Section 3
Sugar Creek Geomorphologic Assessment

3.1 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.

3.1.1 Major Models

Streams exist in a state of dynamic equilibrium in which the forces driving channel form are balanced by the resisting forces. The driving force is gravity. It acts on the stream as the rate at which water and sediment move through a stream. 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) plan form 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.

While gravity and friction are first principles and drivers of channel form at the most fundamental levels, stream managers grapple with their many manifestations including sediment source, sizes and abundance, varying hydrologic conditions, vegetative influences and a broad range of geological influences. 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 such as Sugar Creek, the chosen approach evaluates each channel process separately then develops an integrated assessment using energy relationships.

Although there are three commonly recognized approaches to stream design, each with advantages and limitations (Skidmore et al., 2001), the two simplest approaches, often called analog and empirical methods, explicitly assume equilibrium conditions regarding hydrology and sediment transport. Because Sugar Creek is not in equilibrium, the third approach called the analytical method is more appropriate and was used in this study.

3.1.2 Lane's Relationship

In 1955, E. W. Lane expressed the relationships between the driving and resisting forces for channel change in the following simple proportionality. The expression is also illustrated on **Figure 3.1.1**.

$$Q_S\ D_{50}\ \alpha\ S\ Q_W$$

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 [1]

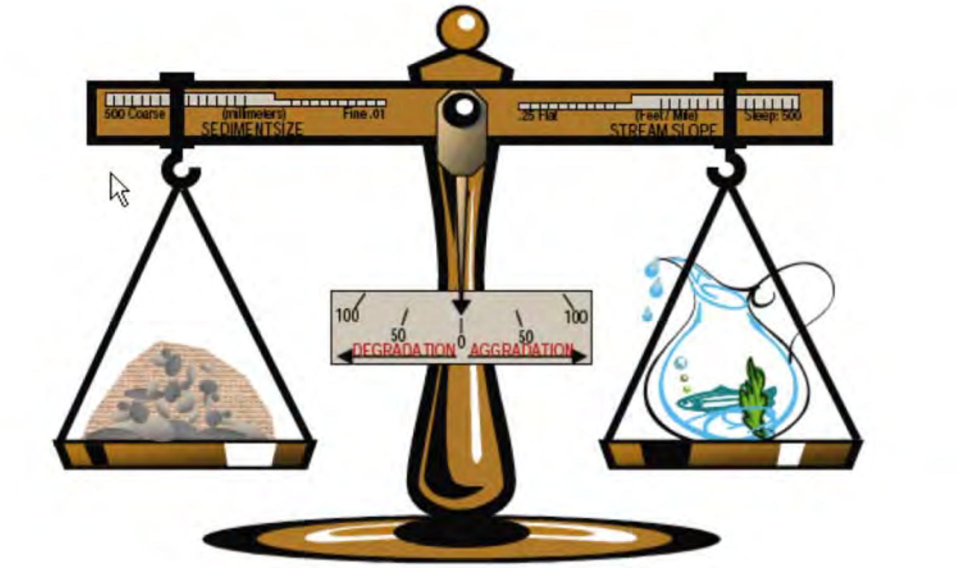


Figure 3.1.1. Lanes Balance - Sediment Load X Sediment Size ∝ Sediment Slope X Water Discharge

Here the D50 stands as proxy for boundary strength and S for channel slope. 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 flow discharge Qw 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 as described below:

> *Initial change:* $Q_W \Uparrow$*; followed by the response:* $Q_S \Uparrow$. With an increase in water flow, the bed slope often remains relatively unchanged at first, so to maintain the proportionality, Qs increases. The increase in sediment load is generated

---

[1] Adapted from Lane, E.W., The Importance of Fluvial Geomorphology in Hydraulic Engineering, J. Hydraulic Engineering, 1955.

by down cutting of the channel bed (incision), scour of the streambanks 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 knick point. Knick points migrate upstream liberating sediment as they progress. When the streambanks exceed their critical height, mass failure ensues. This reconfiguring of the channel geometry continues until the equilibrium described by Lane is reestablished.

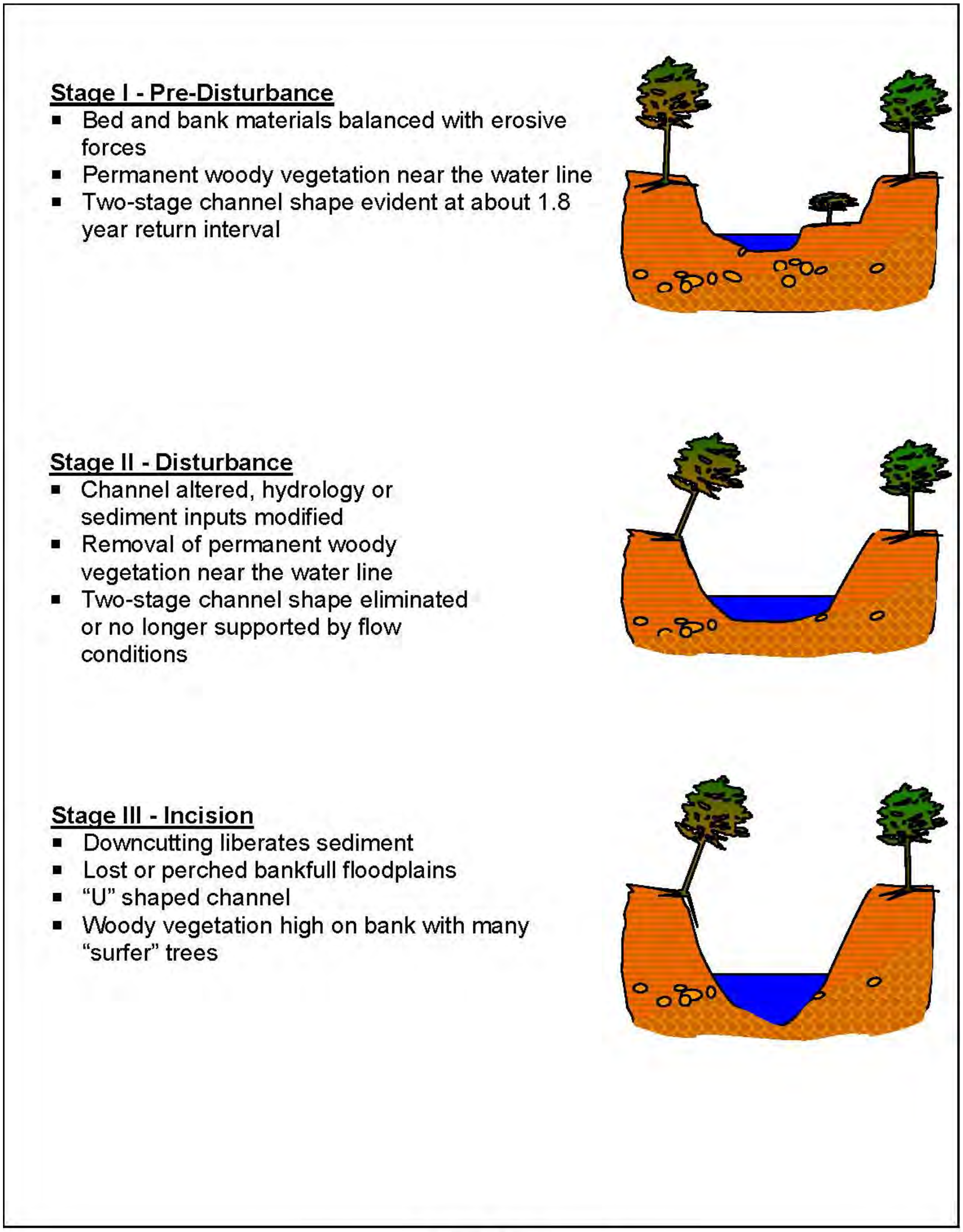
Initial change: Q_W ⇑; followed by the response: S ⇓. If the channel bed is relatively resistant to incision such as in the reaches with clay in the bed, the stream may respond to increased flows by decreasing its slope. The stream accomplishes this decrease in slope by meandering or increasing the channel 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.

Initial change: S ⇑; followed by the response: Q_S ⇑. Increasing channel slope is often accomplished through channel straightening or dredging 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 or dredging, extending the accelerated erosion. The sediment eroded from upstream of the channelization or dredging and deposited downstream counteracts the effect of the channelization or dredging and improvements in flood conveyance are often less than anticipated.

Lane's Relationship is useful for broad conceptual understanding of stream behavior. The following models address stream process more specifically.

3.1.3 Channel Evolution – Evaluating Channel Changes in Cross Section

When considering streams from a management perspective, it is especially helpful to note that streams trend toward the equilibrium condition. In other words, they respond to changes in their watershed by adjusting their shape until they are back in equilibrium. Schumm (1984) and most recently Simon (1989) have described a process by which streams reacquire equilibrium after a disturbance in the watershed. Simon separates changes in channel morphology into six stages: I) Pre-Disturbance, II) Disturbance, III) Incision, IV) Widening, V) Deposition, and VI) Recovery and Reconstruction. Determining the phase of channel evolution in the various project reaches was an important part of the analysis. **Figures 3.1.2 and 3.1.3** illustrate these phases.



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

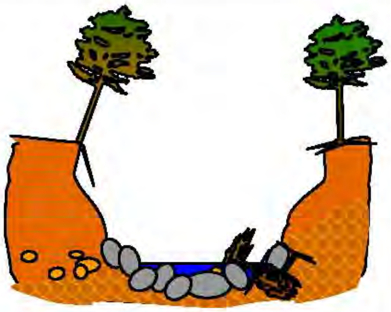
Stage III - Incision

- Downcutting liberates sediment
- Lost or perched bankfull floodplains
- “U” shaped channel
- Woody vegetation high on bank with many “surfer” trees

Figure 3.1.2. Channel Evolution Model

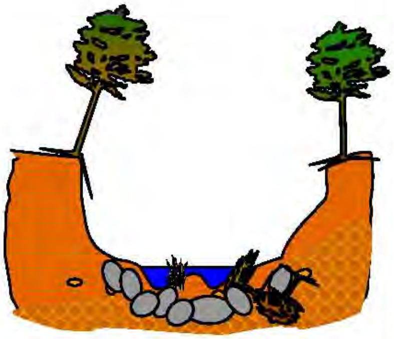
Stage IV - Channel Widening

- 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, rocks fall into channel



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

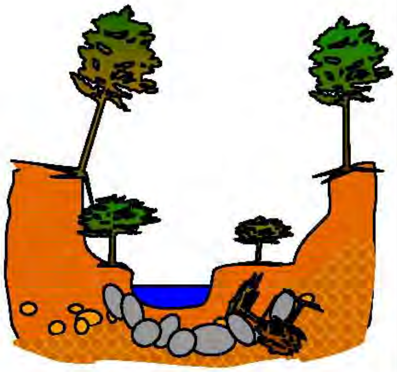


Figure 3.1.3. Channel Evolution Model

At Stage I, the channel is stable and transports the water and sediment delivered to it without significant adjustment **(Figure 3.1.4)**. Although not a universal feature, internal floodplains are common in stable streams including those in the Southeastern US. 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. In urban basins with uncontrolled stormwater discharges this discharge may occur 5 to 10 times each year. 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 direct alteration of channel dimensions or alignment, or increases in the rate, volume or timing of flow.

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 knick point or knick zone. The typical shape of these channels is V- shaped or narrow U-shaped (Figure 3.1.4)**.** Incision proceeds until the channel has reached a stable slope, the incision reaches a more resistant layer or the streambanks begin failing because of mass wasting.

Channel widening through mass wasting of the streambanks, Stage IV, follows incision. Here trees toppled into the stream and banks retreat from abutments and other infrastructure. 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 streambanks exceed their critical height and fail. Both mechanisms may operate in a stream and illustrates this phase (**Figure 3.1.5**).

