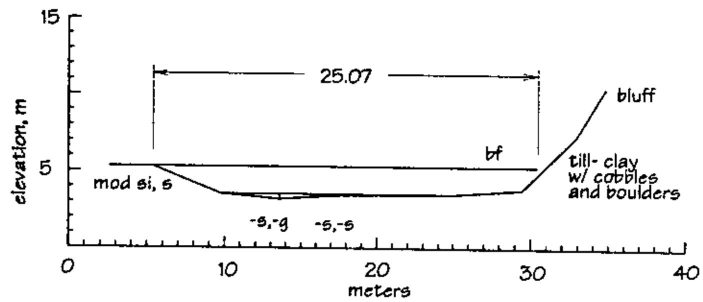




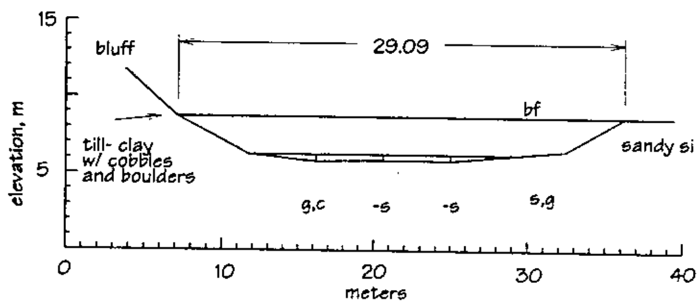
Mackinaw River, MER10 (Merwin Area)



MER10, transect 1
Wbf = 29.24
Abf = 66.5
Dmean = 2.27
w:d = 12.9
Dmax = 2.66
BHmax = 2.67



MER10, transect 3
Wbf = 29.24
Abf = 40.0
Dmean = 1.37
w:d = 21.3
Dmax = 2.08



MER10, transect 5
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Abf = 65.5
Dmean = 2.25
w:d = 12.9
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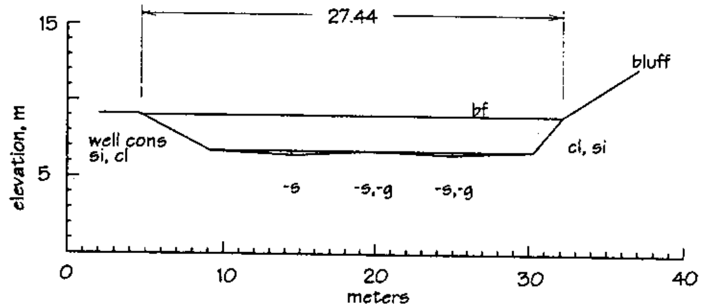
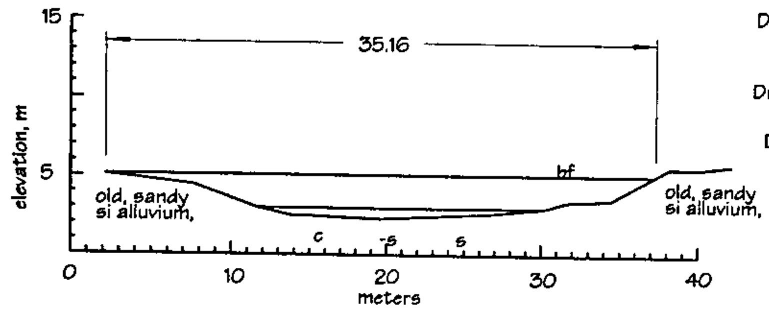


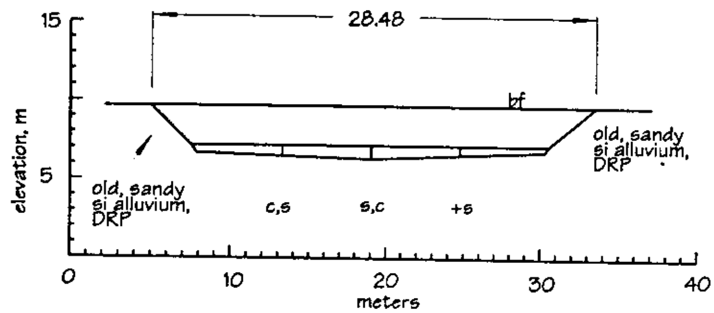
MER10, transect 7
Wbf = 29.24
Abf = 59.2
Dmean = 2.03
w:d = 14.4
Dmax = 2.59

Mackinaw River, site DK-17



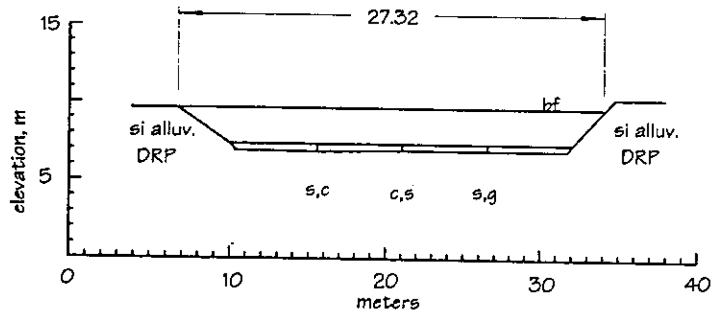
DK-17, transect 3 alternates

Wbf = 35.16 30.81
Abf = 64.76 51.8
Dmean = 1.84 1.68
w:d = 19.11 18.3
Dmax = 2.77



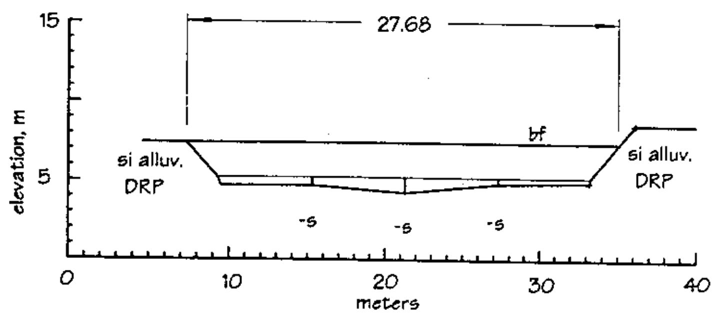
DK-17, transect 4

Wbf = 28.48
Abf = 78.44
Dmean = 2.75
w:d = 10.36
Dmax = 3.36



DK-17, transect 6

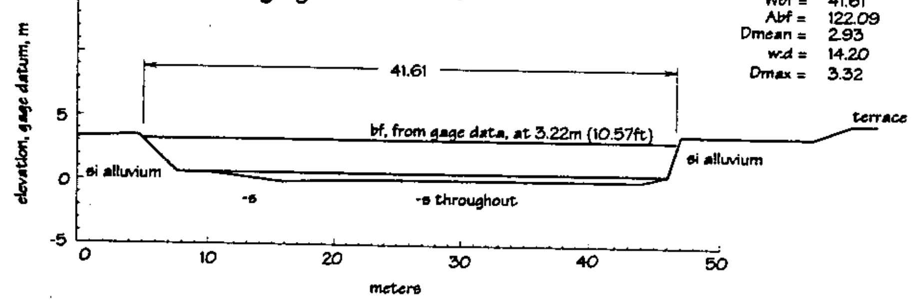
Wbf = 27.32
Abf = 66.45
Dmean = 2.43
w:d = 11.24
Dmax = 2.82

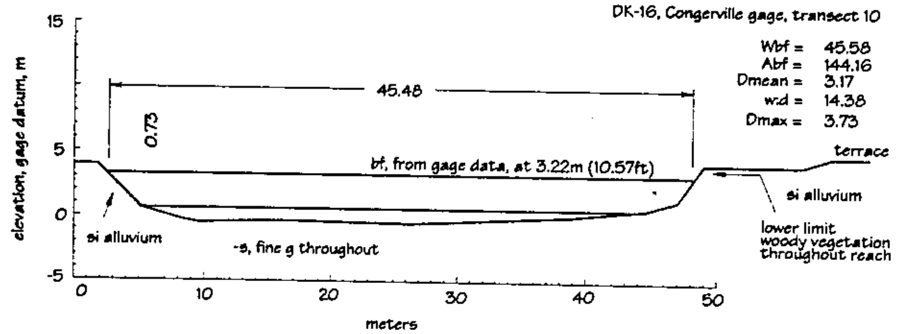


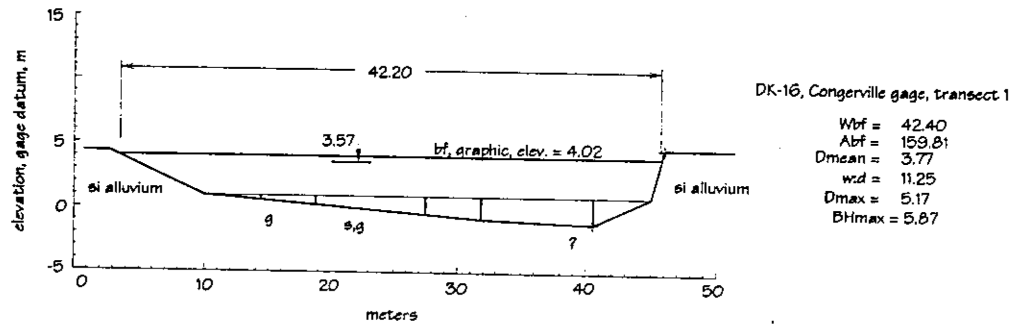
DK-17, transect 9

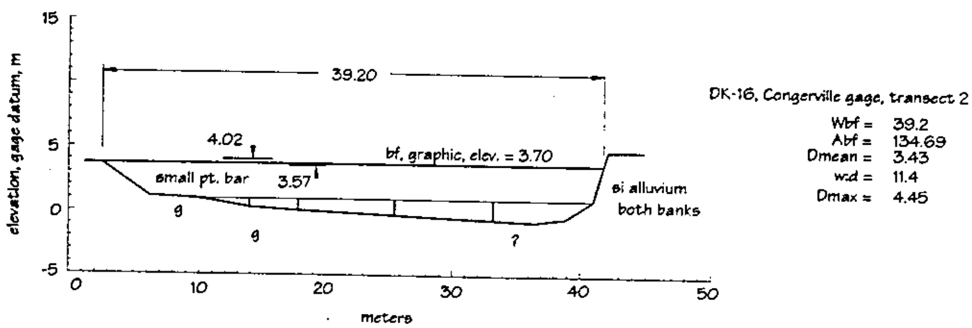
Wbf = 27.68
Abf = 70.30
Dmean = 2.54
w:d = 10.90
Dmax = 3.16
BHmax = 3.69

Mackinaw River
DK-16, Congerville gage site
gage calibration

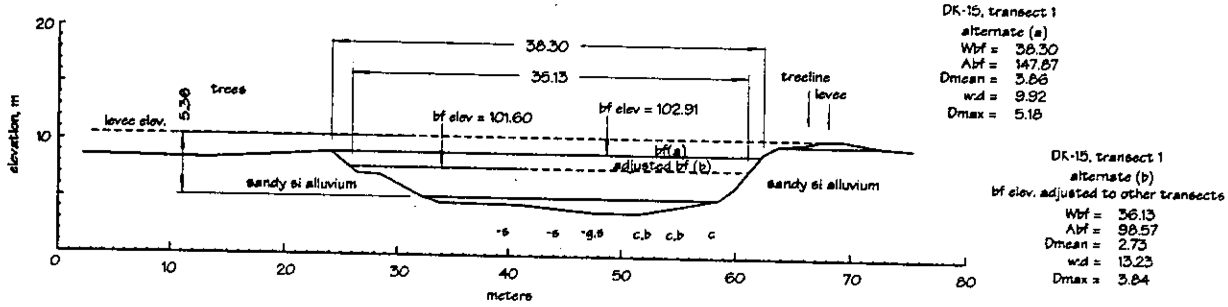


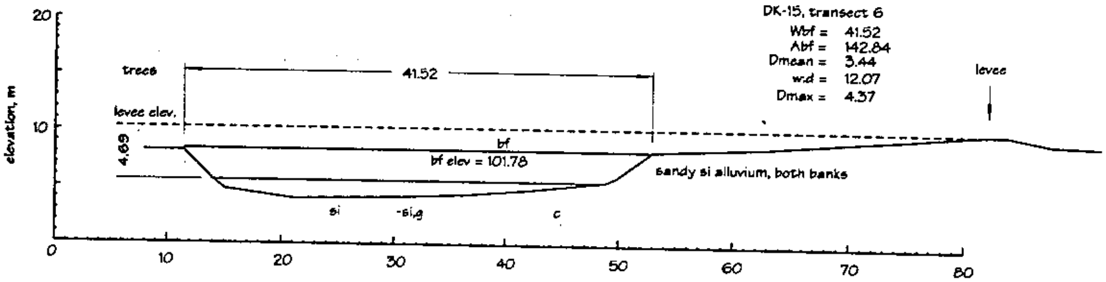


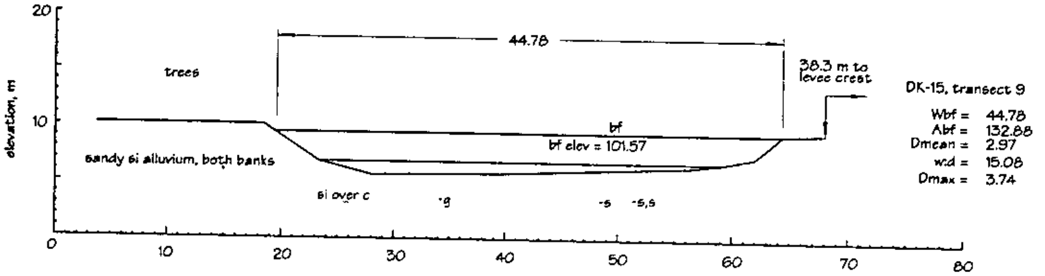


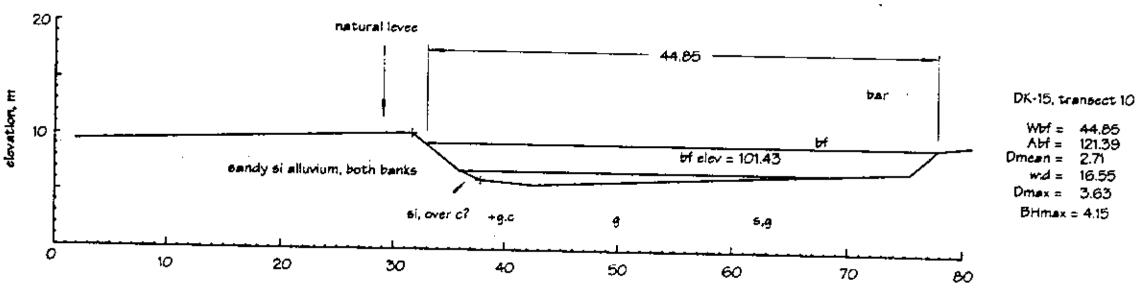


Mackinaw River, site DK-15

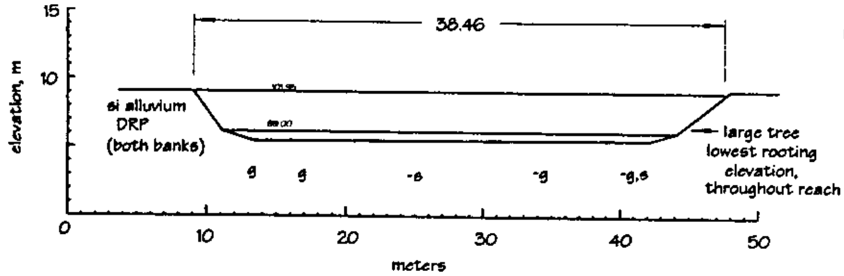








Mackinaw River, site MER-20

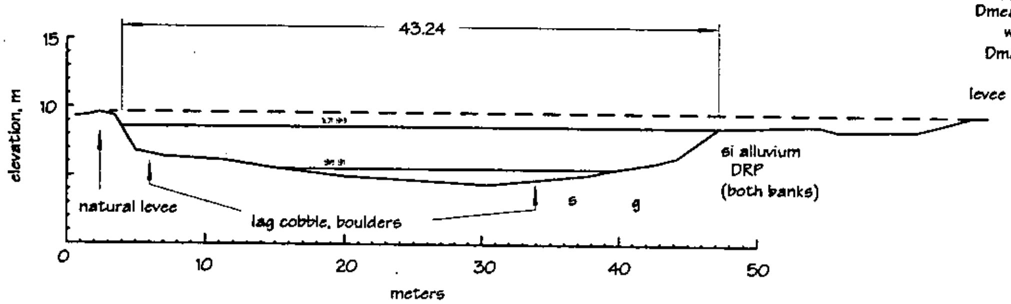


MER-20, transect 1

Wbf = 38.46
Abf = 125.57
Dmean = 3.26
w:d = 11.80
Dmax = 3.65

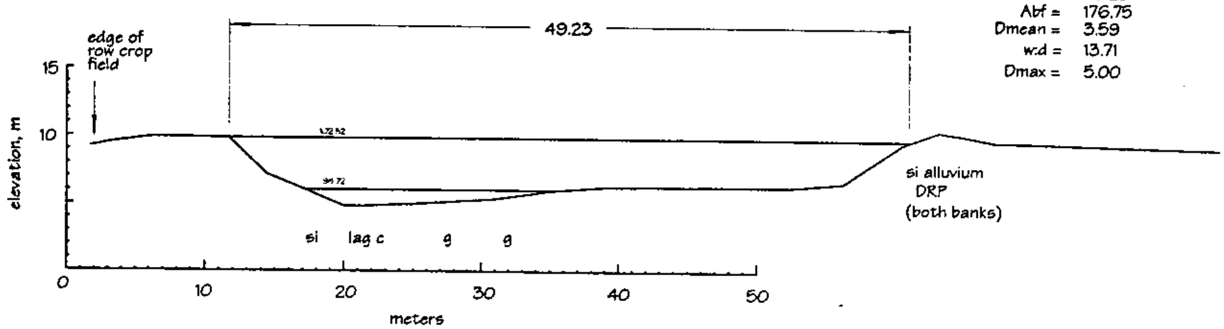
MER-20, transect 4.3

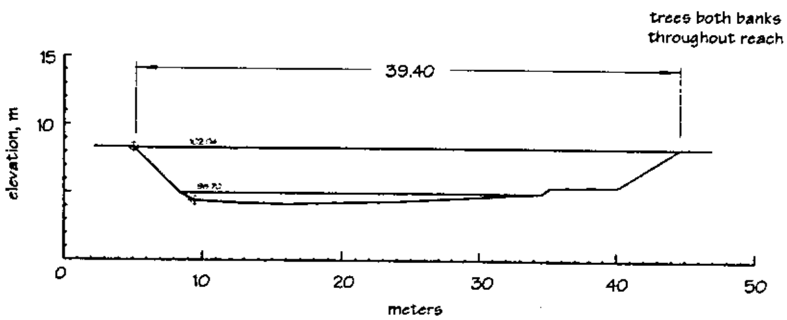
Wbf = 43.24
Abf = 132.63
Dmean = 3.07
w:d = 14.01
Dmax = 4.21



MER-20, transect 6.5

Wbf = 49.23
Abf = 176.75
Dmean = 3.59
w:d = 13.71
Dmax = 5.00

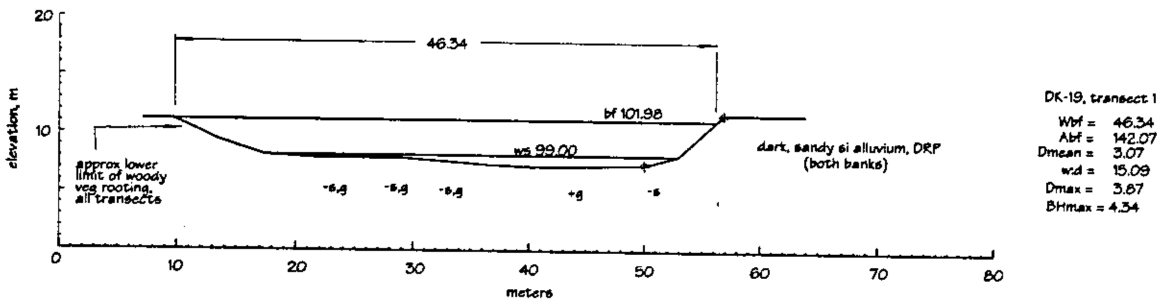


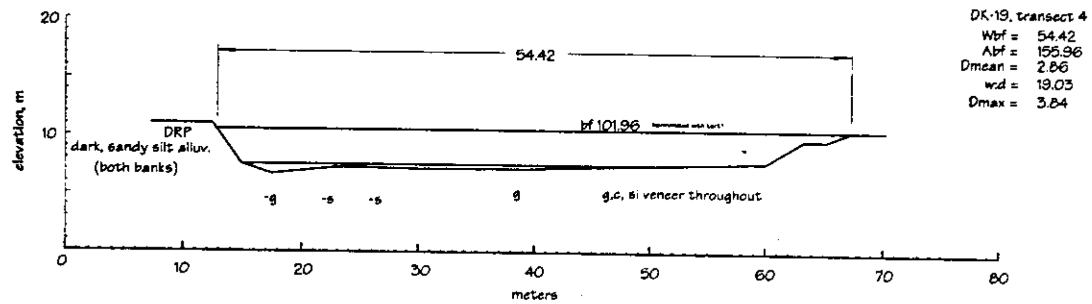


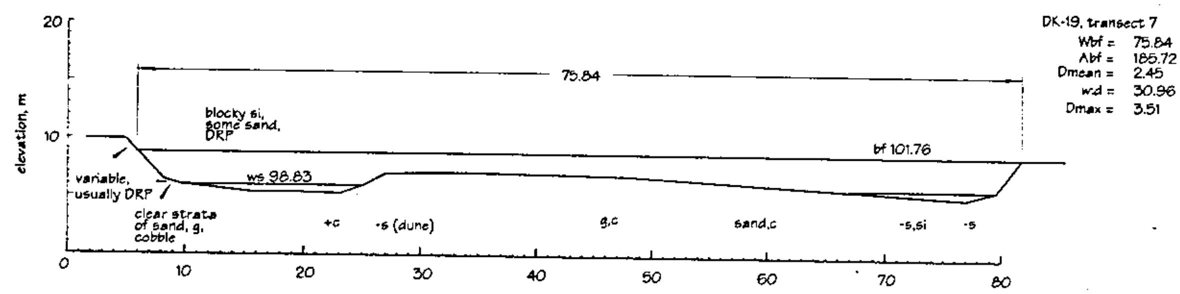
MER-20, transect 8.2

Wbf = 39.40
Abf = 128.51
Dmean = 3.26
w:d = 12.08
Dmax = 4.13
BHmax = 3.94

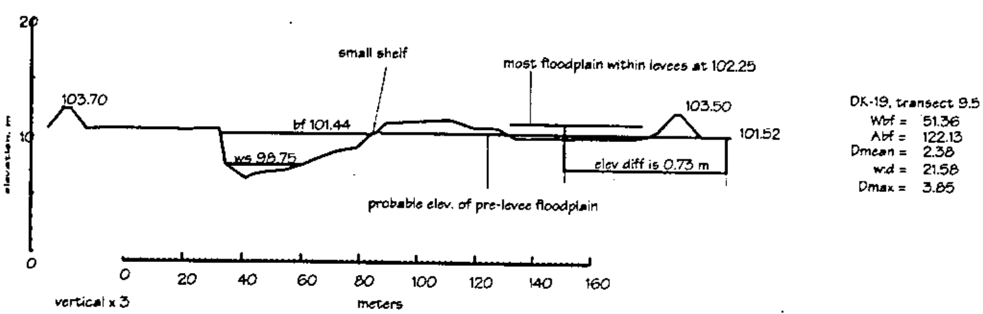
Mackinaw River, site DK-19 (MER22)



