HUTTON BRANCH: CHANNEL RESTORATION OF AN URBAN DRAINAGE WAY

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1. Introduction

Hutton Branch is a major stream draining 9.8 square miles of urban watershed almost entirely within the City of Carrollton. Many reaches of the stream have been extensively channelized in the past. The focus of this paper is the Hutton Branch reach between Josey Lane and Kelly Road. The City's Erosion Control Master Plan, published in 1992, characterized the reach as having "…significant erosion at channel bends and adjacent to steep natural banks with some exposed sewer lines." Recent field observations confirm that erosion in the reach continues to worsen. The historical record reveals that the stream channel has been realigned in several areas, shortening its course and steepening its gradient. This, coupled with the increased rate and duration of flood events due to watershed urbanization, has resulted in increases in stream bank failures, exposure of utility crossings in the reach and threats to adjoining public improvements such as streets and retaining walls.

A number of stream stabilization alternatives, including those from the Erosion Control Master Plan, were considered in this study for this reach of Hutton Branch and its tributaries. One promising alternative plan for Hutton Branch involves restoration of the stream to a more natural state by adding strategically placed meanders and establishing a stable channel for the new flow regime. This paper focuses on the procedures and methodologies used to assess Hutton Branch and develop the channel restoration alternative.

Channel equilibrium occurs when all four variables, sediment discharge, sediment particle size, streamflow, and stream slope, are in balance. Changes in streamflow and sediment variables may occur due to changes in land use. Streams that are free to adjust will generally do so and reestablish new equilibrium conditions over a period ranging from decades to centuries. River and stream restoration seeks to quantify this relationship so that river adjustments, which can cause significant damage to existing urban infrastructure, can be avoided or at least reduced in scope and severity. In this paper, streambank stability for each channel is discussed, as well as the methodology used to design a new more stable channel for the project streams.

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2. Channel Stability Assessment Methodology

a. Design Discharge

The procedure used in the channel stability assessment is shown in Figure 1. The soils, land use, channel and landscape slope, and geology of the basin are evaluated from field and mapped data. From this information, the channel forming discharge is calculated using regression equations and routed flood flow obtained from the unit hydrograph models for the watershed. Prior research has shown the active channel discharge is equivalent to approximately the 1.25-year Return Interval (R.I.) flood computed from Dempster's (1974) regression equations or the 0.5-year R.I computed by the unit hydrograph methods (HEC-1). The difference in the above-cited return periods is due to the treatment of antecedent moisture conditions in the model and possibly inferred loss rates for urban storms. Previous studies by the U.S. Geological Survey have shown similar problems of over prediction for high frequency storms using the unit hydrograph models calibrated for large floods. The SWAT-DEG (Soil Water Assessment Tool-Degradation) model was also run from this preliminary watershed data.

b. Field Assessment

The field survey includes a visual summary of channel conditions by river reach (photographs of the left and right bed and bank). The length interval chosen for data assimilation for urban channels is 200 feet. Four major areas of information are derived from the channel survey. The bed material is documented and selected samples are taken for sieve analysis or a Wolman's pebble count is performed in the field. Sieve analysis and Wolman's pebble count are conducted to determine the varying degree of soil particle sizes contained in the channel streambed. The geology (stratigraphy) of the reach is noted considering rock type, bedding, degree of weathering, and thickness of alluvial soils. Bank stability and degree of erosion is noted, as well as distance to and type of structure that may be impacted by future erosion. Finally, the meander geometry is measured and radius of curvature (Rc) and Rc/(bottom width) is obtained. This information is useful in assessing bend scour and meander migration rates.

