A Fluvial Geomorphic and Sediment Transport Study of the Little River Upstream of Lake Thunderbird Using an Acoustic Doppler Current Profiler (ADCP)

PROJECT REPORT

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Stillwater, Oklahoma 74078-3011

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Student Status	Number	Disciplines
Undergraduate	1	Civil Engineering
M.S.	1	Civil Engineering
Ph.D.	1	Civil Engineering
Post Doc		
Total	3	Civil Engineering

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Context of this Technical Report

This report is being prepared as an annual report for OWRRI grant #2010OK181B. Due to delays in the equipment purchase and the lack of significant rain events during the Fall/Winter of 2010/2011, the study is incomplete. Findings to date will be presented in subsequent sections, but the work, which comprises the dissertation topic for the first author on this report, is ongoing. That document (the dissertation), which is now expected to be finished in Spring 2012, will contain more complete findings from this study. An amended report will also be filed with the OWRRI at that time.

Problem

Sediment transport has a profound impact on streams, rivers, lakes, and impoundments. It affects the morphology of streams and rivers, the life span of lakes and impoundments, due to lost capacity, and the water quality in all water bodies, as many nutrients and contaminants (e.g., metals) are bound to the solid particles being transported. Given its importance however, sediment transport is one of the more poorly quantified water quality variables, primarily due to the difficulty in obtaining accurate estimates of both the suspended fraction, that being transported in the water column, and the bed load fraction, the material moving along the bed. The current research project attempts to fill this knowledge gap by developing a cost-effective, yet accurate measurement protocol utilizing an Acoustic Doppler Current Profiler (ADCP) to measure sediment movement in creeks and rivers. The Little River, a tributary of Lake Thunderbird, due to its proximity to the OU campus and the fact that it is representative of many streams in central Oklahoma, is serving as the test bed for the project.

A bathymetric study of the lake conducted by the OWRB (Oklahoma Water Resources Board) in 2001 found that the pool capacity of the lake has been reduced from 119,600 acre-feet in 1966 to 105,644 acre-feet in 2001 for a loss of capacity of 13,956 acre-feet or 11.7% in 35 years (OWRB, 2002). The observed loss rate of 399 acre-feet/year is 14% higher than the 350 acre-feet/year reportedly estimated by the U.S. Bureau of Reclamation (BOR) in correspondence to OWRB back in 1965 (Flaigg, 1965) and is attributed to "larger grained sediment washed in from the watershed" (OWRB, 2002). McHenry (1974) reports an average annual percentage loss of 0.23% per year for reservoirs predominantly from the Midwest, Texas and California with a capacity between 100,000 and 1,000,000 acre-feet. Lake Thunderbird's loss rate exceeds this value.

Lake Thunderbird, which supplies drinking water to the municipalities of Norman, Midwest City, and Del City, is designated in the Oklahoma Water Quality Standards as a sensitive public and private water supply (SWS) with a nutrient limited watershed. Studies by the Oklahoma Water Resources Board (OWRB, 2005) indicate that the lake is "eutrophic, indicative of high levels of productivity and nutrient rich conditions" due to the fact that the average trophic state index (TSI), using Carlson's TSI (chlorophyll-a), was found to be 58.

The Oklahoma Conservation Commission (OCC) (prepared by Vieux & Associates, 2007) used total phosphorous concentration as a surrogate to estimate the current chlorophyll-a concentration in the lake, finding it to be 30.8 µg/L, three times the State Water Quality Standard of 10 µg/L. Chlorophyll-a concentrations in excess of 20 µg/L result in hyper-eutrophic water conditions with excessive algae growth (OWRB, 2004). OWRB also determined that the turbidity was sufficiently high so that the Fish and Wildlife Propagation, a beneficial use criteria, was deemed to be only partially supported (OWRB, 2005). Data from 2006 indicates that Lake Thunderbird is impaired due to excessive turbidity and low dissolved oxygen.

The OCC study addressed sediment loading to the lake, modeling it as a function of imperviousness, but did not directly measure it. Prior to the current study, there has never been a comprehensive study of the sediment transport characteristics of the Little River and the morphological processes that both drive them and are driven by them. Yet, there is evidence, based upon a preliminary examination, that the Little River is highly unstable and undergoing an evolutionary process of morphological change as a response to increasing urbanization and "channel improvements" made in the past. A reconnaissance study of the river conducted in September 2007 by one of the investigators in the current work revealed clear indications of significant channel incision and widening, including exposed bridge abutments, exposed high pressure gas lines (Fig 1 a), slumping banks, exposed tree roots, fallen trees and tributary head cuts (Fig 1 b). The importance of this cannot be overstated as the ramifications to infrastructure, lost property, and increasing sedimentation rates to the lake are potentially substantial.

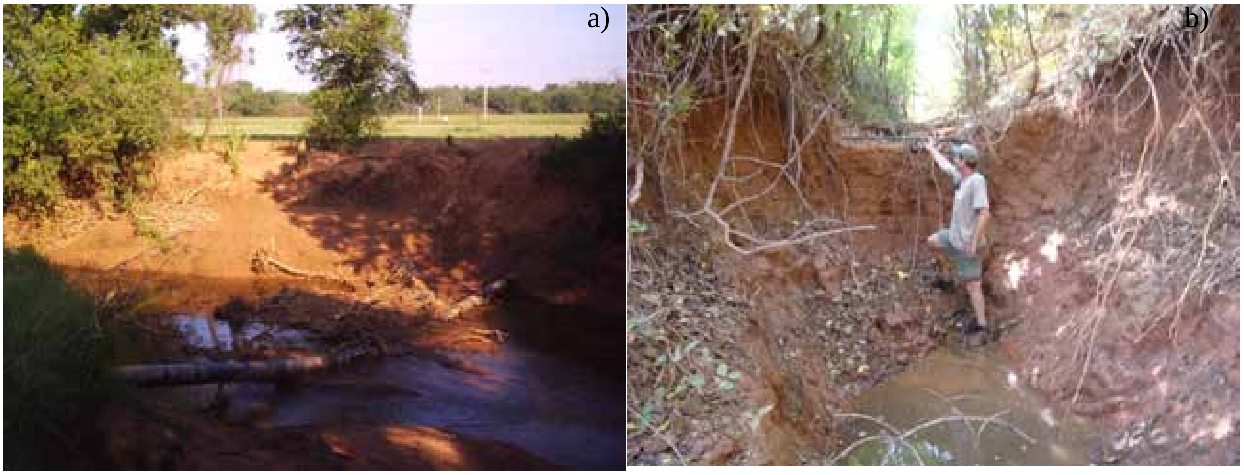


Figure 1: Indications of the Little River channel incision and widening including a) an exposed high pressure gas line and b) tributary head cuts.

Lane (1955) described that the morphology of a channel is the result of several factors, including the sediment load and size transported through the channel, the discharge in the channel and the slope of the channel. The size and load of sediment transported through a channel is balanced by the stream slope and discharge. If the balance is altered, the channel morphology adjusts to accommodate the change. Schumm, et al (1984), and later Simon (Simon, 1989, 1994) developed a process-based classification scheme that describes a natural channel's adaptation to straightening. As shown in Figure 2, the Channel Evolution Model describes a complete "cycle" of bank-slope development from the pre-modified conditions through stages of adjustment to the eventual reestablishment of stable bank conditions. The Little River channel bed, in the reach surveyed in the vicinity of 12th Avenue NE, appears to have recently entered Stage IV of the evolutionary cycle, the degradation and widening phase, and appears to have incised at least 6-8 feet thus far.

To fully understand the significance of this process, one needs only to look at Wildhorse Creek, near Hoover, in Garvin County, Oklahoma. Between 1922 and 1933 the channel was "improved" by constructing a straight 10 feet deep trapezoidal channel with a top width of 25 feet and 2:1 side slopes, as may be seen in Figure 3a (Barclay, 1980). In 1999, Dutnell (2000) found the channel to be 193 feet wide and approximately 25 feet deep. The channel has thus incised approximately 15 feet and experienced a 20-fold increase in cross-sectional area (Figure 3b). It appeared to be at Stage V, the aggradation and widening phase, as there was evidence of deposition on inside bends and point bars were beginning to form. As a result of the experienced erosion, the sediment loading to Lake Texoma, since the "channel improvements" were completed, exceeds 50 million cubic yards.

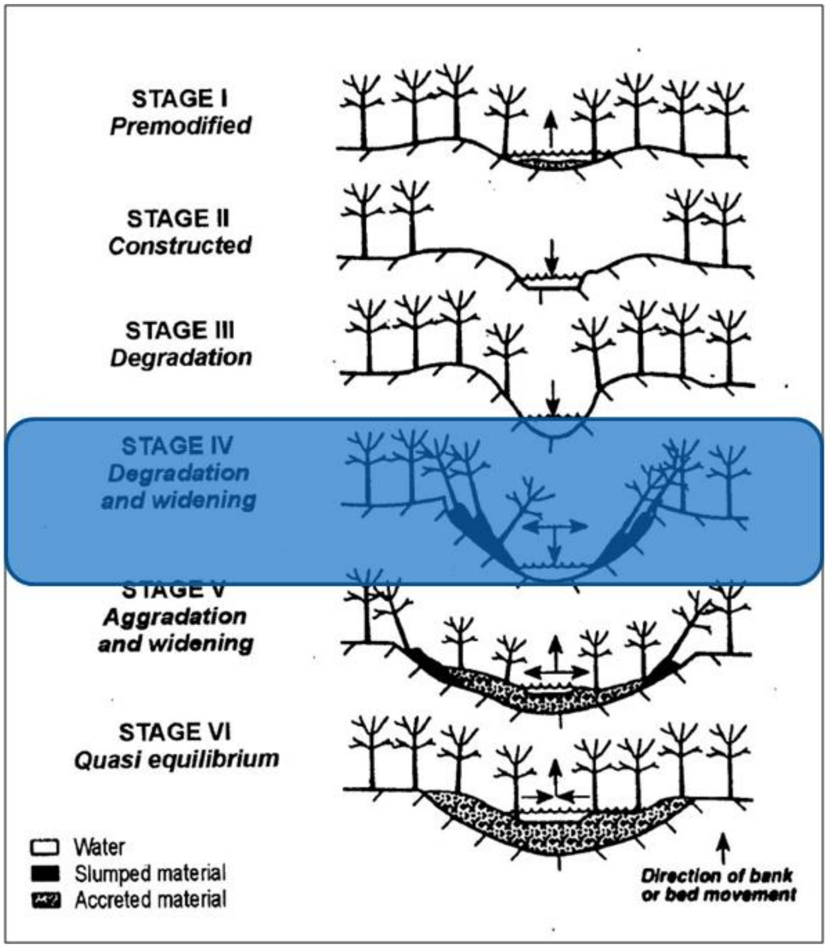
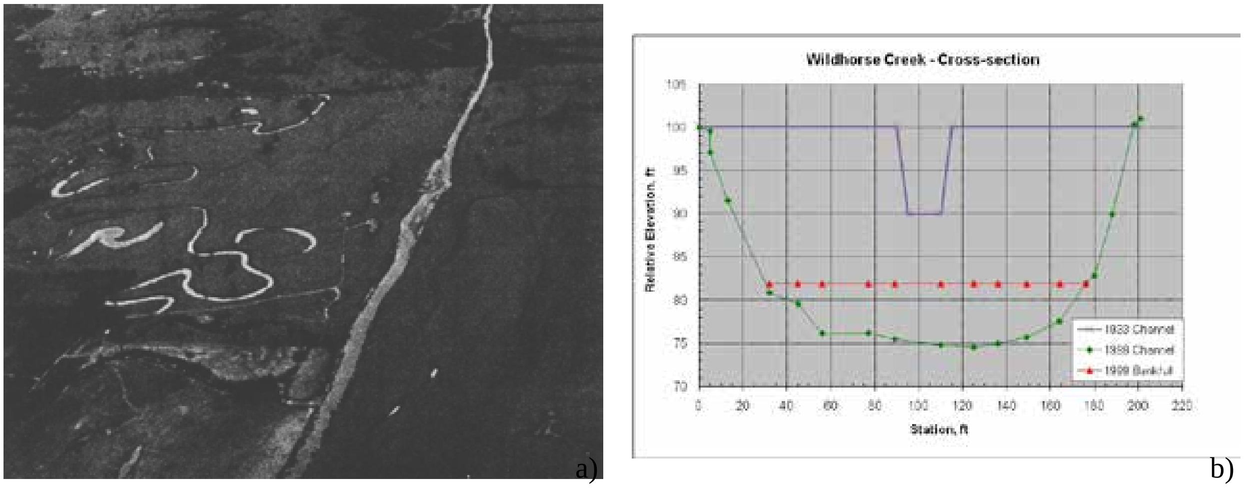


Figure 2: Channel Evolution Model – The Little River is currently at Stage IV, the degradation and widening stage. (Simon (1989))



a)

b)

Figure 3: a) Channelized versus natural meandering Wildhorse Creek channel, in Garvin County, Oklahoma (Barclay, 1980); b) Comparison of Wildhorse Creek channel dimensions in 1933 (Barclay, 1980) and 1999 (Dutnell, 2000)

Little River may, or may not experience the same level of degradation and widening as Wildhorse Creek, but the process is certainly ongoing and the degradation and widening occurring in the channel already appears to be significant. Further, the Little River and Wildhorse Creek are not the only streams that are undergoing this process of change. A large number of the creeks and rivers in the State of Oklahoma are undergoing the exact process described here, i.e., they have been straightened and/or are receiving more flow due to urbanization and thus are incising and widening. The current project is attempting to develop a methodology that may be used for assessing and documenting this process in the State's streams.

Research Objectives

The current study is addressing multiple objectives, including the following:

1) Documentation of the Fluvial Geomorphology (FGM) of the Little River from the headwaters to Lake Thunderbird;
2) Development of discharge and sediment rating curves for the Little River watershed;
3) Development of a frequency-duration curve for the Little River watershed;
4) Estimation of the annual and long-term sediment load to Lake Thunderbird;
5) Estimation of the amount of expected channel degradation for the Little River;
6) Potential recommendations for stopping or slowing the expected channel degradation; and
7) Development of a protocol that may be used by other entities, including GRDA, to estimate sediment loading rates to reservoirs and better understand the sediment transport characteristics of streams flowing within their jurisdiction.