3.1.4 Meander Formation and Migration – Evaluating Channel Change in Plan Form

Adjustments in plan form 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 plan form adjustments can liberate significant sediment and present major erosion hazards. The management requirements of plan form adjustment differ from those of an incising or widening stream. Consequently, distinguishing between these processes was an important part of the investigation and analysis.

Figure 3.1.4. Illustration of a Stable Channel

Figure 3.1.5. Illustration of a Failing (severely incising) Channel

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. This includes pool-riffle patterns and meanders that help maintain an equilibrium condition. Meander formation demonstrates the principle of cause and effect. The cause is the force applied by moving water and sediment and the effect is the shape of stream channel.

To describe the process of meander formation, the distinction between the meander flow or discharge centerline and the channel centerline is important. As illustrated in **Figure 3.1.6**, 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 nonuniform across the channel. These areas of turbulence produce alternating pulses of sediment, scour, and deposition.

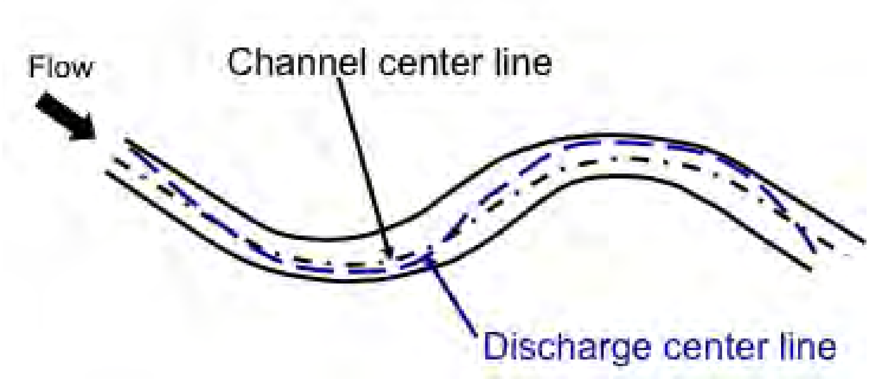


Figure 3.1.6. Mechanics of Meander Creation

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 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. These 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 is highly variable, the riffles and pools occur at 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. **Figure 3.1.7** illustrates riffle geometry in plan form. 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.

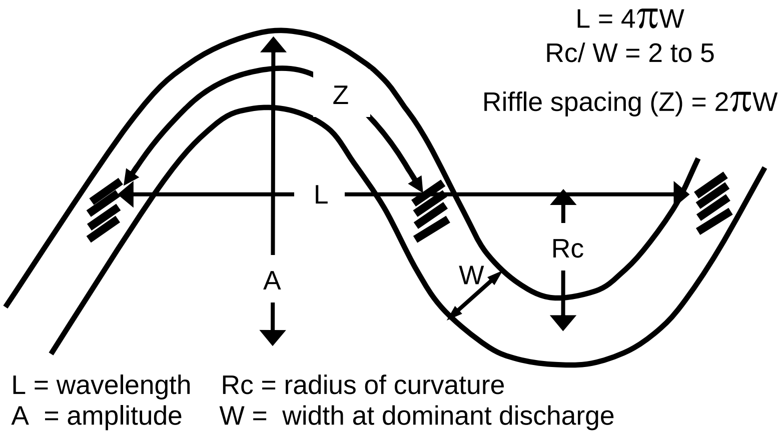


Figure 3.1.7. Meander Geometry

In alluvial streams of homogeneous material such as sand, 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. These relationships between stream width, riffle spacing, meander wavelength and radius of curvature are remarkably consistent for streams and rivers throughout the world.

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 2πW. Meander wavelength is approximately 12 bank widths, which approaches 4πW.

The radius of curvature is also related to the channel width at dominant discharge elevation. The ratio of meander radius of curvature (Rc) 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 an Rc/W ratio from 2 to 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 applicable.

Because the peak stress is just downstream of the apex of each bend, 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. A rapid increase in sediment load delivered from an incising or widening reach upstream is the most likely trigger for accelerated migration in Sugar Creek.

3.1.5 Profile Analysis

Sugar Creek flows through some reaches with clay beds and others with sand beds. Although the clay bed can and does downcut, the sandbed reaches are more prone to rapid incision. A profile analysis reveals reaches where, by virtue of bed slope and material strength, incision is likely. Abrupt changes in channel profile indicate areas where incision is occurring now or where the degradation is arrested by manmade or natural structures. In Sugar Creek, woody debris jams are the most common natural structures restraining the advance of incision. The advancing front of incision is known as a knick point or where slope changes are slightly less abrupt, knick zone. It is especially important to identify and manage incision because it usually precedes processes that are more destructive.

Some designers consider sediment transport competency for major projects by establishing a sediment budget to analyze sediment movement through the designed intervention. More sophisticated techniques include computer based analyses. For small projects, it is usually difficult to justify a sophisticated model. The designer, however, can achieve a basic understanding of sediment transport competency and erosion hazard from data and analyses used to determine water surface elevations. The designer estimates area of erosion and deposition from the continuity of the stream power or boundary shear stress. Routines in the hydraulic models calculate stream power and boundary shear stress. The values of either stream power or boundary shear stress are plotted against the longitudinal profile. The designer compares the zones of highest and lowest values to his field observations of size and distribution of bed material and the location of scour and erosion. The designer then establishes threshold values from these observations. Improved sediment transport competency results from using these threshold values in design. Boundary shear stress is the product of density, depth and slope. The designer predicts areas of scour and erosion by comparing the boundary shear stress to the shear resistance of the bed or bank toe materials. The shear resistance for granular materials is calculated using empirical relationships. The shear resistance for cohesive materials is usually compared to measured or tabulated values.

Lane's proportionality allows the designer to understand and predict the effect of forces on a stream. Energy and continuity equations allow the designer to predict the depth and average velocity at any point. The energy and continuity equations are the bases for understanding the exchange of energy modes. Perhaps the simplest useful way to apply these principles is to think of energy as either kinetic or potential. For the purposes of stormwater, flooding occurs when potential energy is higher than we can accept and accelerated erosion occurs when kinetic energy is higher than we accept.

3.1.6 Temporal and Spatial Implications

The location of a stream in its watershed influences the dominant process in that reach as **Figure 3.1.8** illustrates. Most commonly, the upper reaches and headwaters tributaries are the generators of sediment; the mid section of the watershed usually transports sediment without major sedimentation or erosion and the lowest reaches deposit sediment. This broad pattern holds for each sub-unit of the watershed. So each tributary will have an erosional reach, a transport reach and a depositional reach.

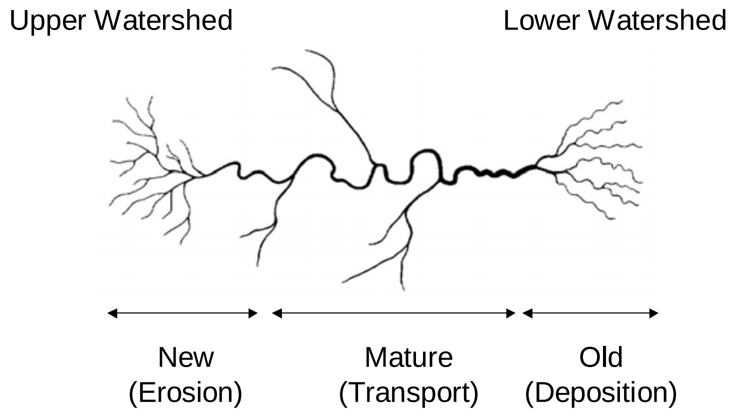


Figure 3.1.8. Influence of Watershed Location on Dominant Process

As shown on **Figure 3.1.9**, the profile of the channel slope becomes flatter progressing downstream. In the most general sense, incision dominates the steep, upper watershed and plan form adjustments are most common in the relatively flat lower watershed.

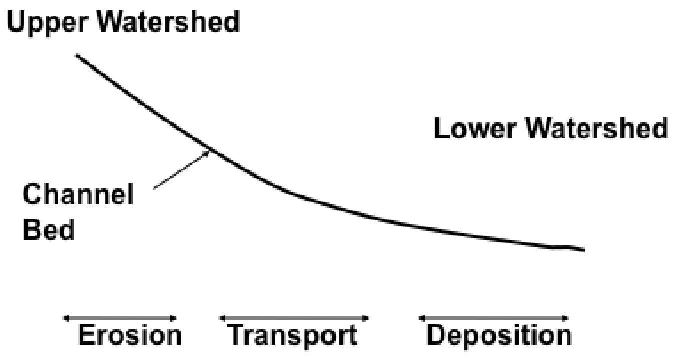


Figure 3.1.9. Sediment Transport Zones

Stream crossings such as bridges and culverts can also reset river formation, as shown on **Figure 3.1.10**. In developing areas, the characteristic profile shape of natural watersheds may be repeated after each hard crossing that influences transport of water and sediment. These obstructions may geomorphically isolate the reach.

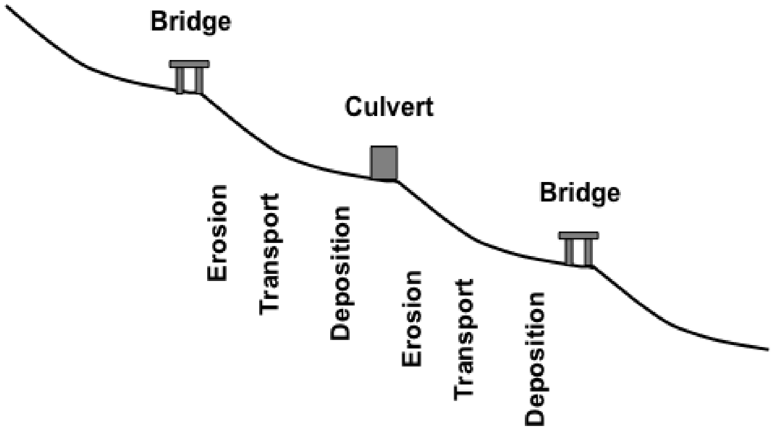


Figure 3.1.10. Geomorphic Isolation by Infrastructure

3.1.7 Sediment Transport

Natural channels transport both water and sediment through the watershed. Sediment and water movement play parallel roles in flood and erosion control and in the performance of bridges and culverts. For this discussion, sediment includes large woody debris, man-introduced materials, and other debris that comes to rest on the streambed. A stream in dynamic equilibrium maintains the movement of water and sediment without sudden and wholesale areas of erosion and deposition. Flow rate governs both the initiation of sediment movement and its deposition. Flow moves material when the system has sufficient kinetic energy and deposits it when the kinetic energy is depleted. As described earlier, gravity, expressed here as hydraulic slope, is the driving force acting on the system. The movement of water transfers that force to dislodge and keep particles moving. **Figure 3.1.11** is a generic hydrograph and sedigraph relating the rate of flow to time. Note that there is a lag between the flow of water and the movement of sediment. The lag represents the flow necessary to exceed the critical shear stress. At the peak water flow, there is often a decrease in the transport of sediment as the hydraulic slope decreases. The falling leg of the hygrograph may coincide with the peak of the sedigraph with the particles already mobile and an increase in hydraulic slope.