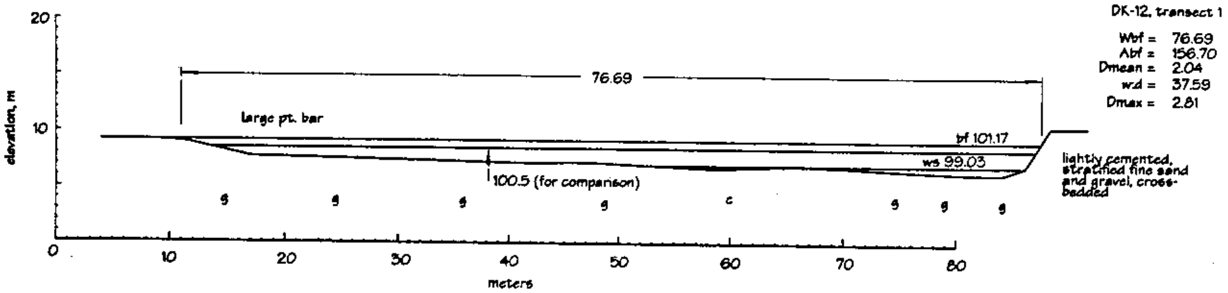


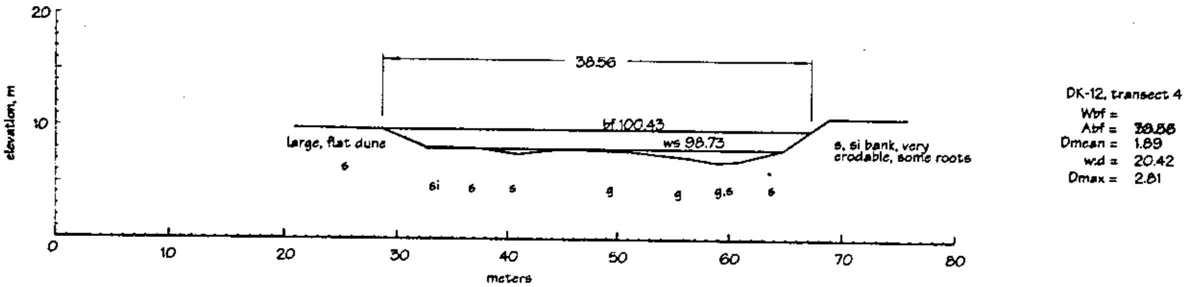


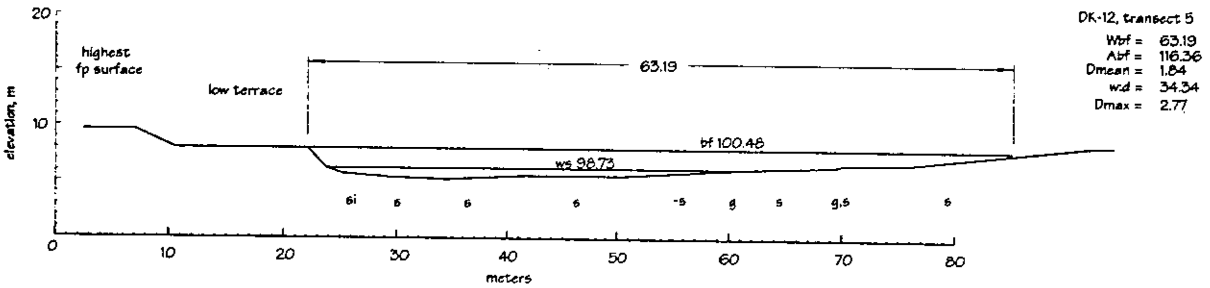
Mackinaw River, DK-19, transect 9.5

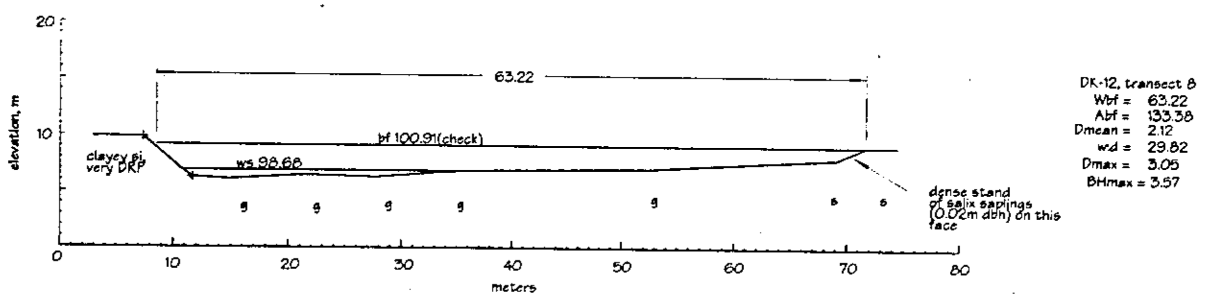


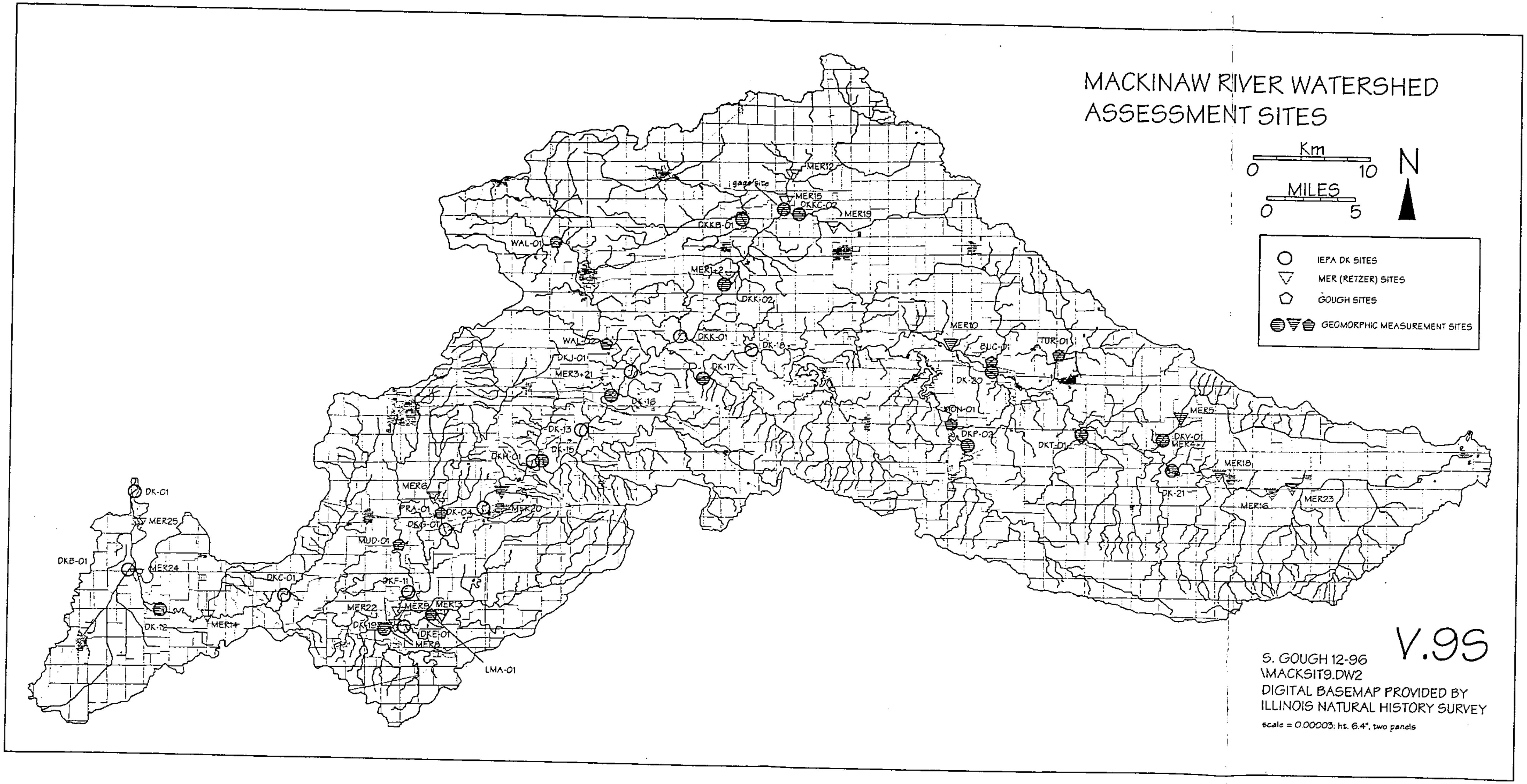
Mackinaw River, DK-12










MACKINAW RIVER WATERSHED
ASSESSMENT SITES
Km
0
10
MILES
0
5
N
IEPA DK SITES
MER (RETZER) SITES
GOUGH SITES
GEOMORPHIC MEASUREMENT SITES
DK-01
MER25
DKB-01
MER24
DK-12
MER14
DKC-01
PKF-11
MER22
MER9
MER13
DK-19
DKE-01
MER8
LMA-01
MUD-01
PRA-01
DK-04
DKG-01
MER6
MER20
DKH-01
DK-13
DK-15
DK-16
MER3+21
DKJ-01
WAL-02
WAL-01
DKK-01
DK-17
DK-18
DKK-02
MER1+2
DKKB-01
MER15
DKKC-02
MER12
MER19
MER10
BUC-01
DK-20
TUR-01
DKP-02
DKT-01
DKV-01
MER5
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DK-21
MER16
MER23
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S. GOUGH 12-96
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DIGITAL BASEMAP PROVIDED BY
ILLINOIS NATURAL HISTORY SURVEY
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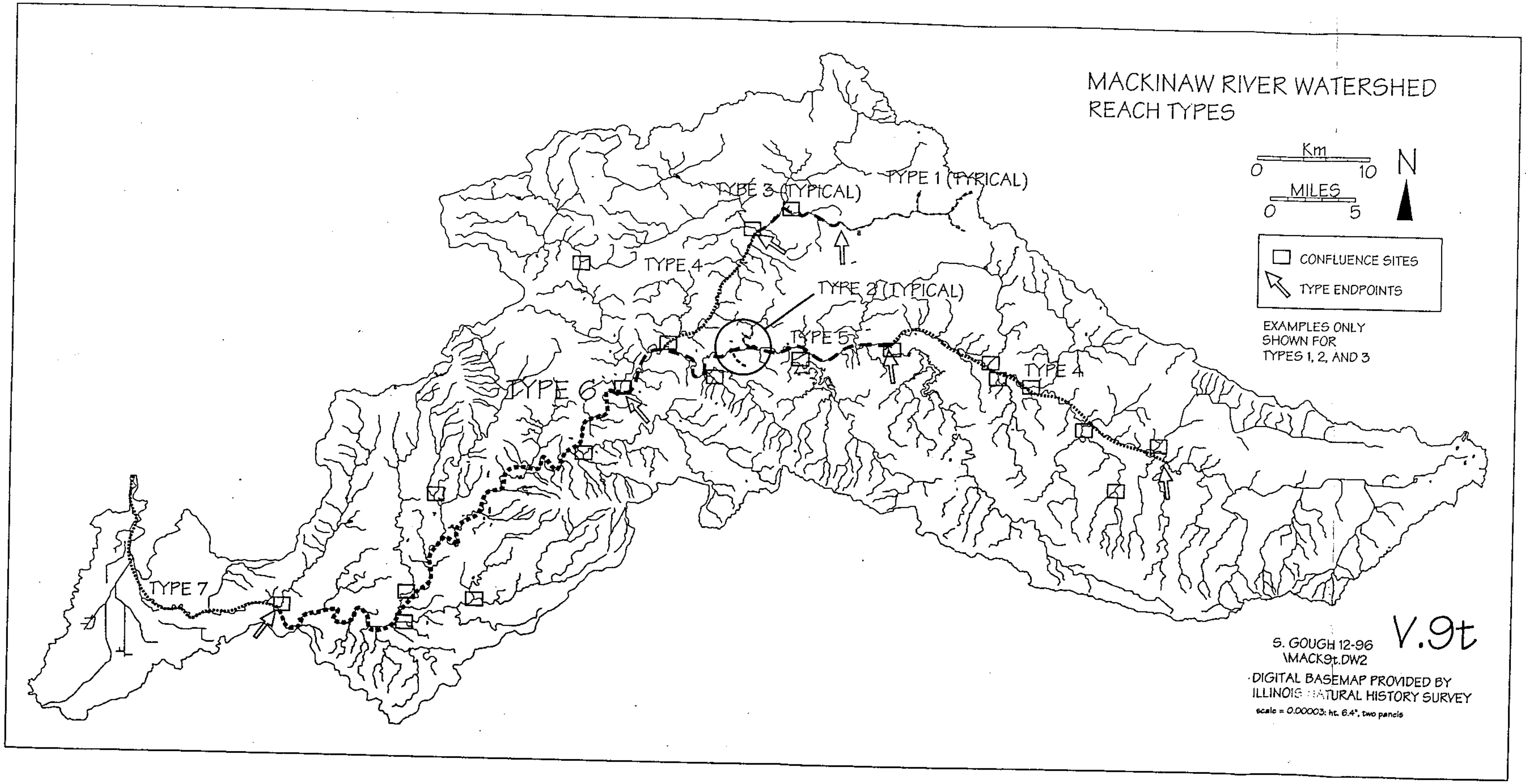
MACKINAW RIVER WATERSHED
REACH TYPES
Km
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10
MILES
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5
N
CONFLUENCE SITES
TYPE ENDPOINTS
EXAMPLES ONLY
SHOWN FOR
TYPES 1, 2, AND 3
TYPE 1 (TYPICAL)
TYPE 3 (TYPICAL)
TYPE 4
TYPE 2 (TYPICAL)
TYPE 5
TYPE 4
TYPE 6
TYPE 7
S. GOUGH 12-96
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DIGITAL BASEMAP PROVIDED BY
ILLINOIS NATURAL HISTORY SURVEY
scale = 0.00003; ht. 6.4", two panels

V.9t

Appendix C.
Abbreviations used in field notes and data graphs.

Abf. Area of the bankfull channel for a transect.

alluv. Abbr. alluvium.

alluvium. River-deposited sediments. Banks are usually composed of alluvium, with important exceptions (e.g. glacial till).

b. Abbr. for boulder or boulders.

bedge. Abbr. for bank edge. In transect survey notes, the point at which a bank clearly changes from horizontal to near-vertical. Usually used with an R or L to indicate left or right bank edge, as RBedge or Lbedge.

BF. Abbr. for bankfull.

bm. Abbr. benchmark. A relatively permanent point used for horizontal and/or vertical control in a survey.

c. Abbr. for cobble or cobbles.

c.v. or CV. Abbr. for current velocity.

cl. Abbr. for clay.

cons. Abbr. consolidated. Applied to sediments, means well-packed (contrasted to, for example, loose sands recently deposited on a bar).

control. Usually applies to the possible state of a channel section. A section is controlled if sediments are unlikely to be moved (or are difficult to move) by the current hydrologic regime. For example, large boulders usually cannot be transported, and thus will control a channel in the vertical dimension when the pave the streambed. Clays often act as vertical and horizontal controls on channel movement and size.

Dmax. Maximum depth of a bankfull channel cross-section, measured from the deepest point to the elevation of the bankfull line.

Dmean. Mean depth of the bankfull channel. Abf/Wbf = Dmean.

drp. Abbr. dense root penetration. Usually applied to bank descriptions, indicates that the bank material is densely penetrated by roots. The hardness of clays sometimes prevents plant rooting.

fp. Abbr. floodplain. A flat surface next to a stream channel. In survey notes, used when surface is flat and not necessarily to denote a particular flooding regime.

g. Abbr. for gravel.

hd or h.d. Abbr. horizontal distance.

herb. veg. Abbr. for herbaceous (i.e. nonwoody) vegetation.

hi. Abbr. for height of instrument in leveling. Usually appears with a number, e.g. hi2.

hor. Abbr. horizontal.

lag. Applied to sediments, lag deposits are left behind when a mixture of particles is eroded from a bank most commonly clayey till containing cobbles and boulders. As fine particles are transported away from the eroded area, lag materials, which are too large to be moved, are left behind. Most often seen at the toe of eroded banks, sometimes in riffles, especially near bluff areas.

LB. Abbr. for left bank (facing downstream), also sometimes called *left descending bank*.

lbws. Abbr. left bank water surface (see LB). Usually the point at which the water surface meets the left bank on a transect, measured both horizontally and vertically. Both lbws and rbws elevations are taken on most transects. If the water surface is laterally flat, this serves as a check on leveling accuracy (the two readings should be within 0.01 or 0.02m, depending on conditions).

LT. Abbr. for largest tree. Usually means the largest tree within one Wbf of a transect endpoint.

mod. Abbr. modern, applied to sediment descriptions, usually means postsettlement or geologically recent.

nd. No data.

pin. A starting point for a survey, usually a transect. A surveying pin stuck into the ground. Also appears with other abbreviations, e.g. LBpin, RBpin, FP pin (pin in floodplain).

pt. bar. Abbr. point bar.

RB. Abbr. for right bank (facing downstream), also sometimes called *right descending bank.*

rbws. Abbr. right bank water surface (see RB). Usually the point at which the water surface meets the right bank on a transect, measured both horizontally and vertically. Both lbws and rbws elevations are taken on most transects. If the water surface is laterally flat, this serves as a check on leveling accuracy (the two readings should be within 0.01 or 0.02m, depending on conditions).

riff. tail. Abbr. riffle tail. The downstream-most point in a riffle, where the water surface becomes flat again.

riff. head. Abbr. riffle head. The upstream-most point in a riffle, just before the water surface begins to drop. Rarely abbr. as *rh.*

s. Abbr. for sand.

si. Abbr. for silt.

terr. Abbr. terrace.

thalweg (Abbr. tweg). The deepest point in a channel transect, or along the long profile.

till. Glacially deposited sediments, most often gravels, cobbles and boulders in a matrix of clay.

tp. Abbr. turning point, a temporary mark used in leveling.

tsct. Abbr. transect (also sometimes just t, or tsect).

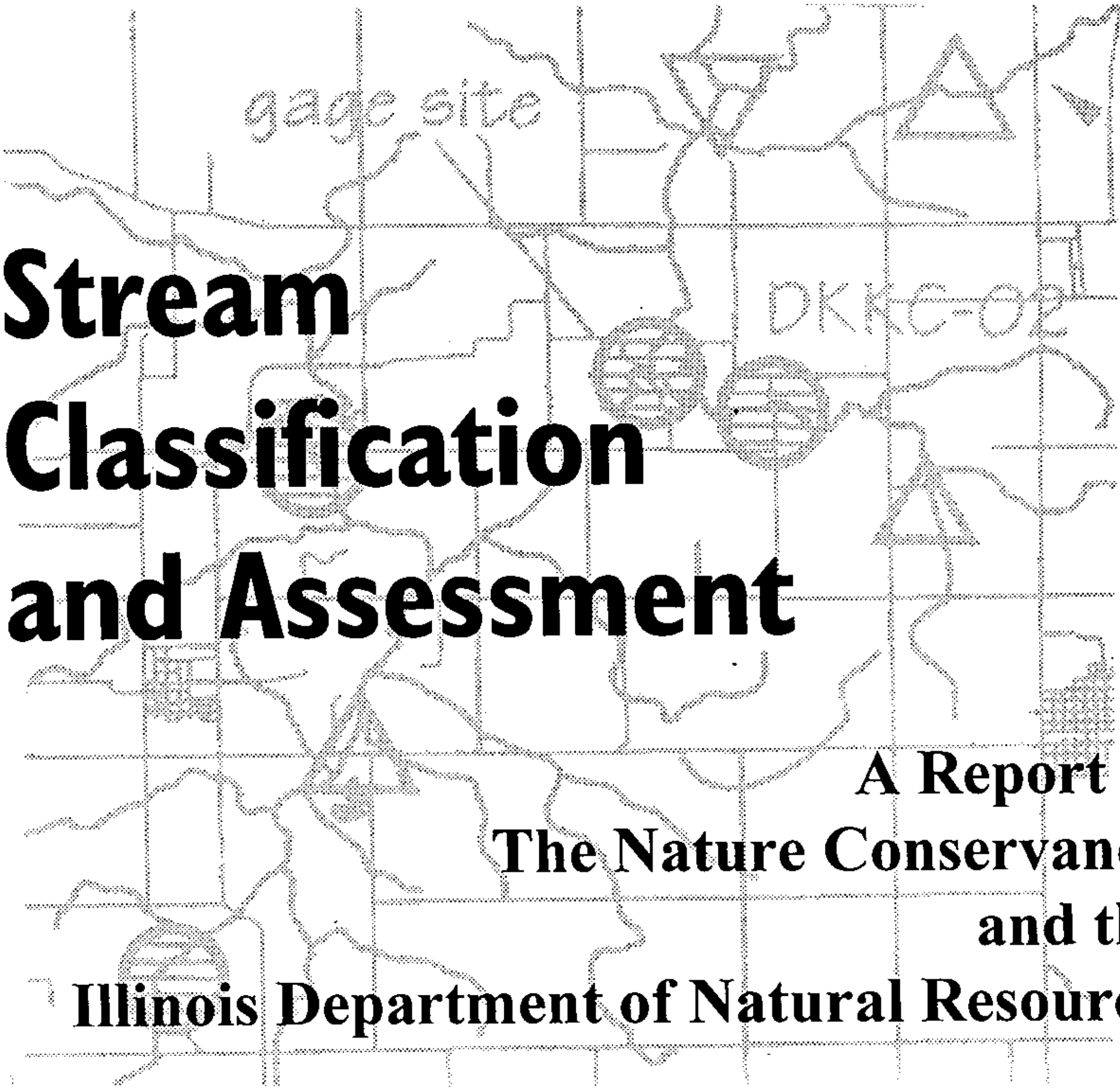
veg. Abbr. for vegetation.

vert. Abbr. vertical.

w:d. Width-to-depth ration of a bankfull channel. Wbf/Dmean = w:d.

Wbf. Bankfull channel width.

ws, ws elev. Abbr. for water surface, water surface elevation, respectively.



Stream Classification and Assessment

A Report to
The Nature Conservancy
and the
Illinois Department of Natural Resources

Steve Gough
Steve Gough & Associates
Stream Ecosystem Management and Research
406 West Healey
Champaign, IL 61820

1997

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Disclaimer

The conclusions and opinions herein are those of the author and not necessarily those of The Nature Conservancy or its cooperators.

Citation

Gough, S.C. 1997. Stream classification and assessment. The Nature Conservancy, Peoria, Illinois Field Office. 72 pages.

Table of Contents

Introduction

In this report, I review river assessment and classification approaches and offer a framework for data collection needed to develop universal assessment and classification of rivers. Although standardized methods and classifications are used for terrestrial ecosystems, especially in the classification of soils, we have no comprehensive analogs for river ecosystems. *Classification* suggests that sets of observations or characteristics can be organized into groups based on similarities and differences. Simple systems are in wide use -- rivers are classified by hydrologic regime as perennial or intermittent, and simple classifications using stream order or drainage area are common (Naiman et al. 1992). Such classifications are inadequate to compare and analyze complex river ecosystems. Ideally, river classification would account for the fluvial processes that form aquatic habitat, enabling determination of a system's present state, its response to disturbance, and its ability to recover (Gordon et al. 1992). *Assessment* is defined here as the collection and analysis of data. Assessments may be used to compare river systems to develop classifications. Assessment and classification may be thought of as a means to diagnose and treat disturbed river ecosystems. While a considerable body of literature on treatment methods exists, methods for holistic analysis (or diagnosis) of river systems are poorly developed, and most are focused on river characteristics typical of the western United States. The approach I propose makes use of this experience and has universal application. I have given special attention, however, to river systems and management problems typical of the Midwest.

The approach I propose considers both the complexity of fluvial ecosystems and the practical constraints faced by researchers and conservationists working in the Midwest. These constraints include a limited supply of suitably trained scientists and technicians, severely impacted watersheds, meager budgets, and limited direct control of watersheds that are largely managed by private landowners. While these constraints present barriers to assessment, they also provide a rationale for classification -- classification can direct limited river restoration and protection resources so that they are used most efficiently. The assessment and classification methods suggested here have been applied to the Mackinaw River Watershed in west-central Illinois, and the results given in a companion report by Gough (1997).

A note on the length and organization of this report: The processes that form river habitat are extremely complex, and many key stream characteristics are interactive. Several important characteristics useful for assessment and classification -- stream power, for example -- are not clearly defined in the much of the literature in which they appear. Because this report is intended for readers with general backgrounds in natural resources management, I offer extended definitions of key diagnostic features and comprehensive discussion of the relationship between these features and fluvial processes that form stream habitat. This report is more than an overview or introduction. It offers a comprehensive review of the literature and suggests detailed methods for readers who intend to study rivers in the field. Thus, although I have made every effort to write clearly and concisely, this report is necessarily lengthy and complex. The summary at the end of this report, however, is a condensation of the entire report and may be considered an executive summary.

Fundamentals of classification systems

Geomorphic systems. Although the need is obvious, few practical, holistic schemes for classifying river systems have been proposed, and only Rosgen's system (Rosgen 1996) has been applied outside a small region. Generally, river classification systems fall into three types; geomorphic systems (e.g. Nanson and Croke 1992), systems based on biota and/or water quality variables such as the Index of Biotic Integrity (IBI), and holistic systems that consider both geomorphology and biota. There are presently no such holistic systems, although Mosley (1987), using data from New Zealand rivers, offers an analysis of key variables for such a system.

Naiman et al. (1992) have written one of the most rigorous discussions and reviews of river classification to date and list important characteristics of such systems: Classification systems should be able to categorize both the types and frequencies of disturbance that affect streams and thus predict adjustments in physical and biotic characteristics.

Among geomorphic systems, Gordon et al. (1992) divide "physical" river classification methods into three types: hydrological, geomorphic and sedimentological, and methods based on a wide combination of physical attributes. Nanson and Croke (1992), in a paper on classification of river floodplains, suggest that geomorphic classification methods fall into three types:

morphological, or those that consider only landform shape and river pattern, ignoring fluvial process,

specific, including classifications developed for inventories of a particular river system. These are tabular listings of river characteristics that generally lack broad applicability and do not order watershed areas or river segments according to similarity. Mollard (1973) offers an example of such a system.

genetic. These systems are process-based. Nanson and Croke (1992) argue that such systems are most useful because the interrelation between river process and floodplain construction is considered. They also note that such systems are inherently difficult to construct because many interacting variables must be considered.

In a review of river classification theory and methods, Mosley (1987) identifies basic rules for classification:

- Classification should be designed for a specific purpose.
- Objects which differ in kind will not fit easily into the same classification.
- The system should not be absolute, but allow change as more information becomes available.
- Differentiating characteristics should be properties of objects classified rather than factors assumed to affect or determine the objects.
- The system should be exhaustive (i.e. include all objects in a given class) and exclusive (objects should fit into only one class).
- Classification should proceed at every stage as far as possible on a single characteristic.
- Differentiating characteristics must be important or relevant to the purpose of classification.
- Properties used to classify at the broader scale levels must be more important for the purpose of classification than those at the finer scale (more detailed) levels.

Mosley notes that few classification systems are likely to conform to all of these rules, and that river systems are particularly difficult to classify because they tend to present features on a continuum. Strict adherence to such rules also seems unrealistic because river systems are made up of so many components and processes, many of which are interactive. Different components and processes dominate different systems, especially across regions (Frissell et al. 1986). It appears that development of a robust, universal, hierarchical system will be difficult at best.

Biological systems. Systems aimed at classifying river biota include the Index of Biotic Integrity (IBI, see e.g. Karr 1991, Allan 1994) and variations including Illinois' Biological Stream Characterization (BSC) system (Page et al. 1992). The IBI method (e.g. Karr 1981) classifies stream ecosystems based on trophic structure (including the proportion of omnivores, insectivores, cyprinids, and piscivores), species richness and abundance, and taxonomic richness (including number of species, species richness, and sometimes the proportion of green sunfish, depending on region). Ecosystems are scored by determining their deviation from that expected for a stream of a similar size in a given region. Essentially, then, a given biotic sample is measured against the best known existing state. Although there are now several regional systems (usually developed by state conservation agencies) that include measurements of physical habitat, most systems are still strongly based on a sample of stream biota. Although some of these methods sample physical habitat, none offer a rigorous determination of the processes that affect physical habitat.