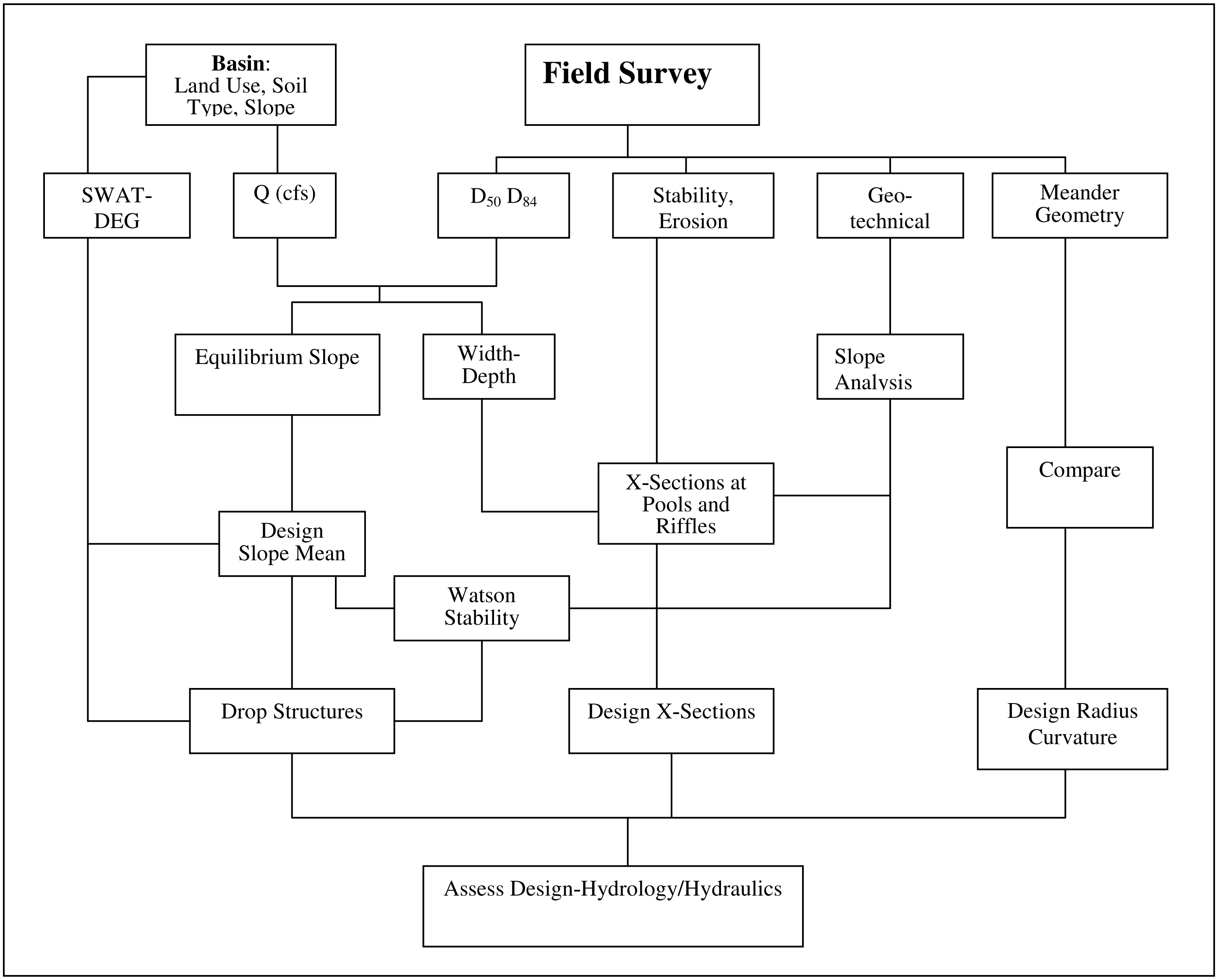


Figure 1: Quantifying River Behavior Flow

c. SWAT-DEG Model

The Soil Water Assessment Tool (SWAT) is designed to simulate watershed processes and the impact of land and water management on water quality. The model operates on a daily time step (infiltration and flood routing can be simulated sub-hourly) and allows a basin to be subdivided into grid cells or natural sub-watersheds. Model sub-basin components include hydrology, weather, sedimentation, soil temperature, plant growth, nutrients, pesticides and agricultural management. The primary considerations in model development stress (1) land management, (2) water quality loadings, (3) flexibility in basin discretization, and (4) continuous time simulation. The model integrates hydrology, soil erosion, plant growth, and nutrient cycling with off-site processes such as channel erosion/deposition, pond and reservoir processes, groundwater flow and climate variability. A complete overview of SWAT is given in the theoretical documentation (Neitsch et al, 2002a) and is summarized in Arnold, et al (1998).

Recently, the channel sediment routing model (DEG) has been modified to simulate downcutting and widening (Allen et al, 1999). An erodibility coefficient (Allen, 1997) is multiplied by tractive force to compute downcutting and the channel slope is adjusted accordingly. Widening of the channel is accomplished through local width-depth ratios derived from measurements of streams in the Texas Blackland Prairie. Modeled results indicate the temporal change in down cutting and channel adjustment, useful in project planning and channel assessment.

d. Equilibrium Slope

The bed material gradation combined with the channel forming discharge is used to estimate the equilibrium or “ultimate” stable channel slope. Up to six methods are used depending on site conditions and the applicability of the equations to assess stable slope under boundary conditions imposed within the design reach. Discharge, site stratigraphy, and bed material information is also used to evaluate future channel width and depth by comparison to regionally derived regression equations. This information, when analyzed with bank stability considerations and pool riffle morphology, allows assessment of stable channel design dimensions for pool and riffle areas over the design reach.

The results of the SWAT-DEG model and the Watson Harvey channel evolution model are used to evaluate the current state of the channel in relation to the forecast equilibrium channel. The SWAT-DEG model allows evaluation of the time it will take for the present channel to reach the forecast equilibrium state given assumptions concerning watershed climate and land use. The Watson Harvey model details where each reach of the channel is in terms of Schumm and Simon’s channel evolutionary sequence.

The equilibrium or design slope, derived from the slope equations, will typically be lower than the existing channel slope due to increased discharge as a result of urbanization of the basin. Because of the confined nature of many urban streams (transportation crossings, houses, commercial structures, alleys), there is typically little room to decrease the channel slope by increasing channel length through meander enlargement. Therefore, most urban channels require the addition of drop structures in order meet derived equilibrium channel slopes. Placement of the structures is based on the amount of predicted degradation, the predicted time rate of degradation, channel sinuosity, and local structural considerations such as utility crossings, storm sewers, and bridge and culvert locations and configurations.