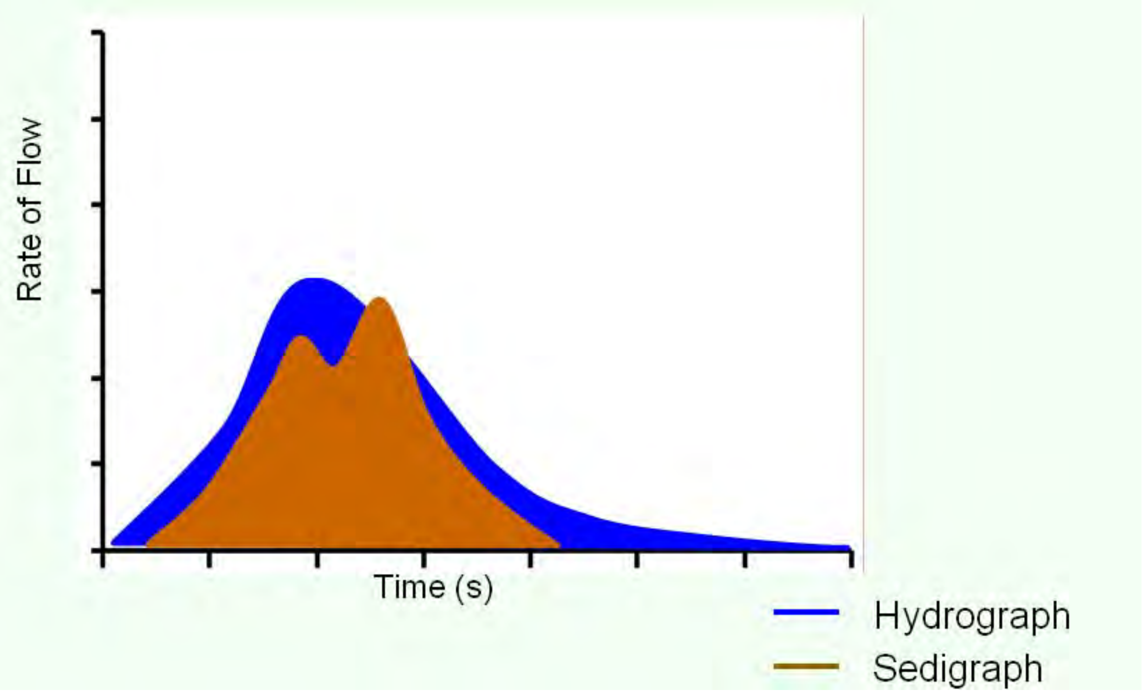


Figure 3.1.11. Influence of Hydrology on Sediment Transport

As the flow recedes and kinetic energy declines, the stream deposits particles of decreasing particle size. This process forms the riffles between pools. In Sugar Creek, this is most apparent where the woody debris jams morphologically behave as riffles. Issues of sediment transport are particularly relevant to stream managers at infrastructure crossings. Bridge, culvert, and pipeline crossings may interrupt the hydraulic slope with predictable, adverse consequences. A crossing backwatered under high flow conditions decreases the hydraulic slope and may induce deposition

that reduces flow capacity. Over-widened or excessively smooth crossings increase hydraulic slope and induce scour. The scour may occur immediately downstream and undermine the structure or may, as the result of an upstream drawdown curve, induce incision. This incision migrates upstream until the stream reaches a stable bed slope.

Management activities that remove or add material to the stream also interrupt equilibrium sediment transport and may have similarly adverse consequences. Snagging, straightening, and widening a channel all disrupt the sediment balance. These and similar activities induce upstream erosion and eventual deposition at the site of disturbance. Undesigned bank armor such as dumped riprap or waste concrete disrupts sediment transport when it migrates into the bed. These large, rough particles induce deposition where they enter the bed but induce scour downstream. Dumping materials on the bed can also reset the pool and riffle sequence if the dumped material becomes the hardest point in the reach.

3.2 Methods of Geomorphic Investigation

The purpose of the geomorphic investigation was threefold: first, to evaluate the physical stability of the stream under current and past conditions; second, to make reasonable predictions about how the stream will change under the proposed future conditions; and third, to make concept-level design recommendations for managing the stream.

3.2.1 Geomorphic Background Investigation

The purpose of the background investigation is assessment of basin behavior as a whole. This provides the context in which to understand the conditions in each reach. The elements of the evaluation were a drainage basin analysis, plan form analysis, and interpretation of historical aerial photographs. The City provided aerial photographs and GIS layers for all three analyses. Both drainage basin analysis and photo interpretation were conducted in general agreement with the methods of Lueder (1959).

The drainage basin analysis provides insight on how local geology influences stream behavior and whether one or more subareas behave in ways distinct from the basin as a whole. This may be an indication that such subareas require different methods of analysis or management.

The meander patterns for Sugar Creek reveal rough guidelines for how the geometries change throughout the watershed. The measurements were conducted in general compliance with Chang (1998), Leopold and Langbein (1969), and USACE (1993). Those areas where meander geometry, particularly radius of curvature, was substantially outside the norm for alluvial streams were noted for closer examination in the field. Other photographic evidence of active channel adjustment such as

multiple in-channel bars, advancing bars, or evidence of systemic mass wasting were also noted for field examination.

3.2.2 Geomorphic Field Investigation

Geomorphologists collected field data on approximately 16,300 linear feet of channel. The detailed investigation was limited to the main stem of Sugar Creek from River Street to the confluence with Two Mile Creek. A reconnaissance level review of approximately 7,200 feet of Hightower Creek and Brown's Canal preceded the main stem field work. Most of the data collection occurred on January 14 and 15, 2010. To improve the efficiency of data collection and reduce the likelihood of transcription errors, all field data were collected in hand-held computers in ArcPad format. The City supplied base data and projection files. Immediately after field collection, all data were downloaded to ArcView files.

The following 10 themes shown in **Table 3.2.1** represent the collected field data. The themes include 109 data parameters.

Table 3.2.1. Geomorphic Field Data

Bed and Bank material type (collected separately) and bed consolidation
Channel bar type and condition
Channel profile
Channel cross section
Erosion and mass wasting
Vegetative bank protection and condition of riparian corridor
Outfalls
Infrastructure crossings
Photographs
Notes

The data organization is a modification of the approach described by Johnson, Gleason, and Hey (1999). Dr. Johnson's team developed an approach of rapid, efficient data collection that is oriented towards assessing stability in streams affected by infrastructure. The paragraphs below detail the data collected and their relevance to channel process.

Material

The material theme consists of 12 bed and bank material parameters, including bed or bank material type, bed material shape, degree of consolidation or imbrication, and approximates bed material gradation (D90, D60, etc.). These data and their distribution through the project reach inform assessments of present and future resistance to erosion. Particle sizes, such as D90 and D50, are 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 bar theme includes 16 parameters. These include extent and type of bed sorting (generally coarse to fine proceeding downstream), pattern of bar placement, bar width relative to stream 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 Features (non-surveyed)

This theme included the location of knick points and the tops of pool-riffle sequences. The height of the knick point, bed material type, presence or absence of debris jams, and erosion patterns are all used to distinguish between active and completed channel incision. Evaluation of pool-riffle sequence, particularly relative to location in plan form, is useful in assessing potential plan form 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 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 failure mode and to distinguish between systemic, local, and geotechnical failures. Scour patterns are also helpful in determining the systemic process driving the erosion.

Vegetation

The vegetation theme contains 16 elements. Vegetative data include the quality, size, and structure of the riparian forest, percent of canopy cover, and presence or absence of invasive species. Native vegetation plays a role in stabilizing stream systems through mechanical reinforcement of streambanks by plant roots, soil moisture management through evapotranspiration, and hydraulic roughness at the bank toes.

Vegetative conditions such as surfed or toppled trees, freshly exposed, or barked over roots are useful in estimating the degree of instability and progress towards recovery.

Outfalls and Infrastructure 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 and Notes

The last two themes mainly include 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 quality assurance and quality control practices, but also to provide the user with a virtual walk through of the study reach.

3.3 Sugar Creek Evaluation

3.3.1 Geomorphic Field Investigation

Most of Sugar Creek is unstable. **Figure 3.3.1** illustrates the dominant processes throughout the mainstem. This stream, including its tributaries has the steep banks and U-shaped cross section that is typical of incised streams. Trees perched on the bank 5-8 feet above the flow line with their exposed barked-over roots indicate that some of these incision episodes occurred years ago. This stream may have worked through the phases of channel evolution many times. Active knick points in the channel bed indicate that some reaches are continuing to incise. Both channelization which steepened the bed slope and increased the shear stress acting on the channel and the increased flow from urban development are the primary causes of the streams' poor physical condition today.

In the upper watershed, instability most commonly occurs as incision, a downward cutting of the channel, migrating upstream from the lower main stem and extending through the tributaries. It is important to note that tributaries and gullies match grade with their receiving waters. This means that an incision event near the bottom of the basin has the potential to migrate through the entire stream network. As the incision moves upstream through the tributaries, some of the sediment generated there is transported down to the mainstem. Between the One Mile Creek confluence and Baytree Road, transient bar building and widening predominate. In the lower reaches, particularly below Baytree Road, deposition is the dominant process.

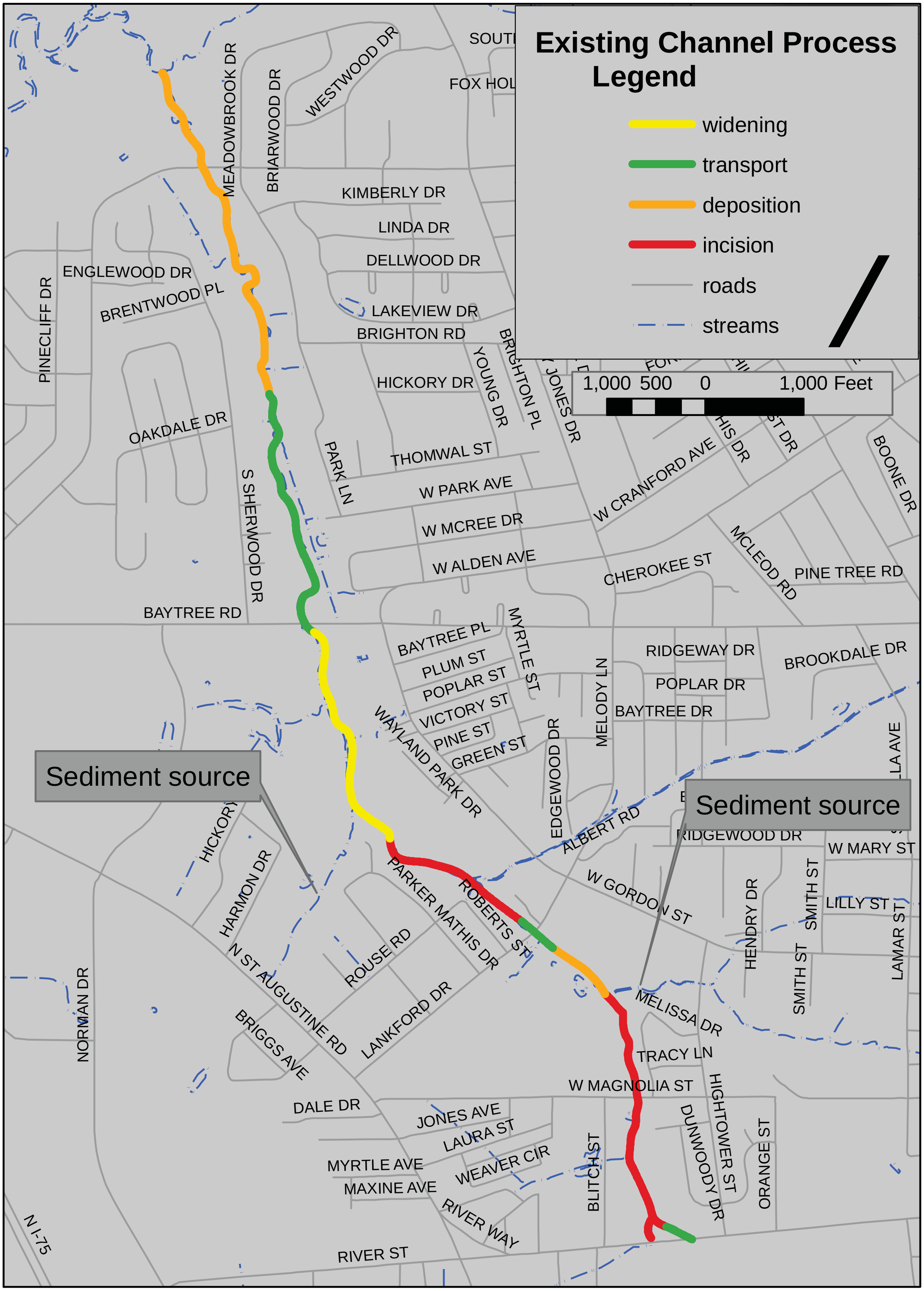


Figure 3.3.1

Dominant Processes through Sugar Creek Main Stem

Where sand and sandy loam dominate, the bed and bank materials are relatively weak and are responsive to increased stress. Conversely, the clay and sandy clay reaches are more resistant to migration. Regardless of the mechanism, streambank failures, though isolated, occur in all parts of the watershed.