Methodology

The methods used to meet the various objectives of the current study are described below. The work centers around the use of a Teledyne RDI Workhorse Rio Grande 600 kHz Acoustic Doppler Current Profiler (ADCP) (see Figure 4) and available off-the-shelf software to estimate stream discharge, suspended sediment concentrations, and at higher flows, the bed load velocities. The equipment and methodology being used in the current project, though relatively new, are becoming more accepted as the use of ADCPs increases. In 2005, the U.S. Geological Survey (USGS), in cooperation with the U.S. Army Corps of Engineers, Detroit District, developed a Quality-Assurance Plan for discharge measurements using ADCPs (Oberg, 2005). More recently, the USGS, recognizing that the use of ADCPs "is now a commonly used method for measuring streamflow," has released guidance on the use of ADCPs for that purpose (Mueller and Wagner, 2009). Similar protocols had previously been developed by the Water Survey of Canada (2004). Both of these publications address all aspects of measuring discharge and bed movement using an ADCP. They do not, however, address measuring suspended sediment concentrations. Software is available on the market that can be used to convert the back-scatter data obtained from the ADCP to sediment concentration using an iterative approach (Aqua Vision, 2009a).

Documentation of the FGM of the Little River from the headwaters to Lake Thunderbird

Documenting the FGM of the Little River requires the surveying of cross-sections and longitudinal bed profiles using traditional surveying methods and a total station. In addition, the project will attempt to measure the elevation of the Little River bed from the lake to the headwaters (or as far up as the channel as possible) using an ADCP in conjunction with a real-time kinematic (RTK) GPS receiver. In this configuration, the RTK determines the elevation of the boat and the ADCP determines the depth from the boat to the bottom of the channel.

Figure 4: Teledyne RDI Workhorse Rio Grande 600 kHz Acoustic Doppler Current Profiler (ADCP) operating from a bridge.

Subtracting the depth from the boat elevation will provide the bed elevation of the channel bottom. An inflatable Saturn "KaBoat" with an electric motor (Figure 5) is to be used to guide the ADCP/RTK down the river. Measurements must be made at intermediate flows so that the water is deep enough for the ADCP to work (>2.5'), but not so swift as to be dangerous. Preferably the work will take place in early fall when the leaves are off of the trees, to allow for better radio reception between the boat GPS and Base GPS, but before the weather gets too cold.

In addition to the surveys, the FGM documentation includes an assessment of stream channel morphology (Rosgen, 1996), evolution (Schumm, et al., 1984; Simon and Hupp, 1986; Simon, 1989; and Simon, 1994), and stability utilizing several different indices, including the Pfankuch Stream Stability Index (Pfankuch 1975), the Bank Erosion Hazard Index (BEHI) (Rosgen, 1996), the Near Bank Stress (NBS) rating (Rosgen,1996), the Channel Stability Index (CSI) as modified by Simon and Klimetz (2008), and the Ozark Streambank Erosion Potential Index (OSEPI) developed by Storm et al. (2010) for streams in the Ozark eco-region. It is not clear if the latter is particularly applicable in the Little River watershed; the data being collected will provide the information needed to determine its applicability in the Little River watershed.

The data from the surveys and the stream channel morphology, evolution and stability assessments are being collected using a TDS Recon Pocket PC. The survey data is being collected using SurveyPro software interfacing with a Sokkia Set 500 Total Station. The stream channel morphology, evolution and stability data is being collected using Excel installed on the Recon. A tabular form was created so that the data required by the various indices could be input into the Recon item by item, line by line. This raw data is then copied and pasted to a "RawData" sheet in a larger, multi-sheet Excel spreadsheet that selects the data needed for each stability index, determines each index and prepares a summary. Indices are being determined at four locations for each reach surveyed. An example of the forms produced by the spreadsheet is shown in Appendix A. The spreadsheets can be made available upon request.

The data from the survey is then combined with the data from the stream channel morphology, evolution and stability assessment to develop a site summary sheet as shown in Appendix B. Photographs of the cross-section and the assessment sites are also included.

Figure 5: The Teledyne RDI Workhorse Rio Grande 600 kHz Acoustic Doppler Current Profiler (ADCP) with Hemisphere RTK-GPS and the inflatable "KaBoat"

Development of discharge and sediment rating curves for the Little River Watershed

Developing discharge and sediment rating curves for the Little River watershed requires measuring the discharge, the concentration of the suspended sediment and bed load movement over a large range of discharges (i.e., at multiple stages), at multiple sites. These sites (shown as triangles in Figure 6) were selected based on being representative of the system being assessed and on site accessibility.

The discharge is being determined using traditional wading methods with a Marsh McBirney Flo-Mate portable velocity meter, and a Teledyne RDI Workhorse Rio Grande 600 kHz Acoustic Doppler Current Profiler (ADCP) mounted to a tethered boat. The Flo-Mate is being used to determine the discharge for lower flows, the ADCP is being used at higher flows, and both are being used at intermediate flows. At higher flows, when most sediment is transported, the Visea Plume Detection Toolbox (PDT) software is being used to convert the back-scatter intensity recorded by the ADCP to suspended sediment concentrations. Visea PDT does this by integrating the back-scatter intensity with information on salinity, temperature and reference measurements of sediment concentrations (Aqua Vision, 2009b). Bed load movement only occurs at high flows, and it is being determined using the ADCP and methods described by the U.S. Geological Survey (Mueller and Wagner, 2009).

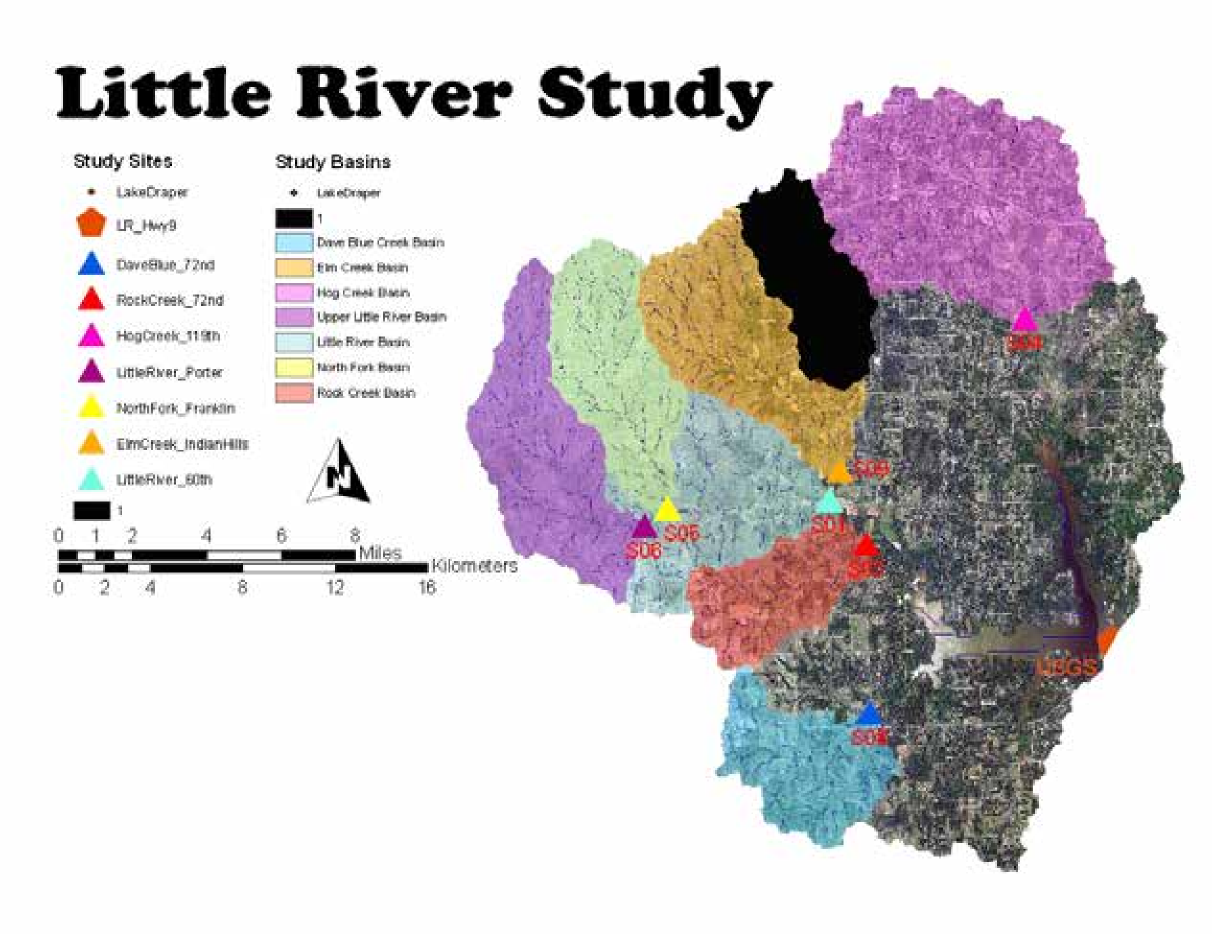


Figure 6: Discharge and Sediment Rating Curve Sites.

The stage, or depth of the water, at the study sites is being measured with HOBO Water Level Data Loggers. HOBOs are pressure transducers that can be set to measure pressure and temperature at varying time steps. For this study the HOBOs are installed in a PVC housing (Figure 7) and mounted to t-posts or re-bar with plastic zip-ties as close to the bottom of the stream as possible. Pressure is being measured every 30 minutes at the seven sites shown in Figure 6. A seventh HOBO is recording atmospheric pressure on the same 30 minute interval. By subtracting the atmospheric pressure from the total pressure of a stream mounted HOBO, the hydrostatic pressure at each HOBO is determined. Knowing the temperature and salinity (assumed to be zero), the density of the water may be determined, and thus the depth of the water above the HOBO may be calculated. Therefore, the HOBOs are essentially providing a record of depth every 30 minutes.

Discharge rating curves that relate stream discharge to channel stage are being developed by measuring discharge at various stages, as provided by the HOBOs. Sediment rating curves that relate sediment discharge to stage are being developed by measuring discharge and sediment concentration at various stages, again as provided by the HOBOs.

Figure 7: HOBO Water Level Logger with PVC housing.

Validation of the data obtained in the Little River watershed is complicated by the fact that there is not a USGS stream gauge on any portion of the river or the creeks upstream of Lake Thunderbird, so there is very little existing flow data for the Little River or its tributaries. Even though several studies have been conducted validating the use of ADCPs for measuring stream discharge (Fulton and Ostrowski, 2008; Everard, 2009; Schinkel, 2009; and Terek, 2009) and sediment movement (Rennie et al., 2002; Kostaschuk et al., 2005; Gaeuman and Jacobson, 2007; and Kim and Voulgaris, 2008) it is still necessary to validate the measurements being taken by the ADCP.

Validation of the use of the ADCP for measuring discharge is being conducted using two approaches. At intermediate flows, when it is still safe to use wading methods, the discharge results are compared to the results from a Marsh McBirney. Validation of higher flows requires measuring discharge at a nearby USGS gauge station and comparing the measured results to the discharge reported by the gauge station. Verification is considered to be achieved if the discharge measurement is within ±5% of the reported gauge discharge. Validation of the suspended sediment is to be accomplished by comparing values obtained using the ADCP to grab samples collected at the time of the measurement.

Unfortunately, there is no reliable means of validating the bedload velocity observed using the ADCP. The quantities of sediment captured in bed-load samplers are highly variable in both space and time. Gaeuman and Jacobson (2007) therefore concluded "conventional physical sampling appears to be the least reliable means for estimating bed-load transport rates in large sand-bed rivers," and therefore should not be used as a means for evaluating the performance of ADCPs. They did note that however that bed-load transport rates estimated from dune migration rates correlated well with ADCP measured bed-load velocities over a wide range of conditions. Obviously, the Little River is not a large sand-bed river, but it is a sand-bed river. It is not completely certain that bed features will be observed sufficient for performing validation in the manner presented, but it is suspected that it might.

Development of frequency-duration curves for the Little River Watershed

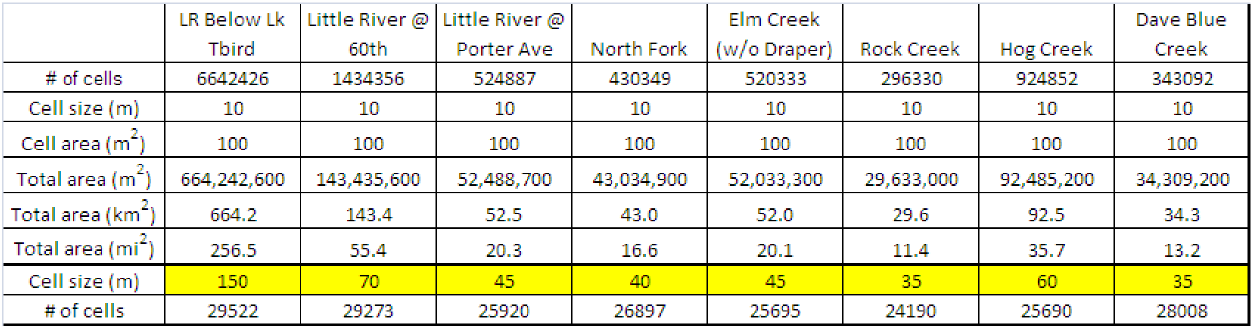
Since long-term information on the discharge history of the Little River is not available, the current study is relying on hydrologic modeling to generate the frequency-duration curve for the Little River and its tributaries. The model used in this study is Vflo which is a physics-based distributed hydrologic model developed by Vieux & Associates, Inc (Vieux, 2007). Vflo uses radar rainfall data for hydrologic input to simulate distributed runoff. The model generates distributed runoff maps covering the watershed and hydrographs at selected drainage network grids.

The rainfall data used in this study is produced by the ScourCast system that performs continuous distributed watershed model simulation and rainfall monitoring. ScourCast provides continuous rainfall at 15-minute intervals at a resolution of 2 kilometers. Model parameters, including roughness, saturated hydraulic conductivity, wetting front suction, and effective porosity are derived in ArcGIS at a resolution of 10 meters from maps of land use and soil type.

In order for the program to function properly, the number of cells imported into Vflo must be less than 30,000. Table 1 shows the minimum cell size that may be used to model the various sub-basins and the entire Lake Thunderbird watershed. The minimum allowable cell size for the sub-basins ranges from 35 square meters for the Dave Blue Creek sub-basin to 70 square meters for the Little River sub-basin above 60th Avenue Northeast. Modeling the entire watershed requires a minimum cell size of 150 square meters. Because ultimately, the entire watershed is to be modeled, a cell size of 150 square meters is being used in the current study. All data, however is at a resolution of 10 meters so future modeling of sub-basins could be conducted using finer resolutions as provided in Table1.

By modeling the sub-basins and generating hydrographs at drainage network grids that correspond to the monitoring sites where the HOBOs are installed, we can calibrate the model using the data collected in the current study. The model, thus calibrated is being used to generate frequency-duration curves, showing the percentage of time various flows are exceeded.