Finally, the combination of equilibrium slope, new channel dimensions, drop structure locations and sizes, bridge alterations, and modifications to channel roughness are modeled to assess the impacts of the modifications on local flood levels and velocities for various design storms. Adjustments are made to make sure that regulatory flood levels within the reach are not increased and threshold velocities not exceeded for the area.

3. Hutton Branch Field Assessment

a. Geologic Setting

Hutton Branch flows within the outcrop of the Eagle Ford Shale. The Eagle Ford can be observed in meander bends and at numerous places in the stream bottom. It is assumed that the units exposed in the study reach belong to the upper Britton member of the Eagle Ford Formation. This is based on the reported outcrop of the Kamp Ranch member in the vicinity of the site (Locality #69, Dallas Geological Society, 1965). The Upper Britton is a fine to coarsely laminated concretion bearing, compaction type clay shale, dark blue in color, unweathered to light olive-tan to gray. Small detrital sandy beds and limestone beds less than six inches thick and ten feet across are scattered throughout this unit.

Soils mapped by the Soil Conservation Service in the study reach are the Trinity Series. These soils consist of poorly drained, moderately deep (40-60 inches) calcareous, clay soils. These soils crack when dry. Cracks can extend to depths of over 30 inches and may be up to 2 cm. wide. The soils are considered moderately erodible with a K factor (Universal Soil Loss Equation) of 0.32.

b. Study Boundaries

The study reach is bounded on the west by Josey Lane and bounded on the east by Kelly Blvd. The main channel of Hutton Branch combines with Stream 6D5 at station 1200. A second unnamed tributary enters the study reach from the south at station 3200. A third tributary stream, Stream 6D3, enters the reach at station 6650. The downstream end of the study is Josey Lane where the stream again enters a culvert which outfalls to a small, channelized reach. The stream is stationed from upstream to downstream for the purpose of the field assessment with station 0 at Kelly Road. Stationing is shown on Figure 8. The field assessment results are sketched on the best topographic map available.

c. Main Reach of Hutton Branch

The detailed results of the channel survey are noted and plotted including bed and bank processes and materials, degree of erosion, and associated land use features. Locations of digital photographs are taken at 200-foot intervals along the stream and noted on the plot.

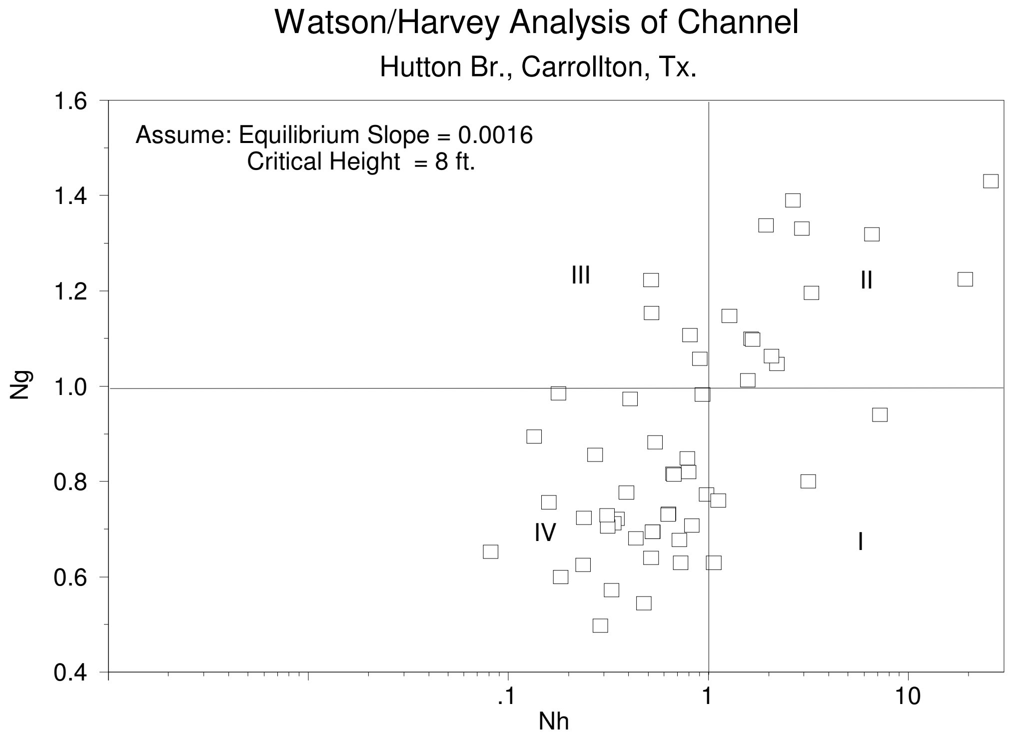
The main stem of the creek can be subdivided into two basic geomorphic sections based on field surveys, the results of the SWAT-DEG model, and the Harvey Watson channel evolution assessment of the stream (Figures 2 and 3). In Figure 2, N_g is the actual bank height/critical bank height. If Ng exceeds 1, the bank will fail. N_h is the actual channel slope/equilibrium channel slope. If N_h is greater than one, the channel degrades. If N_h is less than one, the channel aggradesNumbers on diagram represent the stages in channel evolution from stage I to stage IV representing channel evolution from stable conditions to downcutting and widening to aggradation and ultimate stability. The moving average figure indicates the longitudinal trends in the Stage I to Stage IV classification based on the Ng/Nh diagram. This allows for assessment of downstream changes in channel processes and stability.