Process-based approaches. River classifications based on biological data alone are limited by their exclusion of river processes that form the physical habitat on which river ecosystems are based. It is possible to make determinations of habitat-biota interactions at a point in time using simple measures of habitat, as some biological systems propose to do. Rivers are dynamic systems, however, and reconstruction of past states and prediction of future conditions is impossible unless classification systems consider fluvial process. Naiman et al. (1992), Mosely (1987), Rabeni and Jacobson (1993), Gordon et al. (1992) and Frissell et al. (1986) offer conceptual approaches to process-based river classification. Although Rosgen (1994) offers the most complete description of a process-based method, the foundation of his approach has been questioned by others (Miller and Ritter 1996, Gillilan 1996).

Process-based classification requires a conceptual understanding of how streams are organized, both in space and time (Meador et al. 1993). Classification of river ecosystems offers challenges beyond those presented by classification of terrestrial ecosystems. Terrestrial systems are strongly influenced by proximate controls, e.g. soils, and ultimately, geology. A given stream reach may be strongly influenced by local or proximate controls, but is also shaped by energy and material flows from upstream sources.

An understanding of possible states, at reach to watershed scales, is essential for sound river restoration work. Ideally, a process-based approach provides predictive capability, even in the absence of biological indicators. Process-based classification allows designation of sites for habitat protection and restoration by providing a means to apply appropriate treatments to stream reaches that share similar attributes (Gordon et al. 1992, Rosgen 1994).

Practical classification: Purpose, design, data needs, and constraints

A classification system directed at ecosystem management is necessarily complex because a number of factors, many of which are interactive, determine physical habitat characteristics. At the reach scale, the morphology of a river is the product of interactions between local controls, e.g., riparian vegetation and bank sediments, and the water and sediment flux through it. River characteristics such as drainage area and channel size change in a relatively predictable way along a river channel. Others, such as riparian vegetation, are highly variable, especially in human-influenced watersheds. Values for important variables such as sediment and water discharge are difficult to measure, especially during flood events, and are not generally available to river conservationists. Thus a widely applicable classification system must be flexible and begin with river characteristics that are relatively easy to measure and understand. Ideally, classification should be based on a watershed approach, but managers are often faced with inadequate data on watersheds, and logistical constraints that limit information about, and control of, watersheds above reaches of interest. For these reasons, river classification should be adaptable. It should be watershed-based, but include methods for describing and diagnosing river habitat based on measurements taken at a reach scale, which may be possible using reach scale features that are indirect indicators of fluvial processes that we are unable to measure directly.

Classification systems should also provide a means for river managers and other stakeholders to communicate, understand and properly apply knowledge of river process -- the method used must take into account the perspectives of those who use it and provide a means to conceptualize and present key river habitat elements and processes.

Classification, assessment, and diagnosis. The ideal river classification system would provide a means to order and group river systems on a global scale, and would provide links to terrestrial classification systems. There remains, however, a strong need for a means to simply describe the physical habitat and processes in river ecosystems. Most commonly, river conservationists are faced with easily-stated, practical questions: Is this river reach morphologically stable? What factors caused the extirpation of sensitive fish species from this river segment, and is it possible to manage it for their return? How does the riparian forest along this reach affect its morphology? Sometimes these questions are difficult or impossible to answer with certainty. In most cases, however, river managers lack the most elementary means of addressing them and almost always lack adequate methods to assess and present critical river characteristics. There is still no common method for measurement of even the width of stream channels. To be useful as a management tool a river classification system should offer methods to obtain, organize, and present data on characteristics critical to river structure, process, and habitat.

Perspectives on rivers and watersheds. Rivers are seen in different ways not only by varied professional disciplines but also by other river stakeholders. Civil engineers are generally trained to control rivers, and generally resort to structural means (e.g. armoring banks) to do this. Private landowners may see rivers in the same way -- as needing harsh measures to prevent bank erosion and flooding. Other landowners appreciate the flat, fertile floodplains built by rivers. They understand and accept the farming problems that periodic flooding -- an essential part of this process-- may cause. Some river managers and landowners are willing to compromise while others insist that all negative effects be eliminated. A practical classification system must both present views of rivers that make sense to these varied interests and take into account their inherent knowledge.

River geomorphologists offer a necessarily holistic view of rivers. Civil engineers have an important understanding of fluid mechanics, water management, and slope-stability analysis. Agricultural engineers bring knowledge of water and soil conservation on small channels and upland areas. Private landowners and farmers understand the challenges of agricultural production on river floodplains, and control most of the land area in midwestern watersheds. An understanding of riparian vegetation comes from terrestrial ecology and forestry, and knowledge about the living parts of river ecosystems from aquatic ecology and related disciplines. Holistic approaches to river management, particularly classification and assessment methods, must consider rivers as systems and use technical knowledge and methodology from an array of disciplines.

The scientific disciplines are critical to understanding rivers, but there remains much to be done to transfer this knowledge to important river stakeholders in forms they can use. A strong tendency, especially in the areas of geomorphology, engineering, and aquatic biology, to study and present information quantitatively and from sometimes narrow points of view (see Newson 1992) has led to a neglect of descriptive methods as a powerful alternate means of both gathering and presenting information about rivers.

Reductionist approaches, classification, and assessment problems. The drive to reduce complex river systems to small sets of quantifiable variables has led to frustrated efforts. Cushing et al. (1983), for example, attempted to relate biota to habitat with an analysis of a few physical variables measured at sixteen stream reaches. These researchers decided the relationships were so indistinct that classification had little use. Other workers have tried to measure a number of significant physical habitat features and sort them out using multivariate analysis, usually including biological data. These attempts have generally been unsuccessful. Whittier et al. (1987), for example, applied this approach in a very broad survey of Ohio streams, and concluded that, because physical habitat measurements were not collected "consistently," they were not very useful. Rosgen (1994) has suggested that statistical analysis of biota can be made much more meaningful if data are first stratified according to physical stream characteristics. This is an important potential application of stream classification.

It appears that a sound, practical, broadly applicable (both geographically and across disciplinary boundaries) system must include a mix of quantifiable variables, well-directed description, and presentation of information in modes understandable to a wide audience of stakeholders. This approach must also take into account the processes that control river habitat characteristics.

Constraints to classification systems: Limitations of current theory and systems. Although several conceptual treatments of river classification have been published -- most notably Nanson and Croke (1992), Naiman et al. (1988), Gordon et al. (1992), Meador et al. (1993), and Mosley (1987) -- Rosgen's (1996) stands as the most complete. The fundamental rationale and predictive capabilities of Rosgen's system have been recently questioned (Miller and Ritter 1996), as has its widespread application (Gillilan 1996). And it appears that the system does not work well for midwestern streams (Gough 1997). However, Rosgen's approach meets (at least in theory) several important criteria: it is process-oriented, provides predictive capability, presents detailed field methodology, and is accessible to many conservation professionals, at least on a fundamental level. Rosgen's system also meets, at least in part, proposed theoretical criteria -- it is hierarchical, process-based, and may be broadly applicable. While it relies on field measurements, some of which may be impractical for poorly-funded conservation efforts, it is practically designed:

It draws knowledge and methods from a wide range of disciplines, and is designed to answer practical management questions by predicting possible states of stream reaches.

Training. Rosgen's classification system raises an issue affecting all classification approaches: what training is required for managers to apply classification/diagnosis systems? Although Rosgen offers short courses on the use of his method, there is some controversy over his approach because it fosters the impression that a few weeks of intensive training can substitute for years of study and experience. His system is offered as a classic "cookbook" approach -- a strict field procedure is followed, and stream reaches are classified as one of several types which may have a specific range of morphologic characteristics. Streams that are disturbed may then be restored to a specific morphology using, usually, rather drastic channel alteration methods and/or addition of hydraulic structures. These morphologic characteristics are specified in Rosgen's publications, as are hydraulic structures suitable for various stream types.

If applied by conservation professionals with sound training and experience in the necessary disciplines -- including aquatic biology, fluvial geomorphology, hydrology, and engineering, this system may represent a good starting point. Such people are rare, however, and Rosgen's system is usually applied by professionals with little training or experience in more than one of these disciplines. Perhaps the most severe limitation of such an approach is a lack of understanding of the underlying complexity of river systems, and a failure among river conservationists to appreciate the training and experience necessary to apply rigorous, holistic methods to river conservation problems. Availability of suitably-trained people will continue to strongly influence river management, and should be considered in the development of classification and management approaches.

Classification data. The basic data needs for application of a holistic, watershed-based classification/diagnosis system include information on watershed geology, topography, and soils; climate and hydrology; landuse; and terrestrial and aquatic biota. At a finer level, information about river channels, including basic hydraulic geometry, riparian vegetation, and inchannel microhabitat is needed. For some watersheds, much of this information is available from published sources. For most, the information on biota and reach-scale channel condition must be collected. This data collection, and the interpretation of other data, requires well-developed technical skills in the areas mentioned above. Thus the application of a comprehensive stream classification system to large watersheds will require, usually, a team of scientists and technicians.

Watershed size. Practical spatial scales for watershed management probably vary by region, and depend on the resources available to the managing agency or organization. Frissell et al. (1986) advocate a hierarchical classification system in which the highest level is the stream system -- an entire watershed -- with an approximate linear spatial scale of 10^3m, followed by stream segments (10^2m), reach systems (10^1m), pool/riffle systems (10^0m), and microhabitat systems (10^{-1}m). While the term "reach" is widely used and ill-defined, a reasonable definition for it is a length of channel that is about 20 times the channel's bankfull width. A river segment including several river reaches can be defined as a section of river between two major tributaries (Frissell et al. (1986). The segment should also be a relatively homogenous unit with no discontinuities such as dams or significant changes in physical or chemical properties (Meador et al. 1993). Frissell et al. (1986) focused on high-gradient systems in the Western United States. In low gradient systems, larger units are probably practical. Depending on geology (particularly groundwater processes), relief, and climate, midwestern watersheds with mainstem lengths of less than 10,000 m may not have permanent flow.

The cost and feasibility of classifying and managing a watershed system is greatly dependent on the size of the system at hand. Most biological assessment and modeling work has been done on "wadeable" streams, that is, those in which most of the channel bed can be waded. Assessment systems proposed by the U.S. Geological Survey's National Water-Quality Assessment Program (USGS-NAWQA, Meador et al. 1993) and the U.S. Environmental Protection Agency (USEPA, Kaufmann 1994) specify application only to wadeable streams. Measuring habitat variables within channels where water depth regularly exceeds about 1.5 m becomes prohibitively time-consuming and even more difficult in channels where current velocity is relatively high. Surveying channel cross sections from a boat, for example, is much more time and equipment-intensive than doing so on foot, and assessing bed materials becomes very difficult in deep channels. Thus the lowflow water depth within streams can present a logistical barrier to the measurements necessary for stream classification and assessment.

Relationships between physical habitat and biota: Limitations of habitat--biota models. Assessment and classification schemes used for management of aquatic ecosystems depend on models that link biota and physical habitat conditions (Simonson et al. 1994b). It appears that there are few such models for streams in the midwestern United States, and these models are directed toward management of a single or few species of fish, usually gamefish (e.g. Wisconsin's assessment program, described by Simonson et al. 1994b). Our capability to model the relationships between fish populations and physical habitat remains crude, and even less developed for other stream biota (Frissell and Bayles 1996). Thus far, not even a conceptualization of how a complete stream ecosystem might be modeled for management exists in published form. A comprehensive classification approach should allow for the complexities of biotic interaction within a stream system, along with the complex nature of fluvial form and process. The limitations of our models in both these realms will remain a barrier to such a system for some time to come, however.

A comprehensive stream ecosystem classification system should include the best available knowledge of relationships between stream biota and physical habitat. Variations of the Index of Biotic Integrity (IBI) are widely used (e.g. by the Illinois Department of Conservation and other agencies), but their limitations are serious and generally acknowledged. In general, these models are based on simple assumptions about fish community structure coupled with measurements of physical habitat data. The habitat data are not process-oriented, and all models depend on the assumption that presence of a fish species in a given habitat means that habitat is preferred. For species able to use alternate habitat this premise may not be accurate (Rabeni and Jacobson 1993). Information on habitat needs for various life stages is also lacking -- models that are gamefish-oriented tend to focus on habitat for adult fish (Rabeni and Jacobson 1993). Linking fish and habitat is also complicated because species probably respond to combinations of habitat types (e.g. a pool adjacent to a riffle) rather than individual habitat units (Rabeni and Jacobson 1993). For this reason, reaches should be characterized with an understanding of process and morphology because habitat units tend to occur in groups that can be identified in this way. Further, in disturbed systems, fish species may be displaced to habitat that is not optimum for them (Power et al. 1988). Finally, species presence/absence can be greatly affected by the presence of other species, regardless of habitat characteristics. Power et al. (1988) note that certain species of water striders (an invertebrate) used pool habitat only when trout were absent, and researchers in the Missouri Ozarks have noticed such relationships among species of fish (Terry Finger, pers. comm.).

Other habitat ranking systems, such as Wisconsin's Fish Habitat Rating system (FHR), or Missouri's Stream Habitat Assessment Device (SHAD) use estimated "optimum" habitat conditions for fish. The FHR and SHAD systems score individual habitat elements (e.g. water depth) and sum scores to put reaches in qualitative rankings (e.g. poor to excellent). Simonson et al. (1994b) offer an analysis of models and their use in Wisconsin streams. While such models can be powerful management tools, they depend on subjective estimates of habitat value, and thus must be applied with great care.

The Physical Habitat Simulation System (PHABSIM) is a habitat assessment tool used to estimate the suitability of hydraulic habitat in a river reach. It is often used to determine the effects of changes in discharge from such influences as irrigation withdrawal or dam operation (Gordon et al. 1992). For a given fish species, PHABSIM can be used to determine the quality of habitat (expressed as usable area) within a stream channel at various discharges. This is done by modeling channel hydraulics and comparing values for variables including depth and velocity with values thought to be optimum for that species.

Charles Rabeni , who has done extensive research on fish-habitat relationships in the Ozark Mountains, states that "while our goal is to quantify critical factors of the stream environment, it does not appear that this goal can be attained in the near future." (Rabeni 1990). It appears, however, that stratification by geomorphic types, as recommended by Rosgen (pers. comm., 1995), may greatly enhance our ability to identify critical habitat, especially on a basin scale.

Spatial scale, geomorphology, and data analysis in classification

River ecosystems are best managed at the watershed scale, particularly when limited resources for stream restoration and protection must be applied over a region. Otherwise, degraded areas may get the too much attention while high-quality reaches go unprotected. This can lead to a degradation of high quality sites as attention is focused on improving degraded areas (Doppelt et al. 1993). However, the majority of stream habitat classification and assessment methods now in use are reach-based. Although watershed-based management is now an old idea, most approaches have been very general (e.g. to improve water quality) or fragmented and single-purpose, as in programs aimed at flood control. Holistic watershed management is still a new approach, and there are essentially no models to follow, particularly in the midwestern United States (Gough 1993).

Reach, segment and watershed-scale approaches. Management of stream morphology has traditionally been dominated by reach-scale approaches. Channel stability (including bank erosion) management, habitat restoration/protection, and even flood control are generally approached by assessing and controlling local river characteristics only. Private landowners, who generally perceive river problems as being caused by local conditions, usually take this approach, as do engineers working on channel stability or structures such as bridges or pipeline crossings. Often, very limited resources or legal limitations preclude any other approach -- transportation engineers, for example, are generally not given the freedom or resources to evaluate fluvial process beyond a small spatial area near a bridge, and they consider watershed conditions only as necessary to determine river flows passing through the reach in question. Assessment and classification may be implicitly reach-based. Most habitat assessment schemes, for example, do not mention (or do not define) selection of sites based on even a rough survey of watershed conditions. Most habitat improvement and restoration methodologies are based on the assumption that local problems like bank erosion, for example, are strictly caused by local (i.e. reach-scale) conditions. Management problems may be caused by local conditions, but a sound assessment or classification scheme must include consideration of influences outside a particular reach. This is important in managing a given reach, and critical when limited resources must be allocated over a large area. Analysis of influences beyond the reach-scale requires a means to compare river reaches, understand possible states, and allocate resources to obtain the greatest return.

Local and systemic control of habitat characteristics. Reach-scale management implicitly assumes that habitat quality is locally-controlled. This assumption may come from ignorance of the importance of fluvial inputs to the reach (primarily water and sediment) or the manager's inability (perceived or real) to control these inputs. When an approach is directed at physical alteration of local conditions -- through bank protection, for example -- the methods tend to drive site selection. A reach-based approach tends to promote management methods to control reach-scale problems (very commonly bank erosion), which in turn tends to focus attention on degraded sites where such methods are applicable. The management means (e.g. bank protection) tends to drive the scale and focus of diagnostic approaches, and basin-wide processes may be ignored.

Local controls on channel morphology and habitat quality include bank and bed materials and riparian vegetation. In most midwestern watersheds, private landowners exert considerable and highly variable (from reach to reach) control over streamside vegetation. Systemic, or large-scale, influences include hydrologic regime, which may be strongly influenced by landuse and modification of the drainage network, and basin geology. Over time, changes in hydrologic regime can have profound influences on river morphology. Increases in flood magnitude and frequency commonly destabilize channels. In urbanizing areas, flood peaks can increase several-fold, generally forcing channel enlargement and the resultant instability. Hydrologic changes can be difficult to measure and analyze, and it is particularly difficult to establish the causes of change in large watersheds with complex patterns of landuse.

Other systemic processes are relatively clear, however, given an expanded view, in both space and time, of the river system. Systemic influences can be evaluated by comparing river reaches using even simple means such as historic aerial photography. More powerful analysis is possible though reach-scale morphologic surveys of a number of reaches throughout a river system. This can show which characteristics are locally controlled and which may be influenced by large-scale processes. Even a casual assessment of aerial photographs may show, however, that rapid lateral migration of meander bends is common in a given segment of a river. Thus lateral migration is systemic and must be addressed at the segment or watershed scale. This is true even if morphology is controlled locally -- through widespread destruction of riparian vegetation by landowners, for example. In other cases, it may be clear that bank migration is rare and local control is probably influential. Generally, habitat quality in a basin is best managed by addressing both systemic impacts and local influences such as riparian vegetation.

In general, it is easier and more practical to approach management of systemic problems in small watersheds. Reaches draining large watersheds may be influenced by a wide range of human activities, both in stream channels and valleys and in upland areas. Determining the relative importance of these impacts can be difficult, and managing them can be even more so.

Reach comparison and reference sites. Basin-scale holistic assessments become complex because the components of fluvial systems are highly interactive. Development of a hierarchical classification scheme depends on identification of key controlling variables. Ultimate controls -- climate and geology (Naiman et al. 1992) -- are obvious, but of little use in comparing reaches within small basins. Classification of river systems at segment and reach scales becomes difficult because various characteristics and processes may dominate different reaches (Frissell et al. 1986). Changes in sediment and water flux through a reach will commonly affect its morphology, for example -- in the urbanizing stream example above, channels enlarge in response to increased flood peak magnitudes. Channel enlargement may in turn affect downstream hydrologic conditions, however, because larger channels will route floods differently. In this simple example, we see that classification of channels through either hydrology or morphology alone leaves out important information. Because direct measurement of many important characteristics is both complex and prohibitively expensive, a practical means is needed to compare reaches within a basin using morphological features and indicators of fluvial process. This approach is advocated to some degree by Rosgen (1994, 1996). Frissell et al. (1986) also discuss the utility of classification in comparing similar reaches for determination of possible states and manageability.

Assessment and classification for ecological restoration and protection can be done using reference sites. Reference sites can be selected using existing knowledge about the biota within a basin and general knowledge of impacts to reaches. These sites are assessed and compared with other sites within the basin. As key controlling variables are identified, the possible states of impacted sites can be determined and manageable characteristics changed to restore impacted reaches. Alternately, this approach allows identification of systemic or local influences that may not be practically managed.

I was unable to find any proposed or existing assessment or classification scheme offering a protocol for identifying reaches within a basin to be used as reference sites (although Meador et al. (1993) imply that some method might be used). Practical limitations and preexisting data may strongly influence selection of sample sites. Biological sampling sites, especially if they have been resampled over time, are obvious choices for physical habitat measurements. Most midwestern basins are mostly controlled by private landowners, who may limit access to river reaches. River gaging stations may offer long-term hydrologic and water quality data, and thus be selected as sites for further work on channel habitat and morphology.

In any case, although selection of a network of reference sites may be biased by practical limitations, it is critical that an overall assessment of the basin be made before efforts are focused at the segment and reach scales.

Assessment levels. Rosgen (1996) proposes a "hierarchy of river inventories," shown in Table 1, that provides four levels of assessment beginning at the watershed scale. Level 1 includes assessment of landform, soils, climate, basin relief, valley morphology, and general river pattern. At Level 2, reach- to segment-scale measurements are added, including channel patterns, width:depth ratio, channel materials, and channel slope. Further refinement at Level 3 includes measurements of riparian vegetation, debris occurrence, inchannel habitat, and bank erodability. Level 4 includes direct measurements of sediment transport, bank erosion rates, and biota. Rosgen's (1996) description of methodology focuses primarily on Level 2 classification presented in his 1994 *Catena* article. [There is some inconsistency in published materials. Materials from Mr. Rosgen's course (August, 1995 session workbook, page C21) place watershed and drainage network measurements prior to Level 1, and include classification of reaches in Level 1.] Although other papers have implicitly acknowledged the importance of assessment levels beginning at the watershed scale, e.g., Meador et al. (1993), none have provided a detailed, integrated means to do so.

level of detail	description	information required	objectives
Level 1	broad morphological characterization	landform, geomorphology, climate, basin relief, river profile, general pattern and bank/bed materials	Describe general fluvial features, familiarize workers with basin, produce a general reference document, summarize existing data.
Level 2	morphological and process description (Rosgen's stream types identified)	channel patterns, entrenchment ratios, width:depth ratio, sinuosity, channel materials, slope	Using "reference reaches," against which other reaches can be compared, identifies homogenous stream types
Level 3	Rosgen's "stream state"	riparian vegetation, meander patterns, depositional patterns and other evidence of fluvial process, bank erodability	Provides information on possible states and impacts to both biota and stakeholders. Gives detailed information for comparison with other sites to determine possible states and suitability for restoration/protection.
Level 4	Rosgen's "verification" level	Direct observations of sediment transport, bank erosion rates, etc.	Used to evaluate and verify prediction methodologies.

Table 1. Table of inventory hierarchy. Modified from Rosgen (1994). "Unifying variables" allowing determination of possible states may include bed/bank materials, drainage area, channel modification, and riparian vegetation.

Frissell et al. (1986) provide the most comprehensive discussion of this problem, as well as considerable detail regarding their classification of montaine streams in Oregon and Washington State. In one example, they classify channels in a small (about $5km^2$) mountain watershed according to stream order, slope, valley sideslope morphology, geology (which includes sandstone, siltstone, and alluvium, progressing from upper to lower reaches), and short descriptions. They offer more general variables for classifying habitats by "potential capacity." These are given in Table 2. The authors note that not all variables listed in this table are necessary to classify streams in all circumstances, and that the best indices may vary by region or with study objectives. Methods for incorporating analysis of hydrologic characteristics and upland landuse into classification are notably absent from their otherwise comprehensive conceptualization of watershed-based classification. And, although they provide lists of important variables, their descriptions of key characteristics are (as they note) biased toward the mountainous streams in which they work.

watershed	**stream system**	**segment**	**reach**	**pool/riffle**	**micro-habitat**
biogeoclimatic region	watershed class	stream class	segment class	reach class	pool/riffle class
geology	long profile slope, shape	channel floor lithology	bedrock relief, slope	bed topography	underlying substrate
topography	network structure	channel floor slope	morphogenetic structure or process	water surface slope	overlying substrate
soils		position in drainage network	channel pattern	morphogenetic structure or process	water depth, velocity
climate		valley sideslopes	local sideslopes, floodplain	substrates immovable in <10 yr flood	overhang-ing cover
biota		potential climax vegetation	bank composition	bank configuration	
culture		soil associations	riparian vegetation state		

Table 2. General variables for classifying habitats by potential capacity, from Frissell et al. (1986).

Frissell et al. (1996) cite Godfrey (1977) in discussing the advantages of using a hierarchical classification structure: (a) classification at higher levels reduces the set of variables required at lower levels, (b) it allows integration of data from different sources and of different levels of resolution, and (c) allows managers and scientists to select the level of resolution most appropriate for the objectives at hand. Although development of a broad, consistent body of data for midwestern streams is necessary before a regional classification system can be proposed, such a system will allow managers to select among variables and levels of resolution within regions where fluvial system characteristics are similar. This is true, for example, within much of the Ozark Plateau and in glaciated areas in the Great Lakes region. In glacial lake plains, for example, streams can be remarkably similar over rather large (>10,000 km^2) areas. Such capabilities could greatly extend the limited (and now often shrinking) resources available to scientists and managers. This will require, perhaps above all, development and use of consistent methods of gathering key information. Although methods may vary among regions and organizations, it is critical that certain essential characteristics be measured and reported consistently.

Organization of data and stratification. Rosgen (pers. comm. 1995) offers perhaps one of the strongest arguments for application of fluvial system classification to management and study of river ecosystems: classification of stream segments or reaches allows stratification of them based on physical habitat. This allows us to stratify and group biological information for much more effective understanding of the relationships between biota and habitat. Commonly, researchers in aquatic biology have reported finding very poor relationships between biota characteristics and physical habitat. Generally, only a few habitat variables were measured (e.g. water quality characteristics), however, and only rarely (e.g. Osborne and Wiley 1992) have biotic measurements been stratified according to process-based morphologic features.

The Rosgen classification system. Perhaps the most well-known and broadly used stream classification system is that developed by David Rosgen and commonly known as the *Rosgen system*. Details of the system and its foundations are currently described in copyrighted materials available only by attending short courses given by Rosgen and in a self-published book (Rosgen 1996). The system has been presented in peer-reviewed literature in a 30-page article in the journal *Catena* (Rosgen 1994), and in a self-published book (Rosgen 1996). This paper has been the subject of some controversy, and fundamental premises of the system have been questioned in a response paper also presented in *Catena* (Miller and Ritter 1996).

The Rosgen system's methodology focuses largely on reach-scale assessment, although it does acknowledge watershed-scale assessment and classified reaches can be used to compare streams at the watershed or regional scales. The system centers on fluvial process, and classifies rivers in order to:

> Predict a river's behavior from its appearance;
> Develop specific hydraulic and sediment relations for a given morphological channel type and state;
> Provide a mechanism to extrapolate site-specific data collected in a given stream reach to those of similar character;
> Provide a consistent and reproducible frame of reference of communication for those working with river systems in a variety of professional disciplines (Rosgen 1994).