For all of the reaches described below, the most significant geomorphic features including profile points (riffles, knick points and knick zones) as well as sand bars and debris jams are illustrated on **Figure 3.3.2**. **Figure 3.3.3** integrates the data presented on Figures 3.3.1 and 3.3.2 and demonstrates the connection between channel features and fluvial process.

3.3.2 Major Reaches of the Main Stem

River Street to Lankford Drive:

Channel Length: 3516 feet

Reach Average Bed Slope: 1.00%

The reach begins at John W. Saunders Memorial Park, south of River Street. Much of the park's open space is maintained in turf grass and it did not appear that the hard surfaces had any associated stormwater storage. Even this high in the watershed, the stream is damaged. The channels are incised and while there are some mature pines along the stream, the bank is vegetated with turf, which provides very little erosion protection. Crossing River Street, some of the scoured material from upstream is deposited in the right side of the culvert on the eastern branch. This branch has a roughly 3-foot knick point in clay approximately 250 feet downstream of the culvert (**Figure 3.3.4**). Both the east and west branches have aerial sanitary lines (**Figure 3.3.5**). While water quality sampling is not part of this scope, the stream has areas of abundant foam and the distinctive odor that is indicative of leaking sewer lines (**Figure 3.3.6**).

The reach has a consistent series of knick zones, knick points and glides in a clay bed (**Figure 3.3.7**). Glides are smooth, steep reaches. The knick points are almost certainly actively incising. A comparison of bed shear resistance and applied shear stress from the hydraulic model will be the definitive diagnostic. An abundance of leaning and "surfed" trees as well as trees canted towards the channel low on the bole but straightened back to vertical higher up the trunk is a clear indication that waves of incision have moved through this reach for many years (**Figure 3.3.8**). While local obstructions such as a downed tree cause local sedimentation, there is little systemic sediment deposition until about 400 upstream of W. Magnolia Street. Here sand is deposited over the clay bed as the bed slope flattens. Roughly 80 feet upstream of the W. Magnolia Street culvert is a depositional shelf approximately 2 feet high and 8 feet wide (**Figure 3.3.9**). The stream channel has been over-widened to accommodate the double box culvert. In response to the over-widening, the channel eroded the bed and banks upstream and deposited the sediment in a long, stable shelf along the left descending bank in front of the culvert.

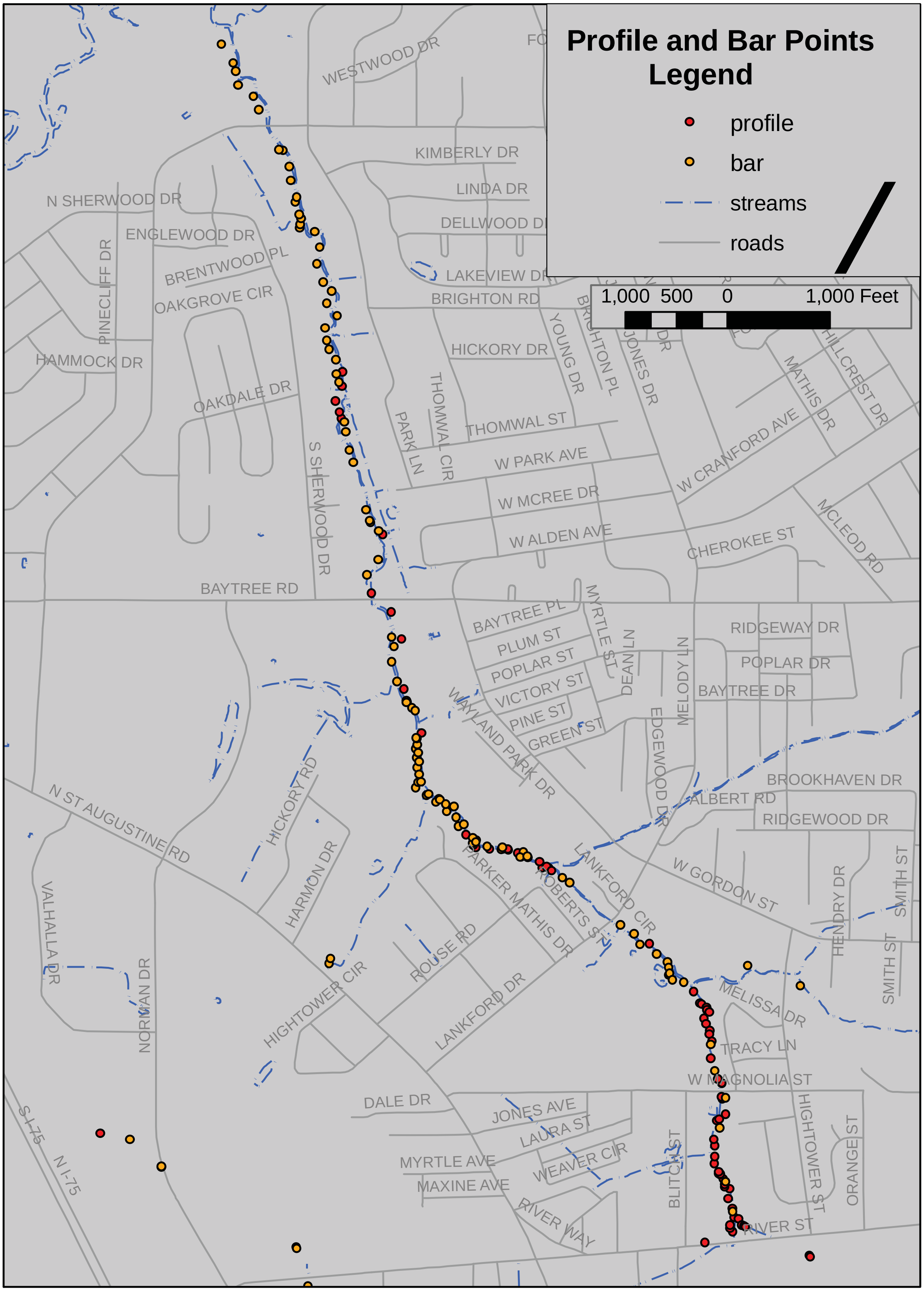


Figure 3.3.2
Geomorphic Features in Sugar Creek

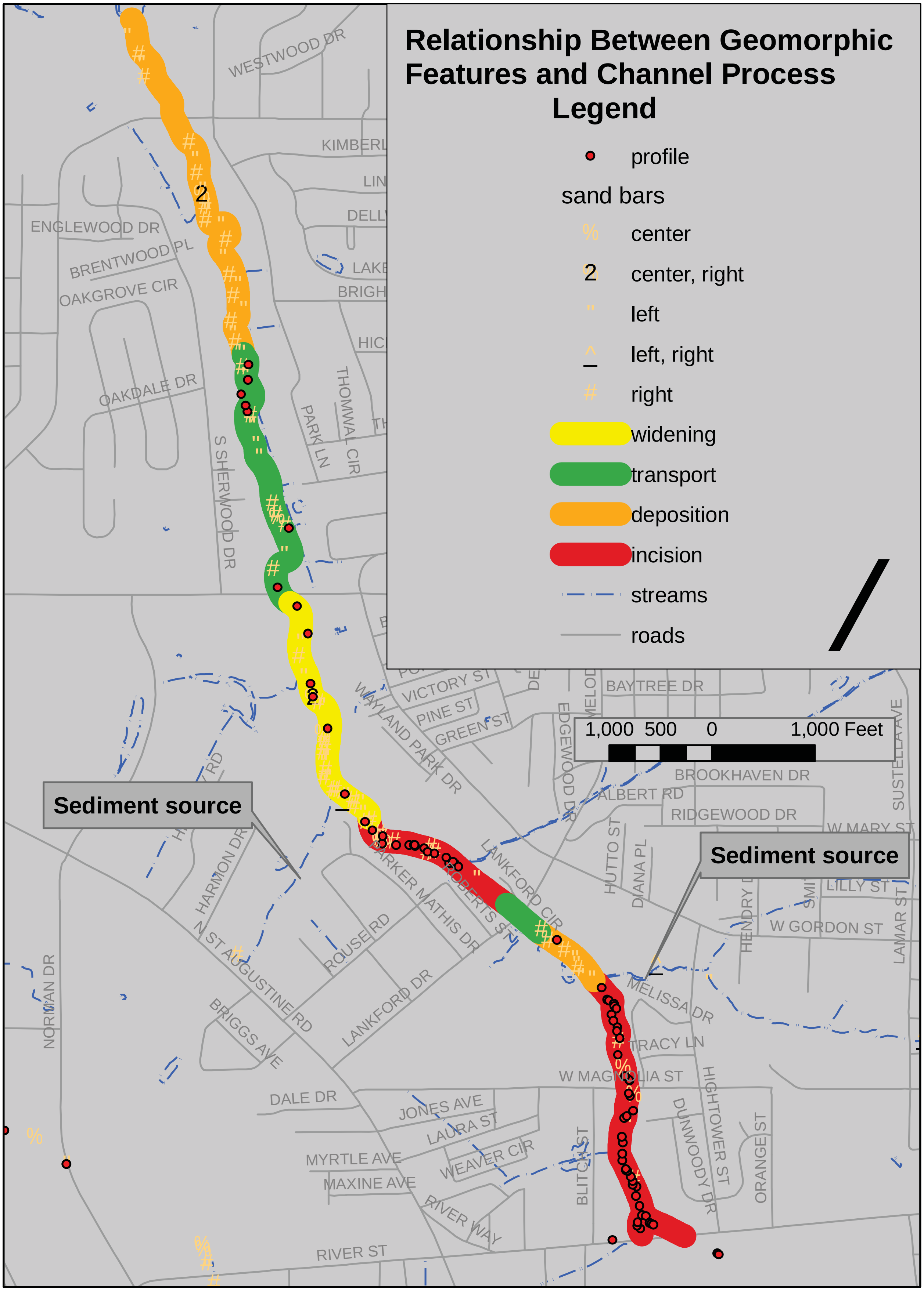


Figure 3.3.3
Geomorphic Features and Channel Processes in Sugar Creek

Figure 3.3.4. Knick Point 250 feet Downstream of River Street

Figure 3.3.5. Aerial Sanitary Lines

Figure 3.3.6. Foam Observations

Figure 3.3.7. Knick Points and Glides

Figure 3.3.8. Indications of Long-term Erosion and Tree Adaptation

Figure 3.3.9. Depositional Shelf 80 feet Upstream of W. Magnolia Street

The bay on the right side of the stream is the preferential flow path during low flows with the left bay receiving flows only in higher flow events. Through this depositional feature, the stream has created a more stable cross-section, one that it will recreate each time its stable channel dimensions are disturbed. This means that if the shelf upstream of the culvert is cleared away in an attempt to increase conveyance, the stream will promptly erode the bed and banks upstream and place that material to form a new shelf.