From station 4400 upstream, the channel is actively downcutting and should be considered in a degrading state. From station 4400 downstream, the channel is aggrading. Evidence for the upstream degradation (downcutting), are oversteepened banks, knickpoints, side channel gullies, and exposed sewer lines. Evidence of downstream aggradation is deposition and formation of large gravel bars and channel widening.

Past aerial photos and the U.S. Geological Survey 7.5 minute Quadrangle show that this reach has been modified several times in the past. The channel has been straightened, and meanders have been cut off. The exact amount of shortening is difficult to determine due to the scale of the project site compared to the scale of the historic documents.

Along Hutton Branch, from the confluence with Stream 6D5 to station 2000, the channel is actively eroding the banks and degrading. Downcutting is causing local slumps in the alluvial material over the Eagle Ford. Flood flows overtop the bank at station 1400 and have scoured the floodplain resulting in exposed trees roots, which will ultimately kill the trees. Between stations 1600 and 2000, the channel has abandoned a meander and is actively downcutting. The meander near the road has active wedge failures occurring at the interface between the alluvium and highly weathered Eagle Ford Shale. The failures are a result of undercutting of the bank and tension cracks in the clay formed during dry periods. The small tributary entering the channel from Le Mans is downcutting Hutton Branch and two slumps are evident in the tributary banks along with local scour.

At station 1800, there is evidence of active floodplain scour. The channel forms two pools at this location due to a pipeline with a gunnite drop structure. This structure appears to be a remedial measure to protect the pipeline. There is active bank scour upstream and downstream of the structure and a large scour pool 4 to 5 feet deep has formed downstream of the pipeline. Eagle Ford shale bedrock is being scoured and plucked from the bottom at this location and is evident in downstream bars. Historical evidence at this locality indicates the channel has been straightened.



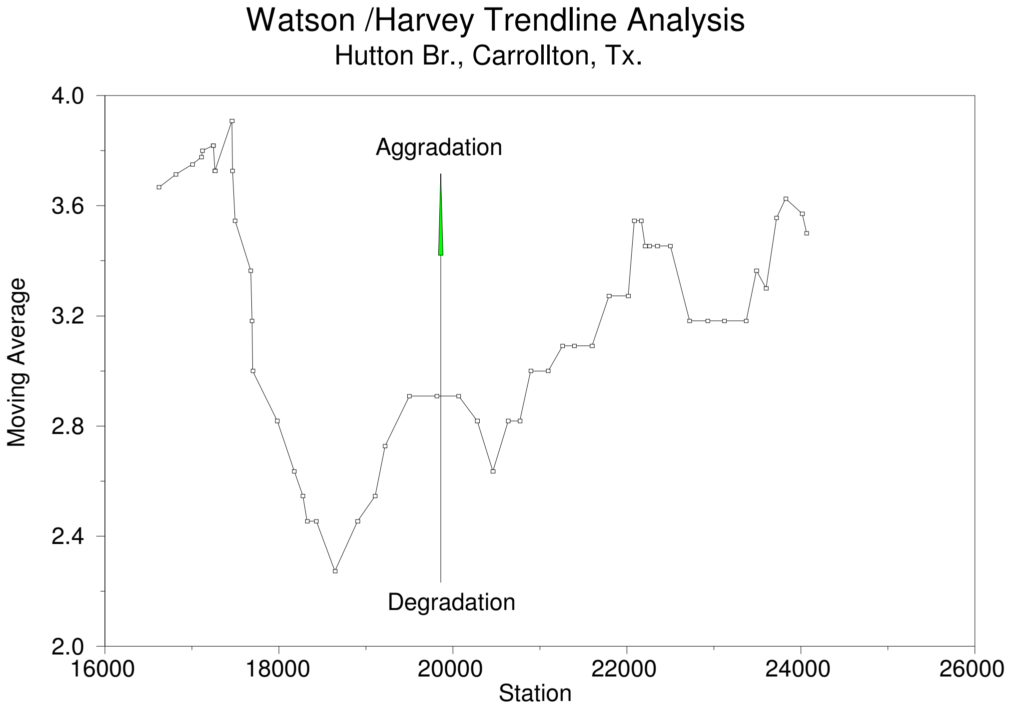


Figure 2 and 3. Results of Watson Harvey Analysis for Hutton Branch

From 2000 to the confluence with an unnamed tributary, the channel banks are actively eroding and a major bar has been deposited just upstream of a cyclone fence crossing. Evidence of erosion includes concrete debris, which has been dumped in an effort to protect another pipeline crossing. The debris forms a small riffle area that interrupts low flow and is associated with downstream scour. The confluence with Unnamed Tributary exhibits channel enlargement, slumping and some bottom scour.

From station 3400 to 4600, the channel is characterized by several pools ranging from 2 to 4 feet deep. This reach is a transition zone between the upstream degradation and the downstream aggradation. Here, the channel banks are moderately scoured and there are some signs of silty clay deposition along the banks. The source of this sediment appears to be from a small tributary at station 3800.