Table 1: Cell Size Determination Results



	LR Below Lk Tbird	Little River @ 60th	Little River @ Porter Ave	North Fork	Elm Creek (w/o Draper)	Rock Creek	Hog Creek	Dave Blue Creek
# of cells	6642426	1434356	524887	430349	520333	296330	924852	343092
Cell size (m)	10	10	10	10	10	10	10	10
Cell area (m^2)	100	100	100	100	100	100	100	100
Total area (m^2)	664,242,600	143,435,600	52,488,700	43,034,900	52,033,300	29,633,000	92,485,200	34,309,200
Total area (km^2)	664.2	143.4	52.5	43.0	52.0	29.6	92.5	34.3
Total area (mi^2)	256.5	55.4	20.3	16.6	20.1	11.4	35.7	13.2
Cell size (m)	150	70	45	40	45	35	60	35
# of cells	29522	29273	25920	26897	25695	24190	25690	28008

Estimation of the annual and long-term sediment load to Lake Thunderbird

Utilizing the information from the sediment rating curves, which allow for estimation of sediment loading rates at various flows, together with the frequency-duration curves, which predict how often a given discharge occurs, the annual sediment yield to Lake Thunderbird is being estimated.

Estimation of the amount of expected channel degradation for the Little River

Using the results of the surveys, including the longitudinal profile survey described above, an estimate of how far the Little River channel has degraded is being made. An estimate of how much farther it is anticipated to degrade will also be made.

Potential recommendations for stopping or slowing the expected channel degradation

Using the results of the surveys and the estimation of expected channel degradation, recommendations on potential methods for stopping or slowing the degradation will be prepared.

Development of sediment loading rates estimation protocol

Upon completion of the study, the lessons learned in the study will be used to develop a protocol for other entities to use to determine sediment loadings in other stream systems.

Principal Findings and Significance

Although delays in purchasing equipment and the lack of significant rain events prevented completion of this study in the proposed time period, the time was spent working on preliminary studies and related research tasks, as presented briefly below. In addition, researchers took the opportunity provided by the lack of rain to become more familiar with operating the equipment and software that it interfaces with. Training on the use of the Hemisphere RTK GPS system was provided by the manufacturer in Scottsdale, AZ in April 2010; and training on the use of ADCPs was obtained at a USGS course in Houston, Texas in January 2011, and at the 2011 USGS Surface-Water Conference and Hydroacoustics Workshop in Tampa, Florida in March 2011.

Documentation of the Fluvial Geomorphology (FGM) of the Little River from the headwaters to Lake Thunderbird

Work on documenting the FGM of the Little River has been somewhat slower than anticipated, mainly due to the lack of survey control in the vicinity of the river. Since the objective is to document the morphology of the entire length of the channel, it is desirable to know locations (Easting and Northing) and elevations to a high degree of accuracy. Methods typically used to measure channel morphology (i.e., a level and tape measure) are insufficient for the current study, and accurately using a total station over the length of the study is proving more time consuming than expected. Further, using the total station is particularly difficult when the leaves are on the trees, due to blocked line-of-site, so the only efficient time to conduct these surveys is in the fall and winter. Thus the surveys, including the longitudinal profile, will be completed this fall.

A couple of FGM surveys have been completed and the results are provided in Appendix B. Each summary sheet includes a legal description of the site location; the drainage area; an aerial photograph of the site showing the points surveyed and the location of the assessment sites; locations of the control points in both Oklahoma State Plane (NAD83-South Zone) coordinates and geodetic coordinates (Lat/Long – Decimal Degrees); a summary of the channel morphology including the bankfull width, the mean bankfull depth, the maximum bankfull depth, the flood prone area width, the bankfull area, the entrenchment ratio, the width to depth ratio, the sinuosity, the slope, the bed material, the Rosgen stream type, and the channel evolution stage; the stream channel stability data for the site that includes the scores and ratings of the various erosion indices (CSI, Pfankuch, BEHI, NBS and OEBSI) for each of the four assessment locations at the site; a cross-section of the site showing the ground, the water surface, the bankfull level and the flood prone area level; and a longitudinal profile plot showing the thalweg, the water surface, the location of the cross-section and surveyed points at the bankfull level and on top of the left and right banks.

Photographs of the sites are also taken at the time of the survey. Photographs are taken of both banks and facing upstream and downstream at the cross-section and of the study bank and facing upstream and downstream at the assessment sites. Photographs of the sites surveyed thus far are provided in Appendix C.

The results thus far are not surprising. They show a channel that is entrenched, with a Rosgen classification of F5 and G5c, and getting wider and deeper, with a channel evolution stage of IV. Practically every metric at every site assessed indicates that the channel is unstable or highly unstable with high to extreme near bank stress. Three other sites have been surveyed but the data has not yet been processed for inclusion in this report.

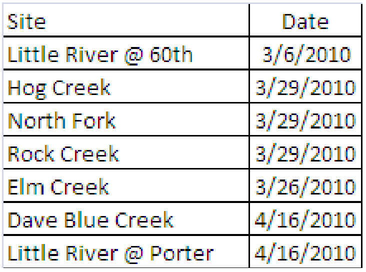
Development of discharge and sediment rating curves for the Little River watershed

The first information required to develop rating curves is a record of stage and discharge. As described above, the stage is being determined every thirty minutes using HOBO water level loggers deployed at seven sites as shown previously in Figure 6. At each of the sites, 18” x ½” iron pins were placed on both sides of the channel and the channel cross-section was surveyed. The elevations of the HOBOs were surveyed relative to the re-bar markers on the left banks.

Plots of the cross-sections, information on the HOBO deployments and aerial photographs of the rating curve sites, are provided in Appendix D. The depth and elevation of the HOBO is based on the elevation of the left pin, which is provided either as a reference elevation or a true elevation, if it has been determined. Two sites, the Little River at 60th and Hog Creek have staff gauges installed and at these sites the datum for the staff gauge was also surveyed relative to the left pin. The aerial photographs show the location of the cross-section and HOBO.

The dates that the HOBOs were deployed at the study sites are provided in Table 2. Plots of the stages recorded for each station, extending from the date of deployment through March 22, 2011 are provided in Appendix E. Perhaps, the most notable feature of the plots is the lack of peaks after September 2010. This is most pronounced at Rock Creek (Figure E-4). Another noteworthy feature is the rise in stage at Elm Creek (Figure E-5) beginning in October 2010. This perplexed the researchers prompting an investigation downstream, which revealed a newly constructed beaver dam that has since seemed to have fallen in disrepair. The last feature of note is the missing data at the Little River at 60th (Figure E-1) in May and August 2010. This occurred due to an error in logging the data. This highlights the necessity of diligence when logging the data and of logging the data at a frequency not to exceed a month.

Table 2: HOBO Deployment Dates



Site	Date
Little River @ 60th	3/6/2010
Hog Creek	3/29/2010
North Fork	3/29/2010
Rock Creek	3/29/2010
Elm Creek	3/26/2010
Dave Blue Creek	4/16/2010
Little River @ Porter	4/16/2010

The discharge has been measured multiple times at each site using the Marsh McBirney Flo-Mate, and multiple times at the Little River at 60th using the ADCP. Unfortunately, discharge has not been measured for larger flow events, due to a lack of precipitation. Plots of Stage versus Discharge for the sites are provided in Appendix F. The coefficient of determination (r^2) is somewhat low for the Little River at 60th, 0.545, fairly good for the Little River at Porter, 0.778, and good at the other sites, ranging from 0.845 to 0.969. The plots are not complete however because of a lack of measurements at higher discharges. This will be remedied in the coming months, provided the weather cooperates.

A few comparisons have been made between discharge measurements taken with the ADCP and measurements taken with the March McBirney. Measurements were taken at Site S01 the Little River at 60th. Table 3 shows the results of those measurements. The comparisons range from very good to very poor. Comparisons were also made between the measurements taken with the ADCP and the reported discharge from an active USGS gauge station. The gauge station used for the comparison was USGS Gauge Number 07240000, the Lake Hefner Canal. The results of those measurements are shown in Table 4.

There are a couple of potential reasons for the inconsistent performance of the ADCP including; operator error, which is very likely, as the investigators are still learning proper field protocol for using the equipment; instrument limitations, another likely reason, as the conditions under which the tests were conducted are near, or at, the limiting conditions in which the instrument will not operate, in that the advertised minimum depth for the 600 kHz Rio Grande is 0.7 meters (2.3 feet). More comparison tests are planned in the upcoming months.

Table 3: Discharge Measurement Comparison between Teledyne RDI Rio Grande 600 and Marsh McBirney Flo-Mate

Date	Mean Depth	ADCP	Marsh McBirney	ADCP % Diff.	Number of Measurements
7/9/2010	2.88	69.80	69.98	-0.3%	10 ADCP; 1 MMB
7/9/2010	2.95	68.49	69.98	-2.1%	10 ADCP; 1 MMB
7/10/2010	2.75	31.78	28.48	11.6%	10 ADCP; 5 MMB
7/10/2010	2.77	31.89	26.31	21.2%	10 ADCP; 4 MMB
7/12/2010	2.83	64.62	60.84	6.2%	10 ADCP; 9 MMB
7/13/2010	2.97	63.79	51.50	23.9%	10 ADCP; 5 MMB
7/13/2010	2.89	55.45	49.89	11.1%	10 ADCP; 5 MMB

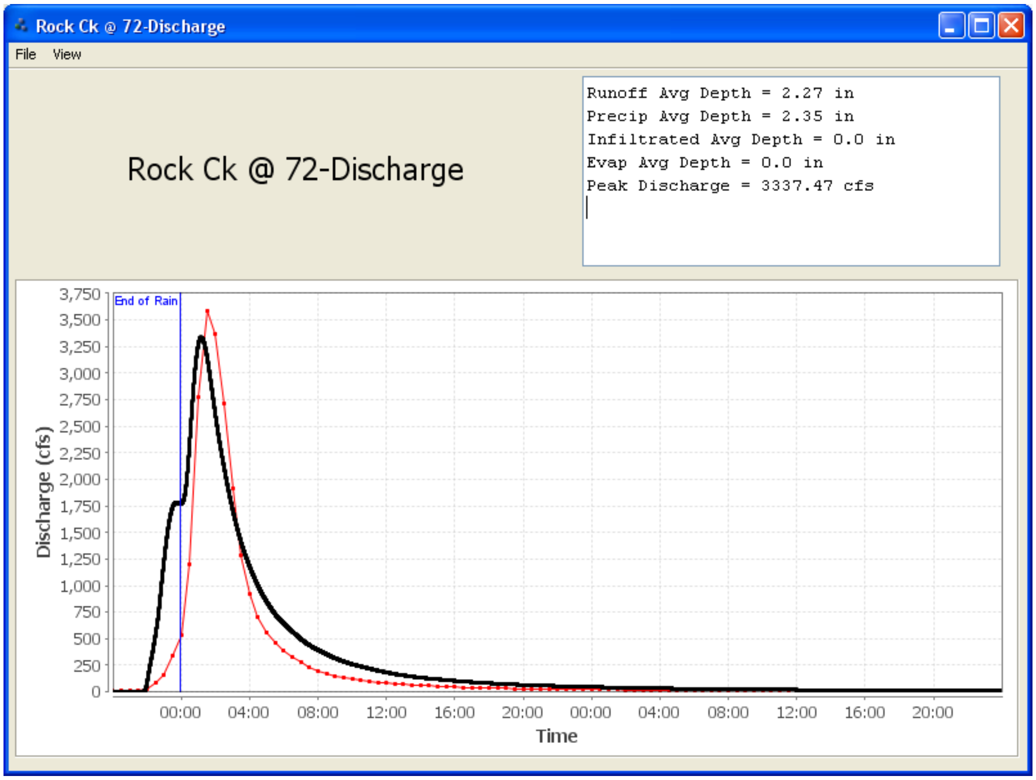
Table 4: Discharge Measurement Comparison between Teledyne RDI Rio Grande 600 and USGS Gauge 07240000 - Lake Hefner Canal

Date	Mean Depth	ADCP	USGS GAUGE	ADCP % Diff.	Number of Measurements
10/1/2010	2.80	21.90	27	-18.9%	10 ADCP
10/1/2010	2.71	21.95	27	-18.7%	10 ADCP
10/28/2010	2.80	84.37	82	2.9%	11 ADCP
10/28/2010	2.80	85.47	82	4.2%	10 ADCP
10/28/2010	2.80	90.17	82	10.0%	10 ADCP
10/28/2010	2.80	89.27	82	8.9%	10 ADCP

Sediment monitoring has yet to be conducted, with the exception of a few samples collected to practice the methods of collection and analysis being used in the study. Comparisons of ADCP results with traditional methods therefore, have not been conducted. A rainy season, or even a couple of severe events, will change that.

Development of a frequency-duration curve for the Little River watershed

Development of frequency-duration curves, as described earlier, is being conducted using Vflo, calibrated to the hydrographs obtained from the study sites, to develop "historical" long term hydrographs, from which the required curves can be constructed. However, the required hydrographs have not been fully developed due to a lack of high flow measurements and the subsequent lack of sufficient discharge rating curves. Nevertheless, the methods described above were tested using data from Rock Creek and rainfall records from July 3rd and 4th, 2010. The Vflo model was calibrated by adjusting model parameters, primarily the imperviousness, which was set to 40 percent at the upper end of Rock Creek with its value decreasing downstream. A plot of the model calibration is provided in Figure 8. The red line is from the site hydrograph generated by the HOBOs and the discharge rating curve and the black line is the model output. Note that the calibration focused on the timing of the event and not the peak discharge, which is questionable due to the incomplete rating curve. Nevertheless, the output shows that the Vflo model can be effectively used to generate a representative hydrograph. More work remains to be done after more validation data has been collected.



```
Runoff Avg Depth = 2.27 in
Precip Avg Depth = 2.35 in
Infiltrated Avg Depth = 0.0 in
Evap Avg Depth = 0.0 in
Peak Discharge = 3337.47 cfs
```

Figure 8: Vflo Calibration Plot for Rock Creek – July 3 and 4, 2010

Estimation of the annual and long-term sediment load to Lake Thunderbird

This work cannot be completed until the previous work is accomplished.

Estimation of the amount of expected channel degradation for the Little River

Early indications are that the channel has incised at least six feet over the last couple of decades but final estimation of the amount of anticipated channel degradation remains to be determined.

Potential recommendations for stopping or slowing the expected channel degradation

Due to the incomplete status of the project, recommendations for stopping or slowing the expected channel degradation cannot be made at this time.

Development of sediment loading rates estimation protocol

Due to the incomplete status of the project, a protocol for estimating sediment loading rates has yet to be developed, although development of such protocol remains a primary objective of the study.

