Executive Summary

This report presents the findings of the geomorphic field reconnaissance and preliminary management recommendations for a reach of Deer Creek, flowing through the Litzsinger Road Ecology Center property in the City of Ladue, Missouri. The study reach includes approximately 2,500 linear feet of stream channel. The data gathering and analytical methods applied during this study are generally consistent with those of US Army Corps of Engineers (USACE) Engineering Manual 1110-2-4000 and the Federal Emergency Management Agency's (FEMA) 1999 report to Congress, *Riverine Erosion Hazard Area Mapping Feasibility Study*.

This report addresses deposition and erosion management through the application of methods based in the science of fluvial geomorphology. Fluvial geomorphology is the discipline that describes how a stream or river changes the landform. As the quantity or timing of water introduced to streams change, so do the streams themselves. The flow of water is the driving force that is balanced by the resisting force of the streambed and channel geometry. It is the interaction between these two types of forces that determines how deposition and erosion occur. Therefore, a thorough understanding of both the driving and resisting forces is required for any successful management.

A complete sub-basin plan for stream management includes both hydrologic/hydraulic and geomorphologic data. An investigation of flood hazards was not included in the analysis.

Based on the results of our analysis, the study reach of Deer Creek is adjusting via meander migration or lateral planform adjustment. While meander migration is a natural phenomenon that occurs without anthropogenic influence, historic aerial photograph review and field reconnaissance data suggests that lateral meander migration along Deer Creek may have been provoked by channelization, a loss of channel sinuosity, and excessive bedload. Evidence of meander adjustment consists of aggradation of bed material along with a pattern of bank scouring and erosion occurring opposite wide, steep-sided point bars.

Preliminary management recommendations were developed based on the field reconnaissance to alleviate the effects of meander migration and protect streamside property against bank erosion. Our recommendations, such as erosion protection, are achieved by working *with* the forces shaping the stream. Conventional approaches focus almost exclusively on increasing the resistance of an eroding feature, usually in the form of hard armor. Reduction in the driving force for channel adjustment is equally as important as increasing the resisting force. The recommendations from our analysis focus on protecting threatened infrastructure and property, and improving the stability of the reach without excessive interventions.

Fundamentals of Fluvial Geomorphology

Fluvial geomorphology is the science of how moving water shapes the land. It is the fundamental discipline of river science and allows the quantitative description of stream behavior now and reasonable predictions of future behavior under specified conditions. Fluvial geomorphology and the related disciplines of hydrology and hydraulic engineering, geology and soil science together provide the technical underpinnings for sound watershed management. The paragraphs that follow are a brief overview of geomorphic principles with emphasis on their application to stream and watershed management.

Major Models

Streams exist in a state of dynamic equilibrium in which the driving forces inducing channel form are balanced by resisting forces. The driving force is gravity, which acts on the stream as the rate at which water and sediment move through a stream, while the resisting forces are the strength of the channel boundary materials and friction expressed as the channel shape. When the driving forces exceed the resisting forces, the stress applied by water or sediment exceeds the channel strength. The stream channel responds by altering its shape in plan, profile and cross-section to accommodate the change in flow volume and applied shear.

Once disturbed, the processes by which streams respond are: 1) incision or degradation, 2) widening, 3) aggradation or deposition and 4) planform adjustments. Through these processes, streams eventually re-establish equilibrium. Determining which process is dominant, and the likely progression of stream processes, is one of the principle challenges of stream management. Given the large number of independent variables and the complex relationships between the many dependent variables, it is reasonable to seek robust, relatively straightforward models that organize these variables. In disturbed systems the chosen approach evaluates each channel process separately, then develops an integrated assessment using energy relationships.

<u>Lane's Relationship</u>

In 1955, E.W. Lane expressed the relationships between the driving and resisting forces for channel change in the following simple proportionality.

$$Q_S \, D_{50} \propto S \, Q_W$$

Where Q_S ≡ Rate of sediment flow
D_{50} ≡ Median size of mobile particles
S ≡ Slope of the channel bed
Q_W ≡ Rate of water flow

Here the D_{50} stands as proxy for boundary strength and S for channel shape. From this relationship, it is clear that a change in any of these parameters will, once a threshold is exceeded, induce a change in one or more of the others. The familiar increase in Q_w associated with urban development illustrates this point well. The response to this increase is some combination of the following: a decrease in channel bed slope (incision), an increase in sediment load (increased erosion) and an increase in the median size of mobile particles. When considering all four parameters, these responses often occur in sequence. The following examples illustrate such responses:

- Initial change: S ↑; response: Q_S ↑. Increasing channel slope is often accomplished through channel straightening to achieve greater flood conveyance or to optimize land development. This increase in slope causes an increase in sediment load, in mobile D_{50} size or both. Bed and banks erode to generate the sediment that deposits downstream where channel slopes are flatter. The effective change in water surface slope may extend upstream well beyond the actual channel straightening, extending the accelerated erosion. The sediment eroded from upstream of the channelization and deposited downstream counteracts the effect of the channelization and improvements in flood conveyance are often less than anticipated.