From station 4600 to Josey Lane, the channel is showing signs of aggradation. There is still abundant bank scour here, but the channel displays developed meanders and a pool riffle system. Deposition of bars appears very active. This is apparently caused by the undersized culvert at Josey Lane that causes low velocities upstream of the bridge and consequently, deposition of bar gravels. These features are of note in this reach. First is the meander from station 4600 to 5000, where the outside of the meander actively abuts the steep slope leading up to Le Mans Drive, a public street. This undercutting is causing slumping and local wedge failures depending on the bank geometry. There has been extensive undercutting in the past as shown by the 4 to 5 foot drop at the local storm sewer outfalls near Le Mans Drive. The stream at this site will ultimately undermine the roadway. The second site is located between stations 5800 to 6200. At this location, the channel is actively eroding the banks causing undercutting and slumping on the outside of the meanders. This location is less about 20 feet from a floodplain lake at a meander. This area is particularly hazardous because the lake is located on the outside of the actively eroding meander. The water in the lake causes high pore pressures, which will tend to make the stream bank slopes very unstable and difficult to maintain in this area. Finally, at station 6600, the channel rests directly on top of exposed eagle Ford Shale. The wetting and drying of this site will cause active slaking and removal of the Eagle Ford Shale. The Eagle Ford is a very weak rock with a second cycle slake index of about 60 percent. This means that 40 percent of the rock volume is lost in two wet dry cycles in the slake test. At this location, a large retaining wall has been constructed on the outside of a meander. The wall footing depth is unknown and the wall's stability could be a future problem. Slumping is already evident downstream of the wall. This area should be closely monitored. From station 6600 to Josey Lane, the channel appears stable. This is thought to reflect the backwater effects from the culvert that reduce local velocities.

4. Channel Design Parameters

A channel design discharge of 1200 cubic feet per second (cfs) was determined for the main stem of Hutton Branch based on three points: (1) This was the calculated discharge for the fully developed basin derived from Dempster's (1974) regression equations, (2) these equations have been shown to define the active channel dimensions in the Dallas and North Texas area (Allen, Arnold, and Skipwith, 2002), and (3) consistency with HEC model results for the study area. Consistency with the HEC-RAS model results is checked and the proposed channel design parameters altered to produce the desired channel velocities in the range of 4 to 5 ft/s.

Based on this channel discharge and results of the Wolman's pebble count for the reach, stable slope equations were used to calculate the design channel slope. The pebble count indicated a D_{50} of 19.5 mm. The equilibrium channel slope is calculated from the six methods discussed earlier. The average of all the methods indicate a design (equilibrium) slope of 0.0016 for the study area, (Figure 4).

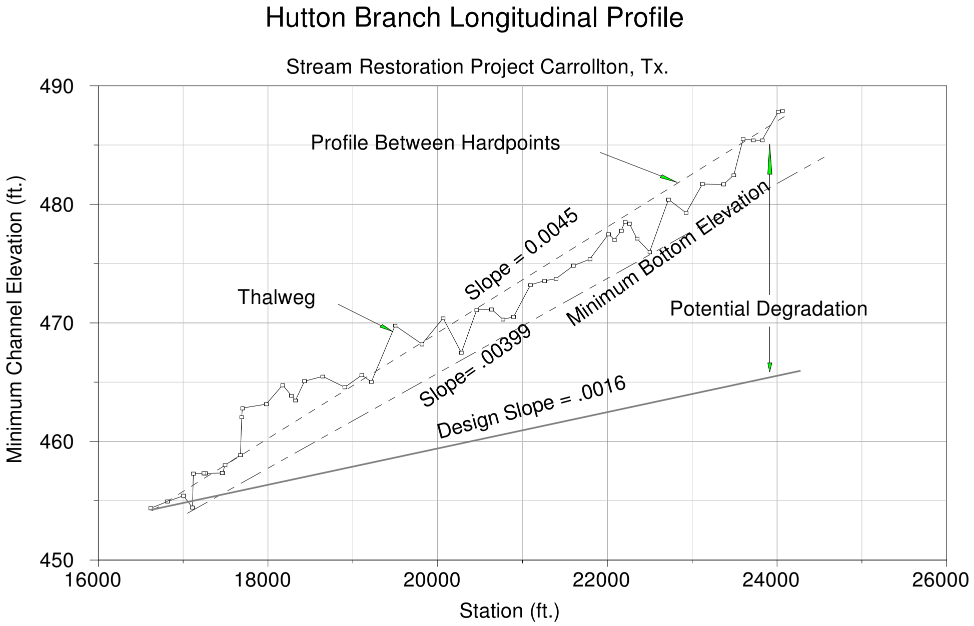


Figure 4: Longitudinal Profile of Hutton Branch and Design Slope

The meander geometry was analyzed for the study reach and indicated a gradual shift in radius of curvature (Rc) along the channel from an Rc of 40 feet on the Unnamed Tributary, to an Rc of 48 feet on the upper portion of Hutton Branch, to an Rc of 80 feet on the downstream portion of Hutton Branch (Figure 5). Stable meander geometry was analyzed using Shields Curve for shear stress and Leopold's sine generated curve function that resulted in a radius of curvature of 114 feet. Williams's empirical equations for river meanders and channel size using active channel width resulted in an Rc of 104 feet. Leopold and Wolman's (1960) equations resulted in an Rc of 101 feet.