The significance of the study is yet to be determined, but already it has provided data on the hydrology of the Lake Thunderbird watershed, in the form of a year's worth of stage data on the major tributaries to the lake. When the rating curves are complete this will provide a record of the discharge to the lake that would not have been developed without the current research, and the HOBOs will be maintained and continue to provide data as long as the researchers are physically capable of doing it. The FGM study is providing detailed information on the morphology of the Little River, which will provide a baseline for future researchers and could be extremely significant if they wanted to look at changes to the channel morphology over time, perhaps due to increased development or climate change. Without a baseline with which to compare, these studies would not be possible. The sediment data to be collected in the study will be invaluable. The samples being collected to validate the effectiveness of the ADCP will provide data that would not have been available without the funding of this project, and if the ADCP is proven to be an effective means of measuring both discharge and sediment, it would be a very significant contribution to science and would be beneficial to many fields of study.

The use of ADCPs for measuring discharge is fairly established. The use of ADCPs to measure sediment is a newly emerging field, a fact that became apparent at the 2011 USGS Surface-Water Conference and Hydroacoustics Workshop in Tampa, Florida. This project, though incomplete at this point, will continue until it addresses each of the stated objectives, and when complete, will add significantly to the research in the field.

Acknowledgments

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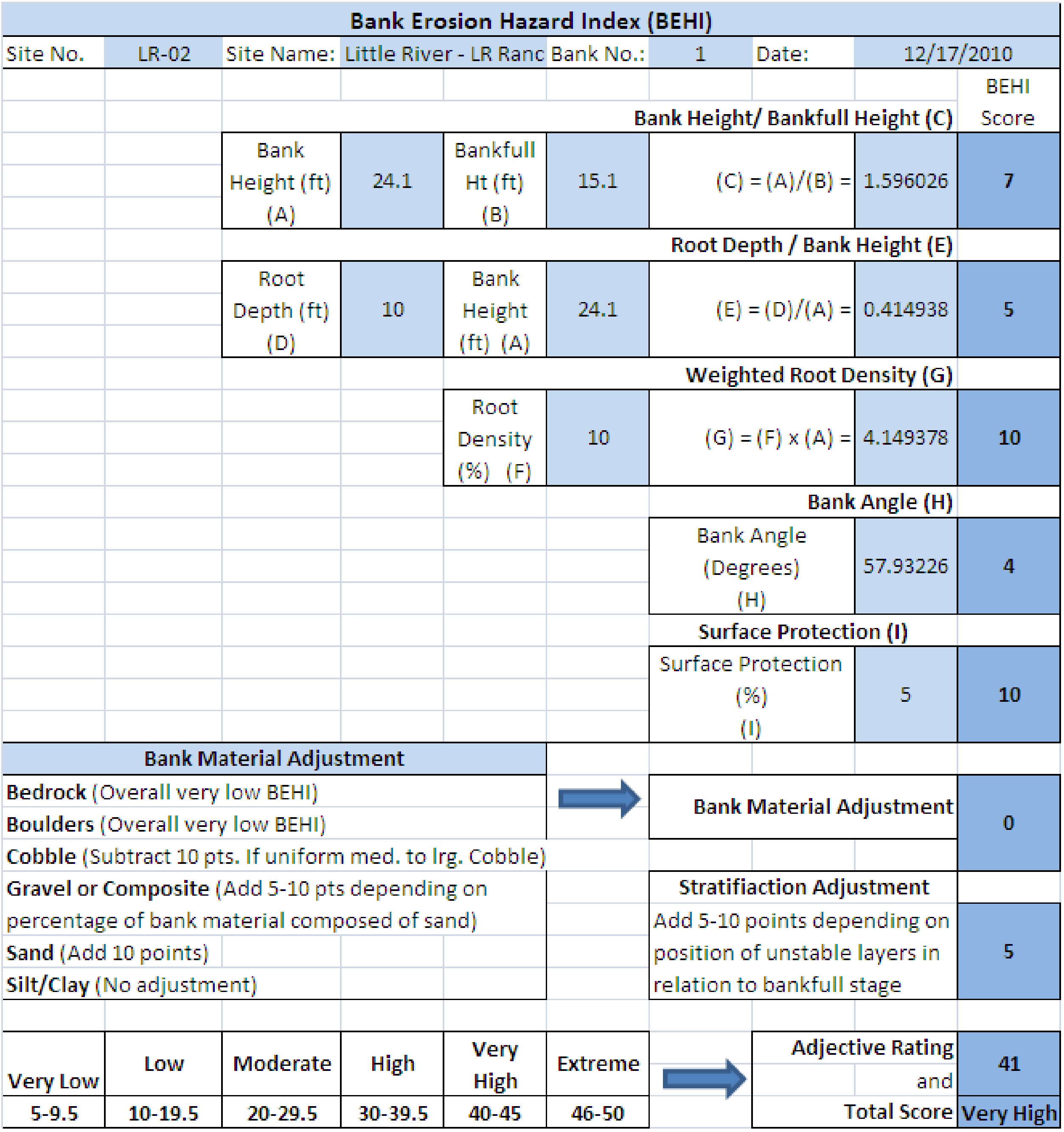
Appendix A – Example of FGM Assessment Forms



Bank Erosion Hazard Index (BEHI)

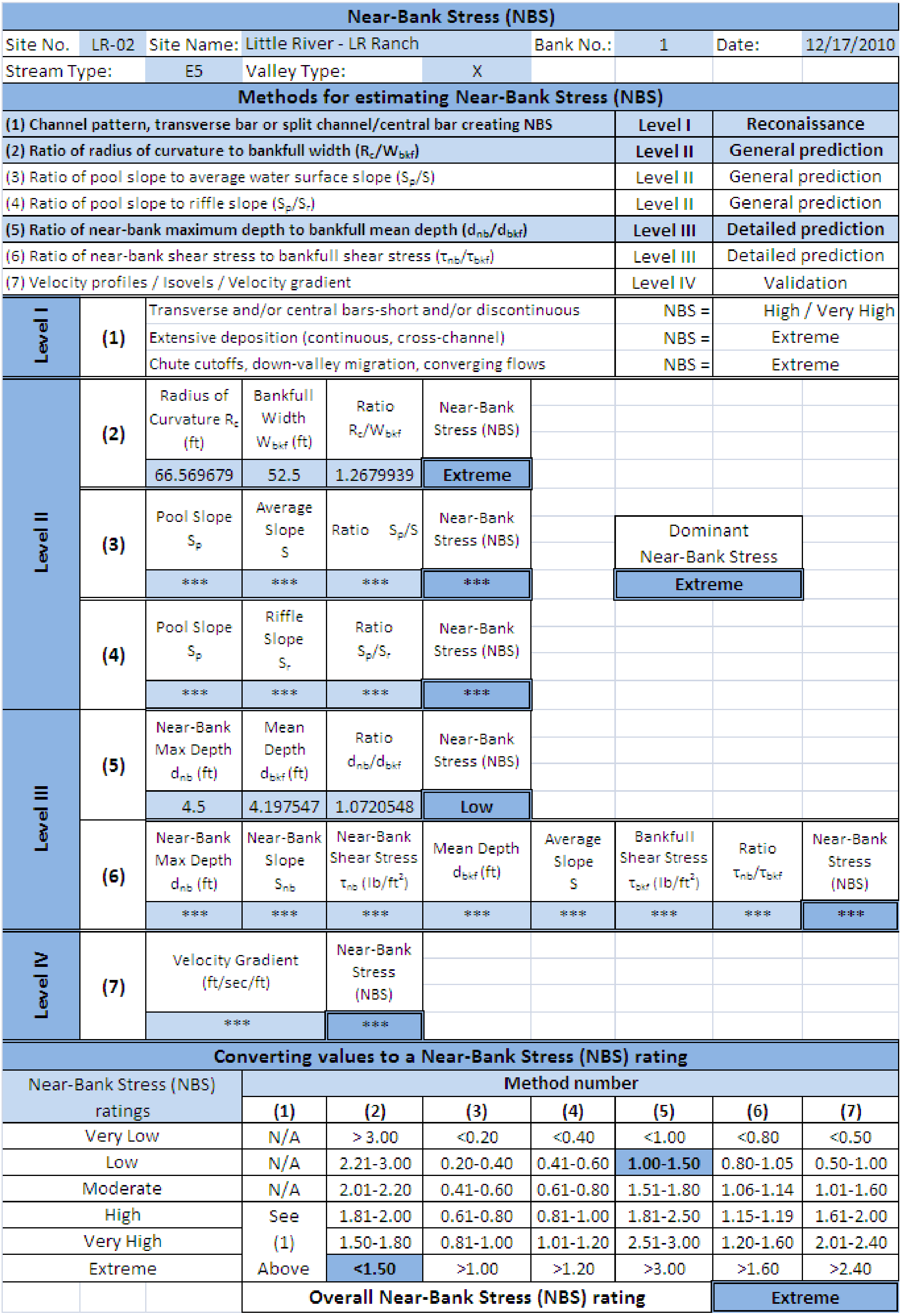
Site No.	LR-02	Site Name:	Little River - LR Ranc	Bank No.:	1	Date:	12/17/2010

						BEHI Score
Bank Height/ Bankfull Height (C)						
Bank Height (ft) (A)	24.1	Bankfull Ht (ft) (B)	15.1	(C) = (A)/(B) =	1.596026	**7**
Root Depth / Bank Height (E)						
Root Depth (ft) (D)	10	Bank Height (ft) (A)	24.1	(E) = (D)/(A) =	0.414938	**5**
Weighted Root Density (G)						
		Root Density (%) (F)	10	(G) = (F) x (A) =	4.149378	**10**
Bank Angle (H)						
				Bank Angle (Degrees) (H)	57.93226	**4**
Surface Protection (I)						
				Surface Protection (%) (I)	5	**10**

Bank Material Adjustment	**Bank Material Adjustment**	**0**
Bedrock (Overall very low BEHI)		
Boulders (Overall very low BEHI)		
Cobble (Subtract 10 pts. If uniform med. to lrg. Cobble)		
Gravel or Composite (Add 5-10 pts depending on percentage of bank material composed of sand)	**Stratifiaction Adjustment**	
Sand (Add 10 points)	Add 5-10 points depending on position of unstable layers in relation to bankfull stage	**5**
Silt/Clay (No adjustment)		

Very Low	**Low**	**Moderate**	**High**	**Very High**	**Extreme**	
5-9.5	**10-19.5**	**20-29.5**	**30-39.5**	**40-45**	**46-50**	
					Adjective Rating and Total Score	**41** **Very High**

Figure A-1: Example Bank Erosion Hazard Index (BEHI) Form



Near-Bank Stress (NBS)

Site No.	LR-02	Site Name:	Little River - LR Ranch	Bank No.:	1	Date:	12/17/2010
Stream Type:	E5	Valley Type:	X				

Methods for estimating Near-Bank Stress (NBS)

(1) Channel pattern, transverse bar or split channel/central bar creating NBS	**Level I**	**Reconaissance**
(2) Ratio of radius of curvature to bankfull width (R_c/W_{bkf})	**Level II**	**General prediction**
(3) Ratio of pool slope to average water surface slope (S_p/S)	Level II	General prediction
(4) Ratio of pool slope to riffle slope (S_p/S_r)	Level II	General prediction
(5) Ratio of near-bank maximum depth to bankfull mean depth (d_{nb}/d_{bkf})	**Level III**	**Detailed prediction**
(6) Ratio of near-bank shear stress to bankfull shear stress (τ_{nb}/τ_{bkf})	Level III	Detailed prediction
(7) Velocity profiles / Isovels / Velocity gradient	Level IV	Validation

Level I	**(1)**	Transverse and/or central bars-short and/or discontinuous	NBS =	High / Very High
		Extensive deposition (continuous, cross-channel)	NBS =	Extreme
		Chute cutoffs, down-valley migration, converging flows	NBS =	Extreme

Level II

	Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	Ratio R_c/W_{bkf}	Near-Bank Stress (NBS)
(2)	66.569679	52.5	1.2679939	**Extreme**

	Pool Slope S_p	Average Slope S	Ratio S_p/S	Near-Bank Stress (NBS)
(3)	***	***	***	***

	Pool Slope S_p	Riffle Slope S_r	Ratio S_p/S_r	Near-Bank Stress (NBS)
(4)	***	***	***	***

Dominant Near-Bank Stress
Extreme

Level III

	Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	Ratio d_{nb}/d_{bkf}	Near-Bank Stress (NBS)
(5)	4.5	4.197547	1.0720548	**Low**

	Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb}/τ_{bkf}	Near-Bank Stress (NBS)
(6)	***	***	***	***	***	***	***	***