- Initial change: Q_W ↑; response: Q_S↑. Often the bed slope remains relatively unchanged at first, so to maintain the proportionality, Q_s increases. The increase in sediment load is generated by down cutting of the channel bed (incision), scour of the stream banks or both. The incision locally steepens the channel slope, compounding the driving force for more erosion. This local steepening of bed slope is called a knickpoint. Knickpoints migrate upstream liberating sediment as they progress. When the stream banks exceed their critical height, mass failure ensues. This reconfiguring of the channel geometry continues until the equilibrium described by Lane is re-established.

- Initial change: Q_W ↑; response: D_{50} ↑. This condition occurs when there is little sediment initially available in the bed or banks. So, to maintain Lane's proportionality, the size of the median mobile particles increases. Under this condition, rock armor that previously protected a structure becomes mobile as the D_{50} increases. Subsequently, the service life of the infrastructure declines. Moreover, the natural bed armoring aggregate, previously mobile only during less frequent floods, becomes mobile during more frequent events and the underlying, more erosion-prone bed and bank materials are exposed to greater and more frequent erosive force.

- Initial change: Q_W ↑; response: S ↓. If the channel bed is relatively resistant to incision, the stream may respond to increased flows by

> decreasing its slope. The stream accomplishes this decrease in slope by meandering or increasing the channel length over the same change in elevation. The downstream progression of point bars (crescent-shaped sediment deposited on the inside bank of stream bends) opposite the downstream progression of eroding and failing cut banks (steeper outside banks of stream bends) are classic signs of meandering.

Lane's Relationship is useful for broad conceptual understanding of stream behavior. It is also valuable for testing hypotheses concerning stream behavior in various scenarios. The following models more specifically address stream process.

Channel Evolution – Evaluating Changes in Cross-Section

Simon (2001) separates changes in channel morphology into six stages: I) Pre-disturbance, II) Disturbance, III) Incision, IV) Widening, V) Deposition, and VI) Recovery and Reconstruction.

At Stage I, the channel is stable and transports the water and sediment delivered to it without significant adjustment. Although not a universal feature, internal floodplains are common in stable streams including those in the Central Midwest. Bankfull floodplains occur at the elevation corresponding to the dominant discharge. The dominant discharge is the flow that, over time, accomplishes the most work on the stream channel. In undisturbed streams, the dominant discharge typically occurs every 1.5 to 2 years. The bankfull floodplain performs a valuable function by lowering the bank shear during higher flows and effectively managing the stream energy.

During Stage II, natural or manmade events disturb the channel. In disturbed systems, the dominant discharge often occurs far more frequently and may not support the development of internal floodplains. Common forms of manipulation include increases in the rate, volume or timing of flow or direct alteration of channel dimensions or alignment.

In Stage III, the stream cuts downward, lowering its channel slope to redistribute energy. This incision process migrates upstream. The migrating face of an incision front is referred to as a knickpoint or knickzone. The typical shape of these channels is V- shaped or narrow U-shaped. Incision proceeds until the channel has reached a stable slope, the incision reaches a more resistant layer or the stream banks begin failing because of mass wasting.

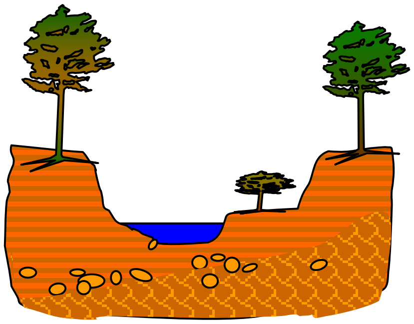
Channel widening through mass wasting of the stream banks, Stage IV, follows incision. There are two common mechanisms of bank failure. Fluvial action erodes soil away from the toe of the slope resulting in a cantilevered bank, which eventually fails through toppling. Alternatively, the incision cuts deeply enough into the bed that the stream banks exceed their critical height and fail. Both mechanisms may operate in a stream.

The next phase of channel evolution is Stage V when the channel has sufficiently widened and begun depositing sediment eroded from upstream reaches in the bed. The deposits occur as channel bars and occasionally as internal floodplains. In Stage VI, the channel regains the equilibrium condition and efficiently transports both water and sediment. If a substantial increase in Q_w precipitated the adjustment, final dimensions of the channel will probably be larger than the pre-disturbance condition.

Each of these phases is depicted in the following figure.

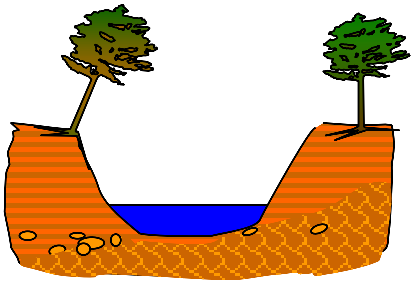
Stage I Pre-disturbance

- Bed and bank materials balanced with erosive forces
- Permanent woody vegetation near the water line
- Two-stage channel shape evident at about 1.8 year return interval



Stage II Disturbance

- Channel altered, hydrology or sediment inputs modified
- Removal of permanent woody vegetation near the water line
- Two-stage channel shape eliminated or no longer supported by flow conditions



Stage III Incision

- Downcutting liberates sediment
- Lost or perched bankfull floodplains
- "U" shaped channel
- Woody vegetation high on bank

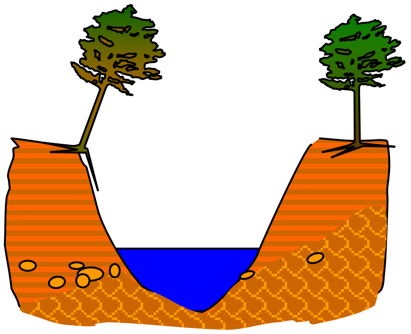
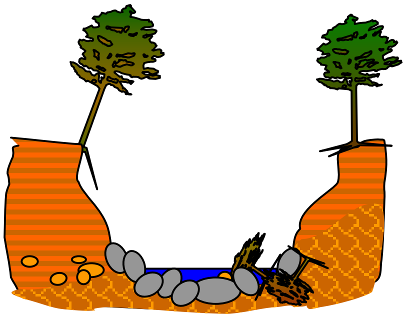


Figure 1: Channel Evolution Model (from Simon, 2001).