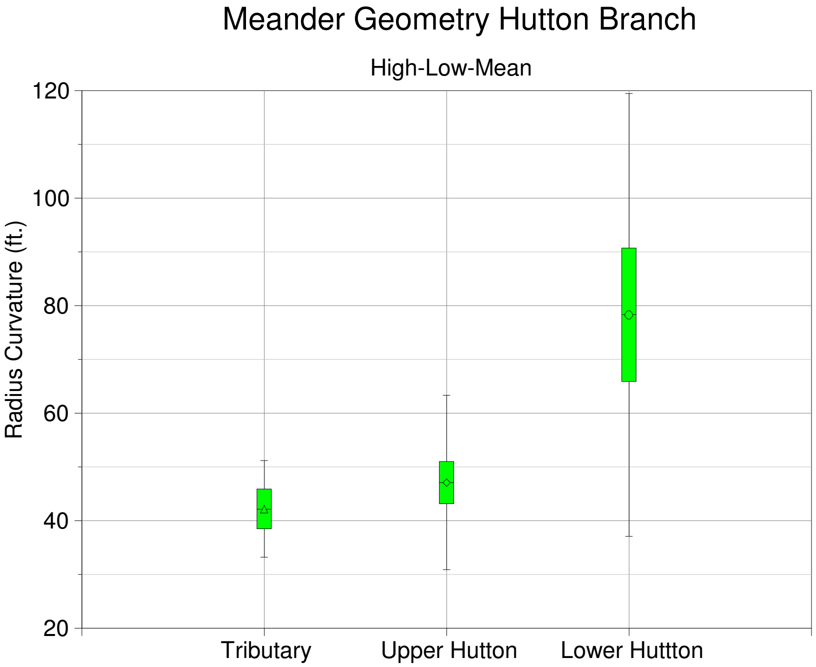


Figure 5. Meander Geometry observed in Hutton Branch

The active channel dimensions were based on four criteria: (1) design discharge, (2) stable bank slopes, (3) bankfull velocities, and (4) pool riffle geometry. Based on the routed flood flows and active channel discharge of approximately 1200 cfs., the channel was modified to account for the remaining criteria. First, the channel banks were cut back to a 3:1 sideslope and 20 foot bottom width with toe protection. The narrower bottom width is necessary to carry the bed material (incipient motion criteria) which prevents localized bar formation and future side slope scour. Without side-slope protection, these clay soils with high plasticity indicies are subject to bank failure by slumping, and if undercut, wedge failures along tension and shrinkage cracks. In pool areas at channel meanders, the inside bend was sloped back at a 5:1 sideslope to account for deposition in this area of the meander and to promote functioning of the pool riffle system. These cross sections were input into the HEC-RAS model for Hutton Branch, and channel velocities were checked against acceptable erosion thresholds (less than 6 feet per second) as shown on Figure 6.