The classification system divides stream channels into eight major types -- A, B, C, D, DA, E, F, and G -- as shown in Figure 1. Stream channels at the reach scale are placed in these types using a hierarchical process that uses several morphologic variables. Characteristic types were developed by Rosgen based on his personal field experience with "hundreds" of rivers in "all the climatic regions of North America" and applications of early versions of the system by workers in various disciplines (Rosgen 1994). Moving downward through the hierarchical classification key, streams are assigned to branches based first on whether they are single or multiple-channeled. Subsequent movement through the key (Figure 1) is based on morphologic measurements that are often given as ranges (e.g. slope is 4-10%).

Defining variables in the system include assignment of channels to single- or multiple-thread channels, entrenchment, width:depth ratio, and sinuosity. With these variables, channel reaches are assigned to one of the eight major classes. Further refinement (in which channels are assigned alphanumeric suffixes, e.g. A1a+) is based on slope range and channel bed materials.

Morphologic variables are largely based on bankfull channel dimensions. The theory and application of bankfull flow are discussed in the following section. They are defined as:

Bankfull width (W_{bf}) is the top width of the wetted channel at bankfull;
bankfull area (A_{bf}) is the cross-sectional area of the bankfull channel;
bankfull mean depth (D_{mean}) is the mean bankfull depth, which can be calculated as (A_{bf} / W_{bf});
bankfull maximum depth (D_{max}) is the maximum distance, at a given cross-section, between the bankfull water surface elevation and the channel bed;
floodprone area width (W_{fpa}) is the channel width at an elevation of $2(D_{max})$, and is further defined as the area "frequently flooded;"
entrenchment ratio is the ratio ($W_{fpa} : W_{bf}$) and is an index of channel incision. The system also uses
Sinuosity, defined at stream length/valley distance;
slope of the water surface along the channel, expressed as a dimensionless fraction, and
D_{50}, or the median particle size of surface bed materials, as well as general descriptions, e.g. sand, gravel, clay.

Figures 2 and 3 show channel cross sections and planform views defining several of these characteristics. Although it appears that Rosgen's system is ill fitted to some midwestern river systems (Gough 1997), many would be classified under this system as type C, described as:

> Low gradient, meandering, point-bar, riffle/pool, alluvial channels with broad, well-defined floodplains; entrenchment ratio >2.2, width:depth ratio >12, sinuosity >1.4, slope <0.02 (Rosgen 1994).

Rosgen (1994) describes this system as useful for determining the possible state of a system and predicting expected changes or evolution as a result of impacts such as devegetation. For example, an E4 stream, which has a low w:d ratio of 2, a slope of 0.006, and sinuosity of 2.5, if stripped of stabilizing vegetation or subjected to increased flood peaks, can broaden and braid to become a D4, which has a very high (for a small stream) w:d ratio of 60, a steeper slope of 0.014, and a sinuosity of only 1.1. The system can, in turn, be used to predict the possible state of a degraded stream, and (according to Mr. Rosgen) design channels based on states and evolutionary processes implied by the classification system, e.g., that C1 streams generally have very good "recovery potential" while A4 and A5 streams, although very sensitive to disturbance, generally have very poor recovery potential. Rosgen (1994, 1996) also provides general management guidelines for stream types, and lists sensitivity to disturbance, sediment supply, streambank erosion potential and the controlling influence of vegetation for major types and subtypes. These are given in descriptive terms, for example, "very low." Rosgen's rationale for classification and his system's ability to predict possible states has been severely criticized, at least in part because he has not adequately disclosed the data used to construct his system (Miller and Ritter 1996).

Fluvial process and river classification and assessment

This section covers basic fluvial process and key indices and indicators of fluvial process. The cross sectional shape of a given river channel is a function of the flow moving through it, the quantity and character of sediment carried by that flow, the nature of bank and bed materials in the channel, and, commonly, the vegetation near and within the channel (Leopold 1994). Flowing water exerts eroding force on the bed and banks of river channels. In relatively stable channels, this force is balanced at every point in a given cross-section by the resisting bed or bank materials (Leopold 1994). Generally, channel dimensions are adjusted, through erosion and deposition of sediment, to the quantity of water moving through the cross-section so that the channel is able to contain all but the highest flows (Knighton 1984). Changes in the discharge or sediment supply to a cross-section or reach of river will tend to alter its morphology, depending on the magnitude of the change and the nature of bank and bed materials. Channels formed of very resistant materials such as clay or bedrock may change little, while channels formed in sandy alluvium may be very sensitive to changes in discharge.

Bankfull flow. In simplest terms, the *bankfull* discharge is that flow which fills a channel without overtopping its banks (Richards 1982). The term has been in use by geomorphologists for decades but has yet to be consistently defined. Although most fluvial gemorphologists are aware of its varied uses and definitions, most managers outside this discipline are not. And even a simple definition of bankfull flow requires a rather complex set of assumptions, so there is considerable confusion over its use. Leopold (1994) offers a detailed discussion of bankfull discharge concept. He argues that bankfull discharge occurs 1 or 2 days a year and has a recurrence interval averaging 1.5 years. This may vary among geomorphic climatic regions, however, so quantitative use of bankfull discharge requires data from local gaging stations (Leopold 1994). Generally, the bankfull discharge, considered over long periods of time, carries most of a river's sediment load (Leopold 1994) even though large, less-frequent floods may show higher transport rates. Conversely, the flows less than bankfull, though much more frequent, tend to move less sediment over time.

Flows above bankfull inundate the flat areas adjacent to the channel or the *floodplain*. Floodplains, by definition, are constructed by rivers *under the present climate or flow regime*. As Leopold (1994) notes, changes in a river's flow regime, either through climate change or human impacts, can alter river morphology and change the spatial and process relationships between a channel and its floodplain. Channels may incise (or downcut) during periods of increased discharge, leaving former floodplains as high terraces.

Determination of bankfull discharge is best made through a combinations of field surveys and gage data, as recommended by Leopold (1994) and Rosgen (pers. comm. 1995). Leopold (1994) details the process by which this can be done. Using long-term gage data, a flood frequency curve is produced. Discharge at the 1.5 year return-interval is determined, and the corresponding stage (water surface elevation) for that discharge is recorded. In the field, cross-sectional and long-profile surveys are made at the gage site, and key geomorphic features are measured. The elevations of features are compared to that for bankfull flow as determined from the gage record. Usually, a clear correlation is found -- a floodplain-channel margin occurs near the elevation for the 1.5-year return-period flood stage. In this way *bankfull indicators* can be identified and used to define the bankfull channel dimensions at other reaches in a watershed or region. The process of correlating long-term gage data with morphological indicators in the field is sometimes called *gage calibration* (D. Rosgen pers. comm. 1995).

Stage-discharge curves for gaging stations often show an inflection point at bankfull -- as discharge exceeds channel capacity and the floodplain is inundated, further increases in discharge are less effective in raising stage. Sometimes bankfull stage for a given channel is relatively well-defined by a channel-floodplain slope break. This slope break should be seen consistently along the profile, and elevations at several points along the long profile should plot roughly parallel to the channel profile defined by the low flow water surface (see examples in Leopold 1994 and Gough 1997). In the absence of a clear slope break, or as correlation, other bank indicators are useful. These include changes in vegetation type and lines on bedrock or clay surfaces. In many midwestern streams the lower limit of permanent woody vegetation in a channel cross section corresponds with bankfull. In some Western streams, a change in tree species to *Salix spp.* indicates bankfull (D. Rosgen pers. comm. 1995). For a given watershed or region, data from several gage calibrations can be combined to produce curves showing expected bankfull channel dimensions for a given watershed area (D. Rosgen pers. comm. 1995). This method was applied at three gage sites on the Mackinaw River in central Illinois and the results reported by Gough (1997).

The relationship between channel morphology and discharge can change between regions. In some regions, use of bankfull channel definitions may have little meaning. In groundwater-dominated systems in the glaciated Great Lakes region, flows are very stable and river stages may change very little over long periods of time. These systems are also very morphologically stable, and much of the material forming channel banks and beds is not transported by the modern flow regime. In this case, woody vegetation is limited primarily by the level of groundwater and does not define a bankfull channel. It is arguable that these are not equilibrium systems because their flows carry very small sediment loads and are not capable of significantly altering channel dimensions through erosion. Essentially, bank and bed material resistance to erosion greatly exceeds the capacity of even the highest contemporary flood flows to erode them.

Use of bankfull channel and flow definitions also implies stable or equilibrium conditions over long periods of time -- at least a few decades. The flow data used to construct recurrence interval curves generally covers this time period. After either natural or anthropomorphic disturbances, some time is required for channel morphology to restabilize. Channels that are not in equilibrium, actively incising urban channels, for example, may show no clear indications of a bankfull channel. Landuse changes may cause flow regimes to change over time, preventing the formation of an equilibrium bankfull channel morphology. And, to some degree, all channels are products of a range of flows and flood events (Pickup 1979). Timing and succession of flood events can cause short-term departures from the regime or equilibrium state, causing deposition during periods of low flow and erosion during extreme floods (Richards 1982). Some watersheds lack gages altogether, precluding which precludes verification of bankfull indicators with gage records within that basin (we may still use gage calibration results from neighboring watersheds, however).

Even so, it appears that formation of river floodplains with relatively stable downchannel morphology and elevation (with respect to the channel's long profile) are common in midwestern streams. Even highly disturbed channels tend to form floodplains (see, for example, Gough 1992 and 1997). These floodplains are usually seen at an elevation lower than that of the pre-disturbance floodplain because disturbed channels often downcut.

Time. Kondolf and Sale (1985) offer an excellent overview of the importance of historical analysis in understanding river system behavior. Predicting or explaining river morphology and process can be difficult because many independent watershed variables (such as rainfall, geology, and landuse) can interact in different ways to produce varied flow and sediment regimes. Many dependent channel variables (such as width, depth, vegetation, and sediment transport) can react in different combinations to any given regime. Rivers thus tend to be unique, and the best information about how a particular river segment behaves is its past history (Kondolf and Sale 1985). The best indication of how a river might respond to vegetation changes, for example, may be contained in records showing past response to vegetation changes (such as in historical aerial photography). Many midwestern riparian areas were cleared of trees in the past, and historic aerial photography shows a wide variation in channel response.

Channel morphology. Simply stated, the morphology of a stream channel depends on a balance between the erosional force exerted on it by moving water and the resistance to erosion of the channel's bed and bank materials. A third important factor is the sediment supply entering the reach.

Stream power. The erosional force exerted by water flowing through a reach can be expressed as *stream power,* the product of discharge and slope. As the amount of water carried by a reach or the slope of the reach increases, the ability of the flow to erode the channel's bed and banks increases. The term stream power, like bankfull, has been used in inconsistent ways. Stream power is expressed in several forms, and its use in the literature is quite confusing (see Ferguson 1987). *Total stream power* can be expressed in watts/m as:

$$\Omega = \rho g Q s$$

And is, essentially, the product of channel slope (**s**) and discharge (**Q**). The other components, which are usually considered constants, are water density ρ, which is approximately 1000 kg/m^3, and gravitational acceleration **g**, which is 9.8 ms^{-2}. If we substitute a value of 10 for the product of ρ and g (which is approximately equal to their actual product of about 10,000, divided by 1000) we get Ω expressed in kilowatts (kw), i.e. $\Omega = 10Qs$ expressed in kwm^{-1}.

Specific stream power is a more meaningful expression for applied fluvial geomorphology. It is total stream power divided by channel width (w) or:

$$\omega = \frac{\rho g Q s}{w} = \frac{\rho g (dwv) s}{w} = \rho g d v s \propto dvs$$

Because Q = dwv, we can substitute these in this expression, and drop out the constants of density and gravitational acceleration to get the proportional dvs (depth x velocity x slope) on the right-hand half of the equation. Specific stream power at bankfull (ω_{bf}) can be calculated using data gathered at gaging stations. Q_{bf} is known from the gage record, slope and W_{bf} are surveyed during the gage calibration procedure, and the following form of the formula is used:

$$\omega_{bf} = \frac{\rho g Q_{bf}\, s}{w_{bf}}$$

Specific stream power gives stream power per unit of bed area for a specific cross-section in units of watts/m^2. Specific stream power tells us how much power is available to erode sediment for a specific area of the channel. It is directly correlated with indicators of that power, like bed material size (and thus resistance to erosion). Small, steep, mountain streams have relatively low *total* stream power, but very high *specific* stream power, and are often armored by large cobbles and boulders. Big rivers such as the lower Mississippi have very high *total* stream power, but it is expended over a very wide channel, and thus *specific* stream power is relatively low -- bed sediments in such rivers are usually dominated by sand or silt. Stream power is further discussed in Richards (1982), chapter 4 of Petts and Foster (1985), and by Ferguson (1987) and Morisawa (1985). A good introduction and the basic derivation can be found in Gordon et al. (1992).

The tractive force approach. The erodability of bank and bed materials is closely related to their size. Generally, as flow velocity increases, ever larger particles are transported. The exact relationship between flow velocity or stream power and sediment transport in streams is very complex in both theory and application, and few studies have successfully measured transport of stream bedload. Newbury and Gaboury (1993) advocate use of an index of *shear stress* on channel margins, sometimes known (especially in engineering circles) as *tractive force*. Flow velocities in river channels are always lowest near the channel boundary due to friction between the boundary and flowing water. Velocity increases at points farther away from the bed and banks and, for a straight, symmetrical channel, is highest in the center. Shear stress is a measure of this *velocity profile*. Shear is highest when the velocity v. depth flux is high, i.e. velocity increases very sharply with distance from the channel boundary. Near-bed velocity profiles can be measured directly only using sophisticated instrumentation.

Newbury offers an approximation of tractive force or shear stress:

$$\tau = 1000(d)(s)$$

where τ = tractive force of flow in kg/m^2,
(multiply by 9.8 for Newtons/m^2)
d = depth of flow in m
s = slope of water surface

Because specific stream power (ω) = dvs, it is related to tractive force thus: $\omega = \tau v$. Newbury and Gaboury suggest that this shear stress can be used to determine stream stability by comparing the size of bed materials to tractive force using the relationship:

tractive force (kg/m^2) = incipient diameter (cm)

where the incipient diameter is the largest particle size moved by a given tractive force (Newbury and Gaboury 1993). Using bankfull depth and channel slope measured in the field, tractive force is calculated. An estimate of the streambed particle size distribution in the reach is compared with tractive force. If the incipient diameter is smaller than most of the particles on the bed surface, the bed is assumed to be stable at bankfull flows (Newbury and Gaboury 1993). Although this approach greatly simplifies a complex process, and has not been field-proven, it provides a very rough estimate of the relative stability of channels.

Bank and bed resistance and channel morphology. Although resistance to erosion generally increases with particle size, cohesive clays can be very resistant to erosion. Silts and clay/silt mixtures can also be resistant to erosion, especially when bound by plant roots. Bank and bed materials dominated by sand are generally the most easily eroded. Large gravel-sized particles (up to about 64mm) become more difficult to move, and few low gradient (less than about 0.002) midwestern streams transport materials of cobble size (above 64mm).

Vegetation can greatly influence the erodability of stream channels. Plant roots can greatly increase the strength of channel margins, and the above-ground parts of trees increase hydraulic roughness and slow flow velocities on banks and floodplains. Little research has been done on the influence of vegetation on channel stability, however. Vegetation, especially trees, appears to be particularly effective when streambanks are composed of silt-clay alluvium that is both cohesive and provides a good rooting medium.

All river channels change through time. At scales of decades, some rivers show little morphological change, others -- particularly those manipulated by people -- are greatly altered. To diagnose and classify changing rivers, we must know past river states, current rates of change, and make reasonable prediction of future states.

Much attention has been focused on horizontal instability, but midwestern streams have commonly shown past episodes of *vertical* instability as well. Even though vertical or *grade* change is often a precursor to horizontal instability, it has generally gone unrecognized and untreated. While horizontally migrating streambanks, and the damage they can cause to property, are usually obvious, vertical erosion may not be, especially to the untrained eye. Over scales of river segments and long periods of time, most rivers show remarkable stability in overall bed elevation. Destabilization of grade can be caused by channelization, inchannel gravel mining or dredging, changes in discharge (especially increases in peak discharge), and by grade-interrupting structures such as dams. Although grade can be raised by sedimentation (such as that seen above a dam), streambed degradation or downcutting is the most commonly seen form of vertical instability.

Vertical stability in river channels varies widely and is strongly influenced by the character of materials at and below the river bed. Many midwestern channels contain materials deposited during glacial drainage (called glaciofluvial sediments). These materials can contain large cobble-to-boulder sized materials that are not transported in modern low-gradient channels, and can form immobile layers that prevent bed degradation. Such materials (or artificial structures) are called *grade controls* because they effectively control the elevation to which a stream's bed can erode.

Channels formed in materials like loess, however, can be very unstable vertically. If flow regimes are altered or grade control is changed, these channels can show rapid downcutting. Grade control is commonly altered through channelization -- when a large river is channelized, its bed elevation may be lowered, which lowers the grade control for all tributaries entering it. Channels so affected may show an initial phase of downcutting followed by widening.

Sinuosity. Sinuosity is a measure of the "curviness" of a river channel. The most commonly used definition is:

SI = channel (or thalweg) distance/downvalley distance

A straight channel has a sinuosity value of 1.0. A very curvy river might have a sinuosity value approaching 2.0. Figure 3b shows how sinuosity is measured. Sinuosity is closely related to grade stability. For a given valley slope and distance, the slope of a river channel will vary directly with its sinuosity. As the river becomes more sinuous, grade decreases. When rivers are ditched or made straight through channelization, their slope is increased. Stream power is directly controlled by river slope, and channelization can double stream power. Rivers that are able to freely erode their banks may control grade through changes in sinuosity -- as they become more sinuous, slope decreases, reducing stream power and thus the tendency to erode banks. In this way channels able to alter their sinuosity will self-regulate slope and stream power so that they are generally in balance with the strength of bed and bank materials. Channelized rivers often show a tendency to reestablish a sinuous path, for example, to regain a slope that is compatible with bank and bed resistance to erosion.

Pool spacing and riffle:pool ratio. At a finer scale, within river reaches, most river channels show variability in slope. Most commonly, we see *pools and riffles*. Pools are deeper sections of the channel in which lowflow current velocity is low. Pools usually (but by no means always) contain relatively fine bed sediments, and the lowflow water surface slope is flat. Riffles are generally composed of coarser materials, commonly gravels and cobbles, and the lowflow water surface drops significantly through the riffle. There is no standard definition for riffles, but a reasonable one (that is commonly used or inferred) requires a significant drop in water surface elevation through the riffle during lowflow conditions. Current velocities are relatively high and water depth is shallow over most riffles during low flows. This distinguishes them from a third commonly-defined feature, called a *run*. While water surface slope is greater than zero in runs, they are deeper and slower than riffles. There is no standard definition for runs.

Pool spacing is a commonly used index. It is widely believed (or inferred, e.g. Newbury and Gaboury 1993) that natural or ecologically healthy streams have a pool spacing of 5 to 7 bankfull channel-widths. That is, measured along the stream thalweg, a riffle should occur about every 5 to 7 times W_{bf}. While this form may be common in some regions, it has yet to be field tested or verified in the Midwest, and I have seen more exceptions to it than conformities.

The pool:riffle ratio is another commonly used index. It is often confused with pool spacing. The pool:riffle ratio is the ratio of pool length to riffle length, measured along the channel thalweg (Hunter 1991).

Pools and riffles are important habitat elements. Many river fishes and invertebrates require one or the other habitat (though they may require proximity to the other as well). The spatial diversity formed by pools and riffles provides diversity in hydraulic habitat -- in depth, velocity, substrate, and cover. Pools provide habitat during critical periods of low flow when adjacent riffles may be dry or nearly so.

Local control of channel process and morphology. The character of a river reach is a product both of local controls, e.g., bed and bank materials, and influences from upstream and downstream. The supply of water and sediment from a reach's watershed are the most obvious upstream controls. These inputs can be influenced at the watershed scale, but are also influenced by local hydraulics. Bridges that severely constrict flood flows can cause changes in reaches immediately downstream -- commonly channel widening and sediment deposition, depending on the vulnerability of the downstream reach. The effects of channelization are highly variable, but generally include an increased sediment supply as rivers erode banks to seek equilibrium. Dredging that sometimes follows channelization can, however, temporarily reduce the supply of sediment to downstream reaches as the dredged reach refills with sediment.

A reach's position in the drainage network determines the influence that adjacent reaches have on it. Reaches near major confluences may be strongly affected by flows in the river they join. The areas near the mouth of a tributary entering a larger river may be commonly inundated by backwater from floods in the larger river. Backwater causes most sediment transport in the tributary to cease, and deposition occurs. At other times, small cloudbursts may cause floods in the tributary without a corresponding rise in stage in the larger river, allowing sediment transport from the tributary. Most such reaches are thus naturally variable in morphology. The effect of backwater generally increases as the drainage area differential between the two channels increases. A large river that may rise 3 m or more to bankfull stage can backwater a small tributary for several hundred meters, especially if that tributary traverses the large river's floodplain.

Conversely, steep tributaries may transport sediments too large for a low-slope main channel to move. These sediments may form fans or small deltas that partially block the larger channel and affect its morphology. Coarse gravels and cobbles deposited in such a way may be major riffle-forming features in large rivers.

Changes in bed and bank materials, especially those controlled by surficial geology, can have profound localized effects on channel form and habitat. Bedrock outcrops on channel beds commonly form very stable, persistent riffles or rapids. Rivers with bedrock valley walls can show high variability in form. In such rivers, reaches flowing within erodable sediments in the valley floodplain tend to have higher w:d ratios and be less stable than reaches that run along bedrock valley walls. Figure 4 shows, in schematic form, the influence of various channel materials on river form for four midwestern regions. Such control on planform can be quite obvious on aerial photographs or large scale (e.g. 1:24,000) topographic maps. Strong local control is evident as tight river bends often showing abrupt turns. Such forms are rarely seen in freely meandering rivers. In glaciated regions, variability in glaciofluvial sediments will cause variability in channel form and process. Glacial tills rich in boulders and/or clay can be very resistant to erosion and act much as bedrock controls do. Glacially-deposited materials composed of fine gravels and sand can act as sediment sources, especially when channels meander into and erode high, steep morainal bluffs. In many glaciated regions, sand from such sources is a primary source of sediment and, in some, a source of habitat degradation, especially for salmonid spawning habitat (Alexander and Hansen 1986).

Riparian vegetation can exert strong local control on river form. The character and influence of riparian vegetation varies widely at both temporal and spatial scales, especially in watersheds that are controlled by many landowners. Riparian vegetation can thus be a highly variable local control on channel form and process. The influence of vegetation is greatly dependent on local conditions, and, although it widely believed that vegetation is a primary control, little research has been done in this area. This is due in part to the difficulty of separating the influence of vegetation from that of the many other characteristics influencing fluvial form and process.

There is strong evidence, however, that plant roots greatly increase the resistance of channel banks to erosion, much as reinforcing rod strengthens concrete. In the only study of its kind, Smith (1976) found that plant roots could increase the shear strength of bank materials by a factor of 20,000. The literature contains numerous references to the effects of vegetation on stability, e.g. Graf (1978), Andrews (1984), Charlton et al. (1978), Hupp (1988), Clifton (1989), and McKenney et al. (1995), with most researchers agreeing that it generally stabilizes channels by increasing bank strength and dissipating hydraulic energy.

Generally, vegetated channels are narrower and deeper (i.e. have lower w:d ratios) than those that are stripped of natural vegetation. Woody vegetation, either shrubby or tree-like species, offers even more protection from erosion. Trees influence channel hydraulics by increasing hydraulic roughness, which generally slows flow velocities on vegetated floodplains streambanks, bars, and other surfaces. Widely spaced trees may have little influence, but dense natural stands of trees can strongly influence both channel and floodplain hydraulics. The effect of vegetation on channel form is influenced by channel size, bank materials, and specific stream power. Channels with relatively weak channel margins and high stream power may be very sensitive to the presence of vegetation (Gough 1993, McKenney et al. 1995). Channel size, particularly bank height (Rosgen 1994) and slope, are also key influences. The lower slopes (or "bank toe," a critical area for bank stability) of steep, high banks are not accessible to most woody plants. Gentler slopes may allow colonization by trees, however. Figure 5b shows these relationships.

River stability. People concerned with river systems are universally interested in stability of river process and morphology. Agricultural landowners are concerned about loss of land to bank erosion and transportation engineers must design river crossings that will survive large floods. River ecosystem stewards need to understand how habitat may change over time and how they may influence that change. Unfortunately both the processes influencing stability and useful means of measuring or estimating it are poorly understood. River stability is often assessed from poor indicators used over periods of time that are too short. It is often assumed, for example, that a river bend that migrated during a recent flood will continue to do so. Such adjustments are often episodic, however, and past instability is not necessarily a good indicator of future change. Extraordinarily large floods can cause episodic instability, as can the exposure of small lenses of relatively weak bank materials. Instability in a given reach is almost universally assumed to be bad for habitat values. In many systems, a certain degree of lateral channel migration is unavoidable, and may be required for ecosystem functions such as regeneration of floodplain plant communities. River stability is important, but it is often given attention more appropriate to other river process, and restoration programs have often focused on stability at the expense of other more important characteristics or policy concerns (Doppelt et al. 1993).

Grade stability. Although rivers may change both their long profile (or grade) and their planform, concerns about stability have usually focused on planform because it is far more obvious. Changes in long profile or average bed elevation, however, can critically influence rivers. While localized instability in planform is common, large-scale changes in the long profile can be systemic and drive large-scale changes in planform. At the reach scale, small changes in the long profile are common even in very stable rivers -- small changes in pool and riffle elevation can occur with unusually large floods or dry spells, with changes in sediment supply to a reach, or due to the hydraulic influence of large woody debris. Systemic changes can occur at the segment or watershed scale. Systemic lowering of a channel's bed, called downcutting or incision, is commonly seen in channels subjected to big increases in discharge from watershed urbanization. Downcutting can also be caused by channelization, dredging, or instream gravel mining. Significant downcutting is often systemic, i.e. it affects rivers on a large scale, both in time and space, and is difficult to assess or control at the reach level. Changes in the vertical control of a reach of river can initiate downcutting in upstream reaches, as well as in all tributaries entering that channel. Emerson (1971), for example, recorded widespread systemic downcutting in the Blackwater River in western Missouri as a result of mainstem channelization. Many of the Blackwater's tributaries cut through erodable silt-dominated materials and were relatively free to erode both vertically and horizontally. A schematic channel cross section for Locust Creek, a similar northern Missouri stream is shown in Figure 4. Rivers can sometimes show a rise in bed elevation as a result of sedimentation, although this is generally not systemic at the watershed scale.