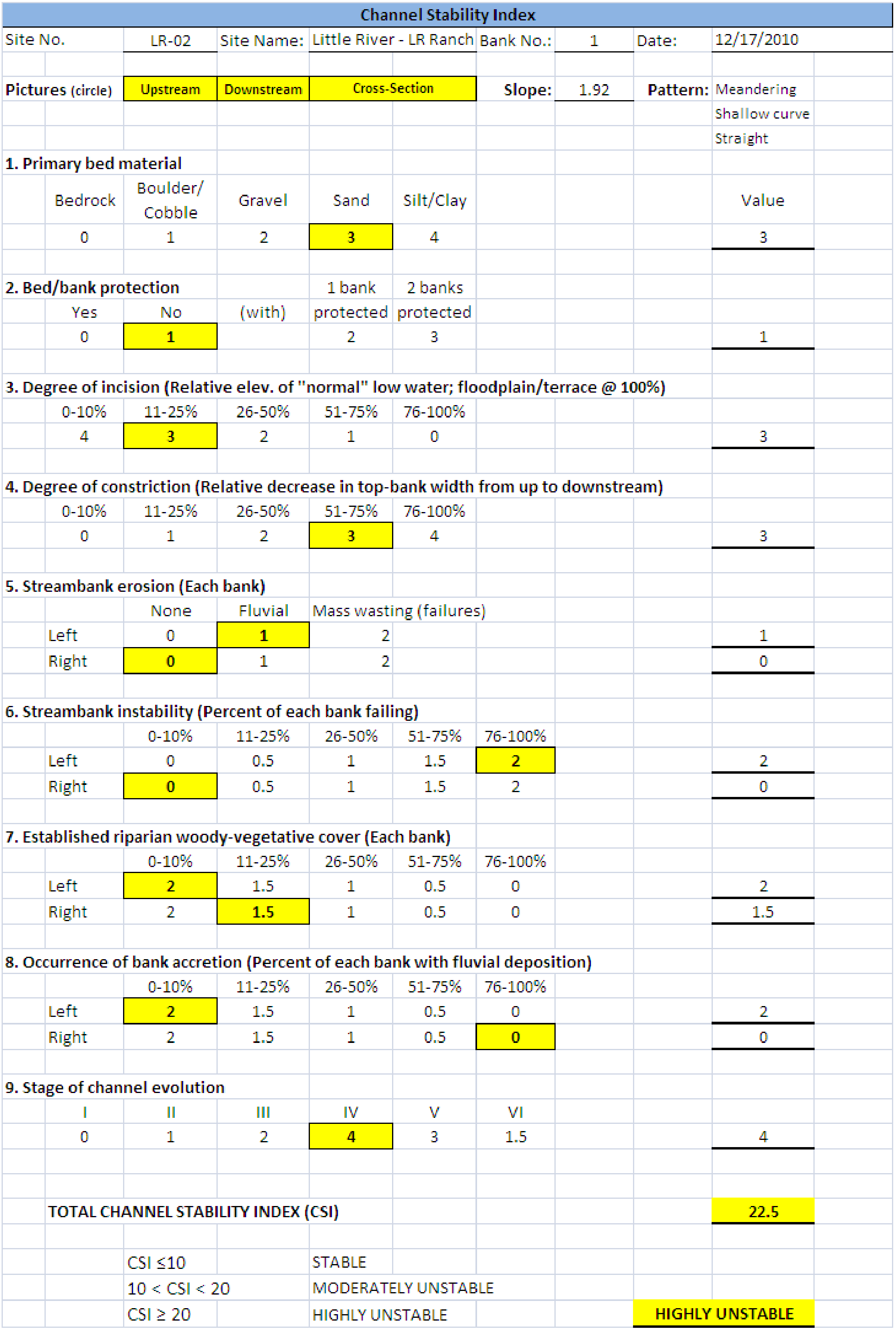
Level IV

	Velocity Gradient (ft/sec/ft)	Near-Bank Stress (NBS)
(7)	***	***

Converting values to a Near-Bank Stress (NBS) rating

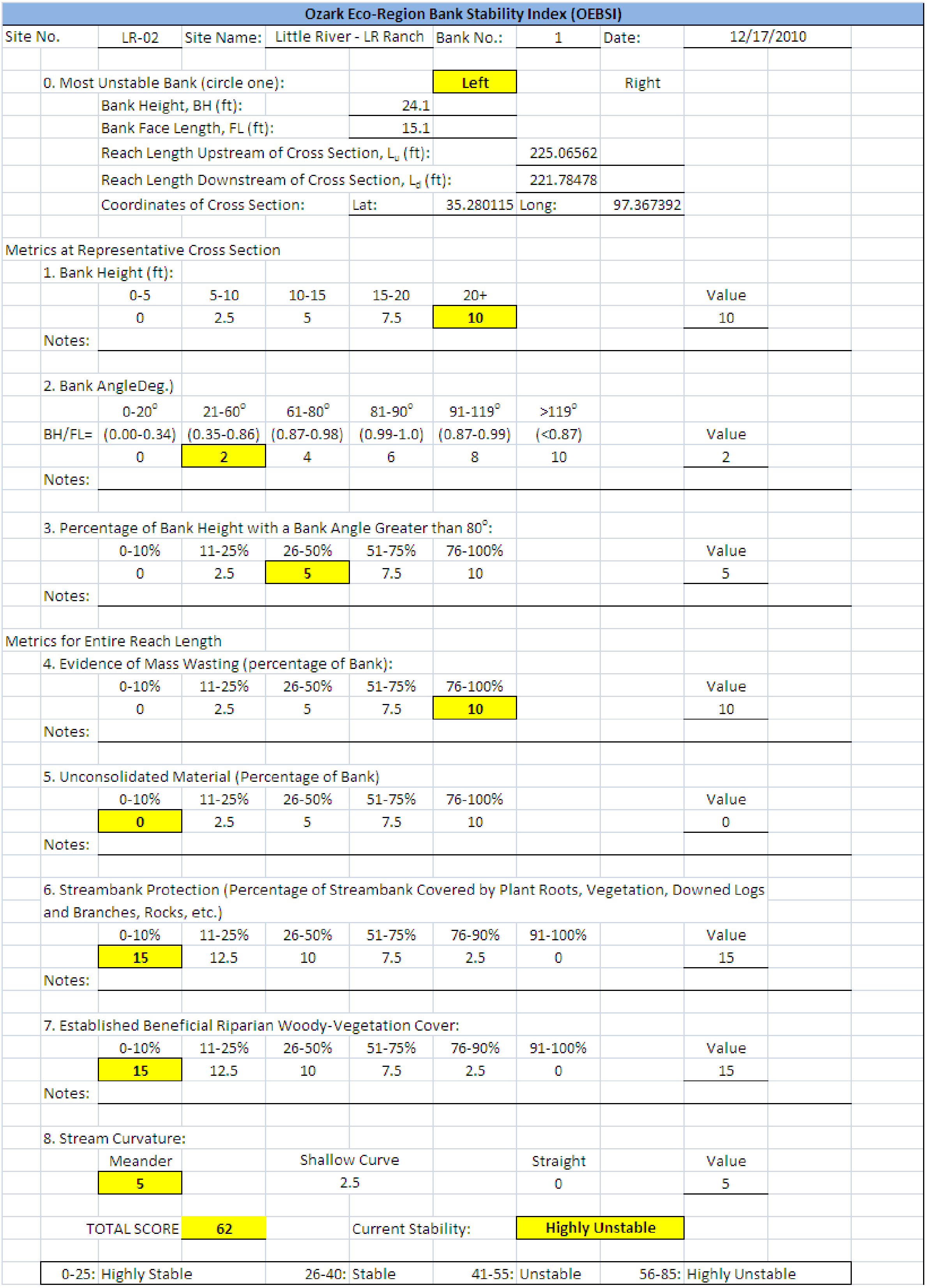
Near-Bank Stress (NBS) ratings	Method number						
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
Very Low	N/A	> 3.00	<0.20	<0.40	<1.00	<0.80	<0.50
Low	N/A	2.21-3.00	0.20-0.40	0.41-0.60	**1.00-1.50**	0.80-1.05	0.50-1.00
Moderate	N/A	2.01-2.20	0.41-0.60	0.61-0.80	1.51-1.80	1.06-1.14	1.01-1.60
High	See	1.81-2.00	0.61-0.80	0.81-1.00	1.81-2.50	1.15-1.19	1.61-2.00
Very High	(1)	1.50-1.80	0.81-1.00	1.01-1.20	2.51-3.00	1.20-1.60	2.01-2.40
Extreme	Above	**<1.50**	>1.00	>1.20	>3.00	>1.60	>2.40
	Overall Near-Bank Stress (NBS) rating					**Extreme**	

Figure A-2: Example of Near Bank Stress (NBS) Form



Channel Stability Index								
Site No.	LR-02	Site Name:	Little River - LR Ranch		Bank No.:	1	Date:	12/17/2010
Pictures (circle)	[✓ Upstream]	[✓ Downstream]	[✓ Cross-Section]		**Slope:**	1.92	**Pattern:**	Meandering
								Shallow curve
								Straight
1. Primary bed material								
Bedrock	Boulder/ Cobble	Gravel	Sand	Silt/Clay				Value
0	1	2	[✓ 3]	4				3
2. Bed/bank protection								
Yes	No	(with)	1 bank protected	2 banks protected				
0	[✓ 1]		2	3				1
3. Degree of incision (Relative elev. of "normal" low water; floodplain/terrace @ 100%)								
0-10%	11-25%	26-50%	51-75%	76-100%				
4	[✓ 3]	2	1	0				3
4. Degree of constriction (Relative decrease in top-bank width from up to downstream)								
0-10%	11-25%	26-50%	51-75%	76-100%				
0	1	2	[✓ 3]	4				3
5. Streambank erosion (Each bank)								
	None	Fluvial	Mass wasting (failures)					
Left	0	[✓ 1]	2					1
Right	[✓ 0]	1	2					0
6. Streambank instability (Percent of each bank failing)								
	0-10%	11-25%	26-50%	51-75%	76-100%			
Left	0	0.5	1	1.5	[✓ 2]			2
Right	[✓ 0]	0.5	1	1.5	2			0
7. Established riparian woody-vegetative cover (Each bank)								
	0-10%	11-25%	26-50%	51-75%	76-100%			
Left	[✓ 2]	1.5	1	0.5	0			2
Right	2	[✓ 1.5]	1	0.5	0			1.5
8. Occurrence of bank accretion (Percent of each bank with fluvial deposition)								
	0-10%	11-25%	26-50%	51-75%	76-100%			
Left	[✓ 2]	1.5	1	0.5	0			2
Right	2	1.5	1	0.5	[✓ 0]			0
9. Stage of channel evolution								
I	II	III	IV	V	VI			
0	1	2	[✓ 4]	3	1.5			4
TOTAL CHANNEL STABILITY INDEX (CSI)								22.5
	CSI ≤10		STABLE					
	10 < CSI < 20		MODERATELY UNSTABLE					
	CSI ≥ 20		HIGHLY UNSTABLE				HIGHLY UNSTABLE	

Figure A-3: Example of Channel Stability Index (CSI) Form



Ozark Eco-Region Bank Stability Index (OEBSI)

Site No.	LR-02	Site Name:	Little River - LR Ranch	Bank No.:	1	Date:	12/17/2010

0. Most Unstable Bank (circle one): [✓ Left] Right

Bank Height, BH (ft): 24.1

Bank Face Length, FL (ft): 15.1

Reach Length Upstream of Cross Section, L_u (ft): 225.06562

Reach Length Downstream of Cross Section, L_d (ft): 221.78478

Coordinates of Cross Section: Lat: 35.280115 Long: 97.367392

Metrics at Representative Cross Section

1. Bank Height (ft):

0-5	5-10	10-15	15-20	20+	Value
0	2.5	5	7.5	[✓ 10]	10

Notes:

2. Bank AngleDeg.)

	0-20°	21-60°	61-80°	81-90°	91-119°	>119°	
BH/FL=	(0.00-0.34)	(0.35-0.86)	(0.87-0.98)	(0.99-1.0)	(0.87-0.99)	(<0.87)	Value
	0	[✓ 2]	4	6	8	10	2

Notes:

3. Percentage of Bank Height with a Bank Angle Greater than 80°:

0-10%	11-25%	26-50%	51-75%	76-100%	Value
0	2.5	[✓ 5]	7.5	10	5

Notes:

Metrics for Entire Reach Length

4. Evidence of Mass Wasting (percentage of Bank):

0-10%	11-25%	26-50%	51-75%	76-100%	Value
0	2.5	5	7.5	[✓ 10]	10

Notes:

5. Unconsolidated Material (Percentage of Bank)

0-10%	11-25%	26-50%	51-75%	76-100%	Value
[✓ 0]	2.5	5	7.5	10	0

Notes:

6. Streambank Protection (Percentage of Streambank Covered by Plant Roots, Vegetation, Downed Logs and Branches, Rocks, etc.)

0-10%	11-25%	26-50%	51-75%	76-90%	91-100%	Value
[✓ 15]	12.5	10	7.5	2.5	0	15

Notes:

7. Established Beneficial Riparian Woody-Vegetation Cover:

0-10%	11-25%	26-50%	51-75%	76-90%	91-100%	Value
[✓ 15]	12.5	10	7.5	2.5	0	15

Notes:

8. Stream Curvature:

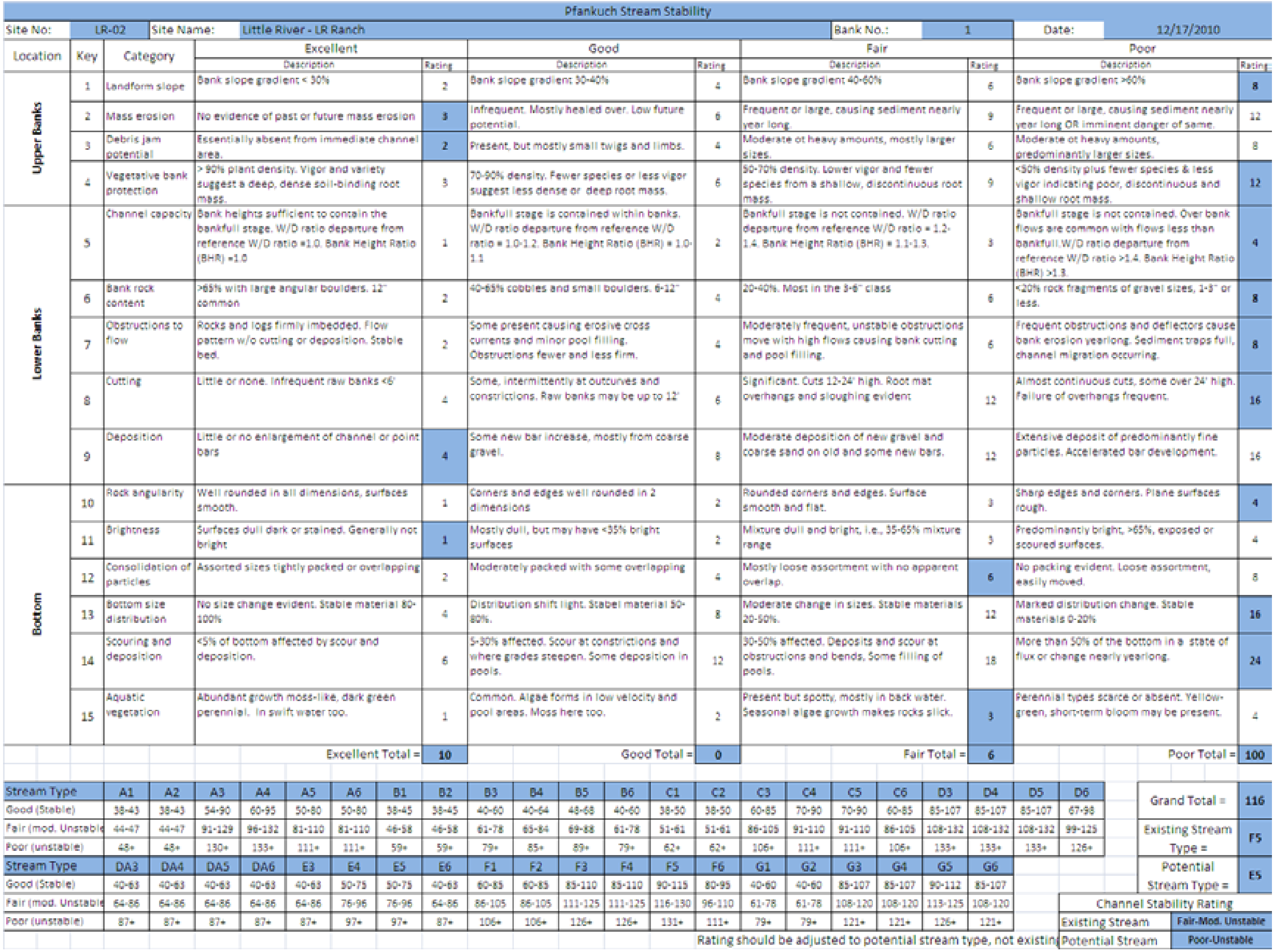
Meander	Shallow Curve	Straight	Value
[✓ 5]	2.5	0	5