On the downstream side of the W. Magnolia Street culvert there are deep, advancing gullies approaching the street through the denuded bank. Proceeding downstream, the gullies are often filled with garbage and debris (**Figure 3.3.10**). Downstream of W. Magnolia Street, the channel steepens again and the knick points are once again common features of the clayey bed, including a 3-foot drop about 400 feet downstream of the W. Magnolia Street culvert (**Figure 3.3.11**). The reach has frequent debris jams usually composed of household garbage dumped into the stream (**Figure 3.3.12**). The knick zones and knick points occur roughly every 50 to 100 feet until the confluence with Brown’s Canal. At this confluence, the dominant fluvial process shifts abruptly from incision to deposition. Brown’s Canal is delivering abundant sand to the main stem. Downstream of the confluence sand bar formation is more common and the bars exert a greater influence on channel stability.

Lankford Drive to Baytree Road

Reach Length: 4315 feet

Reach Average Slope: 0.41%

Proceeding downstream from Lankford Drive, the stream is deeply incised and there is a particularly large log jam storing sediment about 450 feet downstream of the crossing followed by a series of knick points. The depth of incision is approximately 5-7 feet based on the height of mature trees above the low flow line. At the confluence with One Mile Creek, the depositional pattern begins again though to a lesser degree than at the Brown’s Canal confluence. One Mile is also deeply incised and the high channel bars just downstream of the confluence indicate that this stream is also a sediment source. Sugar Creek is storing some of this sand near the confluence. However about 500 feet downstream of the confluence with One Mile, the Sugar Creek bed is exposed clay and the channel is characterized by a series of riffles and relatively small knick points. This sequence of high bars storing sand and in some cases advancing across the channel interspersed with locally steeper clay or gravel bed repeats several times in this reach. While not consolidated or persistent, advancing sand bars are driving scouring flows against the opposite bank, and widening the channel though at a much slower rate than would occur if the bars could consolidate (**Figure 3.3.13**).

Figure 3.3.10. Gullies Filled with Garbage and Debris Downstream of W. Magnolia St.

Figure 3.3.11. Knick Point about 400 feet Downstream of W. Magnolia Street

Figure 3.3.12. Debris Jam Composed of Household Garbage

Figure 3.3.13. Advancing Sand Bars

In the 1,300 feet upstream from Baytree Road, toppling failures are common and debris jams of fallen trees occur approximately every 50 to 75 feet. Rafts of garbage extending the width of the channel and 20 to 30 feet long are trapped on the upstream side of many of these jams (**Figure 3.3.14**).

Baytree Road to near Two Mile Creek confluence

Reach Length: 7794 feet

Reach Average Slope: 0.21%

This reach begins with a 1.5-foot knick point in clay and sand immediately downstream of the Baytree Road Bridge. The channel is more confined than the upper reaches because of extensive rubble dumping on the banks along the railroad alignment and sporadically on the left descending bank as well. The bank heights are consistently near ten feet and are near vertical in the confined reaches. Where bank scour lines are discernable, the consistently occur about five feet above base flow. For roughly 1,500 feet downstream of Baytree Road, the stream transports sediment with little accumulation or bar building. Below this point, deposition is the dominant fluvial process and the stream stores rather than transports sand. There are exposed sanitary lines 2,200 feet downstream of Baytree Road and immediately upstream of the railroad crossing. The upstream line appears to be leaking.

Downstream of the crossing the stream adopts a sinuous plan form with sand point bars and a sand-over-clay bed (**Figure 3.3.15**). Although the lower reach is well treed, the banks are lower and there are fewer log jams than in the upper reaches. While this part of the main stem is not actively incising, the small gullies and tributaries are still cutting down to match grade (**Figure 3.3.16**) from previous waves of incision. In this lower reach extending roughly from just downstream of Brighton to near Gornto Road, there are a few high bars with the characteristic flat surface and woody vegetation of bankfull shelves. Their elevation is about five feet above the flow line. Through this lower reach, trees on both banks are closer to the water line as well. At about 1,200 feet upstream of Gornto Road the stream migrates against a higher bluff for a short distance and the bank scour has toppled several trees. As the slope flattens, the stream drops its coarse gravel at the upstream edge of sand bars.

About 620 feet above the Gornto Road Bridge a dune with riffle formations indicates the beginning of turbulent flows and accompanies a shift in sediment transport from continuous flow to slug flow. Approaching Gornto Road, there is a large log jam and proceeding downstream, sand bar development increases. As the main stem approaches the confluence with Two Mile Creek, the low flow channel abruptly deepens and the bar height increases slightly.

Figure 3.3.14. Garbage Rafts Upstream of Log Jams

Figure 3.3.15. Sand Bars Downstream of Railroad Crossing

Figure 3.3.16. Gullies Cutting Down (incising) to Match Grade

3.3.3 Channel Geometry

Sugar Creek was evaluated in plan, cross section, and profile.

Plan Form

Evaluating the shape of the watershed in plan form provides insight on whether and how parts of the basin differ from one another. For example, sub-basins with stronger soils, higher density of tributaries and storm pipes, or more severe degrees of channel manipulation may require different management approaches than the remaining sub-basins.

Figure 3**.3.17** depicts stable and developing meanders in the project reach. The upper reaches are steep and straight. The process is so dominated by incision that there is little unconsolidated material available to build bars and initiate plan form adjustments. The first concentrated influx of sediment at the Brown's Canal confluence corresponds to the onset of depositional features. Downstream of Brown's Canal, the main stem has a series of meanders that fall well outside the range of stable curves for alluvial streams as described in Section 1. The meanders are too flat for efficient energy management and some degree of sand bar formation directing and concentrating the flow against the opposite banks to increase the amplitude of the curves is indicated. However, the sand bars in this reach are only moderately consolidated and appear too mobile to consistently focus scouring energy under frequent flow conditions. The vulnerability for this reach is under low frequency, high intensity storms where the stream will have sufficient power to increase the amplitude of the meander bends. Bank retreat will likely be episodic, a rare but severe event.

Despite the obvious channelization, the reach below Baytree Road has a largely stable plan form. Outside of the heavily armored areas, the channel has reacquired a sinuous plan form and most of the meanders have or are approaching a stable shape. The few logjams and failing slopes are the result of the downstream extension of the meander limb. Once this curve reaches and equilibrium shape, the adjustment will abate as long as hydrology is not altered further.

Cross Section

The cross sectional shape of a stream channel indicates the stage of channel evolution. When integrated with plan and profile indicators such as bar building or knick points, cross section data are used to determine the dominant channel process. No one data set is adequate to diagnose channel process, the foundation of stream management, but analyzed in the aggregate, it is possible to build a defensible case. **Figure 3.3.18**, developed with data from the SWWM model, illustrates the point.