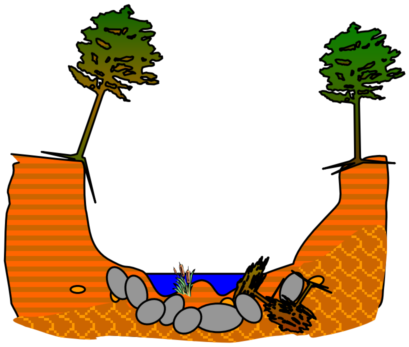
Stage IV Channel Widening

- Widespread bank failures as banks exceed critical height or were undercut by toe scour
- Channel adjusts to new flow regime
- Significant sediment loads generated; most significant erosion hazard in this phase
- Bank armoring generally ineffective



Stage V Deposition

- Deposition begins from liberated sediment
- Vegetation establishes near water line



Stage VI Recovery and Reconstruction

- Bankfull floodplains may be reconstructed from liberated sediment
- Woody vegetation establishes near water line
- Stability re-established

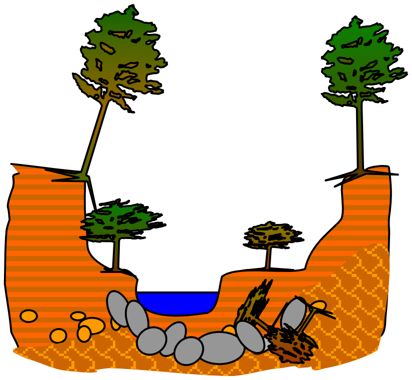


Figure 1: Channel Evolution Model (cont.).

Meander Formation and Migration – Evaluating Channel Change in Planform

Adjustments in planform are common and have an important influence on the sustainability of a stormwater system as well as on the safety and service life of near-stream infrastructure. Some planform adjustments can liberate significant sediment and present major erosion hazards. The management requirements of planform adjustment differ from those of an incising or widening stream. Consequently, distinguishing between these processes is an important part of the analysis.

Straight stream channels are rare and require a narrow set of circumstances to maintain dynamic equilibrium in a natural setting. Like all other open systems, streams adjust their form to minimize the expenditure of energy. The formation of pool-riffle patterns and meanders are consistent with this trend towards maintaining an equilibrium condition. Meanders are complex in both formation and behavior. Meander formation graphically demonstrates the principle of cause and effect in stream mechanics. The cause is the force applied by moving water and sediment and the effect is the shape of stream channel.

To describe the basic process of meander formation, the distinction between the meander flow or discharge centerline and the channel centerline is important. As illustrated in Figure 2, the channel centerline (effect) lags the discharge flowline (cause). The flow in a stream does not progress in straight lines parallel to the stream channel. Rather the flow is comprised of a primary flow oriented downstream and transverse flows oriented perpendicular to the primary flow. Along the discharge flow path, these inward and outward transverse flows are balanced. However, along the channel flow path, there is considerable asymmetry. Because of the variable turbulence and secondary flow patterns, the flow velocity, sediment transport and boundary shear stress are non-uniform across the channel. These areas of turbulence produce alternating pulses of sediment, scour and deposition.