Both downcutting and lateral migration are natural processes. The large canyons in the western U.S. stand as examples of natural downcutting over very long periods of time (see, for example, Leopold 1994). Rapid lateral migration and downcutting can be caused by human-induced changes in channels or watersheds however. These changes are of primary concern for river scientists and managers.

Indicators of stability. Although there are many possible field indicators of channel stability, most of them require considerable training to interpret properly, and few have been systematically described in the literature. Interpretation of morphological indicators of stability thus remains largely in the realm of personal experience and sophisticated understanding of the field methods used by fluvial geomorphologists.

Lateral stability. Lateral (or planform) stability in river systems is best determined by looking at them over as large a time scale as possible. For most regions of the U.S., and especially the agricultural areas of the Midwest, vertical aerial photography is available for the past five decades. Usually at least one image of an area per decade can be obtained. These photographs can clearly show changes in river channel location and rates of lateral movement. Figure 6 shows an analysis of historic channel conditions on the Mackinaw River in central Illinois using vertical aerial photography. USGS 1:24,000 (7.5-minute) topographic maps can also be useful, although most show channel locations for only one point in time. Although these maps are revised for some areas, channel locations are generally not revised. Scales smaller than 1:24,000 are generally not usable to measure changes in channel planform.

The character of bank sediments can also be used to diagnose causes of past lateral movement and predict possible future states -- Figure 5 illustrates typical bank conditions and their relative tendencies to erode. Most commonly, banks erode at the outside bends of meanders. These banks, which often show a near-vertical face, are called *cutbanks*, whether or not they are actively or rapidly eroding. Sands and gravels are generally prone to erosion, while clayey materials are less so, especially if they are bound by plant roots and protected by woody vegetation (in streams with low stream power, herbaceous vegetation may be both the natural presettlement condition and provide adequate bank protection.) Bank stratigraphy, or the nature of horizontal layering in banks, is important as well. It is common to find banks in which the lower bank or toe is composed of sand and gravel. This grades (sometimes sharply) into finer silts and clays toward the top of the bank. While the finer materials may be erosion resistant (especially if vegetated), the sandy materials at the bank toe are easily washed away, leaving no support for the upper bank, which collapses. If, however, the bank toe is composed of coarse material no longer movable by the modern hydrologic regime, the bank may be very stable. At such banks, the coarse material often forms *lag* deposits -- a mass of particles, usually cobble-sized, at the bank toe . The finer materials -- sands and gravels -- usually mixed with the cobbles are eroded away. The lag deposits may form an unusual feature that looks much like a point bar but lies on the outside of a bend.

Vulnerability to erosion increases with bank height. This is particularly true when bank height exceeds the rooting depth of vegetation growing on the bank top and when banks are vertical or nearly so. Banks with gentler slopes may support vegetation and be stable even though the vertical distance from the channel bed to the bank top or floodplain is great.

Local and systemic stability. Reach-scale instability should always be viewed with an understanding of process and morphology in at least the surrounding river segment. Alluvial rivers change over time, especially under stress from landuse and channel alteration. Most rivers will naturally contain reaches that are more susceptible to destabilization than others. These reaches are most likely to show accelerated change. These reaches are also likely to get attention from landowners and river conservationists concerned about river stability. However, when river conservation programs focus on the most unstable sections a river without also assessing stability at the segment and watershed scales, it is easy for conservationists to get the impression that instability is ubiquitous. This is sometimes the case, but it is also common for river systems to contain unstable reaches that, if placed in a wider context, cover a very small fraction of the total watershed river length.

Unstable reaches can often be easily compared with other reaches at the segment scale using maps and aerial photographs. Gough (1993), for example, found that two unstable river bends that had been the focus of much attention and effort to control bank erosion were the only two unstable bends in a twelve-mile long river segment in an Ozark Plateau stream. The rapidly migrating bends along the Mackinaw River shown in Figure 6 are similarly the object of much interest among local residents and professional conservationists. This reach is by far the most unstable section of the entire river, however, and not representative of typical conditions.

Localized instability can be caused by natural changes in bank and bed materials (over space) and artificial changes in riparian vegetation (both in time and space). Human influences include channel alteration, structures such as bridges, and clearing of riparian vegetation -- a very common influence causing accelerated local bank instability.

Floodplains. Floodplains in unimpacted rivers have an intimate process connection with river channels. Alluvial channels adjust their hydraulic geometry and build adjacent floodplains to produce stable conduits for the transport of water and sediment (Nanson and Croke 1992). Most midwestern channels frequently inundate at least a small floodplain, and fill most of their valley surfaces less frequently. Like geomorphically older western systems their valleys may, however, contain high terraces that are not flooded under the present climatic regime.

Nanson and Croke (1992) offer the most thorough review of floodplain process and classification to date. They define *hydraulic floodplains* as the surface next to the channel that is inundated once during a given return period regardless of whether this surface is alluvial or not, and the *genetic floodplain* thus:

> The genetic floodplain we define as the largely horizontally-bedded alluvial landform adjacent to a channel, separated from the channel by banks, and built of sediment transported by the present flow regime (Nanson and Croke 1992).

Floodplains may be the product of both recent and past processes and flow regimes (Nanson and Croke 1992). Along relatively stable channels, the basal (i.e. lower) strata of floodplains and surfaces far from the channel may be the product of long-past processes, while the upper and near-channel portions are formed from recently transported sediments. This can be called a *polyphase floodplain* (Nanson and Croke 1992). Lower floodplain strata composed of coarse particles and clayey till deposited from glaciofluvial processes can act as strong controls on river systems that are unable to rework these materials. Such sediments often form lag deposits. Figure 5a illustrates the effects of these materials on bank stability.

Floodplains may contain several fluvial features, including oxbows (abandoned former channels), natural levees, and highflow channels. Natural levees are formed when sediment is dropped by relatively high velocity channel flows as they spread out onto the floodplain. Hydraulic roughness caused by woody vegetation may play a role in this process. Highflow channels (Figure 3) generally traverse floodplains between meanders and flow only in times of flood.

In midwestern watersheds, floodplains generally contain rich, farmable soils. To avoid crop loss, individual landowners and agencies have leveed parts of many midwestern river systems. Artificial levees and other structures that prevent overbank flows from reaching floodplains reduce *hydraulic connectivity*. Floodplains affect river process by acting as sinks (and sometimes sources) of sediment. They also store water during flood events, and are very important in some systems as sources of nutrients. In large rivers, floodplains form critical aquatic habitat during times of flood (Junk et al. 1989). Leveed river reaches are profoundly altered in ways that are not always obvious. Flood flows and sediment are contained within a narrow channel in leveed reaches, and effectively transported downstream. Exchange of organic materials and nutrients between the floodplain and river channel is cut off.

Levees can affect channel morphology by greatly increasing stream power during large floods. In at least some unleveed midwestern river systems, average flow velocity and stream power does not increase significantly once the bankfull stage is reached (Bhowmik and Stall 1979). Although stage may continue to rise, floodplain rivers generally have a very large storage area to contain this water. In leveed rivers, however, stage may rise significantly above pre-levee elevations, and velocity and stream power may increase significantly. This increases the erosive force of flows, and may have a profound effect on habitat quality.

The effects of levees on flood flow velocity depends greatly on how close they are to a river. If levees are set back from the river channel to retain at least a small active floodplain, their effects are lessened. If levees are set very close to the channel they may become serious management problems both to river conservationists and landowners when the river channel migrates into them. In this case, very high, steep banks are formed, and catastrophic levee failure may occur.

The effects of levees on large, commercially navigable rivers has been studied by the Federal Agencies responsible for them (most commonly the U.S. Army Corps of Engineers). The effects of levees on smaller river systems remains mostly unexamined, however. In some cases, it is clear that the effectiveness of levees in controlling floods is overrated, and they may be very cost-inefficient (Schumm 1994).

Geomorphic thresholds. An effective assessment of river channel morphology and process should consider the concept of geomorphic thresholds. At various scales, fluvial process and response may not be clearly progressive, but may change suddenly in response to a slowly increasing stress (Schumm 1977). Bed sediments, for example, remain immobile as current velocities increase during a flood. At some critical threshold, the sediments begin to move. At the watershed scale, channels may remain relatively stable as landuse changes over time. If flood peak magnitude increases are significant, watershed and segment scale instability may be seen after a threshold of stability is exceeded. In urbanizing watersheds, rather sudden, rapid responses may occur as this threshold is exceeded, even though the preceding changes in hydrology have occurred incrementally.

The concept of thresholds in river process and morphology is complex (see, e.g. Richards 1982). For river conservationists, however, it is critical only to understand and consider that river response to stresses may not be continuous, and that we examine river characteristics that indicate significant thresholds. In some river systems stream power and channel morphology are delicately balanced. In others, bank and bed materials may be relatively erosion-resistant relative to stream power. In the Ozark plateau, for example, bed and bank sediments are generally noncohesive and stream power is relatively high. These systems are greatly influenced by vegetation, and removal of riparian trees can often destabilize an entire reach. Clearly, then, a threshold of stability is crossed when the trees are removed. In other midwestern systems, e.g. the Mackinaw River in Central Illinois, analysis of aerial photographs shows little increase in lateral channel migration after historic episodes of watershed and riparian area deforestation (Gough 1993). In the Mackinaw Basin, stream power is relatively low and the clay-silt bank sediments are much more cohesive. Clearly, then stability thresholds vary.

Thresholds of grade stability can be very important. In river systems where bed sediments are easily moved by current regimes and are not underlain by more resistant material, dramatic and catastrophic stream downcutting can occur if stream power is increased after channelization or hydrologic alteration (e.g. Smith 1976).

Practical river classification and assessment methods

The ideal classification system would be based on a small set of unifying variables. It is clear, however, that different process and morphologic characteristics dominate different river systems, especially across physiographic regions. Certain characteristics are fundamental: watershed topography and geology, channel dimensions and materials, hydraulic regime, channel slope, and riparian vegetation. The influence of these characteristics on form, process, and aquatic habitat quality varies greatly between physiographic regions, however. In the Midwest, data on basic geomorphology, especially fluvial geomorphology, are lacking. Outside of big-river studies, there exist, for example, only two conservation-oriented geomorphic overviews of midwestern watersheds -- Hendrickson and Doonan (1972), and Gough (1993). Other published works, e.g. McKinney et al. (1995) and Jacobson (1995) offer geomorphic descriptions and measurements, but are not intended as broad guides to management In the Midwest even general descriptions of watershed geomorphology are rare.

Rosgen's classification has been applied by few workers in the Midwest (see Gough 1997), there has been criticism of its indiscriminate use by workers untrained in fluvial process and other necessary disciplines (Gillilan 1996), and the published description of it focuses on reach scale methods. The data on which Rosgen's system is based remain unpublished, preventing analysis of its fundamental rationale (Miller and Ritter 1996). While the Rosgen system is described as process-aware, it does not, at least in theory, require an intimate understanding of fluvial process of its users. Such an understanding is critical, and should be a goal of a classification system (Naiman et al. 1992). The methodology published by Meador et al. (1993) offers a detailed methodology for watershed-to-reach scale assessment, but nowhere addresses analysis and utility of the data it produces. This is a shortcoming of many assessment methodologies. Such methods also fail as classification schemes because they are not explicitly designed for practical application in prediction of possible states (excepting rigorous analysis of the results of regional application, which has yet to be done). This lack of flexibility and focus on gathering data precludes practical applications for management such as comparison of stream characteristics. The USEPA Environmental Monitoring and Assessment Program (EMAP) protocols (Kaufmann 1994) provide detailed reach-scale methods, but do not provide for analysis, synthesis, or application of data gathered. These methods, along with recently published papers on classification (e.g. Naiman et al. 1988, Frissell et al. 1986, Newson 1992) provide a broad base of knowledge and theory. It is one thing to list key variables that affect river form and process, and quite another to measure and describe river systems for the purposes of conservation, especially under severe limitations in conservationist training and project budget. Rigid, "one size fits all" approaches, especially those that require expensive quantification of a number of characteristics, may be wasteful because some of the inputs they require are not important in some physiographic regions or for addressing various practical management issues. Clearly, a widely applicable classification system, at least for most physiographic regions of the U.S., must await development of a greater understanding of regional river geomorphology and production of data sets. This can happen only after river conservationists begin to apply relatively standard approaches to their assessments. Standards are needed for at least a minimum set of river characteristics, both for limited reach scale approaches and basin-oriented work. Here I will propose such methods.

For most river systems, the relationship between stream power, sediment supply, and bed and bank erodability is a critical characteristic. This relationship is difficult to strictly quantify, but indicators of it are abundant--channel dimensions and width:depth ratio, bed and bank materials, and historic channel stability. Many of the independent variables affecting this relationship can be effectively described, e.g. bed and bank materials, especially when they are easily correlated with past channel behavior. For example, channels with relatively low slopes, relatively resistant bed and bank materials, and no history of past channel change in vertical or plan form can be reasonably expected to remain stable. The system I propose here makes use of key descriptive variables that are supported by a base of quantified channel characteristics, most importantly channel geometry and reach-scale long profile data. In many ways the assessment and classification system detailed here resembles diagnostic procedures used in medicine--key characteristics are described, and, as necessary, more detailed measurements taken to determine cause and effect. If river process is understood well enough at the regional or watershed scale, diagnosis of critical characteristics controlling stream form and process may require description and measurement of only a few key variables that affect reaches in that area.

Development of a body of information suitable to begin classifying and comparing river systems awaits not just common methods, but also standardized language. Rosgen's classification system is a good first step in this direction, but its products (assignment of a channel to one of a few types) do not necessarily come as a result of an understanding of fluvial process and assessment methodology on the part of its users.

The constraints to classification listed earlier in this report present daunting barriers to the application of assessment and classification methods. Most proposed methods do not consider these constraints, especially the problem of limited resources for river conservation. The approach I offer here, however, considers the logistical limitations commonly faced by river conservationists. Nevertheless, even well designed assessment schemes must consider rivers as very complex systems, and training of river conservationists in the essential scientific and technical fields remains a primary problem to be overcome.

The approach proposed here is designed to provide a minimum framework on which more complex systems can be overlain if necessary. When resources are limited, the additional measurements should be chosen with careful consideration of project goals and the characteristics of the watershed system at hand. From a practical standpoint, it is important that managers understand which characteristics are manageable and which are not.

An assessment program designed for restoration and protection of aquatic habitat should, at an early stage, focus on identification of key impacts to watersheds and which characteristics can be reasonably managed to mitigate or eliminate them. Manageable characteristics are commonly controlled by political or social factors -- private landowners may control most of the manageable resources in a basin. In these cases, assessment resources should be focused on discovery of key river process relationships affecting landowner perception of the relationship between their land management and river habitat quality. In many regions it is critical that assessment focus on the role of riparian forests in stabilizing rivers. Within many midwestern river systems, riparian vegetation is the only key characteristic that can be reasonably managed at the reach scale. Most landowners are concerned about stability, and trees are critical to aquatic ecosystems. This case represents an example of a critical intersection of landowner and conservationist interest that can be better understood through careful design and application of an assessment and classification project.

Classification and assessment variables.

Watershed scale. Meador et al. (1993) offer an extensive list of characteristics for assessment of watershed-scale geomorphic characteristics, and describe methodologies (or references to methods) for obtaining some of them. These include:

drainage area
drainage density
drainage texture
drainage shape
stream length
basin relief
storage (area of wetlands, reservoirs, etc.)
ecoregion
physiographic province
landuse
geologic type
soil type
potential natural vegetation (Kuhler 1970)
wetlands
mean annual precipitation

This list includes characteristics proposed by most other workers. Watershed-scale determination of some of these variables is expensive, and mapping becomes prohibitively expensive. Characteristics such as landuse, however, can be described for small sub-watersheds, and published values are often available from government agencies (e.g. the National Resource Conservation Service or NRCS) for such units. As a *minimum* for watershed-based assessment, I propose these characteristics be measured or obtained from existing sources: drainage area, stream length, basin relief, and landuse.

These indices are supported by analysis and description of past channel planform behavior from historic aerial photographs and maps. Precise mapping of past channel position, even at the segment scale, is very expensive and requires specialized training and equipment. For most midwestern rivers, segment-scale comparisons of past channel behavior are more than adequate to determine the relative stability of planform. These are done by visually comparing historical and modern aerial photographs and noting patterns of channel migration and, in some cases, actually measuring rates of migration. Figure 6 gives an example of a detailed analysis for a reach on the Mackinaw River from Gough (1994). Analysis of past channel behavior should be adaptive. If it is clear that channel migration is a critical management factor for large parts of a basin, detailed analysis may be necessary. If channel migration is clearly local and its cause (e.g. local removal of riparian trees or anomalies in bank materials) can be determined, it need be analyzed in detail only at selected reaches.

Working in Ohio, Whittier et al. (1987) used aerial photographs to assess typical watershed and riparian corridor conditions, detect disturbances, select sampling sites, and provide visual aids for presentations. The only detailed, methods-oriented discussion on the use of aerial photographs to analyze fluvial form and behavior appears to be that of Mollard (1973). He focused on detecting changes in stability (both in time and space), sources of local control of channel form, and safe setbacks for buildings and other structures. Still, this paper is very general, and methods for precise quantification of fluvial morphology from aerial photographs remain in the realm of personal experience. Rosgen (pers. comm. 1995) notes that aerial photographs are superior to 7.5' topographic maps for measuring channel sinuosity. Generally, scales of 1:40,000 or greater (for the photo negative) are needed for such measurements. Most historic aerial photography is done at this scale. More recent photography may be scaled at 1:60,000 or 1:80,000. Stereo aerial photography can be very useful in determining subtle floodplain topography and flow paths. Stereopairs usually show floodplain margins quite clearly. At scales of 1:6,000 or more, some geomorphic channel units can be seen, and large woody debris (whole trees) can be clearly seen. These large scales usually have to be specially flown for particular projects.

Meador et al. (1993) propose the use of Geographical Information Systems (GIS) methods for some of these metrics. GIS is not yet widely available, however, and its use can be expensive. If GIS is not available, drainage area, stream length, and basin relief can be measured from published topographic maps. Maps at a scale of 1:100,000 are sufficient for most of the above metrics. Maps of basin landuse, even at coarse scales, can be very expensive to produce. At a minimum, general *riparian* landuse should be described or roughly quantified at the segment scale for the entire watershed. Table 3 summarizes my recommended watershed and segment-scale measurements.

A *long profile* (or gradient) plot summarizes stream elevation for an entire river. Two examples are given in Figure 7. Long profile plots are constructed by plotting stream distance against elevation. Both of these values can be obtained from topographic maps. Distances and elevations from such maps must be used with care, especially at the segment scale. Elevations are especially subject to error. Over watershed scales, however, long profile plots constructed this way are accurate enough for most uses. Long profile plots will show average riverbed gradient and breaks or changes in slope that can reflect changes in control of stream process and form. The example in Figure 7a, from Hendrickson and Doonan (1972) shows the interaction between bed materials and slope in the Au Sable River in Michigan. In this case, erodable sands dominate the channel bed within low-slope reaches while more erosion-resistant gravels occur in the relatively steep reaches. Figure 7b shows a gradient plot for the Mackinaw River to which important geological and landuse information has been added, as well as points of confluence for large tributaries.

Hydrology and water quality. At the watershed and segment scales, flow regime, water temperature, and water chemistry are critical characteristics affecting habitat quality and fluvial process. Analysis of changes in flow regime is a broad, complex topic outside the scope of this report. Richter et al. (1996) have proposed a method for analysis of changes in flow regime that focuses on determination of goals for ecological restoration. While methods exist to analyze the effects on small changes in flow on habitat (e.g. Instream Incremental Flow Methodology or IFIM), these methods are generally complex and expensive to apply. Analysis of chemical water quality is similarly difficult and expensive, and is limited by the need for multiple time-series sampling over seasons and a wide range of flows.

Segment scale. Specific classification of large watersheds is most practically done at the segment scale. At this scale, general river form and process is generally homogenous enough to concisely describe. Table 4, from Gough (1994), gives a very general segment-scale description for tributaries to the Mackinaw River . Definition of river segments will vary by watershed characteristics, both between and within watersheds. River segments are most clearly defined using confluences. At major confluences, the drainage area of a stream jumps significantly, changing channel dimensions and, especially in heavily impacted watersheds, commonly changing hydrologic regime, sediment supply, and water quality characteristics. Along a mainstem river, for example, entry of a tributary draining more than about 20% of the area drained by the main channel will almost always define a segment boundary. In many cases, however, the confluence zones should be defined as short segments because they are often very different from other river segments.

At the segment scale, generalized management and protection goals and methods can be described, as can aquatic communities, depending on their homogeneity. With some exceptions, such as confluences, biota and river form generally show no distinct boundaries along channels. Those applying assessment and classification methods to studies of biota should understand that segment definition may depend on the objectives of the analysis.

Segments may also be defined by changes in floodplain characteristics such as width or landuse. In watersheds with strong control by glaciofluvial or bedrock geology, segments may be defined according to the degree or type of control on channel form from these materials. Meador et al. (1993) recommend the following metrics at the segment scale:

segment length
elevation
valley sideslope gradient
segment gradient (slope)
channel sinuosity
stream order (by Strahler 1957)
downstream link (by Osborne and Wiley 1992)
water management features (such as dams, channelization, and bridges)

Although Meador et al. include descriptions of geology at the watershed scale, I believe that it is best described at the segment scale (absent access to a detailed GIS map of geology). Reach-scale reference sites can be used for general descriptions of bank and bed materials, sediment transport processes, hydraulic geometry, floodplain connectivity, and riparian corridor management. These metrics represent a minimum. Segment gradient (from topographic maps) and channel sinuosity can be determined from reach-scale analysis as well. Table 3 summarizes my recommended measurements.

Reach scale. At the reach scale, stream features become readily understandable to the field observer. This is the scale at which most people view and analyze streams and at which we can directly measure stream characteristics. Most assessment and classification schemes focus on this scale, whether by design or default, and the majority of river management and manipulation (except for big-river navigation and flood control projects) are done at the reach scale. Table 5 summarizes my recommendations for measurements at the reach scale.

scale	minimum metrics	other metrics
watershed	drainage area stream length basin relief landuse physiographic province general landuse mean annual precipitation discharge from gage data	drainage density drainage texture drainage shape storage (area of wetlands, reservoirs, etc.) ecoregion mapped, quantified landuse (with GIS) geologic type soil types potential natural vegetation (Kuhler 1970) wetland location, area, and type
segment	segment length segment gradient (slope) significant water management features and channel alteration described (such as dams, channelization, and bridges) generalized reach scale data described including: riparian vegetation and landuse, drainage area (as a range), bank and bed materials, sinuosity, and hydraulic geometry	elevation sideslope gradient channel sinuosity stream order (by Strahler 1957) downstream link (by Osborne and Wiley 1992) water management features mapped (with GIS)

Table 3. Watershed and segment scale characteristics for assessment and classification.

Type	Lower Panther Creek
Representative Reach	Reach at 2000E bridge, 4 miles SSW of Secor. Secor 7.5' map.
Description	Lower Panther Creek above Red River confluence. Valley deeply incised into northeastern margin of Eureka Moraine. Relatively steep valley walls, channel borders bluffs in places, including type reach.
Floodplain	Channel is well connected to an active floodplain, although there is a levee made of concrete rubble set well back from the type reach.
Riparian vegetation	Generally good strip of trees along channel margins. Many areas recolonized by trees since 1970. The type reach is bordered by a thick stand of post 1970 maples.
Bank material	Obscured by high water during field work. Most likely silt and clay typical of Cahokia alluvium, with coarser materials at bluff exposures.
Bed material	Not adequately sampled in this study, but probably mostly gravel with sand and cobbles. Data from Short (1988) suggest gravel and cobble with very little sand.
Channel shape, alterations, stability, and planform	Channel appears to be laterally stable, with signs of past incision. U-shaped low flow channel, bordered by a bluff in type reach. Some straightening of reaches above type (from 7.5' map), but channelization not common. Channel generally straight, with meandering imposed by sinuous valley left by glacial drainage.
Inchannel habitat	Woody cover probably restricted to reaches where recent erosion has occurred and large trees have fallen into channel, but otherwise unknown. Riffles probably occur where numerous steep, short tributaries enter from valley walls.

Table 4. Example of a simple segment scale description based on limited field observation and surveys of historic aerial photographs, published geologic data, and maps. From Gough (1994).

Minimum metrics	Other metrics

sinuosity from aerial photographs
photodocumentation
pebble count
gage calibration at gage sites
long profile survey including:
    water surface profile
    bed materials
    bankfull indicator elevations
    indicators of fluvial process
on transects:
    leveled cross-section with all slope breaks included
    flooplain elevation and connectivity to channel
    vegetation, including largest tree
    bed and bank materials, including bank stratification
    root presence/density in bank materials
    aquatic vegetation
	geomorphic units, type and length
	a long profile survey
	a diagrammatic plan map
	at several points on transects:
	    floodplain width
	    bank height
	    bank angle
	    bank surface stability
	    bank shape
	    bank erosion
	    bank woody vegetation (species, size, location)
	    on bars, shelves, islands:
	      woody vegetation
	      percent vegetation cover
	      substrate
	    channel width
	    habitat features
	    aspect (flow azimuth) and sun angle
	    channel depth
	    current velocity
	    bed substrate (including a pebble count)
	    embeddedness
	    aquatic vegetation: submerged, emergent, floating
	    riparian vegetation, herbaceous and woody
	    photodocumentation

Table 5. Reach scale characteristics for assessment and classification.