TOTAL SCORE 62 Current Stability: Highly Unstable

0-25: Highly Stable	26-40: Stable	41-55: Unstable	56-85: Highly Unstable

Figure A-4: Example of Ozark Eco-Region Bank Stability Index (OEBSI) Form

Figure A-5: Example of Pfankuch Stream Stability Form



Pfankuch Stream Stability

Site No:	LR-02	Site Name:	Little River - LR Ranch	Bank No.:	1	Date:	12/17/2010

Location	Key	Category	Excellent Description	Excellent Rating	Good Description	Good Rating	Fair Description	Fair Rating	Poor Description	Poor Rating
Upper Banks	1	Landform slope	Bank slope gradient < 30%	2	Bank slope gradient 30-40%	4	Bank slope gradient 40-60%	6	Bank slope gradient >60%	8
	2	Mass erosion	No evidence of past or future mass erosion	3	Infrequent. Mostly healed over. Low future potential.	6	Frequent or large, causing sediment nearly year long.	9	Frequent or large, causing sediment nearly year long OR imminent danger of same.	12
	3	Debris jam potential	Essentially absent from immediate channel area.	2	Present, but mostly small twigs and limbs.	4	Moderate ot heavy amounts, mostly larger sizes.	6	Moderate ot heavy amounts, predominantly larger sizes.	8
	4	Vegetative bank protection	> 90% plant density. Vigor and variety suggest a deep, dense soil-binding root mass.	3	70-90% density. Fewer species or less vigor suggest less dense or deep root mass.	6	50-70% density. Lower vigor and fewer species from a shallow, discontinuous root mass.	9	<50% density plus fewer species & less vigor indicating poor, discontinuous and shallow root mass.	12
Lower Banks	5	Channel capacity	Bank heights sufficient to contain the bankfull stage. W/D ratio departure from reference W/D ratio =1.0. Bank Height Ratio (BHR) =1.0	1	Bankfull stage is contained within banks. W/D ratio departure from reference W/D ratio = 1.0-1.2. Bank Height Ratio (BHR) = 1.0-1.1	2	Bankfull stage is not contained. W/D ratio departure from reference W/D ratio = 1.2-1.4. Bank Height Ratio (BHR) = 1.1-1.3.	3	Bankfull stage is not contained. Over bank flows are common with flows less than bankfull.W/D ratio departure from reference W/D ratio >1.4. Bank Height Ratio (BHR) >1.3.	4
	6	Bank rock content	>65% with large angular boulders. 12" common	2	40-65% cobbles and small boulders. 6-12"	4	20-40%. Most in the 3-6" class	6	<20% rock fragments of gravel sizes, 1-3" or less.	8
	7	Obstructions to flow	Rocks and logs firmly imbedded. Flow pattern w/o cutting or deposition. Stable bed.	2	Some present causing erosive cross currents and minor pool filling. Obstructions fewer and less firm.	4	Moderately frequent, unstable obstructions move with high flows causing bank cutting and pool filling.	6	Frequent obstructions and deflectors cause bank erosion yearlong. Sediment traps full, channel migration occurring.	8
	8	Cutting	Little or none. Infrequent raw banks <6'	4	Some, intermittently at outcurves and constrictions. Raw banks may be up to 12'	6	Significant. Cuts 12-24' high. Root mat overhangs and sloughing evident	12	Almost continuous cuts, some over 24' high. Failure of overhangs frequent.	16
	9	Deposition	Little or no enlargement of channel or point bars	4	Some new bar increase, mostly from coarse gravel.	8	Moderate deposition of new gravel and coarse sand on old and some new bars.	12	Extensive deposit of predominantly fine particles. Accelerated bar development.	16
Bottom	10	Rock angularity	Well rounded in all dimensions, surfaces smooth.	1	Corners and edges well rounded in 2 dimensions	2	Rounded corners and edges. Surface smooth and flat.	3	Sharp edges and corners. Plane surfaces rough.	4
	11	Brightness	Surfaces dull dark or stained. Generally not bright	1	Mostly dull, but may have <35% bright surfaces	2	Mixture dull and bright, i.e., 35-65% mixture range	3	Predominantly bright, >65%, exposed or scoured surfaces.	4
	12	Consolidation of particles	Assorted sizes tightly packed or overlapping	2	Moderately packed with some overlapping	4	Mostly loose assortment with no apparent overlap.	6	No packing evident. Loose assortment, easily moved.	8
	13	Bottom size distribution	No size change evident. Stable material 80-100%	4	Distribution shift light. Stabel material 50-80%.	8	Moderate change in sizes. Stable materials 20-50%.	12	Marked distribution change. Stable materials 0-20%	16
	14	Scouring and deposition	<5% of bottom affected by scour and deposition.	6	5-30% affected. Scour at constrictions and where grades steepen. Some deposition in pools.	12	30-50% affected. Deposits and scour at obstructions and bends. Some filling of pools.	18	More than 50% of the bottom in a state of flux or change nearly yearlong.	24
	15	Aquatic vegetation	Abundant growth moss-like, dark green perennial. In swift water too.	1	Common. Algae forms in low velocity and pool areas. Moss here too.	2	Present but spotty, mostly in back water. Seasonal algae growth makes rocks slick.	3	Perennial types scarce or absent. Yellow-green, short-term bloom may be present.	4
			Excellent Total =	10	Good Total =	0	Fair Total =	6	Poor Total =	100

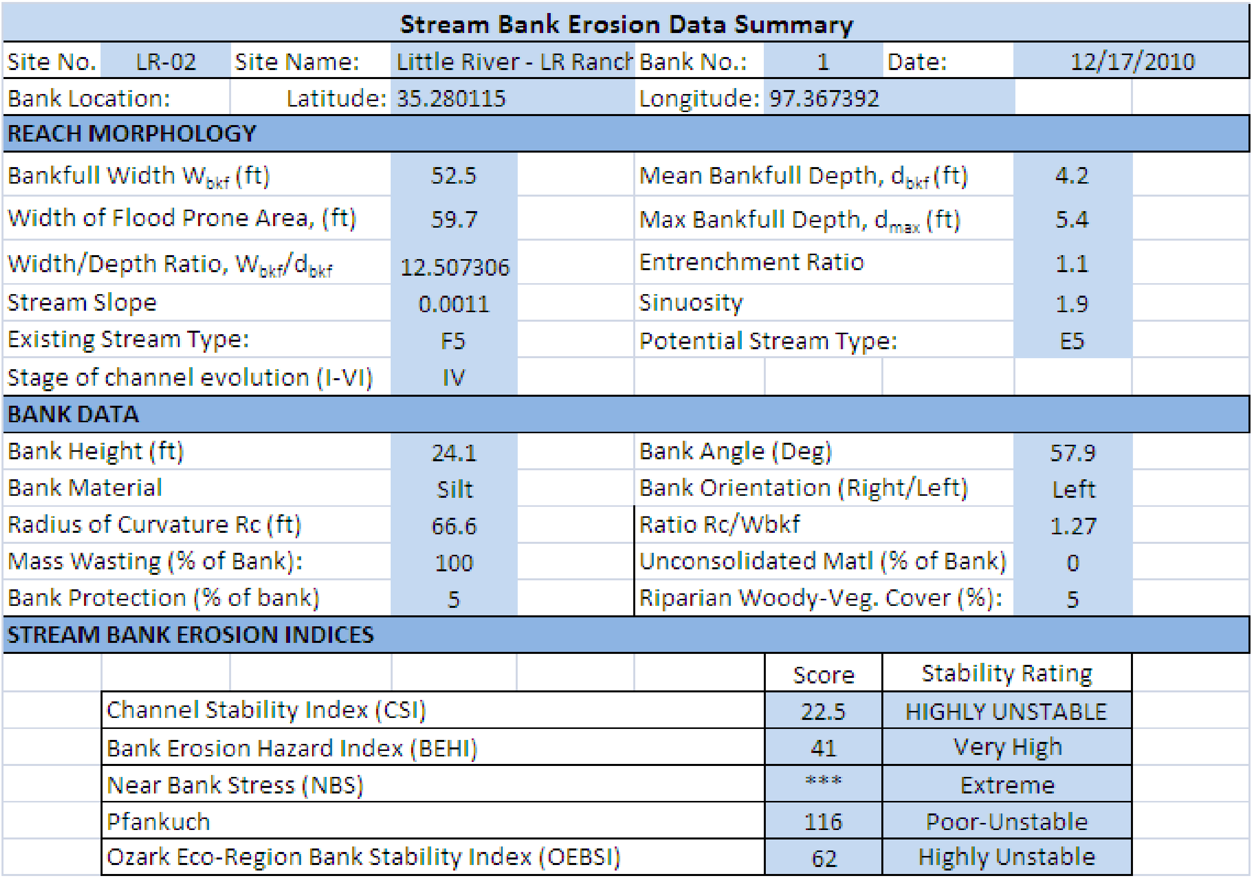
Stream Type	A1	A2	A3	A4	A5	A6	B1	B2	B3	B4	B5	B6	C1	C2	C3	C4	C5	C6	D3	D4	D5	D6
Good (Stable)	38-43	38-43	54-90	60-95	50-80	50-80	38-45	38-45	40-60	40-64	48-68	40-60	38-50	38-50	60-85	70-90	70-90	60-85	85-107	85-107	85-107	67-98
Fair (mod. Unstable	44-47	44-47	91-129	96-132	81-110	81-110	46-58	46-58	61-78	65-84	69-88	61-78	51-61	51-61	86-105	91-110	91-110	86-105	108-132	108-132	108-132	99-125
Poor (unstable)	48+	48+	130+	133+	111+	111+	59+	59+	79+	85+	89+	79+	62+	62+	106+	111+	111+	106+	133+	133+	133+	126+

Stream Type	DA3	DA4	DA5	DA6	E3	E4	E5	E6	F1	F2	F3	F4	F5	F6	G1	G2	G3	G4	G5	G6
Good (Stable)	40-63	40-63	40-63	40-63	40-63	50-75	50-75	40-63	60-85	60-85	85-110	85-110	90-115	80-95	40-60	40-60	85-107	85-107	90-112	85-107
Fair (mod. Unstable	64-86	64-86	64-86	64-86	64-86	76-96	76-96	64-86	86-105	86-105	111-125	111-125	116-130	96-110	61-78	61-78	108-120	108-120	113-125	108-120
Poor (unstable)	87+	87+	87+	87+	87+	97+	97+	87+	106+	106+	126+	126+	131+	111+	79+	79+	121+	121+	126+	121+

Rating should be adjusted to potential stream type, not existing

Grand Total =	116
Existing Stream Type =	F5
Potential Stream Type =	E5

Channel Stability Rating	
Existing Stream	Fair-Mod. Unstable
Potential Stream	Poor-Unstable



Stream Bank Erosion Data Summary							
Site No.	LR-02	Site Name:	Little River - LR Ranch	Bank No.:	1	Date:	12/17/2010
Bank Location:		Latitude:	35.280115	Longitude:	97.367392		

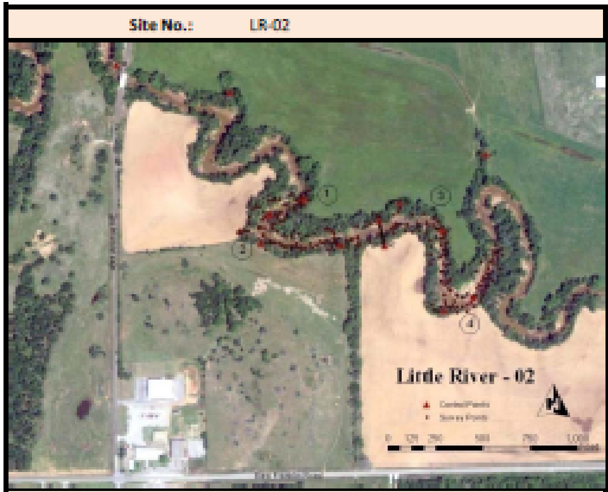
REACH MORPHOLOGY			
Bankfull Width W_{bkf} (ft)	52.5	Mean Bankfull Depth, d_{bkf} (ft)	4.2
Width of Flood Prone Area, (ft)	59.7	Max Bankfull Depth, d_{max} (ft)	5.4
Width/Depth Ratio, W_{bkf}/d_{bkf}	12.507306	Entrenchment Ratio	1.1
Stream Slope	0.0011	Sinuosity	1.9
Existing Stream Type:	F5	Potential Stream Type:	E5
Stage of channel evolution (I-VI)	IV		
BANK DATA			
Bank Height (ft)	24.1	Bank Angle (Deg)	57.9
Bank Material	Silt	Bank Orientation (Right/Left)	Left
Radius of Curvature Rc (ft)	66.6	Ratio Rc/Wbkf	1.27
Mass Wasting (% of Bank):	100	Unconsolidated Matl (% of Bank)	0
Bank Protection (% of bank)	5	Riparian Woody-Veg. Cover (%):	5

STREAM BANK EROSION INDICES		
	Score	Stability Rating
Channel Stability Index (CSI)	22.5	HIGHLY UNSTABLE
Bank Erosion Hazard Index (BEHI)	41	Very High
Near Bank Stress (NBS)	***	Extreme
Pfankuch	116	Poor-Unstable
Ozark Eco-Region Bank Stability Index (OEBSI)	62	Highly Unstable

Figure A-6: Example of Stream Bank Erosion Data Summary Form

Appendix B – FGM Site Summary Sheets

Site No.:	LR-02
Site Name:	Little River - 02
Legal Description:	SW 1/4, Sect. 1, T9N-R2W, Cleveland Co.
Drainage Area (mi^2):	53.9



Cross Section Survey Control

OK State Plane NAD83, South Zone (U.S. Foot); NAVD88 (U.S. Foot)

Left Pin		***Right Pin***	
Name:	LR02-LT	**Name:**	LR02-RT
Easting:	2157712.814	**Easting:**	2157741.681
Northing:	709007.639	**Northing:**	708870.849
Elevation:	1062.15	**Elevation:**	1066.07

Geodetic Coordinates (Decimal Degrees)