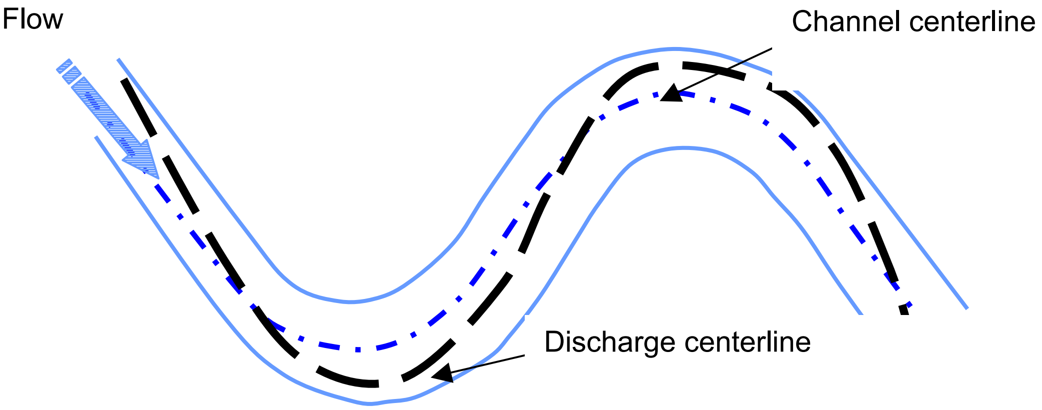
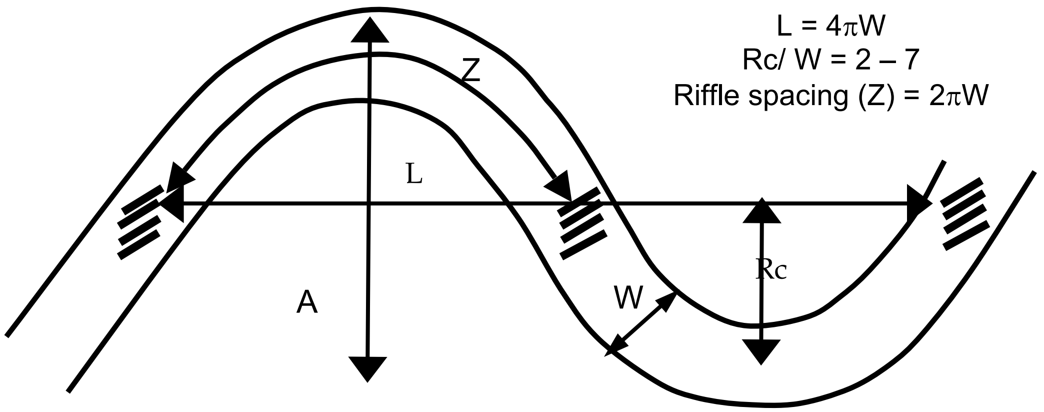


Figure 2: Channel centerline vs. discharge centerline.

Areas of scour and deposition alternate along the axis of discharge flow producing a pool along the outer bend and a corresponding point bar on the inner bend. As the pattern of scour and deposition alternates from one side of the channel to the other, the thalweg (deepest portion of the channel cross section) and maximum flow velocity cross over the center of the channel. Theses cross over points become the riffles. The alternating pattern of bar building and bank scour causes straight streams to evolve into meandering ones with a sinuous pattern. Specifically, this is how channelized reaches eventually reacquire a sinuous shape.

Although the process of creating riffles and pools encompasses highly variable processes, the riffles and pools occur at generally predictable intervals. The spacing of these riffles or pools along the thalweg relates closely to the width of the stream at the elevation of dominant discharge. The figure below illustrates riffle geometry in planform. Further, the spacing of the pools, which are near the outside bend and slightly downstream of the maximum curvature of the meander, have essentially the same relationship to channel width as the riffles.

In alluvial streams of homogeneous material, meanders take the form of sine-generated curves. Leopold and Langbein (1969) demonstrated that this shape is the most hydraulically efficient form for turning water. Further, Chang (1998) presents a more analytical assessment of this meander plan geometry. These relationships between stream width, riffle spacing, meander wavelength and radius of curvature are remarkably consistent for streams and rivers throughout the world.



$L = 4\pi W$

$Rc/ W = 2 – 7$

Riffle spacing (Z) = $2\pi W$

L = wavelength   Rc = radius of curvature

A = amplitude   W = width at dominant discharge

Figure 3: Meander geometry.

Most stable relationships in channel geometry include the channel width at the elevation corresponding to the dominant discharge. Riffle spacing (Z) generally occurs every 6.3 bank widths (W), where W is the width at the dominant discharge. This spacing is essentially $2\pi W$. Meander wavelength is approximately 12 bank widths, which approaches $4\pi W$.

The radius of curvature is also related to the channel width at dominant discharge elevation. The ratio of meander radius of curvature (R_c) to channel width (W) generally ranges between 2 and 7. Bagnold's (from Thorne et al, 1997) investigation of energy losses at bends confirmed the empirical observations by determining that flow energy losses are minimized through this shape. A tighter radius causes a flow separation and severe energy losses, a hydraulic inefficiency that is not persistent. In natural rivers, channel bends erode to a R_c/W ratio of 2-5 and then maintain that form, which indicates that the hydraulic efficiency is optimized by this form.

In streams containing heterogeneous media and in confined channels, the meander pattern is interrupted by variations in bank structure, infrastructure, confluences, geologic features and channel manipulation. Streams out of equilibrium also display distortions in meander pattern and growth. Nevertheless, the fundamental relationships describing these patterns remain broadly applicable.

Consistent with the location of peak stress downstream of each bend apex, meander waveforms migrate downstream. In stable streams, the meander migration generally occurs at a rate that does not affect infrastructure. However, accelerated migration may pose a substantial risk. While meander amplitudes can subside, the primary concern for most watershed managers is an increase in meander amplitude. The apex of the meander bend is rarely symmetrical and tends to skew downstream. As is the case of meander formation, the asymmetry of flow velocities strongly influences meander progression laterally and downstream. All of the processes that drive the formation of meanders remain active in the migration of meanders. As discussed previously, the discharge flow path (meander path) and the channel centerline are out of phase. The channel centerline lags the flow path because the channel formation is the feedback in response to the flow pattern. The point of maximum flow curvature is slightly downstream of the point of maximum channel curvature. Therefore, the boundary shear stress is highest slightly downstream of the bend apex. When the shear stress at this point exceeds the resistance of the bank, failure ensues and the eroded bank material migrates downstream to deposit in the subsequent point bar.