Site selection. Nowhere in the literature are suggestions given for selection of sampling sites within a basin. For some studies, random sampling might be applied, but the extreme variability in midwestern watersheds (particularly in riparian landuse) would require use of stratified random sampling. More practically, sites should be selected based on (a) project objectives and manageability of key characteristics, (b) available sampling resources, and (c) preexisting data sources, and most importantly, (d) results of the watershed and segment scale surveys.

Rosgen (pers. comm. 1995) suggests that "reference sites" be established to intensely sample channel morphology. These reference sites can be picked according to project objectives--if ecological protection and restoration is a primary objective, then reference sites should be chosen to represent the best known conditions, based on existing knowledge and the watershed and segment scale analyses. These sites are then compared to less healthy sites to determine possible states and, perhaps, explain differences in aquatic communities. Sampling intensity, methods, number of sites, and their location will depend on project resources. If budgets allow, sites of varying health may be chosen for comparison. Preexisting data sources may strongly influence site selection. USGS gaging sites should always be closely considered as sites, especially when gage calibrations are needed for determination of bankfull indicators. Existing biotic sampling sites should be favored, especially if time series samples are available. Water quality sampling sites should be considered as well, although these are often chosen for easy access rather than habitat quality.

Reaches may be defined using multiples of bankfull width (Rosgen 1994). Bankfull width is a logical unit for both determining sample reach length and as a normalizing value in analysis of geomorphic data. Variables such as cutbank height and floodplain width are most meaningful when plotted against W_{bf}, especially when W_{bf} is strongly correlated with drainage area. There is no consensus in the literature regarding reach length, although many researchers agree that reach-scale measurements should include a reach at least 20 times as long as channel width (some papers specify W_{bf}, others do not define channel width, meaning, probably, that low flow channel width was used). The USEPA EMAP protocol specifies 40 times "channel width", and Rosgen (unpublished workshop materials) recommends 20-30 times W_{bf} ($20W_{bf}$-$30W_{bf}$). The Wisconsin DNR protocols currently use reach lengths of up to 35 times channel width. This length, however, is based on fish sampling logistics more than habitat sampling needs, however (John Lyons, pers. comm. 1995). Simonson (1993) and Simonson et al. (1994a, 1994b) discuss habitat sampling in Wisconsin streams. Wang et al. (1995) continued this work by analyzing in detail the results of habitat sampling using various methods and reach scales.

For many streams, especially smaller channels, a reach length of $20W_{bf}$ will include a full meander cycle and at least two pool-riffle sequences (Rosgen pers. comm. 1995, Leopold 1964, Meador et al. 1993). Meador et al. (1993) specify that reaches should include at least two examples of all "geomorphic units" representative of the segment being sampled. Geomorphic units include pools, riffles, (called "hydraulic habitat units" by Jacobson and Rabeni (1993)) and point bars. In the absence of repeating geomorphic units, Meador et al. (1993) recommend using a reach length of $20W_{bf}$.

Many midwestern streams appear to lack repeating stream features at this scale, especially those strongly influenced by bedrock or glacial geology (see Gough 1997, Gough 1993). Sampling reaches of $20W_{bf}$ probably represent, however, a reasonable reach length for analysis of habitat and fluvial morphology (see Gough 1997). For reaches draining roughly less than 400 km^2, a single worker, using a laser level, can complete a basic survey in one day (Gough 1997). Reaches of $20W_{bf}$ may become prohibitively long for larger drainage areas, however. Gough (1997), working in the Mackinaw River watershed in Central Illinois, found that W_{bf} exceeded 30 m for reaches draining >400 km^2. Sample reaches of 20W_{bf} became prohibitively long (at W_{bf} = 30 m, 20W_{bf} is 600 m), and reaches of 10W_{bf} were used.

Reach scale measurements and description. Most river biota and habitat assessment schemes have focused on the reach scale, and a number of variables have been proposed as important. Meador et al. (1993) offer what is by far the most exhaustive list. The USEPA EMAP protocols recommend nearly as many metrics. Excluding general notes and location information, Meador et al. recommend:

- geomorphic units, type and length
- a long profile survey
- a diagrammatic plan map
- at several points on transects:
  - floodplain width
  - bank height
  - bank angle
  - bank surface stability
  - bank shape
  - bank erosion
  - bank woody vegetation (species, size, location)
  - on bars, shelves, islands:
    - woody vegetation
    - percent vegetation
    - cover
    - substrate
- on transects (cont'd.):
  - channel width
  - habitat features
  - aspect (flow azimuth) and sun angle
  - channel depth
  - current velocity
  - bed substrate (including a pebble count)
  - embeddedness
  - aquatic vegetation: submerged, emergent, floating
  - riparian vegetation, herbaceous and woody
  - photodocumentation

This method produces a large amount of data for a reach, much of it in tabular form, and Meador et al. (1993) do not make clear how it might be used or analyzed. Most assessment programs in the Midwest are (or will be) performed by very small teams of conservationists with limited resources. This requires a streamlined field procedure that produces easily comprehended and communicated results. The reach scale procedure I propose here meets those needs, while still providing a spatial skeleton (a long profile survey and transects) that allows inclusion of more detailed measurements such as those proposed above. The method I propose here also gathers data (with few exceptions, notably the pebble count) needed for application of the Rosgen stream classification system.

It also allows for flexibility in use among regions. In coldwater, groundwater-dominated, morphologically stable streams of the northern Great Lakes region, for example, many of the variables listed above will be relatively unchanging over long reaches and even river segments. In some of these systems, conservationists are primarily concerned with managing submerged cover and bed sediments (spawning gravels) at very small scales, and would thus focus on those characteristics. In a hydrologically flashy, high energy stream capable of freely changing planform, hydraulic geometry, lateral stability, riparian trees, and pool volumes may be of critical concern. If watershed-to-segment assessment is unneeded or unavailable, this method gives a strong reach scale characterization needed for bare-bones design of restoration or protection projects. Finally, the method is compatible with long-term *monitoring* of geomorphic and habitat change at the reach-scale.

The following section gives rationale for use of variables in this assessment scheme. Specific methods and field procedures are concisely listed in a following section.

Reach scale methods and rationale.

Long profile survey. The long profile survey forms a spatial skeleton for other habitat measurements and provides information about streambed elevation, flow depth, and channel slope. The long profile is at least $20W_{bf}$ in length. Using leveling equipment (laser levels are particularly well suited), elevations are taken at the channel *thalweg* (the deepest point at each cross section) at intervals of no less than $0.5W_{bf}$, or at significant breaks in channel slope. At each leveling point, the substrate is also described, and the depth of water is recorded. The elevation of other key linear features may also be recorded, including bankfull indicators and terraces, especially when cutbanks have encroached on the terraces, leaving high bank edges. Other information can be recorded during the long profile survey, such as cultural feature crossings (e.g. powerlines or fences), and tributary confluences. A plotted long profile survey is given in Figure 8.

Photodocumentation. Depending on stream characteristics at least two photographs should be taken. The location and direction of these photographs should be recorded in relation to the long profile. These photographs will show general stream characteristics, be very useful for presentation of information, and will give information about riparian vegetation that is very difficult to measure quantitatively, particularly canopy closure and shading. If possible, the photographs should show transects (which can be marked with survey flagging). Photographs are usually taken from the channel center and along the channel thalweg, although high cutbanks sometimes provide good vantage points. Close-ups of key features can also be taken. It is critical that photographs be carefully documented in field notes so they may be tied to other data and repeated over time to show changes in stream characteristics.

Transects. Transects cross the stream channel perpendicular to bankfull flow and provide critical information about channel geometry and habitat features. Figure 10 shows four transects from Buck Creek in the Mackinaw River Watershed in central Illinois. Transect endpoints should extend some distance beyond the bankfull flow elevation, depending on floodplain features. Transect cross sections are leveled and spatially tied to the long profile survey. As the transect is surveyed, key information is gathered at selected points and referenced to location along the transect. In this way, information is recorded efficiently in the field and spatially related to points on the transect. Figure 2 is a schematic showing several possible channel features and definitions for hydraulic geometry calculations.

If bankfull indicators are present (or bankfull elevation is known from a nearby gage), transects produce W_{bf}, and provide profile information from which A_{bf}, D_{mean}, D_{max}, and cutbank height can be determined.

Transect location and spacing. Simonson et al. (1994a) recommend a minimum transect spacing of 1 "mean stream width" for transects for assessment of streams in Wisconsin (this is not clearly specified, but is probably the low flow width). Unless channels are extremely monotonous (e.g. constructed ditches) I recommend a minimum of four transects for a $20W_{bf}$ reach. A more thorough survey for engineering design might include ten transects. Rosgen (in unpublished proprietary workshop materials, 1995) recommends that transects be located in inflection points between pools and riffles where the channel is generally narrowest and most stable. Location of the transects should depend, however, on the goals of assessment and final use of the data. If the site contains high cutbanks, for example, at least one transect should record such a cross section. Gough (1997) chose transects subjectively in the field, and attempted to sample the array of channel conditions seen at each reach, considering not only differences in channel dimensions but in bank and bed materials and other characteristics.

Transect spacing should not be regular (unless transects are run at very close intervals). Because some channels show spacing of features at multiples of W_{bf}, regularly spaced transects may be biased toward a particular feature.

Transects: Floodplain and channel materials. The characteristics of floodplain and channel surface materials are recorded along transects during the transect survey. A list of materials is given in Appendix A. As experience and training allow, key indicators of geomorphic process, which are often indicated by organic and mineral materials, are also recorded. Unconsolidated, unvegetated sand dunes may indicate recent deposition on floodplains, for example. Very soft silt or sand deposits (in which you may sink several inches) in channels are usually the result of recent sedimentation. Generally, cutbanks at outside bends show the best exposures of bank materials. Considerable experience may be required to interpret exposures of bank materials.

Streambank materials are described with particular attention to particle size, sedimentary origin, and stratigraphy. Particle size greatly affects bank stability and the ability of plants to colonize banks. Clay-dominated materials may not be colonized by plants at all. Even though they may look "raw" and vulnerable to erosion, the same density and cohesion that prevents plant roots from penetrating these materials also makes them relatively resistant to erosion. Sand-dominated materials are generally highly erodable and may be too dry (because they have little water-holding capacity) to support plants.

Bank materials are often stratified. Those of fluvial origin generally show a fining-upwards stratigraphy so that, for example, gravels and cobbles appear in the lower bank and silty materials near the top. Figure 4 shows an example of stratifications common to four midwestern regions, and Figure 5 shows the effects of stratification on bank resistance to erosion.

Bed materials are described along the transect (and also the long profile survey) so that all significant populations of particles are recorded. Generally the coarsest materials in a cross section are found at the thalweg. The dominant size class is always recorded. A second class may be noted as well, especially when materials are highly sorted--glaciofluvial materials may be gravel embedded in a matrix of clay, for example. Fluvial process should always be kept in mind when examining these materials--this is an important intangible part of the process of understanding river form and process. Are the materials likely to be moved by the present flow regime? Are they very poorly consolidated (and thus likely to have been recently deposited)? What patterns of particle size are apparent along a given reach? Such questions may be very difficult to answer using data from a rigidly designed field method, but may be readily apparent from observation in the field. It is critically important when describing bank and bed materials that are highly resistant to erosion and thus may act as strong horizontal or vertical controls on channel form. Large cobble or boulder dominated reaches are not uncommon in some low gradient streams. When even rough calculations of stream power (or shear stress) show it is highly unlikely that these materials are movable, it may be clear that they act as vertical control, meaning that vertical adjustment in the reach is unlikely. Glacial sediments deposited by glacial or glaciofluvial processes are often much larger in size than sediments moved by modern flow regimes, and may act as both horizontal and vertical control. It is likely that many modern midwestern channels have downcut as a response to human changes in watersheds, and in many cases this downcutting was probably halted by coarse glaciofluvial materials and/or clayey till. This may account for the common appearance of well-armored, stable channel beds in glaciated regions.

Pebble counts. The *pebble count*, first proposed by Wolman (1954) is a method for sampling and describing coarse bed materials. There now exist several papers suggesting improvements and variations of this method. Generally, it is a technique for sampling bed sediments and producing particle-size distributions. These data are key indicators of fluvial process and habitat quality. There is now considerable difference of opinion regarding the utility and application of pebble count techniques for stream assessment. In its most basic form, the method is applied by randomly selecting 100 streambed particles and measuring their size. Particles are placed in size classes. Dunne and Leopold (1978) recommend Wentworth size classes beginning at 2mm increasing by a factor of approximately $\sqrt{2}$: <2, 2.6, 4, 4.5, 5.6, 8, 11, 16, 22, 32, 45, 64, 90, 128, 180, 256, etc. Practically, it is difficult to randomly sample particles below about 8mm, and some workers (e.g. Kondolf, pers. comm., 1995) excluded these. A frequency distribution plot of these data is produced. From this plot, a commonly used metric, the D_{50} value, is produced. The D_{50} is the median particle size for a sample.

Rosgen (in unpublished workshop materials, 1995) recommends samples of 10 particles at 10 separate sections of a stream reach. The sampling is stratified so that pool and riffle areas are sampled in proportion to their length--if a reach's length is 30% riffle and 70% pool habitat, then 30 particles are taken from riffle transects and 70 from pool transects. Bevenger and King (1995) have proposed a "zig-zag" method in which a bankfull-to-bankfull and downstream zig-zag pattern is followed and particles are sampled at approximately one-stride (two or three step) intervals. Kondolf and Li (1992) note, however, that such methods do not account for the very high variability in particle size groups seen in most river channels. Rosgen's method does acknowledge a likely pool-to-riffle difference. Kondolf and Li (1992) recognize that patches of similar distributions can be observed in streams, and that much more meaningful pebble-count data can be obtained by sampling these patches separately. Such sampling is very time-consuming, however. As a bare minimum, I recommend that particle size patches be identified and the group containing the largest material obviously being transported by the present flow regime be identified. This patch is sampled. Although this method is probably subject to observer error, and it is arguable that even experienced observers may not be able to identify such a group, I believe that this method provides the most meaningful information if only one patch can be sampled in a reach. If the correct patch is identified, this pebble count will give a good indicator of the maximum specific stream power in a reach. Such patches are found in riffles and sometimes at the heads (upstream ends) of gravel bars.

Newbury and Gaboury (1993) use the shear stress relationship for channel characterization. They recommend the use of pebble counts to compare shear stresses (from the depth-slope product) with particle size distributions to make an estimate of the potential erodability of channel materials. This method may be useful as a rough indicator and is relatively easy to apply, but the relationship between estimated shear stress and bed mobility is tenuous, and this method may be subject to large errors.

Variability in bed sediments should be described not only at the reach scale, but for segments as well. Some stream systems, particularly sand-bed streams, have remarkable homogeneity, while those dominated by glaciofluvial materials may show high variability in bed materials.

Transects: Vegetation and geomorphic process indicators. At each transect, size (diameter at breast height) and taxa (to genus or species) of the largest tree within $0.5W_{bf}$ of the transect's intersection with bankfull elevation should be recorded as a minimum descriptor of riparian forest character. The largest tree is used because this indicates maximum age of the forest. Many midwestern riparian forests have been periodically devegetated for row cropping or grazing within the past few decades, and the oldest trees present indicate when forests were allowed to regrow. Much more detailed descriptions of riparian forests can be made using methods common to studies of forest ecology. In streams dominated by row crops or those that are naturally bordered by nonwoody plants, other methods must be used.

Woody vegetation can provide clear indicators of fluvial process. Channels often contain clearly-defined surfaces, e.g. floodplains, terraces, and point bars. Woody vegetation on these surfaces can show the age of the surfaces, their stability, and the nature of hydraulic forces imposed on them. Age can be very clearly defined in some cases. Single-aged thickets of willows (*Salix spp.*) or cottonwoods (*Populus spp.*) on a bar may show its age. Point bars in actively migrating channels may show crescent-shaped "scrolls" of single aged trees that are progressively younger in a channelward direction. The age and spacing of scrolls indicates the rate and direction of channel migration (see Osterkamp and Hupp 1984). Conversely, very old trees near the base of a point bar (where it rises to bankfull elevation) indicate channel stability. Both these features may be prominent in recent and historical aerials photographs. Bent and broken trees indicate flood flow direction and velocity. Deposition of sediment will bury the root collars of trees. A lack of basal flare (i.e. the trees emerge from the ground straight-sided) in such trees indicates deposition. Such trees are sometimes called "telephone pole trees." Relationships between vegetation and geomorphic form and process are discussed in detail by Osterkamp and Hupp (1984), Hupp and Osterkamp (1986) and Hupp (1988).

A transect should be conceptually divided into areas of relative homogeneity in vegetation type, age, or indication of fluvial process, and these areas described and spatially located on the transect. Photodocumentation of riparian vegetation can be very useful in showing indicators of process and other characteristics that are difficult to otherwise record.

Inchannel sedimentary features. Inchannel sedimentary features include bars and channel *shelves*. A channel shelf is a longitudinal (along the channel) feature with a relatively flat upper surface that may closely resemble a small floodplain, but is below the bankfull elevation. Channel shelves may be covered by vegetation, especially in low energy streams. These features are discussed by Osterkamp and Hupp (1984). Channel shelves may be quite stable morphologically. Bars are usually less stable and occur at elevations near that of the channel's bed. Bars formed of coarse material may be very stable, however. Richards (1982), citing Smith (1974), lists bar types as longitudinal, transverse, point, and diagonal (p. 220), and gives growth patterns for these types. Point bars are easily identifiable as crescent-shaped forms that occur inside meander bends. Point bar features should always be described as part of reach scale surveys. Large point bars showing little or no vegetation and signs of active sedimentation are strong indicators of lateral channel movement.

Bars may or may not be emergent, and their margins with other features, especially riffles, are indistinct. Numerous unvegetated bars are generally indicators of active channel movement and high bedload transport in a channel. In larger channels, these bars are easily seen on aerial photographs and are good indicators of channel conditions at the segment and watershed scale. The vegetation on inchannel features below bankfull is strongly influenced by flood flows and may show indicators of flow velocity (e.g. tree bending) and frequency through bark scars and damage that is dateable using dendrogeomorphologic methods. This vegetation is also very close to the lowflow channel and may be submerged during periods of moderate flow (e.g. spring flooding). This intimate connection with the wetted channel makes this vegetation relatively important ecologically. Transects may be run though bars and other inchannel features to establish their morphology as shown in Figures 9 and 10.

Hydrology and flow. At the reach scale, there are abundant indicators of flood processes, including sediment transport. Total sediment transport through a reach is, of course, not apparent from post-flood indicators, but evidence of *net* sediment transport--the balance between erosion and deposition in a reach, is. River stability has been defined in terms of net sediment transport. If sediment entering a river reach equals that leaving the reach, it can be considered stable, at least in terms of sediment transport. The position of a reach in the drainage net should be considered in assessing and weighting indicators of sediment transport. Confluence zones, for example may show episodic sedimentation when they are backwatered.

Indicators of changes in flow regime include recent channel incision and obviously fresh, abundant deposition. The latter is often apparent also in ditches which have been recently dredged -- in this case, channel dimensions are oversized for the flow regime, and deposition occurs as the channel seeks a balance between channel size, flow regime, and sediment transport. Chronic reach and segment scale indicators of recent bank erosion, especially when seen concurrently on opposing banks, are often the result of increases in peak flows. This condition is common in urbanizing watersheds where runoff control methods have been neglected.

This methodology does not include measurement of current velocities and discharge. This data can be gathered as part of the transect surveys, however, using standard methodology (see Gordon et al., 1992, for example).

Monitoring. Monitoring of morphological change is a powerful tool for determining potential future states and the effects of changes in inputs to a reach. Monitoring can also show the effects of restoration projects on stream channel morphology and habitat quality. A full discussion of monitoring theory and methods is outside this report, but both Kondolf and Micheli (1995) and Harrelson et al. (1994) offer detailed analyses of this topic. The methodology here can be easily adapted to monitoring by adopting more precise horizontal measurement methods and installing permanent benchmarks along the sample reach to provide precise vertical and horizontal reference points. This allows measurements to be repeated over time. The precise measurements and installation of benchmarks needed to detect small changes in channel morphology are much more time consuming, however. These surveying methods also require a greater degree of skill. Mistakes or imprecision in measurement that are well within acceptable limits for measurements of gross channel morphology will render monitoring data useless because real changes in channel morphology over time cannot be separated from surveying errors.

Reach comparison and determination of possible states. The assessment methods described here provide a strong framework for assessment of possible states through understanding of fluvial process at reaches. They also provide a powerful means to determine possible states by comparing reaches, an approach proposed by Rosgen (pers. comm. 1995). Most assessment schemes allow, at least in theory, comparison of reaches, but the characteristics they measure do not allow meaningful comparisons. Hydraulic geometry and bed/bank materials are critical controlling variables, but are seldom assessed adequately to allow reach comparisons.

Possible states determination through reach comparison is done by grouping reach data according to critical controlling characteristics for a particular watershed or region. Key characteristics determining fluvial form and habitat quality may then be identified, especially if historic information is considered. Many midwestern channels have shown instability after clearing of riparian trees, for example, and comparison of devegetated reaches with vegetated reaches can show the effects of trees on channel form and stability. This comparison is done through time by using historic aerial photography (See Figure 10) and at a point in time by comparing vegetated with devegetated reaches that are similar in other characteristics.

The assessment methods proposed here also allow stratification of data for aquatic biota if such information is available for measured reaches. Much more meaningful analyses of such data can be made if aquatic communities are compared among sites that are similar in fluvial form and process. Such comparison and analysis may also show biotic potential by allowing us to understand potential for degraded or impacted reaches to be restored.

Field Methods

Site location. Reach location is determined from segment scale analysis. Table 6 gives a list of key site characteristics. If at all possible, the site should be located with permanent horizontal and vertical reference points. These points should be carefully described so they may be relocated. I strongly recommend setting permanent benchmarks.

Initial reconnaissance. Walk the reach, looking for suitable reach endpoints and noting key site characteristics. Begin the survey at the margin of a habitat unit (riffles work well) if possible. Look for characteristics that might be unusual for this river segment. In general, the reach should be representative of its segment. If the reach is near a structure such as a bridge, be sure that the structure is not significantly influencing the reach. Plan survey instrument set points during this reconnaissance.

Stationing. Choose an endpoint and mark stationing for the reach. Stationing is measured to the nearest 0.5m along the channel thalweg and is marked with surveying flags. Use at least 10 stations per reach: if the reach is $20W_{bf}$ long, each of these stations are $2W_{bf}$ apart. Flags may be used between stations if necessary, and supplementary stations may be set upstream and downstream of the main stations. Supplementary stations may be used if gradient is very low and a horizontal distance greater than $20W_{bf}$ is needed to accurately measure it.

Survey the long profile. Beginning at the most upstream station, take thalweg elevations at least every $1W_{bf}$ along the channel to the nearest 0.001 m (or 0.01 ft). It is best to survey all slope breaks if possible. At each elevation point, record substrate character. Elevations of bankfull indicators and inchannel features may also be recorded during the long profile survey. Also note major habitat features such as riffles and pools, especially if they are poorly expressed and thus not clear from elevation changes (as viewed in a plot of the long profile). Note significant horizontal and vertical geomorphic control features (e.g. lag particles or bedrock exposures). Water surface elevation may be measured by reading the depth from the level rod at each rod set and adding this elevation to the bed elevation. Note the elevation of the lowest-growing permanent woody vegetation in the reach (i.e. those trees nearest the lowflow channel).

Survey transects. Choose at least four sites along the long profile on which to survey transects. These should represent the array of channel conditions seen on the site. If time allows surveying of more than four transects, you may group transects according to their planform location. For example, choose two or more transects near the apex of meander bends, other transects in riffles, and more transects in other habitat units, depending on the nature of the reach being surveyed. Transects locations are described using long profile stationing. Begin transects well outside the bankfull channel, and survey from left to right bank if possible. Note vegetation type, sedimentation and scour, bank materials and stratigraphy, bed materials, and inchannel features such as channel shelves. Table 7 gives size classes and codes for particle size descriptions. Note presence/absence of plant roots in bare cutbanks. Figure 10 shows examples of transects, and Figure 9 is a schematic showing several common channel features. Elevations are surveyed to the nearest 0.001m vertical and 0.01m horizontal. All significant slope breaks should be recorded. Water surface elevation is recorded. Record the width of the wooded riparian forest if it is narrow, and the land use outside this strip. Note any barriers to channel-floodplain connection (e.g. levees). If floodmarks are present, record their elevation. As a minimum indicator of riparian trees species and age, record the diameter (dbh) and genus (as a minimum) of the largest tree within $1.0W_{bf}$ of the intersection of the transect line and bankfull elevation for both right and left channel banks.

Habitat features. The horizontal and vertical control established by this survey forms a framework on which habitat features may be overlain. In systems where it is an important habitat feature, large woody debris may be measured by recording the average width and length of all debris >0.10m in diameter and >1.0m long. These values are summed by station ($20W_{bf}$ in length). Large woody debris may also be stratified according to channel position by recording whether it appears in the lowflow (wetted) channel or within the bankfull channel but not the lowflow channel.

Photodocumentation and general notes. Depending on reach length and sinuosity, take at least two photographs of the reach before pulling the station flags. Note the position and direction of each photo in relation to long profile stationing, and note which transects are visible. Close-ups of features of special interest, e.g. bank stratigraphy may be taken. Provide visual scale if possible -- a person is best for down-channel photographs, and scale rulers should always be present in close-up photographs.

Pebble count. Identify a population of particles that appear have been transported by the present flow regime. These may occur in riffles and at the heads of bars (excepting, usually, point bars). Using standard pebble count procedure (see Kondolf and Li, 1992) record the diameters of 100 particles. If resources allow, pebble counts may be done for other populations as well.