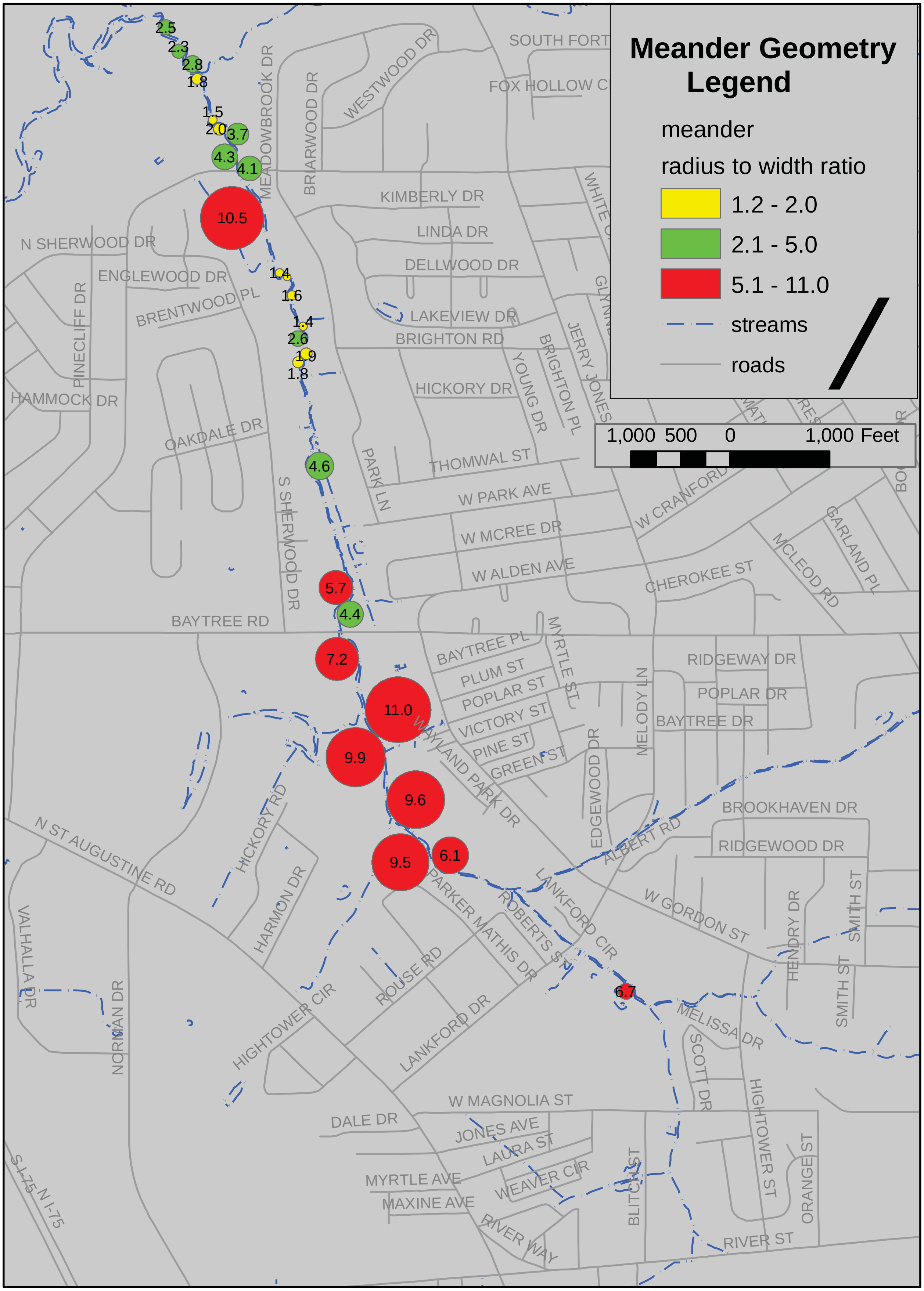


Figure 3.3.17
Stable and Developing Meanders in Sugar Creek

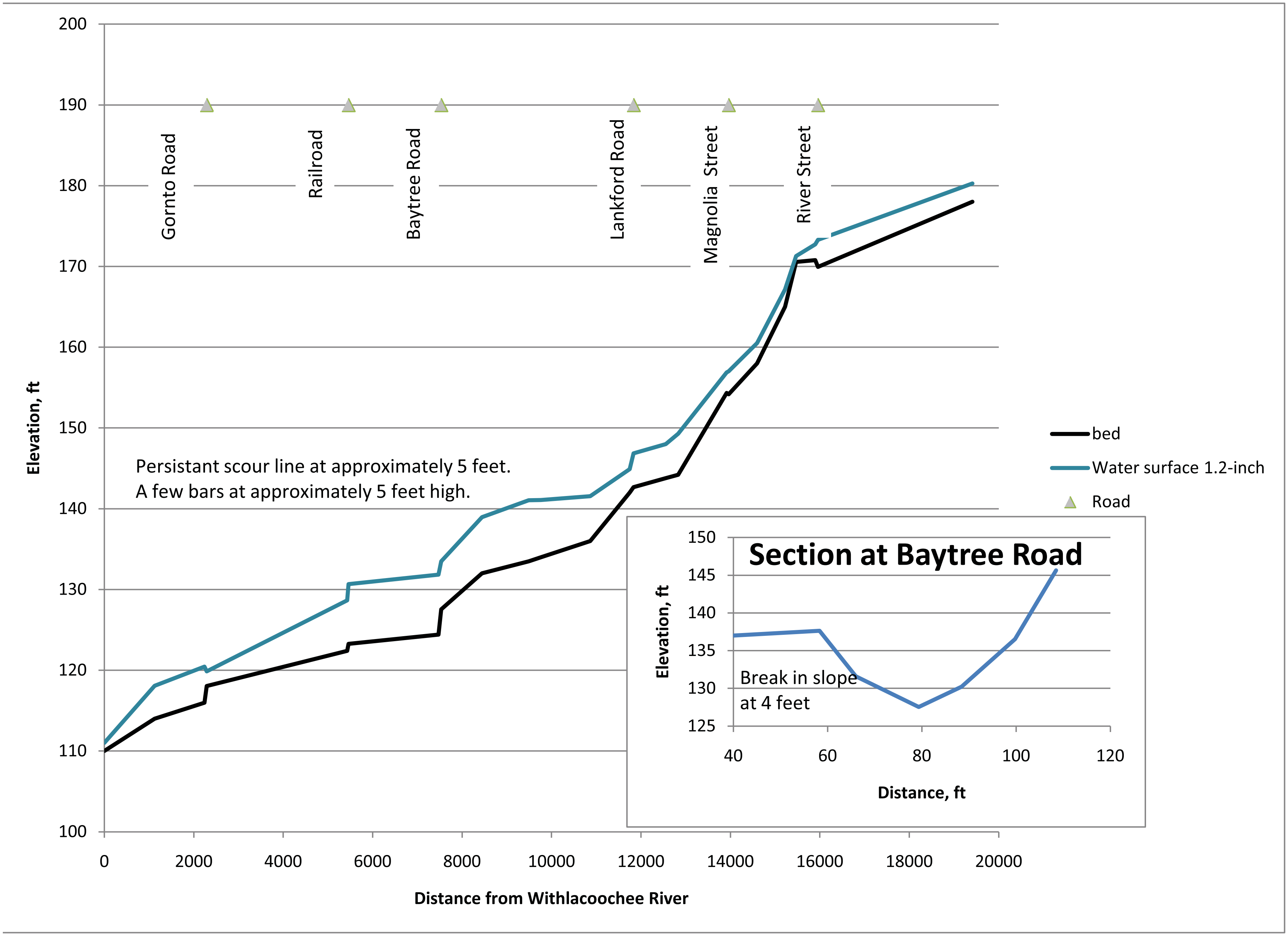


Figure 3.3.18
Channel Bed Profile and Water Surface Elevations

Here channel bed profile and the water surface elevation at a 1.2-inch rainfall are compared to persistent scour lines and stable bar heights. The scour lines and bar elevations used in this analysis are generally at the lowest elevation of a persistent, extended scour line and a vegetated, consolidated bar. In many stable streams, these features occur at a consistent elevation corresponding to the dominant discharge, roughly the 1.8-year return interval. The field investigation revealed very few bankfull features at any elevation. Those few features identified as potential bankfull floodplains occurred at elevations between 2 and 5 feet above channel bed depending on distance from the Withlacoochee River.

Longitudinal Profile

The longitudinal profile of a stream is one of the most useful diagnostic tools for determining the fluvial processes active in a stream system. **Figure 3.3.19** illustrates the stream in profile and depicts the reach average and bed slope. The figure includes an idealized profile of a stable, pre-incision bed. The juxtaposition of the bed and idealized profiles indicates areas of incision and deposition. Road crossings and the railroad crossing interrupt the geomorphic processes by limiting the upstream advance of incision. Sediment is stored upstream of Baytree Road and Lankford Drive. The relationship between bed profile, water surface profile, applied shear and geomorphic processes well be discussed further in Section 3.4.

3.3.4 Boundary Material

The bed and bank materials are composed of the native soil, large woody debris, introduce debris and rock, vegetation, and groundwater.

Soil

The main stem and major tributaries flow through Johnston loam; the upper tributaries generally flow through any of several sandy loams. The stream has incised to a resistive clay layer. Loam over clay occurs in the upper reaches and may occur throughout the basin. However, the loam is often more sandy downstream. Much of the city soil is now classified as urban land but it is likely that the underlying soil is Tifton loamy sand; a wide band of this formation runs from southwest to the northeast of the city. Compared to the adjacent watersheds, the Sugar Creek system is slightly less sandy and more loamy. The bed of the stream is generally stiff clay that is overlain by a washload of fine sand. The published value for the shear resistance of stiff clay is 0.26 psf. Based on the applied bed shear calculated from the hydraulic model and observations in the stream, scour occurs at values greater than 0.27 psf. The stiff clay, debris and the washload of sand determines the morphology of the stream.

Debris

This discussion of debris includes large woody debris, dumped concrete, rock, and other waste. Other waste includes discarded appliances, household garbage, and similar materials. There are extended areas of waste concrete dumped on the streambanks particularly north of Baytree Road.

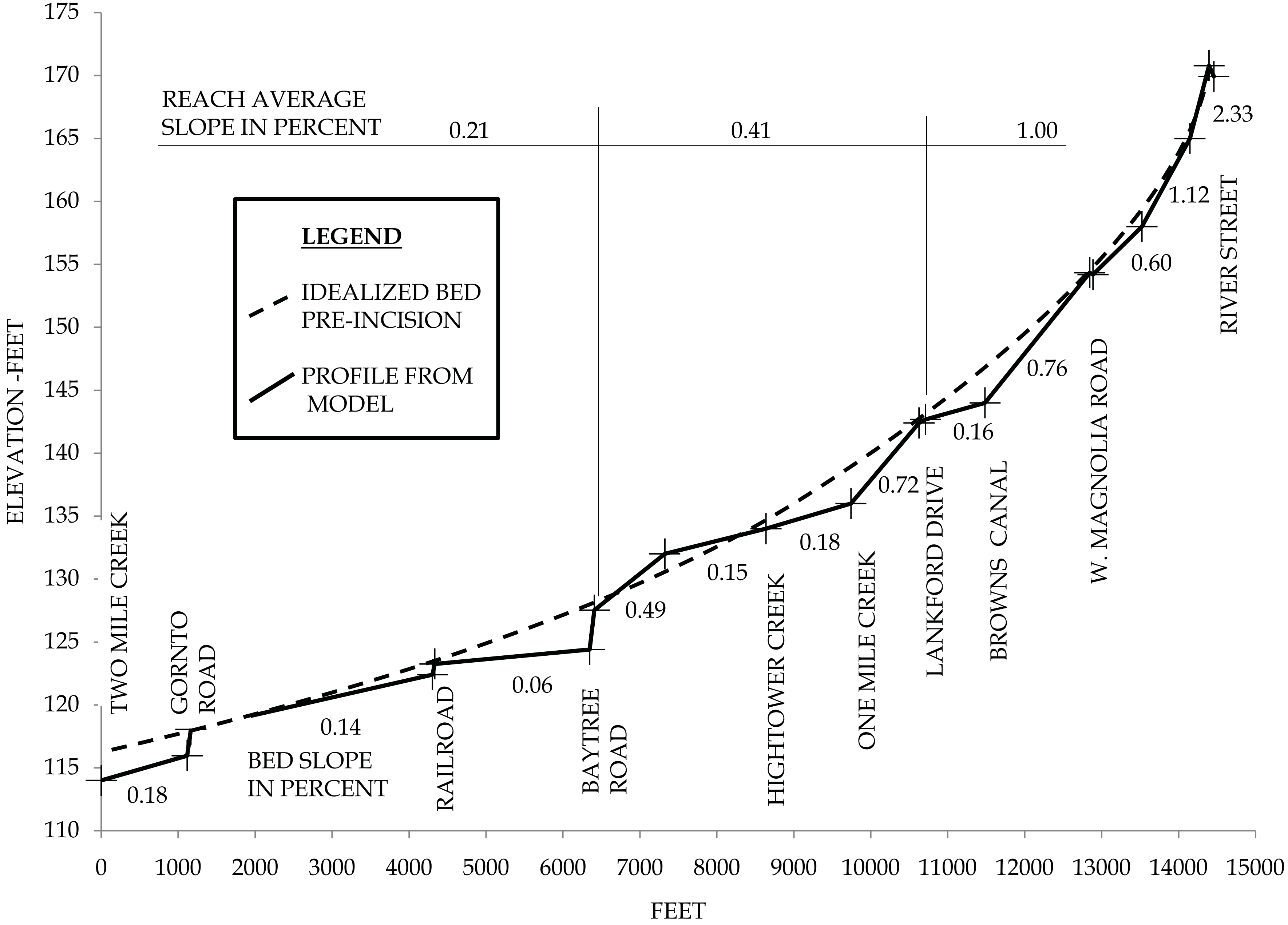


Figure 3.3.19
Stream Profile and Bed Slope

Whether intended to stabilize a failing bank, arrest incision or dispose of waste, the dumped material in the stream in general is not effective in improving stream stability and in some cases aggravates the instability. It may also degrade water quality and cause culvert/bridge bloackage.

The natural response to incision in this region is the development of woody debris jams. As trees and shrubs fall into the creek, the woody debris is distributed throughout the system forming a pool and riffle system. The debris jams generate the profile form that manages energy. The jams reinforce the bed and increase the hydraulic roughness dissipating erosive energy. The backwater effect of the jams lowers the hydraulic gradient for low flows. The critical shear resistance for woody debris is estimated at 3 psf. While debris jams may contribute to local flooding, they also reinforce local stability. Removal of debris jams without reinforcing the bed usually leads to incision, widening, or meandering.

Vegetation

The riparian corridor of Sugar Creek is in variable condition with some areas densely forested and others denuded. While there are many stands of mature trees remaining, the stream has incised below the root zone for most of the watershed. In stable, natural streams trees populate the banks near the water line. The vigor and integrity of riparian vegetation plays an important role in the physical, chemical and biological health of stream systems. Diverse stands of healthy native vegetation process and sequester pollutants, attenuate the volume and timing of surface runoff, moderate soil moisture, and increase the shear strength of streambanks. By adjusting the rate of evapotranspiration as plant-available moisture varies, trees and shrubs moderate the extremes of soil moisture and help maintain optimum moisture for soil strength. Because Sugar Creek has incised roughly 8 to 10 feet in its mid and lower reaches, the stream is cut off from the riparian corridor and the connection between surface water and the adjacent uplands (**Figure 3.3.20**) are damaged reaches where the vegetation has been removed are far more prone to gully formation.

3.4 Hydraulics

The hydraulic model estimates flows, velocities, and water surface elevations for a series of flow events. Although it was not specifically developed to determine geomorphic processes, analysis of the results can be used to interpret observations and to index calculated applied tractive shears. The average applied shear was calculated for each segment modeled. A segment is the reach between two cross-sections. The locations of cross-sections were chosen for hydraulic modeling prior to field observations of geomorphic process. The average depth and slope between the cross-sections were used to calculate the reach average shear. Actual applied shear will vary over the segment as a function of depth, hydraulic slope and density of the water which is influenced by suspended particles and temperature.

Figure 3.3.20. Incision has let to Vegetation Damage

Figure 3.4.1 present the results of the analysis of the hydraulic model in relationship to geomorphic process. The horizontal axis is the distance used in the model, from the confluence of Sugar Creek and the Withlacoochee River. The calculated water surface elevation for the 1.2-inch rain event is plotted along with the bed profile used in the model. The 1.2-inch rain event flow was chosen over other flow events since that water surface elevation most closely matches the elevation of indicators of the stream–forming flow.