Left Pin		***Right Pin***	
Lat. (N):	35.279874529	**Lat. (N):**	35.279498241
Long. (W):	97.366076193	**Long. (W):**	97.36598236

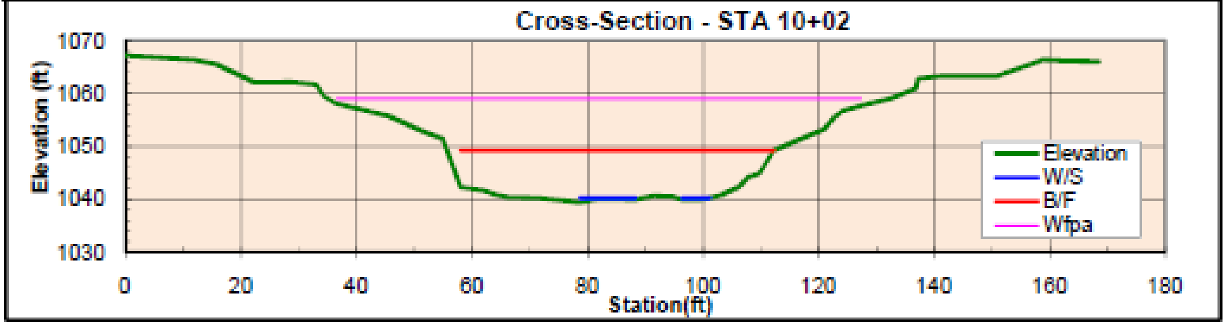
Channel Morphology Data

Bankfull Width (ft):	56.52
Mean Bankfull Depth (ft):	8.09
Maximum Bankfull Depth (ft):	9.78
Flood Prone Area Width (ft):	92.83
Bankfull Area (ft^2):	457.52
Entrenchment Ratio:	1.64
Width/Depth Ratio:	6.98
Sinuosity:	1.92
Slope:	0.0011
Bed Material:	Sand

Rosgen Stream Type:	F5
Channel Evolution Stage:	IV

Stream Channel Stability Data

Bank No.	1	2	3	4
CSI Score:	22.5	22.5	24	25
Rating:	HIGHLY UNSTABLE	HIGHLY UNSTABLE	HIGHLY UNSTABLE	HIGHLY UNSTABLE
Pfankuch Score:	116	114	122	118
Rating:	Poor- Unstable	Poor- Unstable	Poor- Unstable	Poor- Unstable
BEHI Score:	41	34.5	34	37.5
Rating:	Very High	High	High	High
NBS Score:	***	***	***	***
Rating:	Extreme	Extreme	Low	Extreme
OEBSI Score:	62	62	65	69
Rating:	Highly Unstable	Highly Unstable	Highly Unstable	Highly Unstable



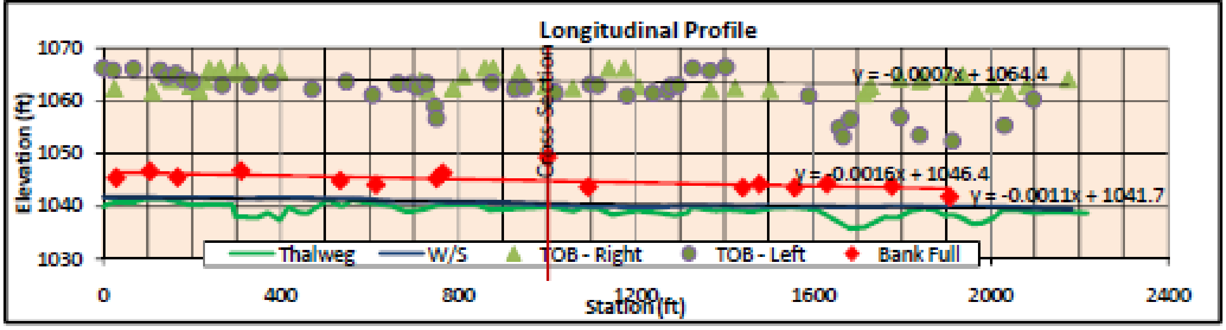
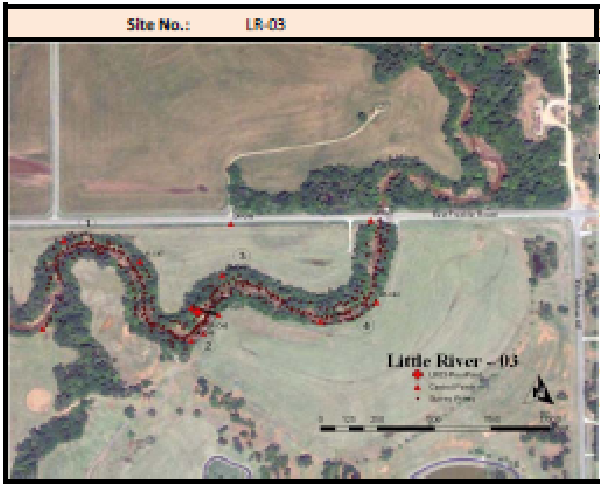


Figure B-1: Site Summary Sheet – Little River -02

Site No.:	LR-03
Site Name:	Little River - 03
Legal Description:	NW 1/4, Sect. 10, T9N-R2W, Cleveland Co.
Drainage Area (mi^2):	47.4



Cross Section Survey Control

OK State Plane NAD83, South Zone (U.S. Foot); NAVD88 (U.S. Foot)

Left Pin		***Right Pin***	
Name:	LR-03LT	**Name:**	LR-03RT
Easting:	2149376.872	**Easting:**	2149495.76
Northing:	707217.5692	**Northing:**	707184.9514
Elevation:	1081.0	**Elevation:**	1083.55

Geodetic Coordinates (Decimal Degrees)

Left Pin		***Right Pin***	
Lat. (N):	35.275097464	**Lat. (N):**	35.275005895
Long. (W):	97.394039596	**Long. (W):**	97.39364197

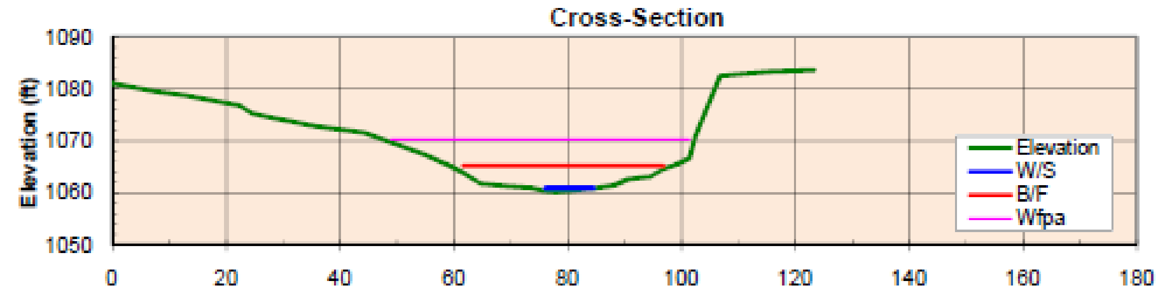
Channel Morphology Data

Bankfull Width (ft):	39.10
Mean Bankfull Depth (ft):	3.30
Maximum Bankfull Depth (ft):	5.03
Flood Prone Area Width (ft):	53.87
Bankfull Area (ft^2):	128.90
Entrenchment Ratio:	1.38
Width/Depth Ratio:	11.86
Sinuosity:	1.66
Slope:	0.0009
Bed Material:	Sand

Rosgen Stream Type:	G5c
Channel Evolution Stage:	IV

Stream Channel Stability Data

Bank No.	1	2	3	4
CSI Score:	22.5	27	25	20.5
Rating:	Highly unstable	Highly unstable	Highly unstable	Highly unstable
Pfankuch Score:	116	99	109	99
Rating:	Poor-Unstable	Poor-Unstable	Poor-Unstable	Poor-Unstable
BEHI Score:	41	35.5	35.5	28.5
Rating:	Very High	High	High	Moderate
NBS Score:	***	***	***	***
Rating:	Extreme	Moderate	High	High
OESBI Score:	62	77	52	57
Rating:	Highly unstable	Highly unstable	Unstable	Highly unstable



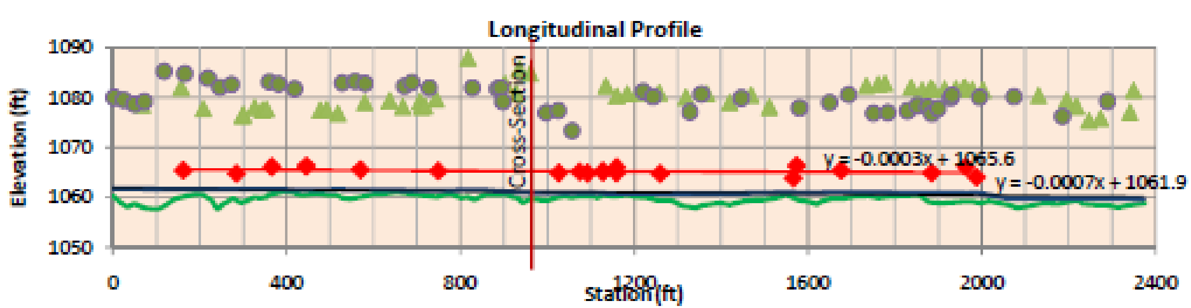


Figure B-2: Site Summary Sheet – Little River -03

Appendix C – FGM Site Photographs

Cross Section Photographs

Figure 1: LR-02 Cross Section - Facing upstream.

Figure 2: LR-02 Cross Section - Facing downstream.

Figure 3: LR-02 Cross Section - Left Bank.

Figure 4: LR-02 Cross Section - Right Bank.

Figure C-1: Cross-Section Photographs at LR-02

Assessment Banks Photographs


Figure 5: LR-02 Bank 1 - Bank


Figure 8: LR-02 Bank 2 - Bank


Figure 6: LR-02 Bank 1 - Facing upstream


Figure 9: LR-02 Bank 2 - Facing upstream


Figure 7: LR-02 Bank 1 - Facing downstream


Figure 10: LR-02 Bank 2 - Facing downstream

Figure C-2: Assessment Site Photographs at LR-02

Assessment Banks Photographs


Figure 11: LR-02 Bank 3 - Bank


Figure 14: LR-02 Bank 4 - Bank


Figure 12: LR-02 Bank 3 - Facing upstream


Figure 15: LR-02 Bank 4 - Facing upstream


Figure 13: LR-02 Bank 3 - Facing downstream


Figure 16: LR-02 Bank 4 - Facing downstream

Figure C-3: Assessment Site Photographs at LR-02 (Cont.)

Cross Section Photographs

Figure 1: LR-03 Cross Section - Facing upstream.

Figure 2: LR-03 Cross Section - Facing downstream.

Figure 3: LR-03 Cross Section - Left Bank.

Figure 4: LR-03 Cross Section - Right Bank.

Figure C-4: Cross-Section Photographs at LR-03

Assessment Banks Photographs


Figure 5: LR-03 Bank 1 - Bank


Figure 8: LR-03 Bank 2 - Bank


Figure 6: LR-03 Bank 1 - Facing upstream


Figure 9: LR-03 Bank 2 - Facing upstream


Figure 7: LR-03 Bank 1 - Facing downstream


Figure 10: LR-03 Bank 2 - Facing downstream

Figure C-5: Assessment Site Photographs at LR-03

Assessment Banks Photographs

Figure 11: LR-03 Bank 3 - Bank

Figure 14: LR-03 Bank 4 - Bank

Figure 12: LR-03 Bank 3 - Facing upstream

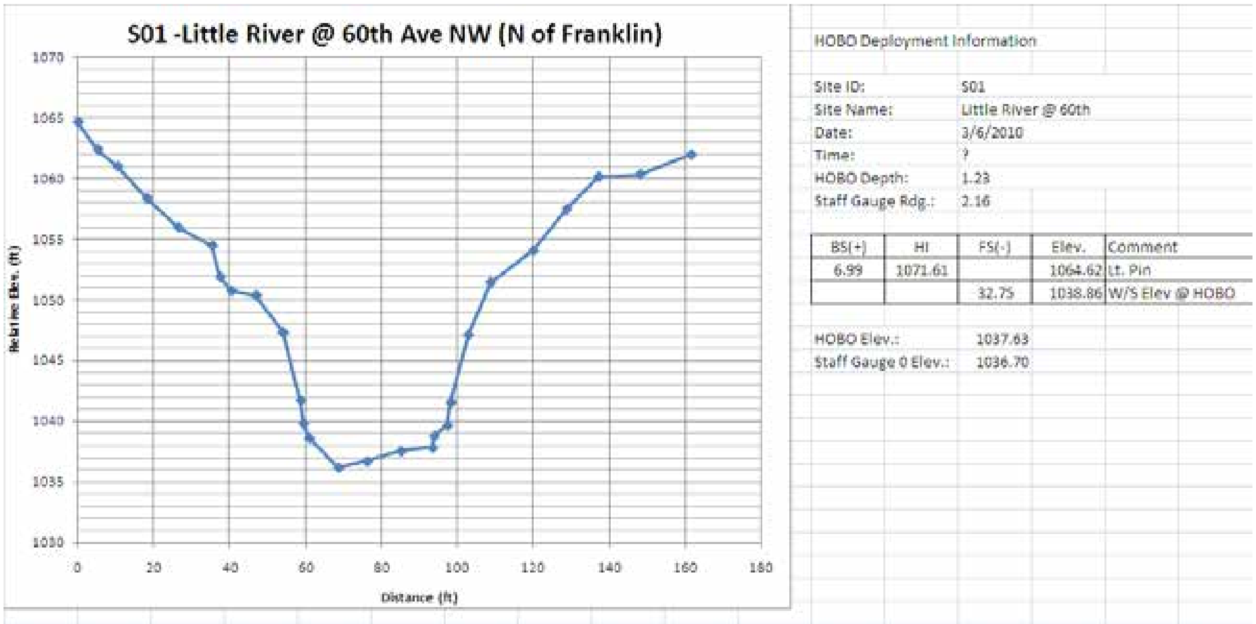
Figure 15: LR-03 Bank 4 - Facing upstream

Figure 13: LR-03 Bank 3 - Facing downstream

Figure 16: LR-03 Bank 4 - Facing downstream

Figure C-6: Assessment Site Photographs at LR-03 (Cont.)