Geomorphic Evaluation, Data Gathering & Interpretation

The objective of our geomorphic analysis is to understand the stream dynamics and dominant fluvial process. This allows the designer to properly assess the likely response of the stream to a proposed action.

Geomorphic Background Investigation

The geomorphic evaluation consists of two phases: 1) the background investigation and 2) the geomorphic field investigation. The purpose of the background investigation is to provide an initial assessment of basin behavior as a whole. The evaluation included review of published soils data, flow data, and historic aerial photographs.

Soil Data

Review of USDA soils data provides insight on how local soils and underlying geology influences stream behavior. Local changes in soil type may indicate whether a particular reach of stream behaves in ways distinct from the entire watershed, revealing which areas may require different methods of management.

According to the USDA's 1982 publication, *Soil Survey of St. Louis County and St. Louis City, Missouri*, the study reach of Deer Creek flows through two major soil groups: Menfro-Urban land complex and Wilbur silt loam.

Menfro-Urban land complex, 5 to 9 percent slopes, consists of moderately sloping, well-drained Menfro soils and intermingled areas of Urban land. The Urban land part of this complex is covered by streets, parking lots, buildings, and other structures that so obscure or alter the soils that identification of the series is not feasible. The Menfro soils in this complex are in yards, open spaces between buildings, parks, gardens, and undeveloped random tracts. Permeability is moderate in the Menfro soils and moderate to moderately slow in reworked areas. The Urban land is impervious to water. Surface runoff is medium in this complex.

Wilbur silt loam is a nearly level, moderately well-drained soil found in small stream bottoms and adjacent to the channel of larger streams. This soil is frequently flooded, with moderate permeability, and slow surface runoff. Available water capacity is very high, and a seasonal high water table is at a depth of 3 feet or more during winter and in spring.

Flow Data

Daily streamflow data was obtained from the USGS (USGS Gage 07010055 Deer Creek at Litzsinger Road at Ladue, MO), available online at: http://nwis.waterdata.usgs.gov/mo/nwis/discharge/?site_no=07010055. USGS streamflow data was then correlated with NOAA Precipitation Data, available online at: http://www.crh.noaa.gov/lsx/f6.php.

Based upon the analysis of available streamflow and precipitation data, the dominant discharge for the study reach of Deer Creek was estimated to be approximately 560cfs, resulting from 2.6-inch, 24-hour precipitation events. This data corresponds closely with dominant discharge indicators measured in the field, such as scour and debris lines, occurring 4 to 6 feet above the channel bed.

Historic Aerial Photographs

Historic aerial photographs were examined for evidence of changes in the watershed that may have provoked the adjustments observed today. Digital aerial photographs were available from 1937 to 2002. The earliest aerial photographs reveal important background information about the watershed prior to widespread sub-urban development.

Prior to 1953, much of the Deer Creek Watershed from Litzsinger Road north to Highway 40 was undeveloped forest. By 1968, increasing sub-urban development resulted in a conversion of the original forest cover to large residential lot development. The once meandering channel had been straightened or channelized to accommodate residential development south of Highway 40. Additional channelization occurred between 1968 and 1981, with the removal of a large meander loop immediately upstream of the Litzsinger Ecology Center property. The net effect of channelization from 1968 to 1997 was an estimated loss of nearly 1, 000 linear feet of channel, or a reduction in reach sinuosity (channel length/valley length) from 1.9 to 1.4.

Geomorphic Field Investigation

The data gathering and analytical methods applied during the geomorphic field investigation are generally consistent with those of US Army Corps of Engineers (USACE) Engineering Manual 1110-2-4000, the Federal Emergency Management Agency's (FEMA) 1999 report to Congress, *Riverine Erosion Hazard Area Mapping Feasibility Study*, and professional river engineering literature (Thorne et al, 1997, Thorne, 1998). The methods adapted from these sources recognize that deposition and erosion hazards are inseparable, and are both consequences of the self-adjusting nature of rivers and streams.

Geomorphic data was collected on approximately 2,500 linear feet of channel. Data collection occurred during November of 2005. To improve the efficiency of data collection and reduce the likelihood of transcription error, all field data were collected in a hand-held computer in ArcPad format. Rayming® GPS units relayed location data to the computers via Bluetooth® interface. St. Louis County floodplain and drainage maps were used as base data, with Missouri State Plane 1927 projection. Immediately after field data collection, all data were downloaded to ArcView GIS format files.

The following data sets were compiled as a result of the field reconnaissance:

- Bank and bed materials
- Channel bed material consolidation and armoring
- Bar development
- Average bank slope angle
- Bank height
- Channel width
- Vegetative bank protection
- Riparian corridor condition
- Bank cutting
- Mass wasting
- Obstructions, flow deflectors (walls, bluffs) and sediment traps
- Channel constriction
- Indicators of effective discharge, scour and debris lines
- Representative channel cross sections

These data sets represent a total of 109 different data parameters, which are categorized in ArcPad by ten major themes. These themes include: 1) Material, 2) Bar, 3) Profile, 4) Channel Dimensions, 5) Erosion & Mass Wasting, 6) Vegetation, 7) Outfalls, 8) Crossings, 9) Photos, and 10) Notes.

The data organization is a modification of the approach described by Johnson, Gleason and Hey, (2001). Dr. Johnson's team developed an approach of rapid, efficient data collection, oriented towards assessing stability in streams affected by infrastructure. The following paragraphs describe the data collected and their relevance to channel process.