3.4.1 Analysis of Water Surface Profile

For streams in dynamic equilibrium, the slope of the water surface is generally parallel to the bed so long as there is relatively continuous hydraulic resistance. If the applied shear is greater than the resisting shear the stream will erode the bed or banks, whichever is weaker, and deposit material in areas of lower applied shear until the slope of the water surface matches the bed. Areas of lower applied shear include the shadow of obstructions, the inside of bends and/or mechanically over widened reaches, and are not necessarily continuous across or along the bed. Several examples of diverging and converging water surface and bed slopes are obvious in Figure 3.4.1. The reaches from Browns Canal confluence to River Street and from Hightower Creek confluence and Lankford Drive are incising. The bed slope is steeper than the water surface slope. The reach from the Withlacoochee River to the Railroad crossing is meandering. Meandering is a normal process and in this case is not the rapid meander advance often observed in urbanized areas. The bed slope is flatter than the water surface slope as is the case near Browns Canal. Meandering occurs in reaches with sufficient or excess supplies of sediment, generally with deposition increasing from upstream to downstream. In Sugar Creek, frequent flows that are higher than the stream-forming flow are confined in the previously incised channel and disturb the sediment, thereby preventing consolidation and the establishment of persistent vegetation.

Sand bars are transient. During a flow event, sand is probably deposited then eroded and re-deposited at different times within the same event. Whenever the combination of hydraulic slope and depth of flow are sufficient, the sand is eroded. If either the slope flattens or the depth decreases, then sand is deposited. Washload sand may be deposited as the depth increases faster than the hydraulic slope at the beginning of a storm. This sand is then scoured as the slope increases. Generally at the peak of the flow, the slope will flatten and sand will deposit. As the flow recedes, the hydraulic slope increases, again scouring the sand. As the depth decreases, the sand is again deposited. This complex and transient pattern of sand deposition in each rainfall event is critically important and any effort to modify Sugar Creek must fully account for this dynamic occurance.

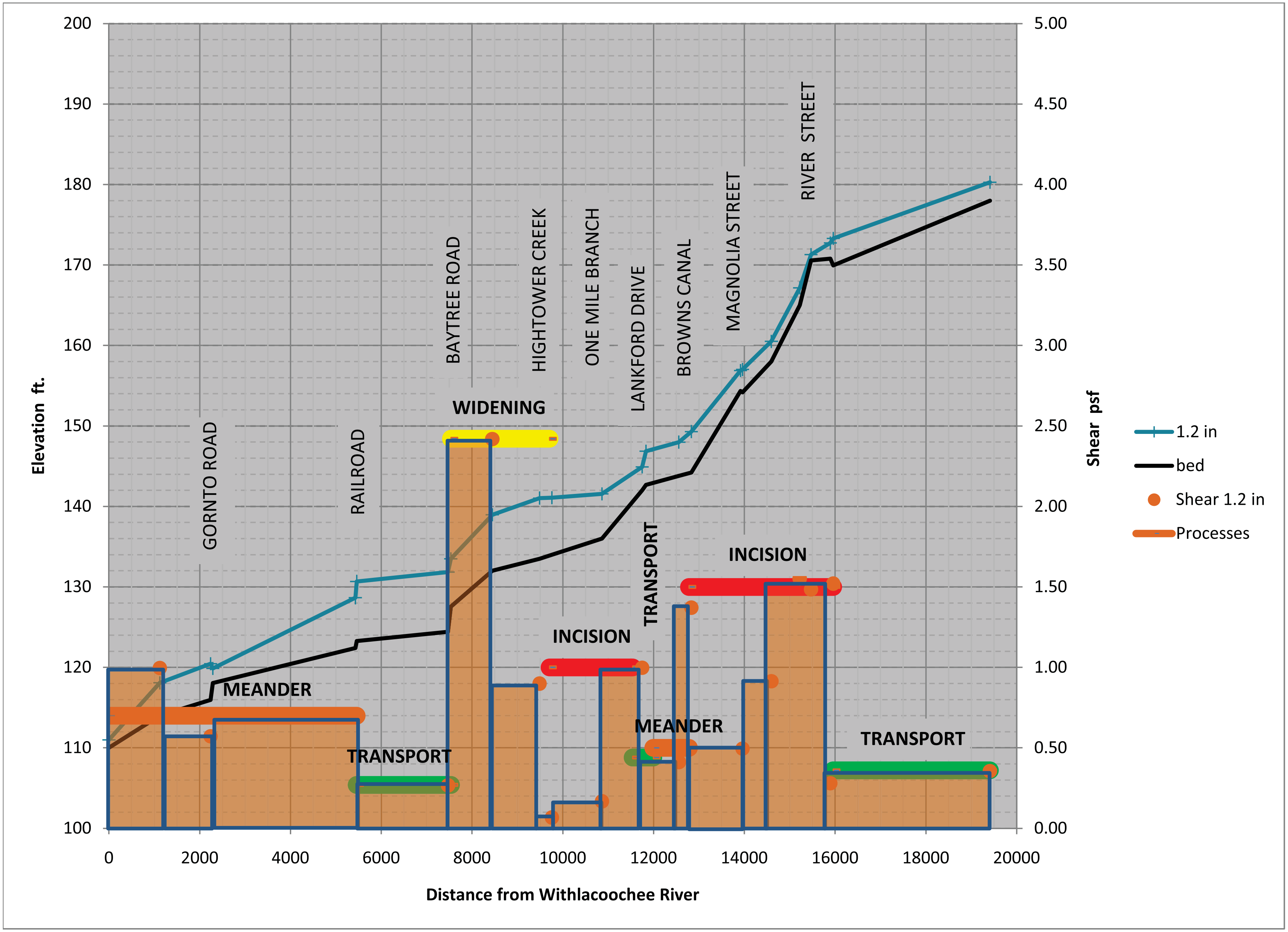


Figure 3.4.1
Hydraulic Model Results and Geomorphic Process Relationship

3.4.2 Tractive Shear

Included in Figure 3.4.1 is a bar chart depicting the calculated value of average applied tractive shear for each hydraulic segment. Values of shear are in pounds per square foot plotted against a secondary vertical axis. Geomorphic processes define the reaches and are indicated by the horizontal bars. Values for applied shear are assigned for each geomorphically defined reach from the values of the included hydraulic segments. Values of assigned applied shear are an index and are used to compare reaches. Actual value of applied shear will vary over the reach and may vary from the calculated values.

The calculated values correlate well with the observed processes and with the values of resistive shear reported in the literature. Transport reaches occur where the applied shear is equal to the resistive shear. A minor increase in tractive shear could trigger either incision or, if woody debris is available, widening. Widening is occurring between Baytree Road and Hightower Creek in the area of the highest calculated applied shear. Values through bridges and culverts are not included. These structures are armored to limit scour. The high sediment load from Hightower Creek is deposited as point bars and in the shadow of debris focusing flow against the banks. The debris jams are sufficiently strong to limit incision by protecting the bed, however, the banks are exposed between jams and are slowly scouring. Jams are naturally occurring and may direct flow into the bank, trap sediment and trash and cause scour immediately downstream of a jam. If jams are removed to increase hydraulic efficiency the bed and banks may rapidly erode.

Incision occurs between Hightower Creek and Lankford Road and between Browns Canal and River Street. These are reaches with calculated shears greater than the resisting shear and with little washload. Meandering occurs downstream of the railroad bridge and for a short reach dowstream of Browns Canal confluence. The calculated applied shear values are greater than the value for resisting shear but are less than the value observed for incision. Meandering only occurs in reaches with sufficient or excess sediment to form bars. The majority of sediment is transient washload that does not consolidate as point bars. Meandering appears to be progressing at a slow rate with episodic advances only during higher flows. In general, the banks are sufficiently strong to resist rapid meander advance. If sediment is removed to limit meandering or to increase hydraulic efficiency, it will re-deposit as it is eroded from upstream reaches and tributaries.

Table 3.4.1 presents the calculated ranges of applied tractive shear for observed geomorphic processes.

Table 3.4.1. Geomorphic Processes and Calculated Applied Tractive Shear

Process	Calculated Applied Tractive Shear in PSF
Transport	< 0.27
Deposition with meander	0.41 – 0.70
Incision	1.00 – 1.50
Widening with woody debris jams	2.42

3.4.3 Hydraulic Model and Geomorphic Process

Based on the results of the comparison of the hydraulic and geomorphic models, the hydraulic model may be used to predict geomorphic processes when integrated with field observations. The results of modeling future conditions can be used to predict the geomorphic response to the new conditions. Fluvial processes correlate well to applied shear. In turn, the sediment supply which is controlled by the applied shear stress has a defining influence on the dominant process. Meandering and widening only occur in reaches with sediment deposition. Widening occurs only in reaches with woody debris jams. Incision and transport only occur in areas of limited sediment supply. When relating each fluvial process to bed slope: Incision occurs when the bed slope is greater than the 1.2-in event water surface slope. Deposition and meander occurs when the bed slope is greater than the water surface slope. Transport occurs when the applied shear is near or less than the resistive shear and the slope of the bed and water surface are similar.

3.5 Sediment Transport

Sugar Creek is capable to transport sediment throughout the watershed. Once dislodged, the clay particles are easily transported; sand deposits only in reaches with low bed slope or debris jams. Because urban development has increased the frequency of flows, the sand has less time between flow events to consolidate into bars and for stabilizing vegetation to establish. So, although a great deal of sandy sediment is delivered to the stream, most of it is stored in transient bars and accumulates in stable formations only in the lower reaches.

3.6 Methods of Management

3.6.1 Watershed-Scale Stability - Arrest Channel Incision

Arresting channel incision is one of the most beneficial actions available to stabilize the Sugar Creek Watershed. Incision causes most of the problems throughout the basin including mass wasting, scoured or sediment crossings, and plan form adjustment. Fortunately, incision responds well to treatment. Stopping the incision “short circuits” the cycle of channel evolution and improves the likelihood that the channel will self-heal. The knick points and knick zones are sites where the hydraulic slope is locally high enough to induce upstream-migrating erosion. Grade control structures will lower the slope below the threshold for bed erosion in this stream. To

improve the durability of the structures, it is advisable to dissipate energy gradually rather than as a concentrated drop. For this application, Newbury style grade control structures offer compelling advantages over concrete or sheet pile drop structures. These rock structures, illustrated on **Figure 3.6.1,** provide artificial riffles along the streambed. In addition to distributing energy, these rock structures improve water quality by increasing dissolved oxygen and providing refuge for benthic organisms.

While these structures are robust and simple to install, their suitability is limited to cohesive soils. This is an appropriate technique for the clayey soils in the basin. It is not appropriate for the sandy soils.

Sugar Creek continues to use local materials to stabilize its own grade and move to a more stable equilibrium condition. The frequent log jams are holding the grade at knick points. Extensive engineering evaluations of the stabilizing effect of large woody debris have been conducted at the National Sedimentation Laboratory in Mississippi and elsewhere throughout the US. Use of these structures should also be considered in Sugar Creek.