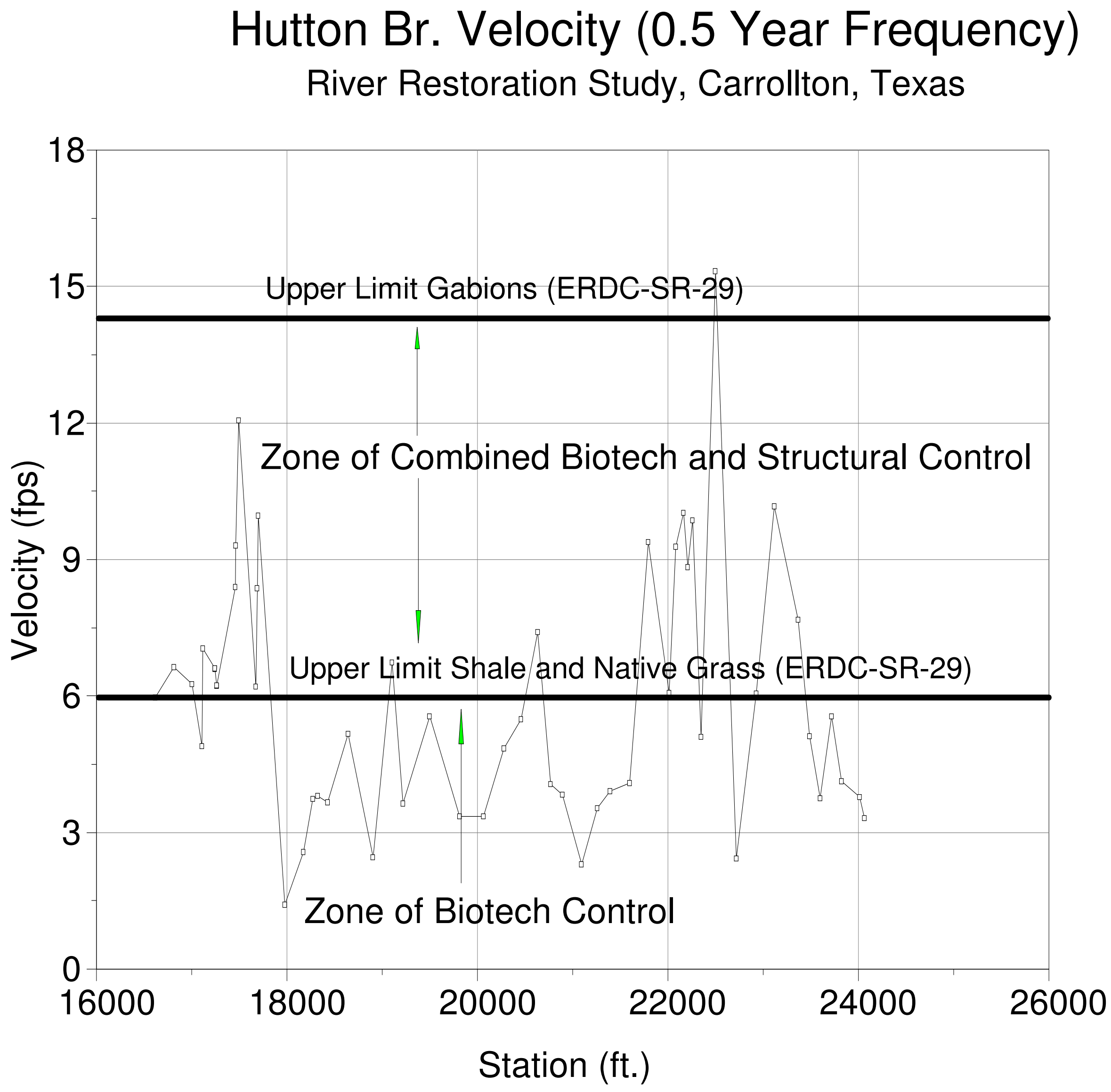


Figure 6: Velocity of Hutton Branch Channel (HEC-RAS results) Before Channel Alterations

To sustain the design equilibrium slope of 0.0016 within the project limits, grade control structures had to be added. These structures allow the new channel design to maintain the desired slope without further downcutting (see Figure 7). In addition, bank armor (toe protection) was added along the outside slopes of meander bends. This was done to prevent lateral migration of the channel due to scour during the larger floods. Feature locations and the recommended alternative alignment for Hutton Branch are displayed on Figure 8.

Figure 7: Longitudinal Profile of Hutton Branch and Design Slope

The resulting plan for Hutton Branch between Josey Lane and Kelly Road is to restore the channel to a natural section and alignment. Stable channel design velocities will be maintained while floodwater surface elevations are kept at or below existing levels. In addition, a more stable, composite channel shape is proposed that will more efficiently pass the lower flood events and minimize channel instability. The typical section is 37.5-foot channel bottom width and 3:1 side slopes for a depth of 5 feet. The active channel would be completely earthen with a depth of 5 feet and a top width of 67.5 feet. The design depth is based on the amount of flow required by the channel to contain the 1.25-year flood. Side slopes of 4:1 covered with erosion control matting would extend to portions of the channel that are not armored.

In order to achieve a more stable, yet natural channel alignment, meanders will be introduced. The channel will be realigned between station 177+65 and station 229+40. At each meander, the active channel top width would increase to 77.5 feet. The side slope of the inside bank of the channel is flattened to 5:1 to simulate a natural meandering channel section. On the outside bank, loose stone riprap will be placed to protect the slopes. At utility crossings or where right-of-way is being restricted, a gabion wall will be used.

The design slope of 0.0016 is used throughout the reach. To achieve this equilibrium slope, 6 drop structures will be needed. The drop structures also protect utility crossings. The drop structures would be located at stations 185+15, 194+18 (above an 18-inch and 21-inch wastewater line), 215+64 (above a 21-inch wastewater line), 221+73 (above a 15-inch wastewater line). The last drop structure would be located at station 230+13 above a 15-inch and 21-inch wastewater line.

The recommended plan can be implemented without any increase in water surface elevation for the 100-year flood on Hutton Branch. The change in water surface elevation for the 100-year flood ranges from a decrease of 0.02 feet to 1.95 feet.

Proposed work includes 107,000 cubic yards of channel excavation and the placing of 29,000 cubic yards of fill. The total estimated cost for the recommended plan, including clearing, filling, re-grading, and re-vegetating areas along the banks of Hutton Branch, is $2,863,000.

5. Habitat Creation

The re-alignment of Hutton Branch together with the stream bank stabilization, provide the opportunity to create habitat for both terrestrial and aquatic fauna and flora. Elements conducive towards the establishment of stream habitat include:

- plants associated with streams and stream banks,
- shading of the water surface,
- stream riffles and pools, and

- underwater structures including water plants and tree root systems.