Material

The Material data theme consists of 12 individual bed and bank material data parameters, including material type, bed material shape, whether or not bed material is consolidated or imbricated, and approximate bed material gradation (D90, D60, etc.). Documentation of bed and bank materials and their distribution through the project reach informs assessments of present and future resistance to erosion. Rock or gravel sizes, such as D90 and D60, are used as indicators of stream power. In addition, consolidation and imbrication of bed material is used in conjunction with bar data to evaluate sediment transport competency.

Bar

The Bar theme is used primarily for developing an understanding of sediment transport, an often overlooked, but critically important stream process. The competence of the stream to carry its sediment load strongly influences both flooding and erosion. In short, a stable stream will transport the sediment load delivered to it without scouring its bed. If the stream has insufficient transport competence, the channel bed will aggrade and flood elevations may rise.

Conversely, if the stream has excess transport capacity, it will scour the channel bed and banks.

The Bar theme includes 16 data parameters, used in combination with bed material data to evaluate sediment transport competency. These include extent and type of bed sorting, pattern of bar placement, bar width relative to bed width, consolidation, vegetative condition and other indicators of potential bar advance. Assessment of bar condition is particularly useful in distinguishing between widening and meander adjustment, two stream processes associated with systemic bank failures. Bar evaluation is also helpful in temporal analysis of stream process and helps distinguish between ongoing and completed channel adjustments.

Profile (non-surveyed)

The longitudinal (long) profile is among the more important diagnostic methods in fluvial geomorphology. The long profile is a surveyed description of the bed slope, accomplished by traversing the channel and surveying the elevation of the thalweg profile. The long profile is particularly useful for diagnosing and locating channel incision and reveals sudden breaks in bed slope called knickpoints and the subtler but still recognizable change in slope over a short distance, indicating a knickzone.

While we recommend a surveyed long profile for final stream intervention designs, for the purposes of a field reconnaissance we visually identify and record the location of knickpoints in lieu of a long profile. The height of the knickpoint, bed material type, presence or absence of debris jams, and erosion patterns are all used to distinguish between active and completed channel incision. In addition, evaluation of pool-riffle sequence particularly relative to location in planform is useful in assessing potential planform migration.

Channel Dimensions

The Channel Dimensions theme is essentially channel cross-section information. In this theme, there are 27 parameters, including bed width, bank height, bank angle, top of bank width, scour line elevation, and lower limit of woody vegetation. The combined bank height and angle data are useful in distinguishing between fluvial and geotechnical causes of bank failure and, therefore, the appropriate approach to management.

Erosion and Mass Wasting

The Erosion and Mass Wasting theme includes both quantitative and qualitative data parameters used to identify lengths of channel experiencing active erosion or mass wasting, as well as the dominant mode of failure, such as scour, toppling, flow, wedge, or circular failure. Identifying the type of mass wasting is essential to understanding the mode of failure and to distinguish between systemic, local, or geotechnical failures. Scour patterns are also helpful when determining the systemic process driving the erosion.

Vegetation

The Vegetation theme contains 16 data parameters. Vegetative data includes the quality, size and structure of the riparian forest, percent of canopy cover and presence or absence of invasive species. Vegetative conditions such as “surfed” or toppled trees and freshly exposed roots are useful in estimating the degree of instability and progress towards recovery. In addition, the presence of native vegetation plays a role in stabilizing stream systems through mechanical reinforcement of stream banks by plant roots, soil moisture management through evapotranspiration, and hydraulic roughness at the bank toes.

Dominant and sub-dominant tree species and the successional status of the riparian corridor are also important to urban stream management. Invasive non-native species, such as bush honeysuckle, can interrupt the succession of more desirable tree and understory species that would not only provide greater habitat and ecological benefits, but also provide improved bank stability and scour resistance when compared to the shallow-rooted honeysuckles. From the same data, we can also infer the timing and degree of disturbance. For example, sudden changes in vegetation type often accompany localized problems, which helps distinguish between systemic and local concerns. Vegetative status also indicates how well the stream banks will respond to soil biostabilization and provides insight into the potential for habitat recovery.

Outfalls & Crossings

The Outfall and Crossing themes locate in-stream or near stream infrastructure. The location of outfalls, bridges and culverts is essential when considering design limitations and construction access. In addition, the condition of in-stream infrastructure can also provide clues to past and present channel conditions. For example, culverts and crossings can also act as process indicators. Undermined outfalls and culverts indicate the extent of channel incision, while discontinuities in energy distribution and sediment transport can be inferred from the depth and consolidation of deposits in culvert or bridge bays.

Photos & Notes

The last two themes are used mainly for recording supporting or miscellaneous information. Notes generally consist of short site descriptions or information that does not otherwise fit into any of the previously mentioned themes. Photos are taken at regular intervals, not only for internal QAQC practices, but to provide the client with a virtual walk-through of the study reach.

Reach Summary

Stream: Deer Creek
Watershed: Deer Creek Watershed
Length: Approximately 2,500 feet
Location: The study reach flows south from the northern property line of the Litzsinger Ecology Center to the Litzsinger Road Bridge.