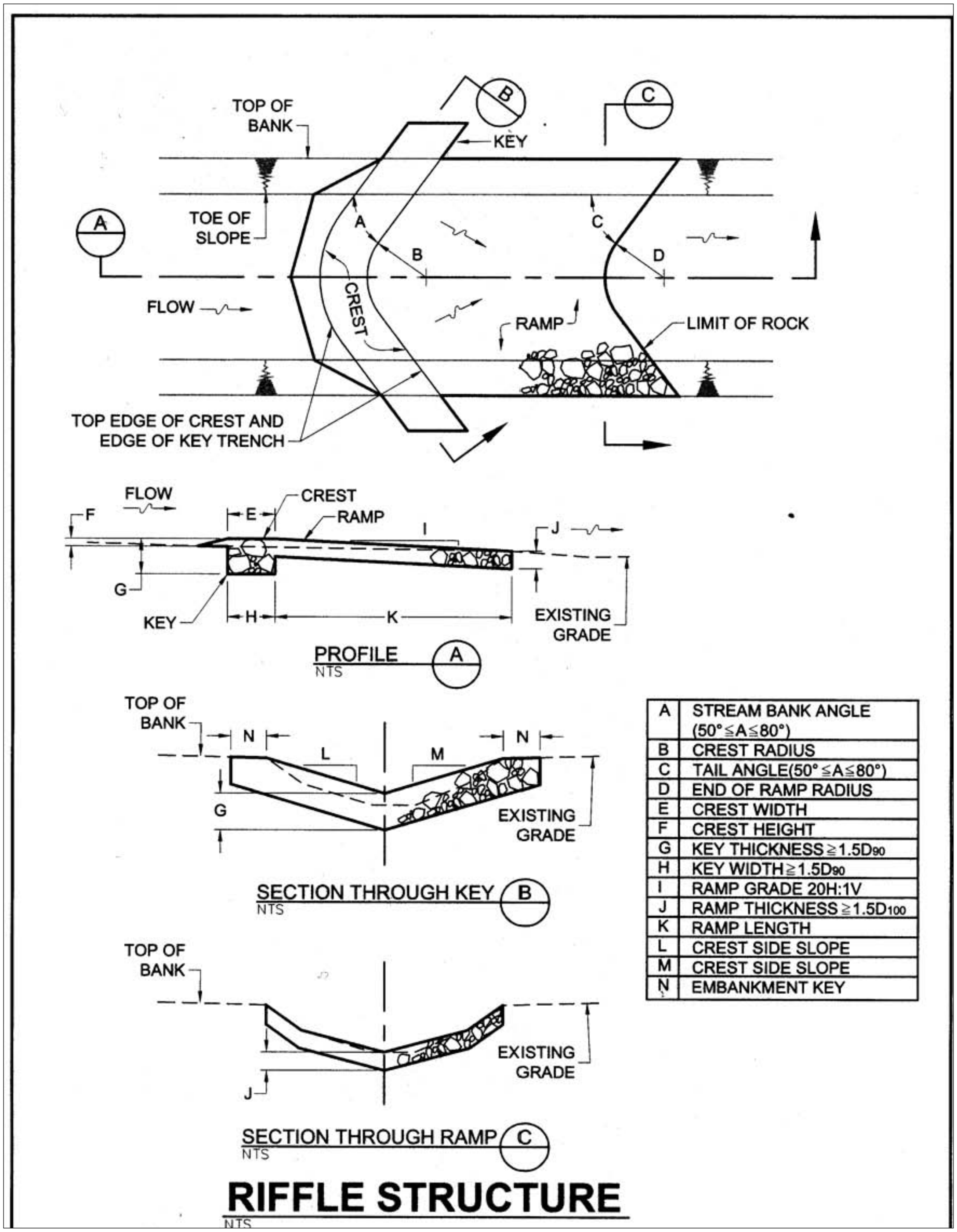
Water Quality

The second major issue influencing this stream is the poor water quality. Trash, sewage and sediment all compromise the quality of Sugar Creek. The generation of excess sediment can be managed by controlling incision as described above. During the field work, the team noted that nearly every manhole along the stream was leaking and the distinctive odor of raw sewage was pervasive. Patches of brownish foam were common near sewer pipes.

The trash sources include roadside ditches and direct dumping into the stream. The trash load in this stream is exceptionally high, and includes used diapers, kitchen garbage, bedding, furniture, electrical wires and scrap metal. In some reaches it was not possible to assess the bed material due to the thickness of the garbage layer.

Streams are a natural attractor for children and play structures occur along the stream edge. The pollution in this stream poses a serious risk of disease and injury and children should be strongly discouraged from playing in the stream until the trash and sewage are eliminated.

The leaking manholes and sewer pipes should be repaired immediately and protected from future damage. The garbage should be removed from the creek and an education and enforcement program to prevent further pollution should be implemented.



A	STREAM BANK ANGLE (50° ≤ A ≤ 80°)
B	CREST RADIUS
C	TAIL ANGLE(50° ≤ A ≤ 80°)
D	END OF RAMP RADIUS
E	CREST WIDTH
F	CREST HEIGHT
G	KEY THICKNESS ≥ 1.5D90
H	KEY WIDTH ≥ 1.5D90
I	RAMP GRADE 20H:1V
J	RAMP THICKNESS ≥ 1.5D100
K	RAMP LENGTH
L	CREST SIDE SLOPE
M	CREST SIDE SLOPE
N	EMBANKMENT KEY

Figure 3.6.1 Grade Control Structures (Newbury Style)

3.6.2 Local Stability Prevents Incision and Protects Infrastructure

The organizing principle for local stability is, like systemic stability, energy management. The goal is to manage energy throughout the intervention so that neither scour nor deposition is induced in the adjoining reaches. This implies managing hydraulic roughness, focusing flows and achieving an equilibrium channel shape. Sugar Creek's incision threatens sanitary pipes near the flow line and protecting those pipes should be a high priority.

Similarly, some culverts such as that at W. Magnolia Drive cause incision. Widening a channel to achieve the desired conveyance often causes more problems than it solves. At W. Magnolia Drive, the channel was widened to roughly twice its equilibrium width. In response, the channel incised upstream and deposited the material it generated immediately upstream of the culvert to recreate its stable shape. In doing so, the capacity of the culvert is reduced.

Culverts and bridges can be designed or retrofitted to provide any desired level of service while protecting stream stability. The installation of new drainage structures should take into account the natural channel configuration at the location of the improvement. Long-term observations of stream channels and structures have shown that natural channels once modified will return to their original size and shape without routine maintenance. This phenomenon occurs at the W. Magnolia Street culvert. Therefore, by accounting for this natural tendency during design, long-term maintenance cost can be reduced.

Typically, natural channels have a two-stage configuration. The first stage handles flows up to the 1.5- to 2-year flood. This stage is typically referred to as the primary channel or flow-way. The second stage handles flows from larger flood events and is better known as the floodway.

Accounting for the natural channel configuration in the design of improvements translates to the construction of nonsymmetrical structures. Using the traditional approach, a culvert designed with three parallel box culverts would be designed around all three culverts being constructed with the same invert, requiring the channel bed to be artificially widened to match the new opening width. **Figure 3.6.2** shows an example of a typical traditional installation. Typically, structures constructed with this approach have siltation problems that either require a significant amount of maintenance and/or a significant reduction in the flow capacity of the structure.

This problem can be avoided by accommodating the stable channel shape in the design. Through this approach, the inverts and shape of parallel culverts would be adjusted to match the shape of the natural channel. The primary culvert would be set at the natural channel invert and any secondary culverts would be set at a higher elevation, matching the flow line of the flood channel. This type of configuration is referred to as a conservation culvert design, which is shown on **Figure 3.6.3**. Through applying this design concept, flood flow capacity of the structure can be maintained while reducing the amount of routine maintenance (i.e., culvert cleaning). However, when applying this approach, the engineer should be careful to verify that the flow capacity of the modified design is contained below the peak flood elevation.

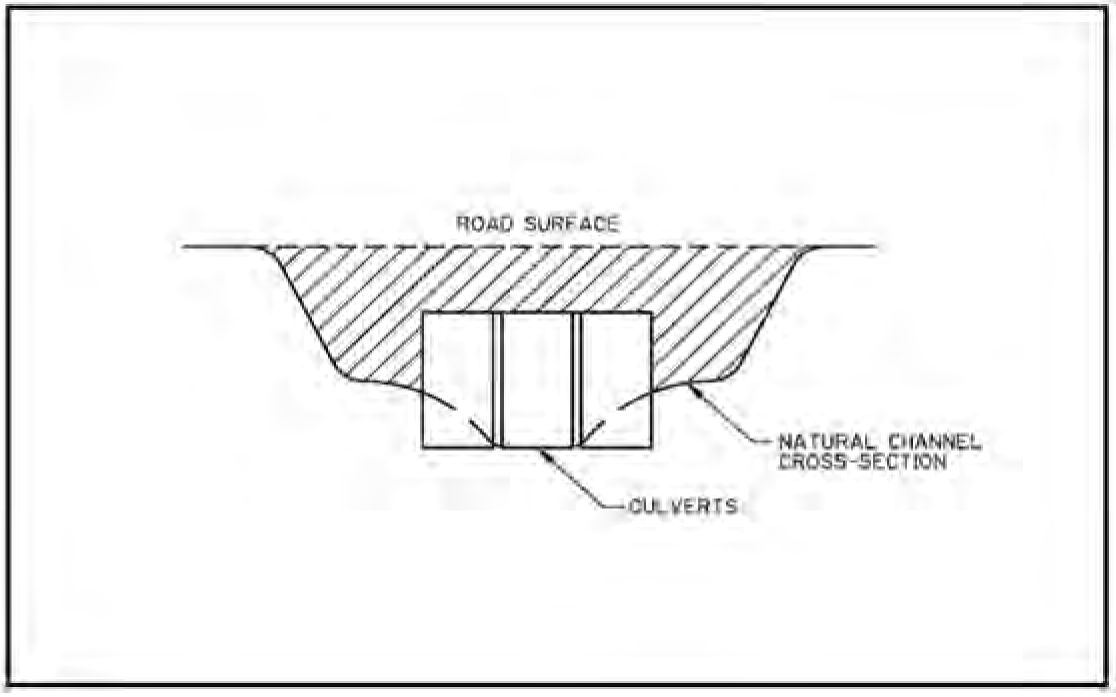


Figure 3.6.2 Traditional Installation for Culvert

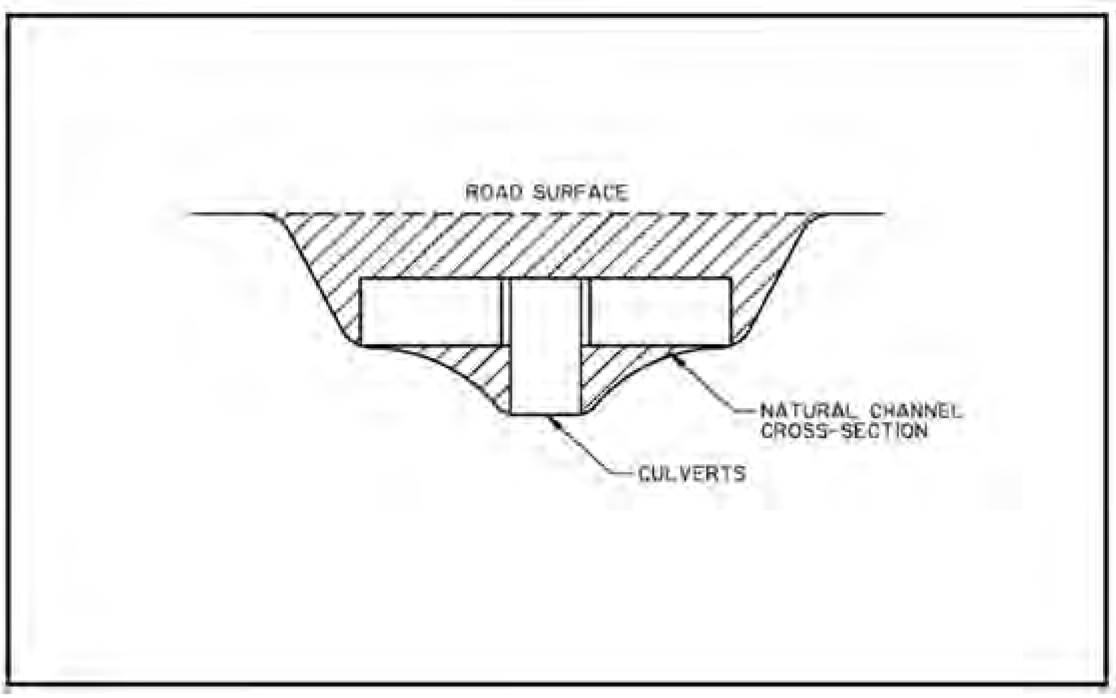


Figure 3.6.3 Conservation Culvert Design