Elements supportive to the establishment of terrestrial habitat include a mixture of trees, shrubs and grasses indigenous to the region. A cross section of a natural stream typically consists of a series of plant communities differentiated due to their distance from the water channel and/or depth of the underlying water table. Plant selection in the stream corridor should be configured to mimic a natural situation as follows:

- Channel Edge Plants; including Bald Cypress (Taxodium distichum), Black Willow (Salix nigra) and Common Persimmon (Diospyros viginiana).
- Mesic Prairie; including American Elm (Ulmus American), Honey Locust (Gleditsia tracanthos) and Green or Red Ash (Fraxinus pennsylvanica).
- Blackland Prairie; including Live Oak (Quercus viginiana) and Shumard Red Oak (Quercus shumardii).

Shading of the water surface helps cool the stream and provides protection to aquatic life. Shading is typically obtained by overhanging tree branches. All natural streams consist of a series of riffles and pools, which are extremely important to the health of an aquatic environment. Each has its own value as a living environment with riffles providing the added benefit of water aeration.

6. Conclusions

A channel restoration design was developed for Hutton Branch that follows the stable channel design process described in this section of the report. Planform geometry was developed and as a result a more natural meandering channel alignment was developed. The proposed stabilized channel satisfied the required velocity limits based upon the Manning's analysis. Verification of the velocities and channel carrying capacity was fulfilled by detailed hydraulic modeling process. The channel restoration plan cost compared favorably with the cost of other, more structural channel stabilization techniques such as channel armoring.

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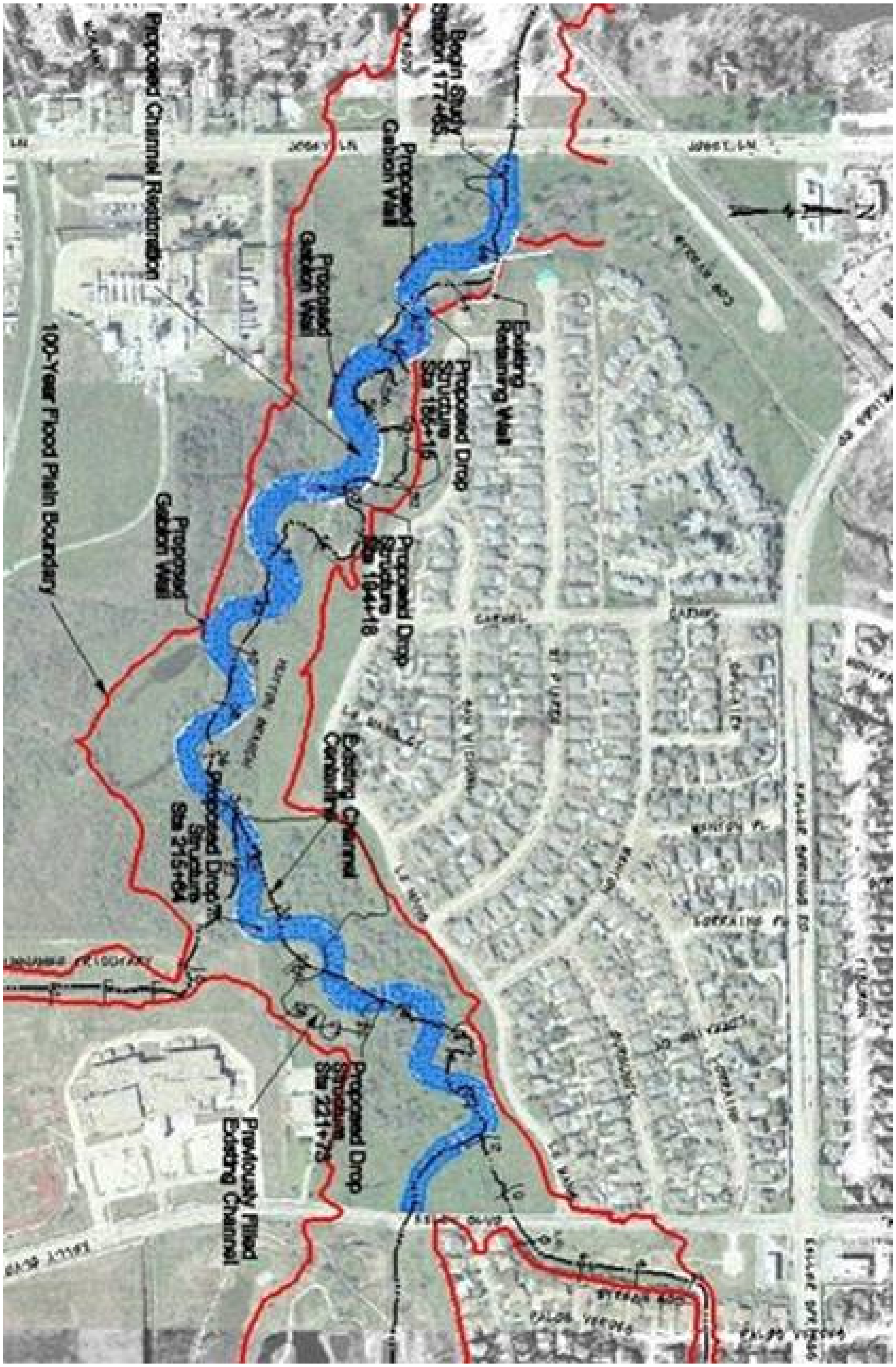

Figure 7: Proposed Channel Restoration Plan