Geomorphology:

<u>Dominant Fluvial Process</u>

Based on our geomorphic analysis, the study reach of Deer Creek appears to be adjusting in planform via meander migration. Meander migration includes lateral channel shift, expressed as an annual rate of distance moved perpendicular to the channel centerline, and down-valley migration, the annual distance moved downstream along the river valley. While meander migration is a natural phenomenon that occurs without anthropogenic influence, it may be exacerbated by watershed disturbances such as land use changes or urbanization, bridge or culvert construction, or the removal of riparian vegetation. Lateral meander migration along Deer Creek may have been provoked by loss of channel sinuosity due to channelization and excessive bedload. Since the channel bed is relatively resistant to incision, with exposed bedrock observed throughout the study reach, the stream has responded to increased flows by decreasing its slope via meandering, thereby increasing the channel length over the same change in elevation.

Evidence of meander adjustment includes the aggradation of bed material accompanied by the downstream progression of severe bank scouring opposite wide, steep-sided point bars. Erosion and mass wasting along meandering reaches occurs preferentially on the outside of meanders and extends downstream from the apex of the meander. Point bars are typically semi-consolidated, with steep downstream angles, and a bar width that exceeds the existing low flow channel width.

Indicators of meander adjustment –

- Aggradation of gravel and cobble bed material
- Preferential scour occurring on the outside of meanders
- Steep-sided point bars
- Bar width exceeding low flow channel width

Current Conditions

The study reach of Deer Creek begins at the northern property line of the Litzsinger Ecology Center. The channel bed width ranges from 30 to 40 feet and 50 to 100 feet wide from the top of either bank. Bed material is comprised of consolidated gravel and cobble bed material, with an average particle size of approximately 8 to 12 inches for D90 and 2 to 4 inches for D60.

Depositional gravel bars are common along this reach of Deer Creek. The bars are semi-consolidated, with relatively steep downstream angles (at 30 to 50 degree angles). Bar width exceeds the existing low flow channel width throughout the meandering reach, and bar height was measured from 6 to 7 feet above the existing water surface elevation.

Both stream banks are composed of silty clay soil, with occasional outcrops of exposed limestone bedrock or cherty parent material at the bank toe. Stable, vegetated banks along the study reach have been estimated to range in height from 4 to 12 feet at slopes of 10 to 50 degrees. Banks standing at angles greater than 60 degrees and exceeding 8 feet in height tend to be unstable and are prone to continued erosion or mass wasting until a stable bank height and slope is achieved. This includes many of the scoured banks occurring on the outside of meanders, accounting for more than half of the total length of channel bank along the study reach. Some scoured banks measure 10 to 12 feet in height and stand nearly vertical, at angles upwards of 70 degrees.

The riparian corridor is wide through the Ecology Center property, exceeding more than 100 feet in width along most of the reach, with the exception of the section of stream in close proximity to the entrance road and Ecology Center buildings along the top of the right descending bank. Overhanging trees, “surfed” trees and undercut root masses are present along this reach, indicating fresh bank scouring as well as past incision events that have left most mature trees perched 4 to 5 feet above the existing channel bed. The lower limit of woody vegetation varies widely, ranging from 1 to 8 feet above the channel bed, and is, therefore, an unreliable indicator of dominant discharge along this reach. However, deep scour lines consistently occurred 4 to 5 feet above the channel bed, indicating the depth of stream-forming flows.

Recommendations

Rates of lateral channel movement are generally related to the size of the channel. Annual migration rates typically range from 10 percent of the channel width to as high as 20 percent (Hooke, 1997). For Deer Creek, this would translate into a maximum annual bank recession of approximately 3 to 6 feet. Vegetative interventions, including bank revegetation, corridor expansion, and the removal and suppression of invasive plant species, have likely increased the resistance of streambanks to shear stress and erosion.

Riparian vegetation stabilizes streams hydrologically, hydraulically and mechanically. The hydrologic effect derives from trees' ability to withdraw water from the soil through evapotranspiration. The resulting increase in soil matric suction increases soil strength. The mechanical reinforcement derives from transfer of load from soil to root fibers under shear stress conditions. The mechanisms of soil-root interaction and the magnitude of root reinforcement have been investigated by Collison[1], Gray and Leiser[2], Wu and others. Through root reinforcement, soil shear strength can be doubled in well-vegetated soils. Finally, riparian vegetation protects stream banks through hydraulic interactions. The hydraulic roughness, afforded by flexible vegetation, shifts the high velocity flows away from the stream bank. By selectively shifting the high velocity flows toward the center of the channel, the shear stress on the stream bank is reduced thereby reducing scour at the toe of the slope.

However, while previously constructed, exclusively vegetative interventions may have slowed the advance of bank scouring and erosion, additional intervention strategies are necessary to mitigate the influence of meander adjustment. Controlling meander adjustment can be achieved by manipulating slope or bedload. Based upon the shape and angularity of the bed material occurring throughout the study reach of Deer Creek, much of the material has originated upstream and been transported some distance from elsewhere in the watershed. Therefore, limiting the influence of bedload would be difficult at best, but directing deposition of bed material and centering the channel thalweg is possible. This could be accomplished with the construction of rock stream barbs, directional weirs, or similar structures. Similarly, cross-channel weirs or grade controls can be used to induce a local reduction in channel slope, thereby reducing stream power and erosive energy.