General Notes					
site (DK)	BUC-01				
watershed	Buck Creek				
location/bridge	First bridge above mouth, in Money Creek Tsp.				
landowner	Jane Doe				
by	Gough				
date(s)	6/5/96				
weather	cool, sunny, calm				
recent rain?	week before (5/27-28) when channel flowed bankful (photos of this), heavy, light rain last few days				
water temp (C)	14.5	**time/date**	11:30a	**air temp**	22.5
water temp (C)		**time/date**			
water temp (C)		**time/date**			
wq notes	cloudy				
flow	see notes--high				
notebook location	book 3, p. 107				
Wbf (m)	10				
Wbf multiplier between transects (1 or 2)	2				
water surface elev. below bridge.	bridge deck is 0.275m above hi4, at RB dnstr. edge, near where deck meets grade. Figure in notes (p. 114). *Hi = height of instrument*	**from point, if other than bridge deck.**			
ws elev at bridge (or bm) relative to profile survey	ws flat from bridge to transect 1	*ws = water surface*			
change in water surface elevation during survey?	no	**change (m)**			
transect types/notes	4 leveled	tst numbers increase going DOWNstream			
benchmarks	none other than bridge				
transect location	Transect 1 is 57m downstream of downstream RB bridge piling				
hwm's *hwm = high water mark*	yes, see transects, and long profile. From flooding a week before				
general notes:					

Table 6. General notes for reach scale survey, including reach location information and horizontal and vertical control using a nearby bridge. The W_{bf} multiplier indicates stationing for the long profile and transect location. In this case, Wbf = 10m and the Wbf multiplier is 2. Stations are thus 20m apart and station 1.0 is 20m upstream of station 2.0. Italicized entries are explanations for this example only.

BR	bedrock	>4000mm	smooth surface or hardpan bigger than a car
BRR	rough bedrock	>4000mm	bigger than a car
B	boulders	>250 - 4000mm	basketball to car size
C	cobbles	64 - 250mm	tennis ball to basketball
G	gravel	2 - 64mm	ladybug to tennis ball
S	sand	0.06 - 2mm	smaller than ladybug, but visible as particles, and feels gritty to fingers
Si	Silt	<0.06mm	not gritty, but not sticky and cohesive
Cl	Clay		not gritty, sticky and cohesive
Other	wood, junk, riprap, etc.		

Table 7. Particle size descriptions. If a thin layer of silt covers materials, the underlying materials are described and the layer of silt is noted. Adapted from USEPA EMAP draft protocols in Kaufmann (1994).

Summary

In this report, I review river assessment and classification approaches and offer a framework for data collection needed to develop universal assessment and classification of rivers. Although standardized methods and classifications are used for terrestrial ecosystems, especially in the classification of soils, we have no analogs for river ecosystems. Classification suggests that sets of observations or characteristics can be organized into groups based on similarities and differences Ideally, river classification would account for the fluvial processes that form aquatic habitat, enabling determination of the system's present state, its response to disturbance, and its ability to recover (Gordon et al. 1992). *Assessment* is defined here as the collection and analysis of data. Assessments may be used to compare river systems and their components to develop classifications. Assessment and classification may be thought of as a means to diagnose and treat disturbed river ecosystems.

The approach I propose considers both the complexity of fluvial ecosystems and the practical constraints faced by researchers and conservationists working in the Midwest. These constraints include a limited supply of suitably trained scientists and technicians, severely impacted watersheds, meager budgets, and limited direct control of watersheds that are largely managed by private landowners. While these constraints present barriers to assessment, they also provide a rationale for classification -- classification can direct limited river restoration and protection resources so that they are used most efficiently. The assessment and classification methods suggested here have been applied to the Mackinaw River Watershed in west-central Illinois, and the results given in a companion report by Gough (1997).

River classification approaches fall into three groups: geomorphic systems, systems based on biota and/or water quality variables, and holistic systems that consider both geomorphology and biota. No holistic systems have yet been proposed in the literature. Among geomorphic systems, Gordon et al. (1992) divide "physical" river classification methods into three types: hydrological, geomorphic and sedimentological, and methods based on a wide combination of physical attributes. Nanson and Croke (1992) suggest that geomorphic classification methods fall into three types: morphological, specific, and genetic.

Systems aimed at classifying river biota include the Index of Biotic Integrity (IBI, see e.g. Karr 1991, Allen 1994). Although some of these methods include geomorphic information to some degree, they generally ignore river processes that form the physical habitat on which river ecosystems are based. Rivers are dynamic systems and reconstruction of past states and prediction of future conditions is impossible unless classification systems consider fluvial process.

Fluvial systems are made up of many interactive components and processes. Different components and processes dominate different river systems, especially across regions (Frissell et al. 1986). This complexity will make development of a

comprehensive classification difficult at best. A widely applicable classification system must be flexible and begin with river characteristics that are relatively easy to measure and understand in a relatively predictable way along a river channel. This can be done by assessing reach-scale features that are indirect indicators of fluvial processes that we are unable to measure directly.

Classification systems should also provide a means for river managers, scientists, and other stakeholders to understand and apply knowledge of river process. An effective classification system must take into account the special knowledge held by these varied interests and present views of rivers that make sense to them. A classification system should also provide a clear, practical means to describe and diagnose river conditions at the reach scale to allow clear communication among these groups. A shortage of suitably-trained people will continue to strongly influence river management, and should be considered in the development of classification and management approaches.

The ideal river classification system would provide a means to order and group river systems on a global scale, and would provide links to terrestrial classification systems. There remains, however, a strong need for a means to simply describe the physical habitat and processes in river ecosystems. There is still no consistently applied method for measurement of even the width of stream channels. To be useful as a management tool, a river classification system should offer methods to both measure and present characteristics critical to river structure, process, and habitat.

A strong tendency, especially in the areas of geomorphology, engineering, and aquatic biology, to study and present information quantitatively and from sometimes narrow points of view (see Newson 1992) has led to a neglect of powerful alternate means of both gathering and presenting information about rivers. Rosgen (1994) has suggested that statistical analysis of biota can be made much more meaningful if data are first stratified according to physical stream characteristics. This is an important potential application of stream classification. Classification methods must present river form and process in understandable ways (Warren 1979) including use of descriptive methods. A broadly applicable system must include a mix of quantifiable variables, well-directed description, and presentation of information in modes understandable to a wide audience of stakeholders.

Several conceptual treatments of river classification have been published, including Mosley (1987), Naiman et al. (1988), Nanson and Croke (1992), Gordon et al. (1992), and Meador et al. (1993). Although Rosgen's (1996) stands as the most complete, its fundamental rationale and predictive capabilities have been questioned (Miller and Ritter 1996), as has its indiscriminate application (Gillilan 1996). And it appears that the system does not account for the characteristics of some midwestern streams (Gough 1997).

The basic data required for application of a holistic, watershed-based classification/diagnosis include information on watershed geology, topography, and soils; climate and hydrology; landuse; and terrestrial and aquatic biota. At a finer level, information about river channels, including basic hydraulic geometry, riparian vegetation, and inchannel microhabitat is needed. For most watersheds, information on biota and reach-scale channel characteristics must be collected. Collection and interpretation of this data requires technical skill in a range of disciplines. Thus the application of a comprehensive stream classification system to large watersheds will usually require a team of scientists and technicians.

Frissell et al. (1986) advocate a hierarchical classification system in which the highest level is the stream system (a watershed) with an approximate linear spatial scale of 10^3m, followed by stream segments (10^2m), reach systems (10^1m), pool/riffle systems (10^0m), and microhabitat systems (10^{-1}m). The term "reach" is widely used but ill-defined. A reasonable definition is a length of channel that is about 20 times the channel's bankfull width. A river segment can be defined as a section of river between two major tributaries (Frissell et al. 1986).

Assessment and classification schemes used for management of aquatic ecosystems depend on models that link biota and physical habitat conditions (Simonson et al. 1994b). There are few such models for streams in the midwestern United States, and most are directed toward management of a single or few species of gamefish. Our capability to model the relationships between fish populations and physical habitat remains crude, and even less developed for other stream biota (Frissell and Bayles 1996). Thus far, not even a conceptualization of how a complete stream ecosystem might be modeled for management exists in published form. The limitations of our models in both these realms will remain a barrier to comprehensive stream classification for some time to come.

River habitat is influenced by characteristics and processes at a range of temporal and spatial scales. Although management of stream habitat has been dominated by reach-scale approaches, watershed-scale assessments are more efficient, particularly when limited resources for stream restoration and protection must be applied over a region. This is still a new approach, however, and there are no comprehensive models to follow, particularly in the midwestern United States (Gough 1993). Management problems such as channel stability may be caused by local conditions, but sound assessments must include analysis of influences outside a particular reach. Habitat quality is best managed by addressing both systemic (large-scale) impacts and local influences. Local (reach-scale) controls on channel morphology and habitat quality include bank and bed materials and riparian vegetation. In most midwestern watersheds, private landowners exert spatially variable control over riparian vegetation. Systemic influences include hydrologic regime and basin geology. Over time, changes in hydrologic regime can have profound influences on river morphology. Watershed-scale assessment and classification provides a means to compare river reaches, understand possible states, and optimize allocation of scarce management resources.

Systemic influences can be evaluated by comparing river reaches using even simple means such as historical aerial photography. More powerful analysis is possible though reach-scale morphologic surveys of a number of reaches throughout a river system. Basin-scale holistic assessments become complex because the components of fluvial systems are highly interactive. Development of a hierarchical classification scheme depends on identification of key controlling variables. Ultimate controls -- climate and geology (Naiman et al. 1992) -- are obvious, but may be of little use in comparing reaches within small basins because they tend to be homogenous over this scale. Classification of river systems at segment and reach scales can be difficult because controlling variables may vary between reaches (Frissell et al. 1986). Because direct measurement of many important characteristics is complex and expensive, a practical means is needed to compare reaches within a basin using morphological features and indicators of fluvial process. This can be done using reference reaches that are measured in detail and compared to less rigorously-assessed reaches. This approach is advocated to some degree by Rosgen (1994, 1996) and Frissell et al. (1986), who discuss the use of classification in comparing reaches to determine possible states and manageability. I was unable to find any proposed or existing assessment or classification scheme that provided a systemic means of identifying reaches within a basin to be used as reference sites. Selection of sampling (or reference) sites must be based on an understanding of the watershed in which they lie.

Classification and assessment measurements should be arranged hierarchically. Frissell et al. (1996) cite Godfrey (1977) on the advantages of using a hierarchical classification structure: (a) classification at higher levels reduces the set of variables required at lower levels, (b) it allows integration of data from different sources and of different levels of resolution, and (c) allows managers and scientists to select the level of resolution most appropriate for the objectives at hand. Although development of a broad, consistent body of data for midwestern streams is necessary before a regional classification system can be proposed, such a system will allow managers to select among variables and levels of resolution within regions where fluvial system characteristics are similar. Although methods may vary among regions and organizations, development of the data needed for regional classification requires that key fluvial system characteristics be measured and reported consistently.

Perhaps the most well-known and broadly used stream classification system is that developed by David Rosgen, commonly known as the *Rosgen system* (Rosgen 1996). The system has been the subject of some controversy, and its fundamental rationale has been questioned by Miller and Ritter (1996). The system focuses largely on reach-scale assessment of morphology and process. Reaches are assigned to one of the eight major classes using a hierarchical process that considers several morphologic variables. These variables are largely based on bankfull channel dimensions and include assignment of channels to single- or multiple-thread channels, entrenchment, width:depth ratio, and sinuosity.

A classification and assessment system must be based on an understanding of the processes that form river channels and habitat. The cross-sectional shape of a given river channel is a function of the flow moving through it, the quantity and character of sediment carried by that flow, the nature of bank and bed materials in the channel, and, commonly, the vegetation near and within the channel (Leopold 1994). Flowing water exerts eroding force on the bed and banks of river channels. The erosional force exerted by water flowing through a reach can be expressed as *stream power,* the product of discharge and slope. Generally, channel dimensions are adjusted, through erosion and deposition of sediment, to the quantity of water moving through the cross-section so that the channel is able to contain all but the highest flows (Knighton, 1984). Changes in the discharge or sediment supply to a cross-section or reach of river will tend to alter its morphology. Riparian trees strongly influence bank strength, flood flow characteristics, and channel stability in many midwestern rivers.

The bankfull discharge is that flow which fills a channel without overtopping its banks (Richards 1982). This discharge and the corresponding channel cross-section that conveys it have special significance and utility in analyzing channel morphology. Leopold (1994) suggests that bankfull discharge occurs 1 or 2 days a year and has a recurrence interval averaging 1.5 years. This may vary among geomorphic climatic regions, however, so quantitative use of bankfull discharge requires data from local gaging stations (Leopold 1994). Determination of bankfull discharge is best made through a combinations of field surveys and gage data, as recommended by Leopold (1994). In this way bankfull indicators can be identified and used to define the bankfull channel dimensions at other reaches in a watershed or region. This method was applied at three gage sites on the Mackinaw River in central Illinois and the results reported by Gough (1997).

Rivers thus tend to be unique, and the best information about how a particular river segment behaves is its past history (Kondolf and Sale 1985). Many midwestern riparian areas were cleared of trees in the past, and historic aerial photography shows a wide variation in channel response. Reach-scale instability should always be viewed with an understanding of process and morphology in at least the surrounding river segment. Most rivers will naturally contain reaches that are more susceptible to destabilization than others. Causes of instability can be determined by comparing reaches at the segment scale using maps, aerial photographs, and data from the assessment methods recommended here.

Alluvial channels adjust their hydraulic geometry and build adjacent floodplains to produce stable conduits for the transport of water and sediment (Nanson and Croke 1992). Levees disrupt this process, and affect channel morphology by greatly increasing local stream power and eliminating floodplain storage of water and sediment during large floods. In some cases, it is clear that the effectiveness of levees in controlling floods is overrated, and they may be very economically inefficient (Schumm 1994).

Clearly, a widely applicable classification system must await development of a greater understanding of regional river geomorphology and production of data sets. This can happen only after river conservationists begin to apply relatively standard approaches to their assessments. The system I propose here makes use of key descriptive variables that are supported by a base of quantified channel characteristics, most importantly channel geometry and reach-scale long profile data. In many ways the assessment and classification system detailed here resembles diagnostic procedures used in medicine--key characteristics are described, and, as necessary, more detailed measurements taken to determine cause and effect. The approach I offer here is designed to provide a minimum framework on which more complex systems can be overlain if necessary and allows for the logistical limitations commonly faced by river conservationists.

As a minimum for watershed-scale assessment, I suggest drainage area, stream length, and basin relief be measured and that landuse be characterized. Specific classification of large watersheds is most practically done at the segment scale. At this scale, river form and process is generally homogenous enough to concisely describe. At the segment scale, generalized management and protection goals and methods can be described, as can aquatic communities. Segments may also be defined by changes in floodplain characteristics such as width or landuse. Recommended segment-scale measurements include segment length, sinuosity, hydraulic geometry, and gradient, along with descriptive or quantitative information on water management features (including channel alteration), riparian vegetation, bank materials, and bed materials.

Reach-scale data needed for assessment and classification include sinuosity, photodocumentation, pebble counts, gage calibrations, and long profile surveys that include information on water surface and bed profiles, bed materials, bankfull indicators, large woody debris, and other indicators of fluvial process. At transects, I recommend including information on cross-sectional hydraulic geometry, floodplain morphology and hydraulic connectivity, riparian vegetation, bank and bed materials (including stratification), and aquatic vegetation. Nowhere in the literature are suggestions given for selection of reach-scale sampling sites within a basin. Sites should be selected based on (a) project objectives and manageability of key characteristics, (b) available sampling resources, (c) preexisting data sources (e.g. long-term biotic sampling sites), and most importantly, (d) results of the watershed and segment scale surveys. Sampling intensity, methods, number of sites, and site location will depend on project resources.

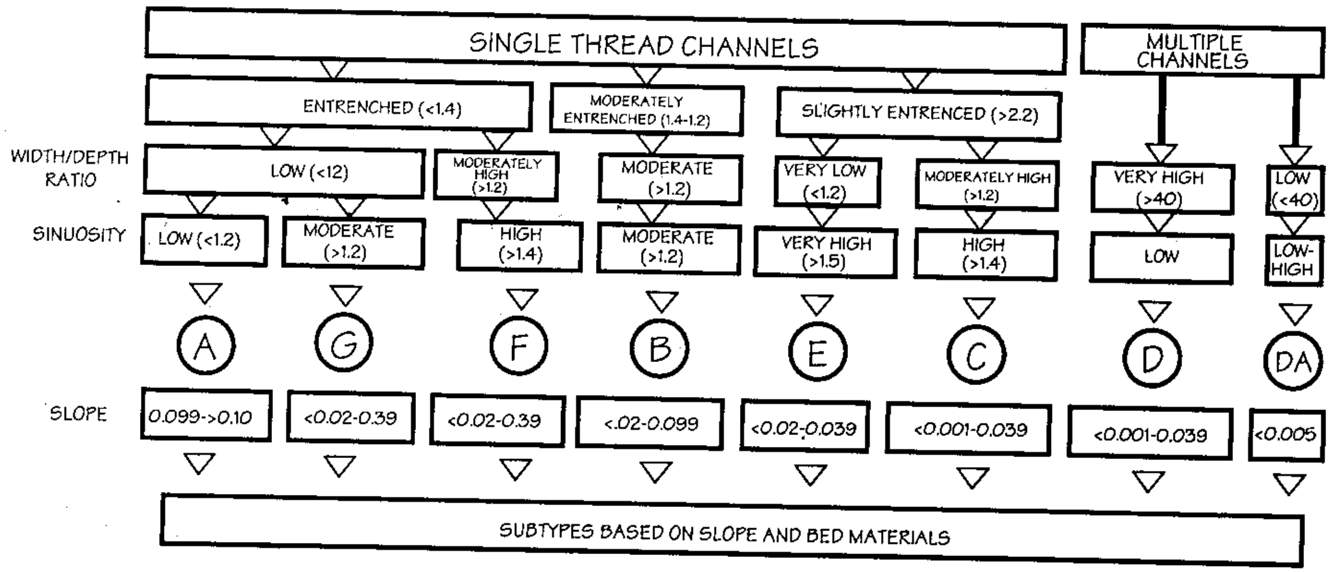

Figure 1. Key to the Rosgen classification system. This figure is simplified from Rosgen (1994) to illustrate determination of the eight major stream types.

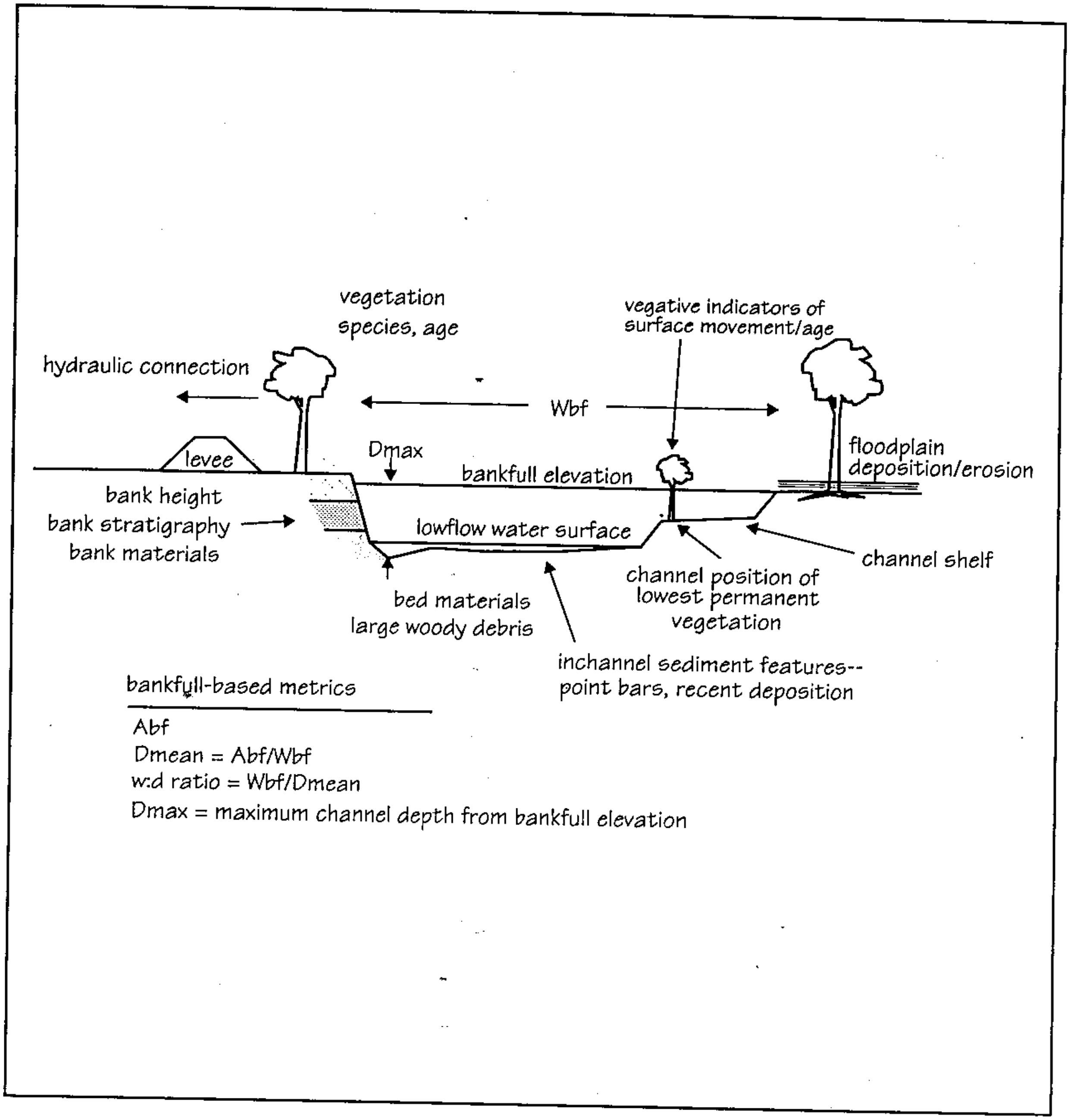

Figure 2. Schematic of a channel cross section showing important channel features and indicators of fluvial process.

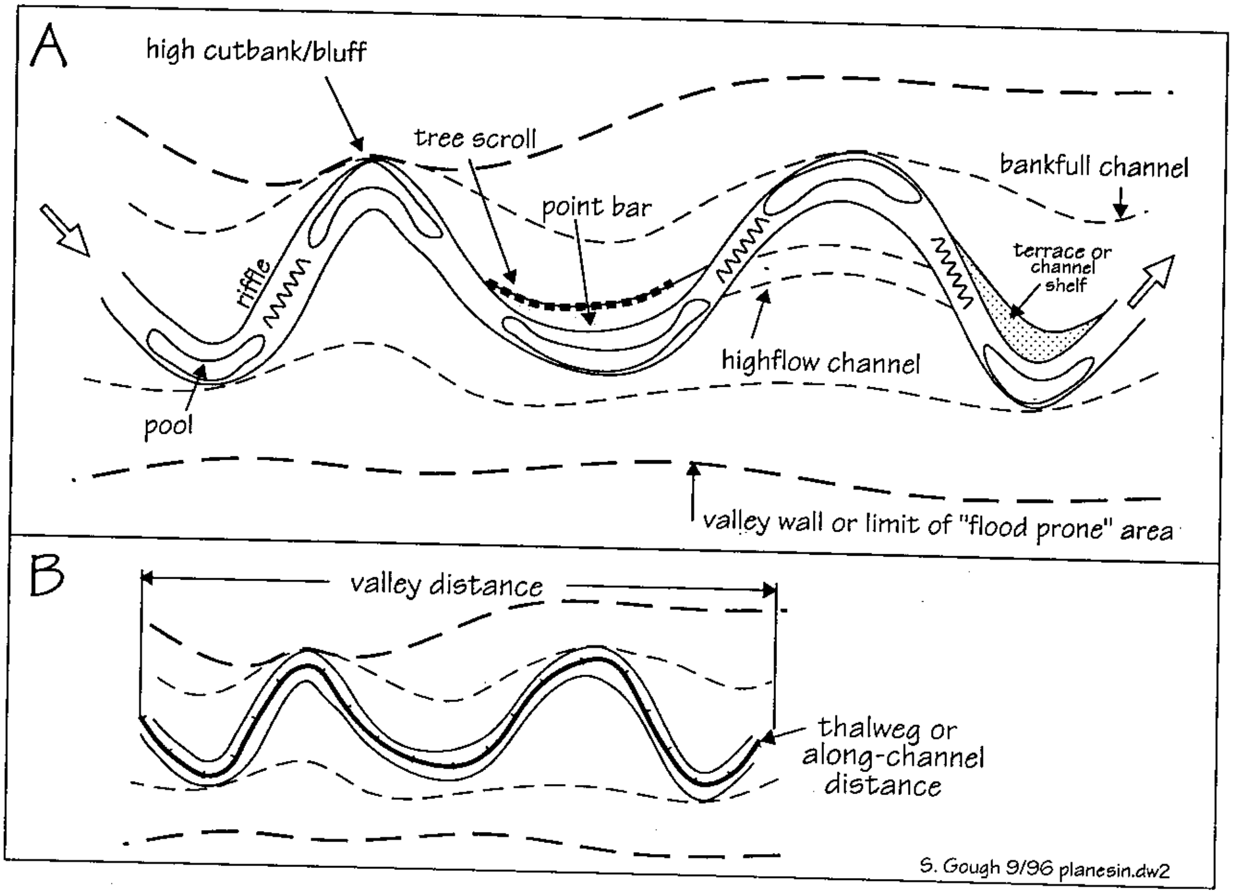

Figure 3. (A) Schematic of a river channel and valley showing important geomorphic features. (B) Definition diagram for channel sinuosity. The river valley here is drawn relatively straight. If a river's valley curves, valley distance is measured along the center of the valley and curves as well (as does the thalweg measurement).