Each of these intervention strategies employs the advantageous use of hard points. This allows the designer to balance energy, flow of water and flow of sediment by adjusting the distribution of energy. The simplest application of hard

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[1] Collison, A. and A. Simon, Proceedings American Society of Civil Engineers, Environment and Water Resource Institute Conference, Reno, NV 2001

[2] Gray, D.H. and A.T. Leiser, Biotechnical Slope Protection and Erosion Control, Krieger, Publishing Company, Malabar, FL, 1989

points is energy management using hydraulic roughness. Rough points created by designed structures or vegetation direct flow away from vulnerable areas. Strategic use of hydraulic roughness also dissipates energy and lowers the stress on bed and banks in general.

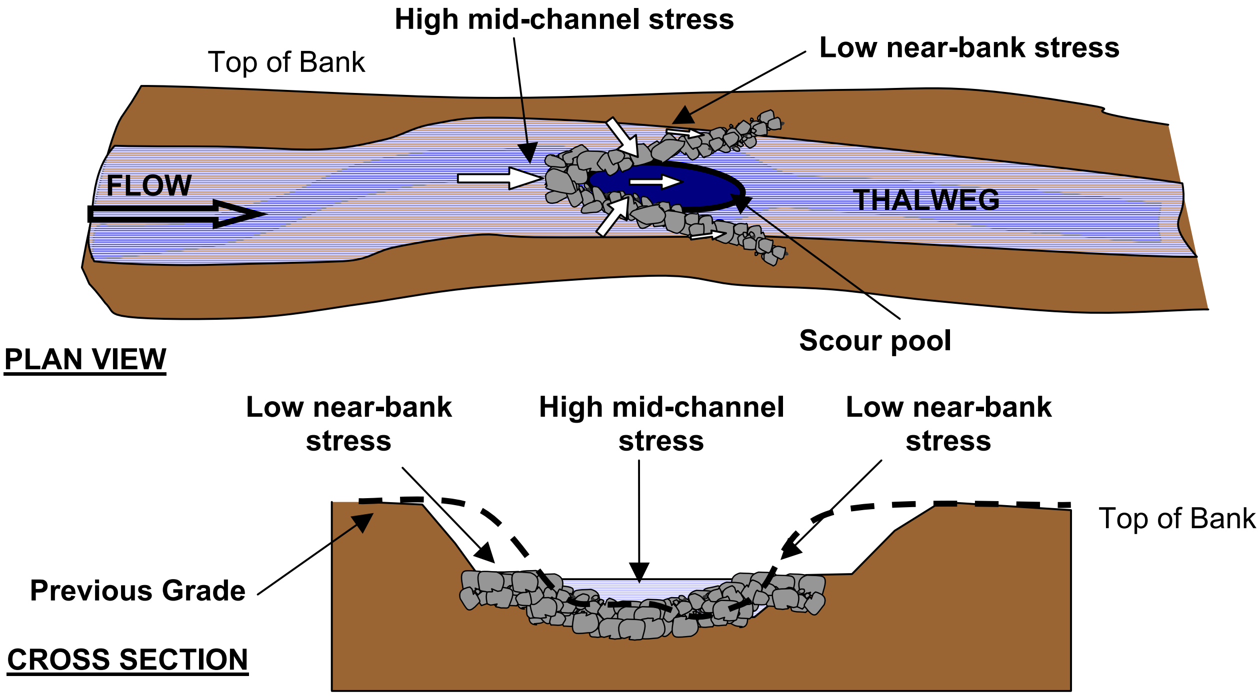

Figure 4: Schematic of cross-channel rock weir.

Maintaining the capacity to transport bedload through the study reach of Deer Creek is equally important for maintaining channel stability. This latter characteristic usually requires that high shear stress be maintained in the center of the channel. Shear stress is a function of depth of flow and slope. A cross-channel rock weir that is pointed upstream and angled down from the bank to the center of the channel has both the maximum depth and slope in the center of the channel. Flow depth decreases gradually as the weir approaches the bank. Although water piles up due to drag along the stream bank, slope for the upstream pointed structure decreases parallel to the bank. Because the weir is pointed upstream, the slope parallel to the bank is lower because the crest width is longer relative to the bank rather than perpendicular to the weir. The distribution of shear stress is non-uniform across the rock weir. The unit shear stress (shear stress per unit width) is high in the center of the channel and near zero at the stream bank. Therefore, upstream directed structures fulfill both requirements; near bank stress is low and the center channel stress is high. In-stream structures need not be symmetrical. Often the departure angles are different on the left and right sides of the structure when guiding flow through a meander or protecting bridge piers is part of the design intent. Figure 4 illustrates the shear stress distribution across a common type of rock weir.

We recommend completing a detailed design analysis, including a hydrologic/hydraulic analysis to confirm the diagnosis presented in this report. This would allow the design and strategic placement of structures such as cross-channel rock weirs to center the thalweg and reduce near-bank shear stress. In addition, vegetated rock toe armor and stream barbs along the outside of meanders would protect eroding banks from continued toe scour, and direct the thalweg away from critical infrastructure and threatened property, such as the entrance road and Ecology Center buildings.

Trail erosion along the top of the right descending bank is an additional concern of the Center. We recommend evaluating and designing erosion control measures such as coir log flow spreaders, vegetated sills, or a variety of other techniques to address overbank erosion.