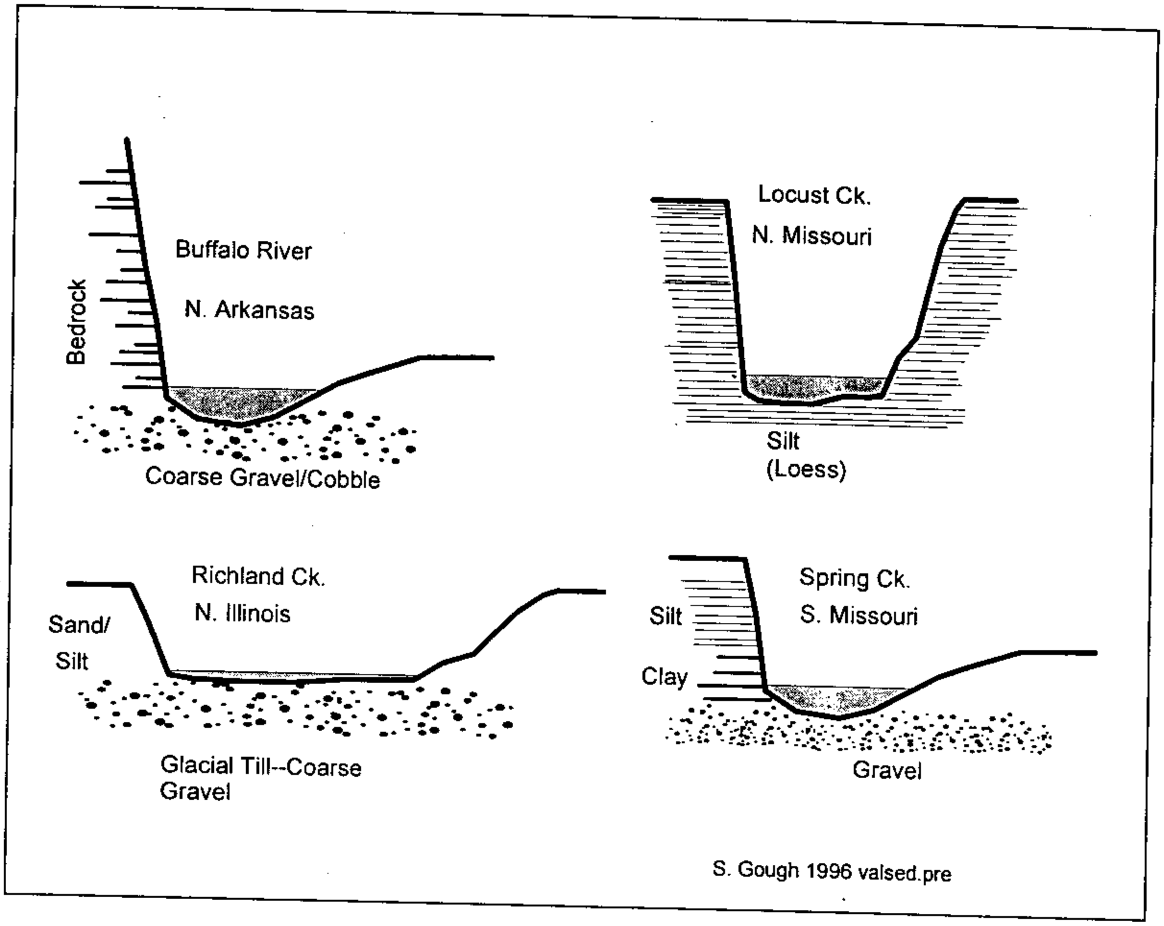

Figure 4. Schematic cross-sections from streams in four regions, showing the effects of bank and bed materials on channel form. The Buffalo River and Spring Creek lie in the Ozark Plateau region. These streams have high specific stream power but are controlled bedrock and clay bank materials (respectively) and are laterally stable and have a low w:d ratio. Locust Creek's bed and banks are composed of silty material. After channelization and changes in watershed landuse, this channel responded by downcutting. Sections of this creek show severe lateral erosion and channel widening as this process continues. Richland Creek, a tributary to the Illinios River, is impacted by flow regime changes and channelization. Its sandy banks are relatively weak and channel widening and lateral erosion have resulted in a very high w:d ratio.

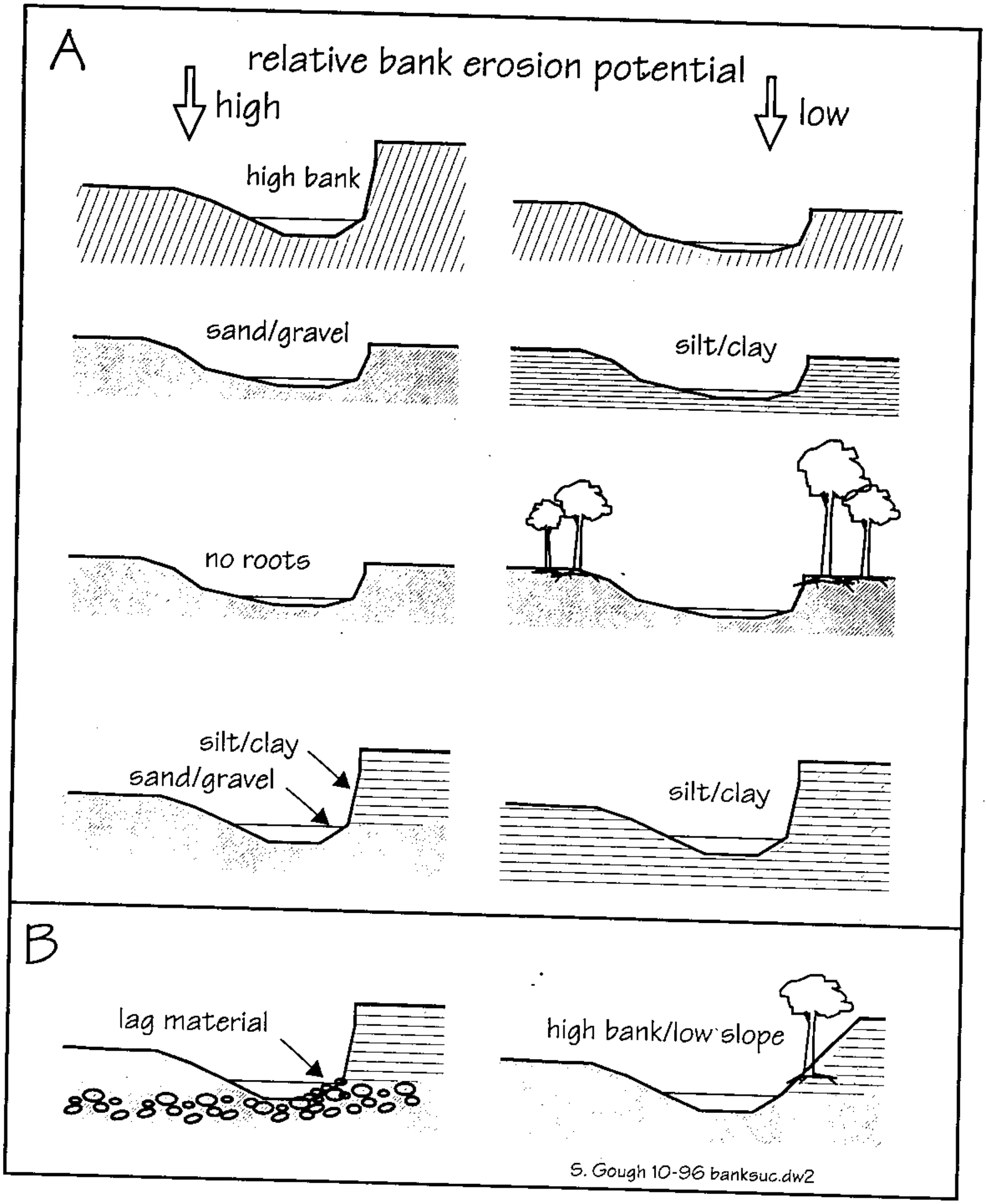

Figure 5. Cartoon showing the influence of bank morphology, materials, and vegetation on erosion potential. (A) Relative erosion potential. Banks in the left column are more prone to erosion than those at right. (B) Two situations in which relatively high banks may be stable: when slope is relatively low and vegetation can colonize the bank, and when coarse lag materials stabilize the bank toe.

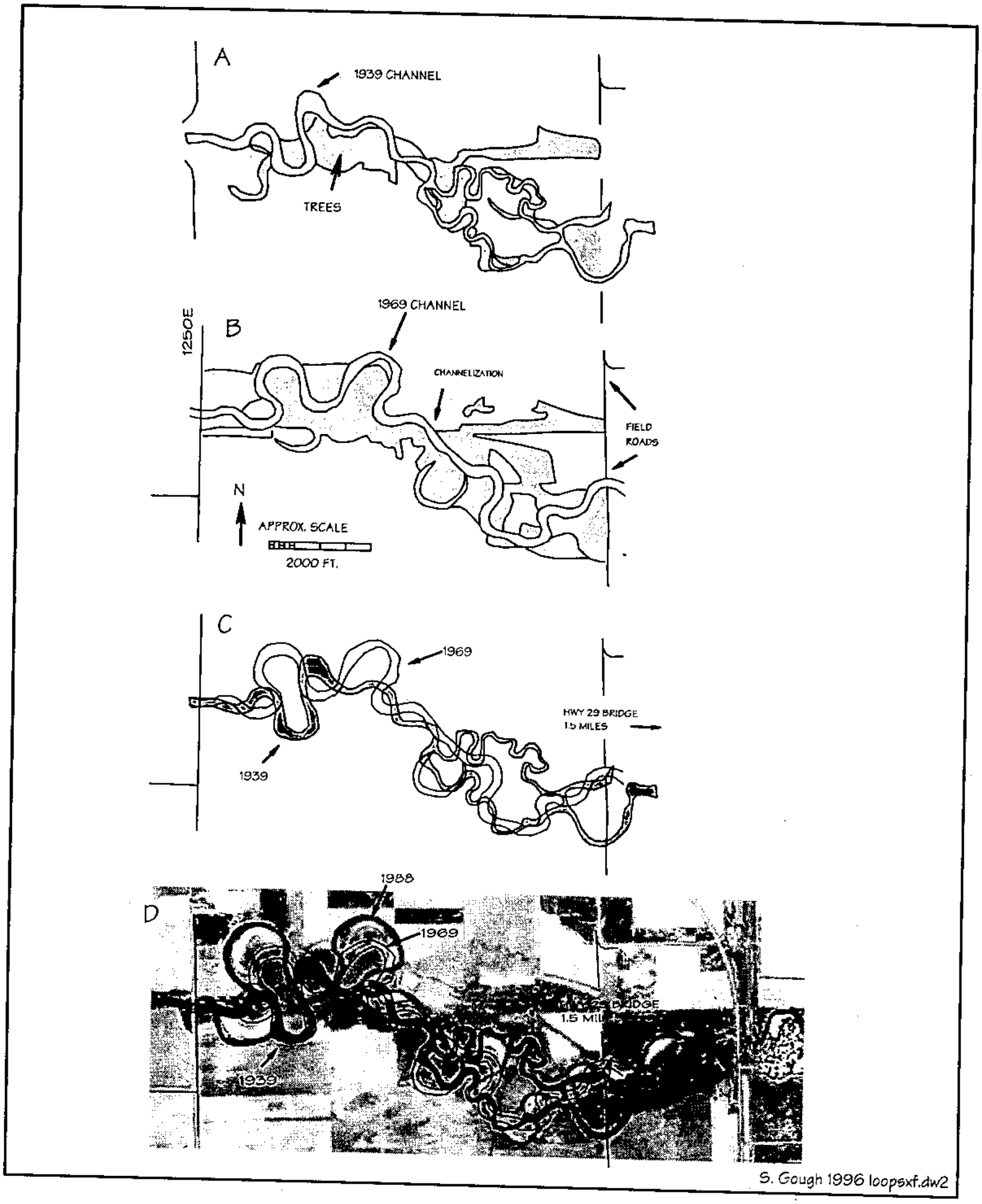

Figure 6. Changes in the Mackinaw River above Highway 1250E, Tazewell County, Illinois from 1939 to 1988. From USDA aerial photographs. (A) the 1939 channel and wooded areas, (B) the 1969 channel and wooded areas, (C) the 1939 and 1969 channels superimposed, and (D) the 1939 and 1969 channels overlain on a 1988 aerial photograph. This section of the Mackinaw River is impacted by channelization and other flood control measures and is migrating laterally through highly erodable sandy bank materials.

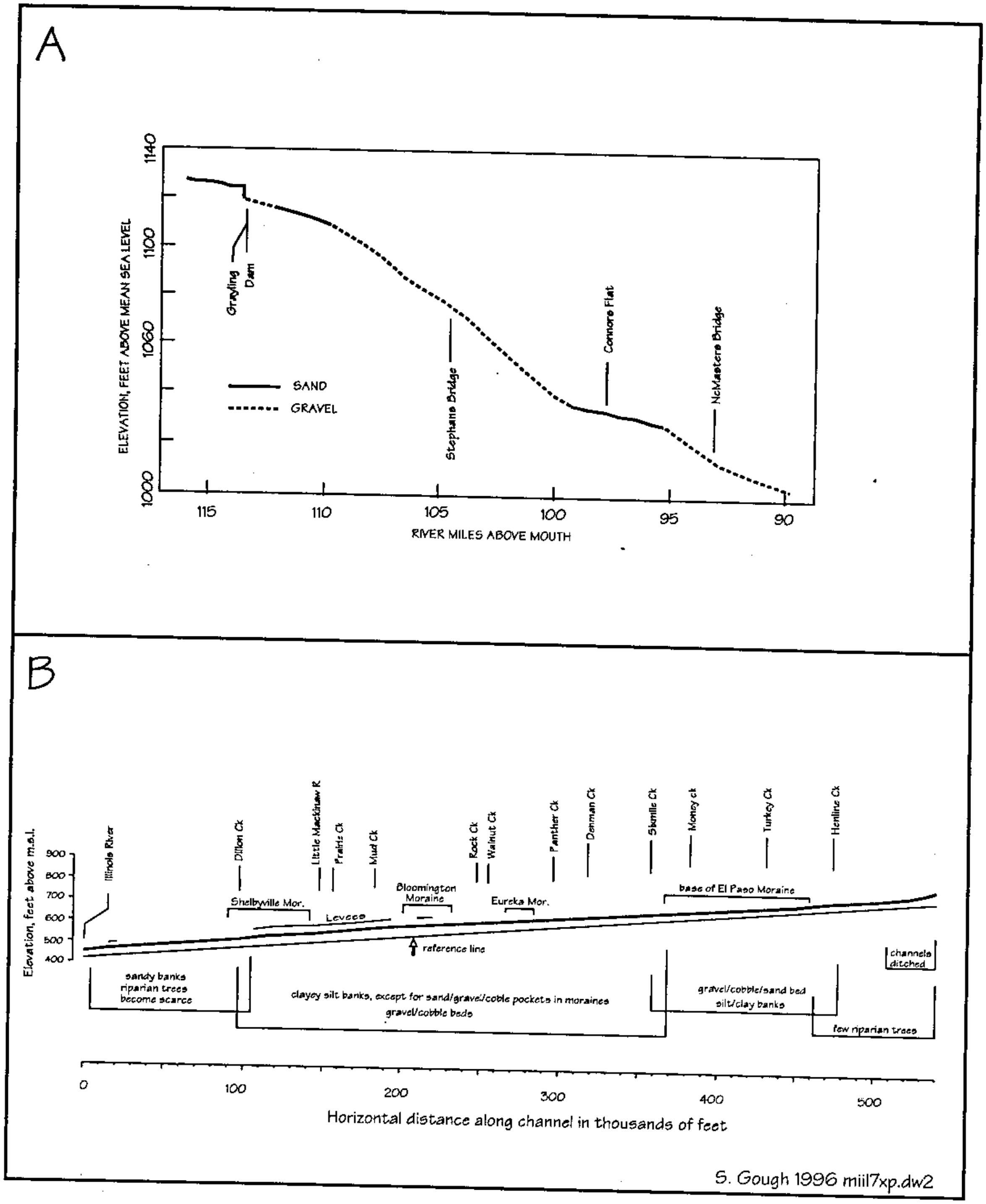

Figure 7. Long profile plots. (A) The Au Sable River in the western lower peninsula of Michigan. Note the correlation between bed materials and channel slope. From Hendrickson and Doonan 1972. (B) The Mackinaw River in central Illinois, from 1:100,000 topographic maps, showing tributary confluences, moraines, levees, riparian conditions and geology. A straight reference line below the profile shows the relative homogeneity of slope for this river, which is strongly controlled by glaciofluvial materials.

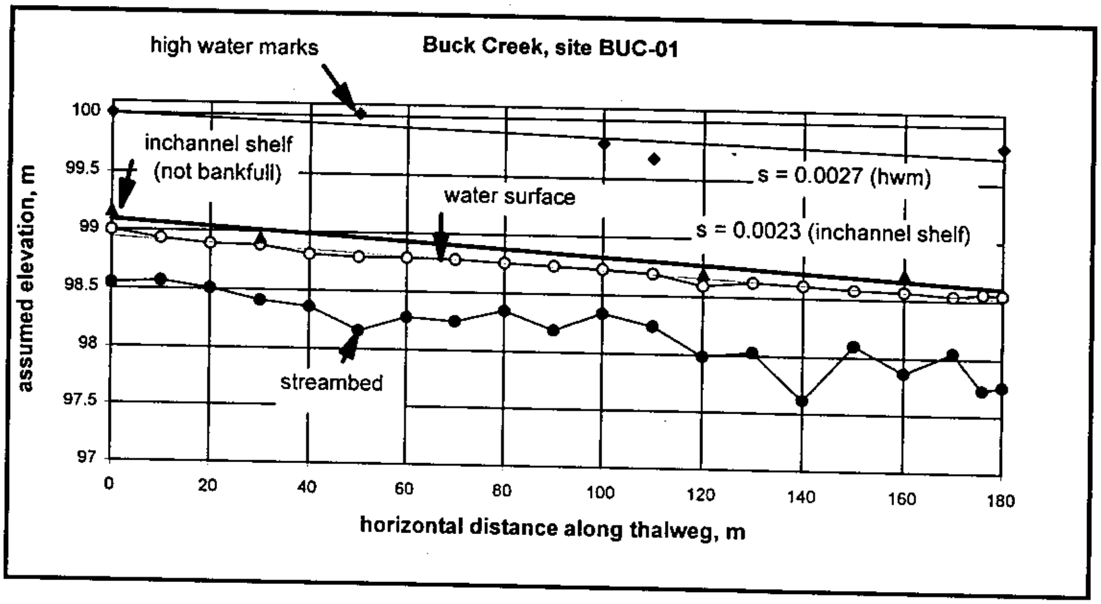

Figure 8. Long profile survey from Buck Creek in the Mackinaw River Watershed, Illinois. High water marks (diamonds) were surveyed from debris lines left after a recent flood that peaked at about bankfull. Slopes (s) are shown for an inchannel shelf (triangles) and the high water marks. The water surface was well above summer lowflow conditions during this survey.

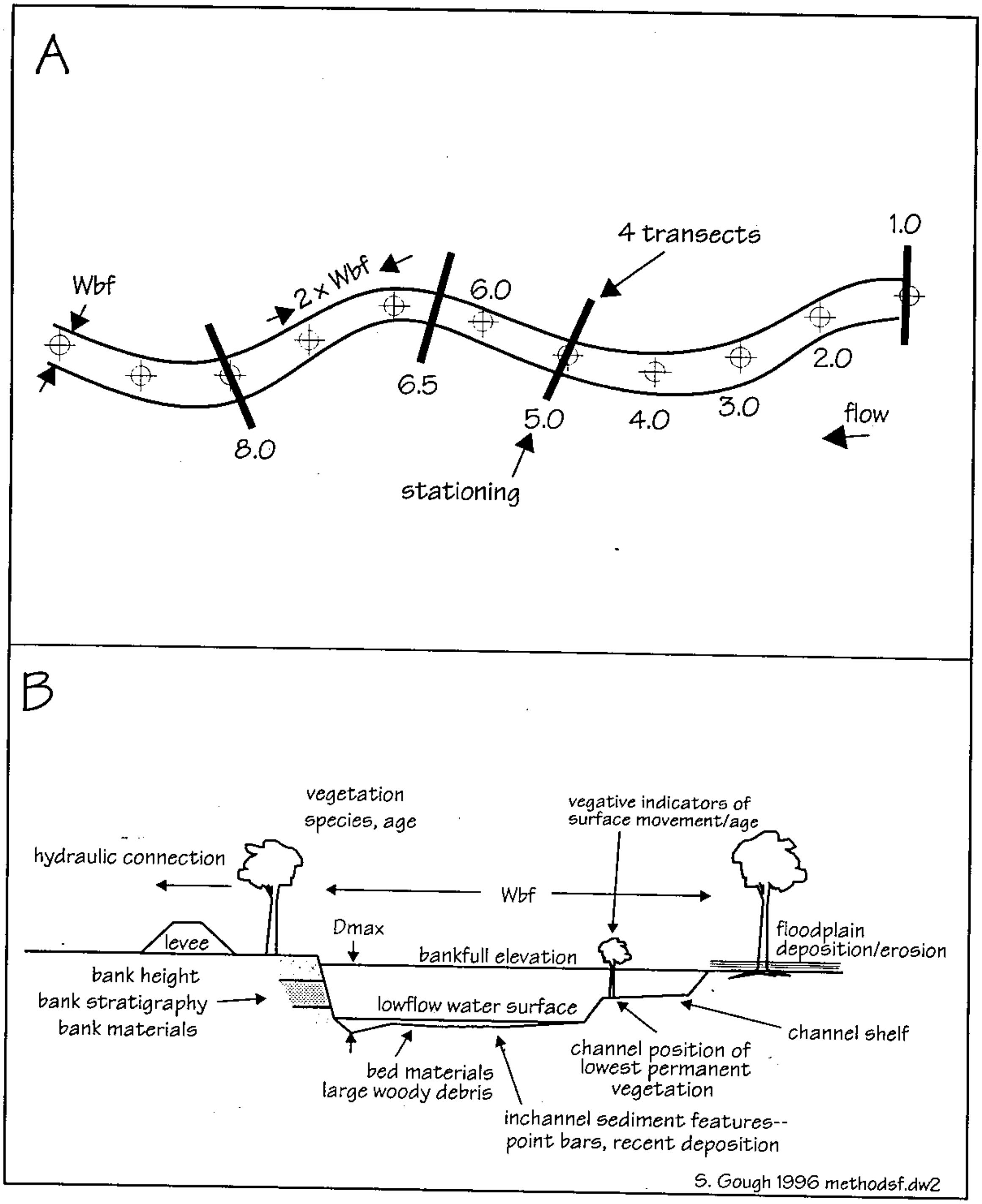

Figure 9. Definition diagrams (A) for reach stationing at multiples of W_{bf}, and (B) transects, showing characteristics used in assessment and classification.

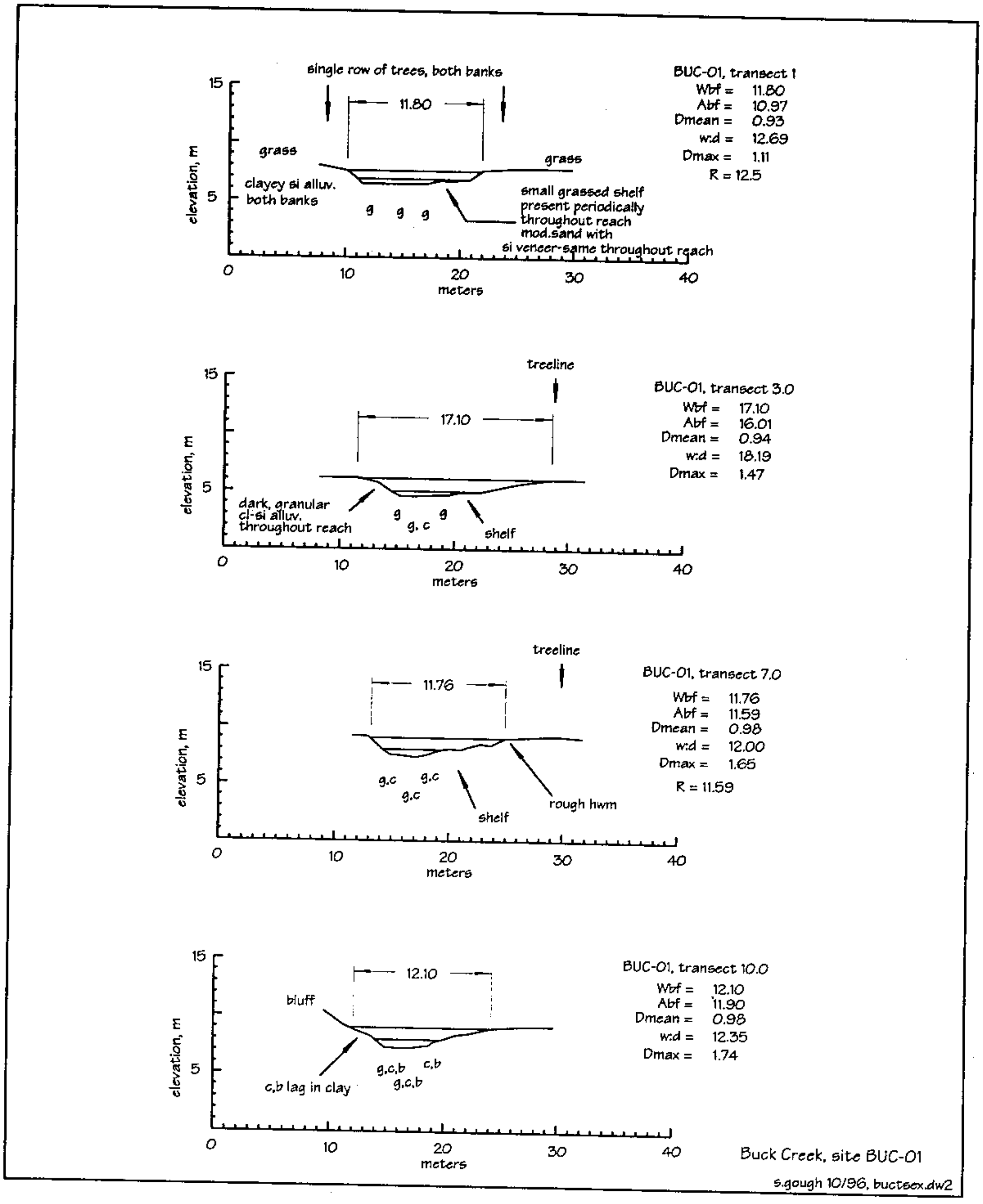

Figure 10. Four transects from Buck Creek in the Mackinaw River Watershed, Illinois, showing geomorphic surfaces, vegetation, and bank and bed materials. Channel geometry is also shown, including hydraulic radius (R) for transect 1. Flow is into the page. A small right bank inchannel shelf can be seen in transects 1.0, 3.0, and 7.0. Transects are numbered by stationing tied to the long profile survey and based on multiples of W_{bf}. Elevations are assumed.

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