Appendix D –Rating Curve Site Information



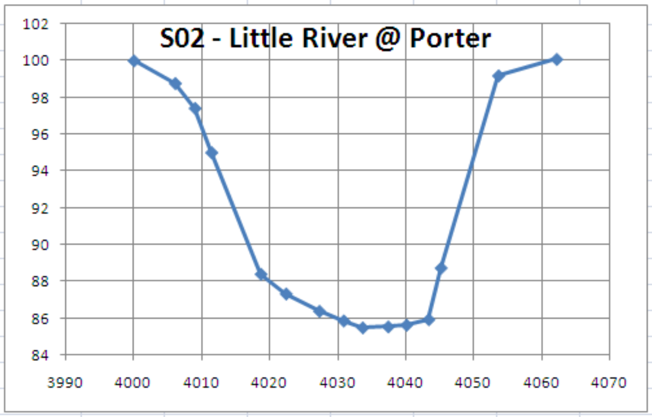
HOBO Deployment Information

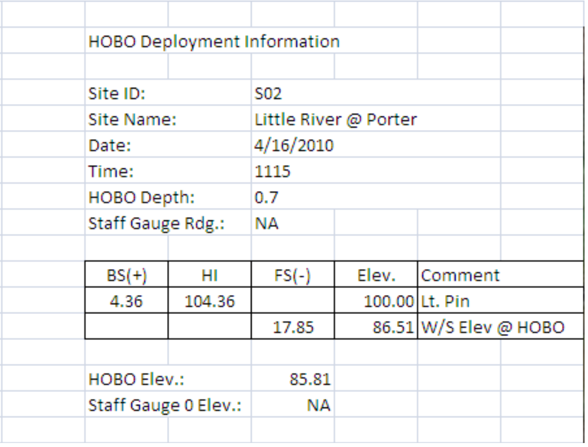
Site ID:	S01
Site Name:	Little River @ 60th
Date:	3/6/2010
Time:	?
HOBO Depth:	1.23
Staff Gauge Rdg.:	2.16

BS(+)	HI	FS(-)	Elev.	Comment
6.99	1071.61		1064.62	Lt. Pin
		32.75	1038.86	W/S Elev @ HOBO

HOBO Elev.:	1037.63
Staff Gauge 0 Elev.:	1036.70

Figure D-1: Rating Curve Site Information – S01 – Little River @ 60th





HOBO Deployment Information

Site ID:	S02
Site Name:	Little River @ Porter
Date:	4/16/2010
Time:	1115
HOBO Depth:	0.7
Staff Gauge Rdg.:	NA

BS(+)	HI	FS(-)	Elev.	Comment
4.36	104.36		100.00	Lt. Pin
		17.85	86.51	W/S Elev @ HOBO

HOBO Elev.:	85.81
Staff Gauge 0 Elev.:	NA

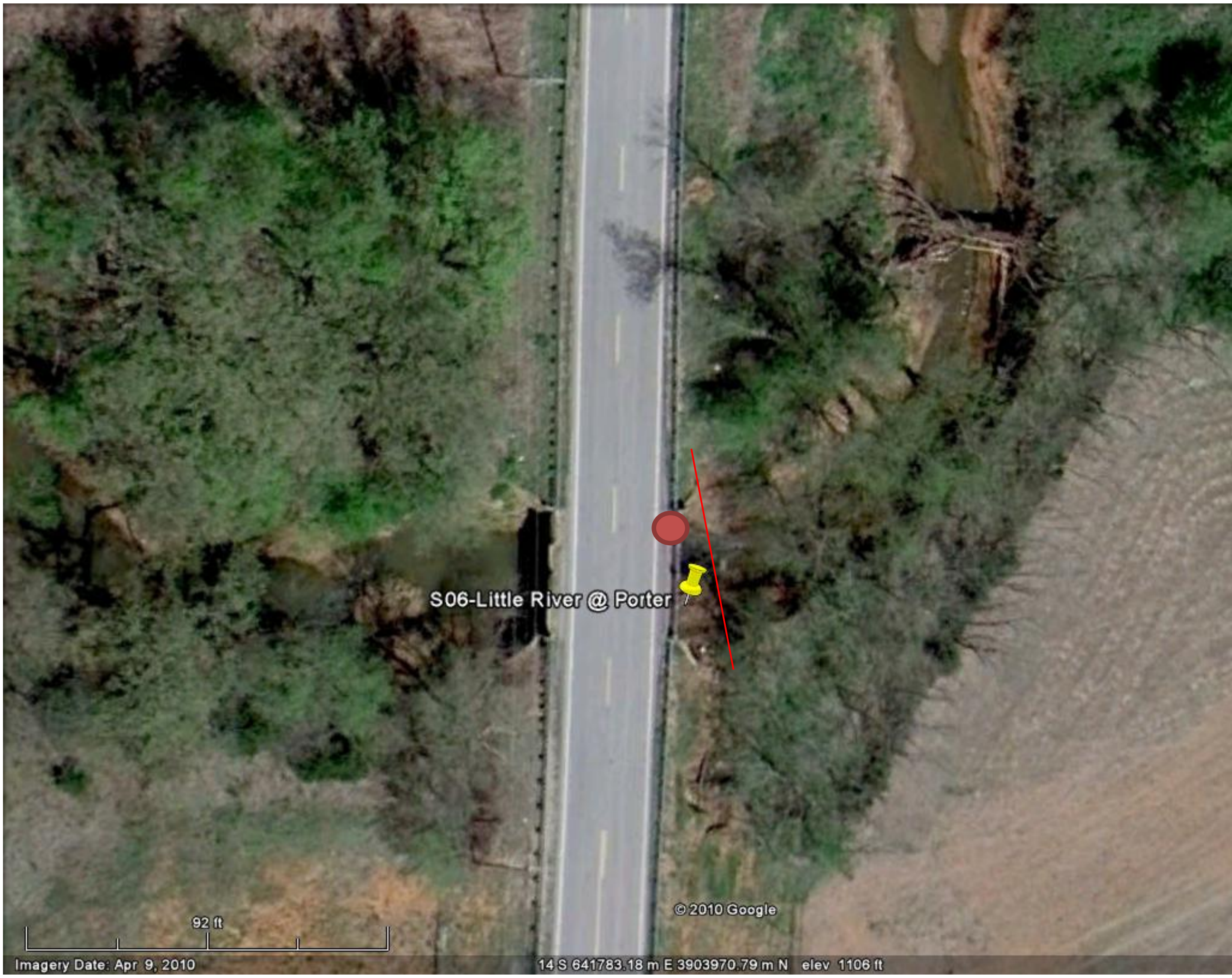
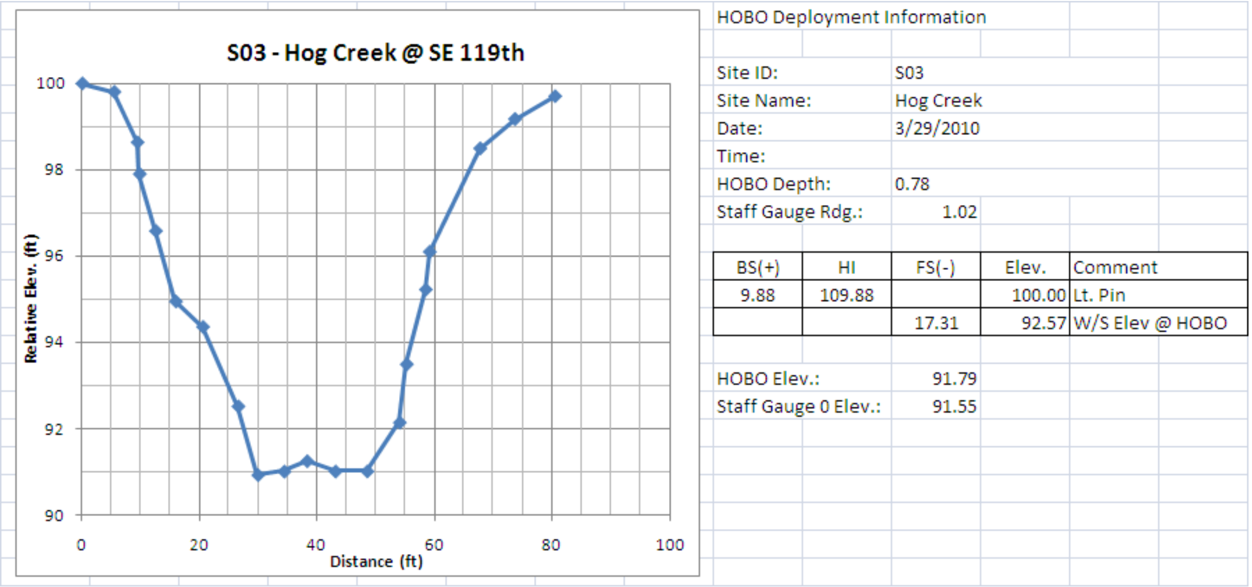


Figure D-2: Rating Curve Site Information – S02 – Little River @ Porter



HOBO Deployment Information

Site ID:	S03
Site Name:	Hog Creek
Date:	3/29/2010
Time:	
HOBO Depth:	0.78
Staff Gauge Rdg.:	1.02

BS(+)	HI	FS(-)	Elev.	Comment
9.88	109.88		100.00	Lt. Pin
		17.31	92.57	W/S Elev @ HOBO

HOBO Elev.:	91.79
Staff Gauge 0 Elev.:	91.55

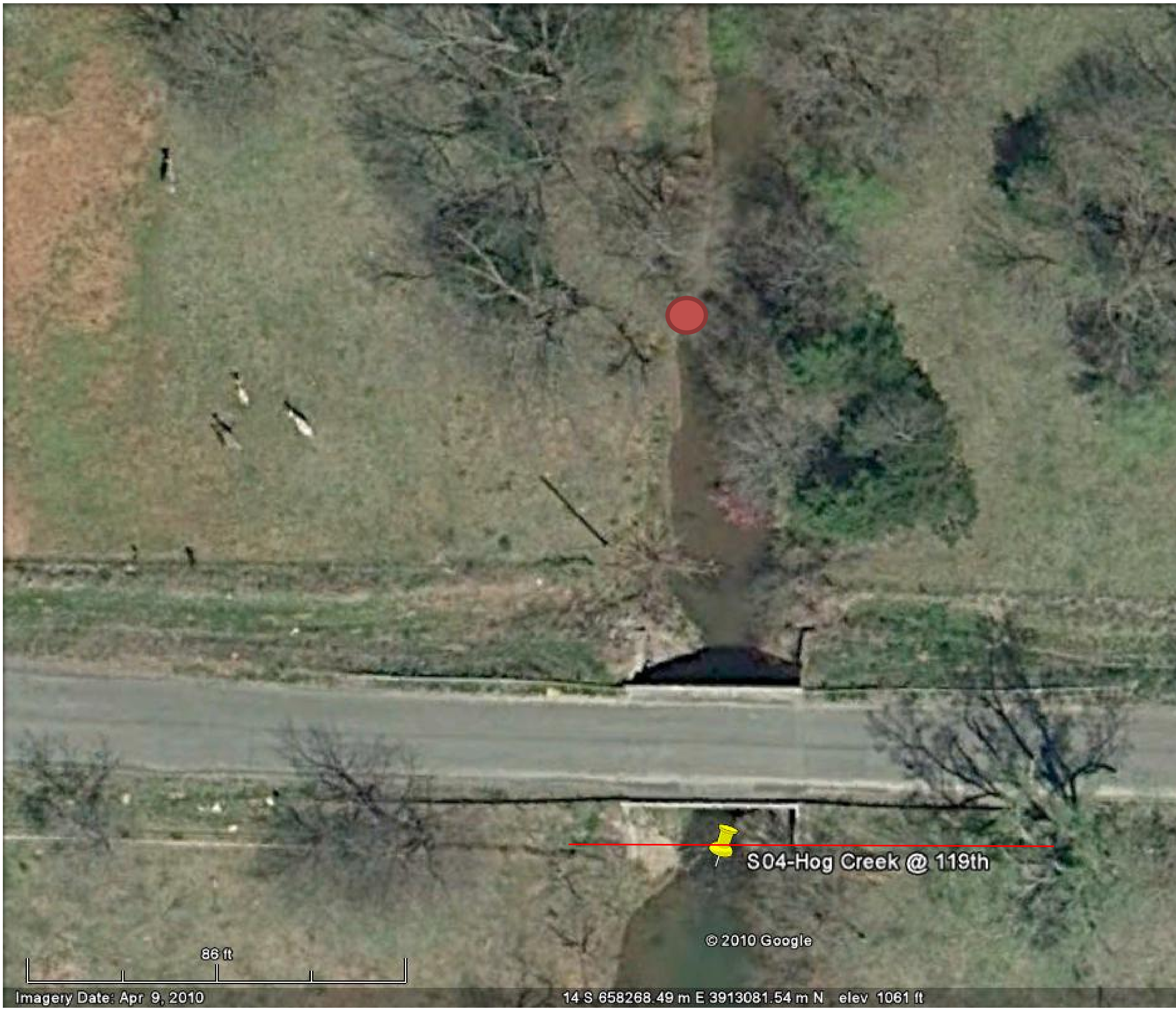
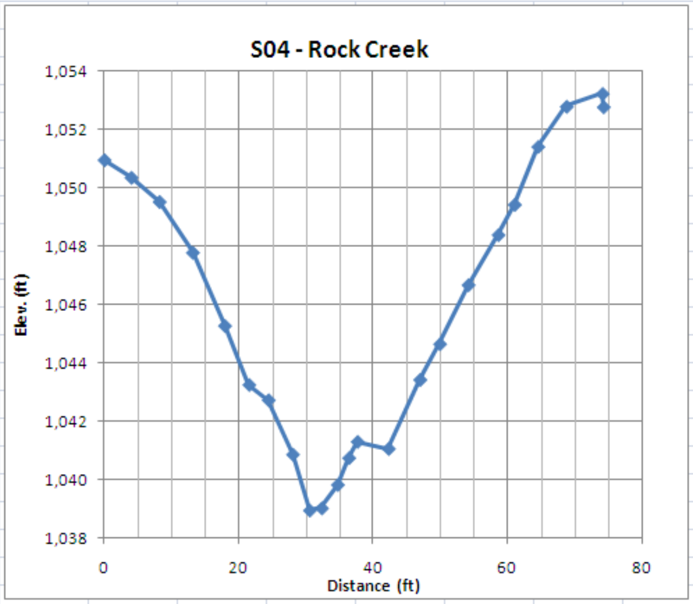


Figure D-3: Rating Curve Site Information – S03 – Hog Creek @ SE 119th



HOBO Deployment Information

Site ID:	S04
Site Name:	Rock Creek
Date:	3/29/2010
Time:	
HOBO Depth:	0.83
Staff Gauge Rdg.:	NA

BS(+)	HI	FS(-)	Elev.	Comment
4.52	1055.49		1050.97	Lt. Pin
		14.81	1040.68	W/S Elev @ HOBO

HOBO Elev.:	1039.85
Staff Gauge 0 Elev.:	NA

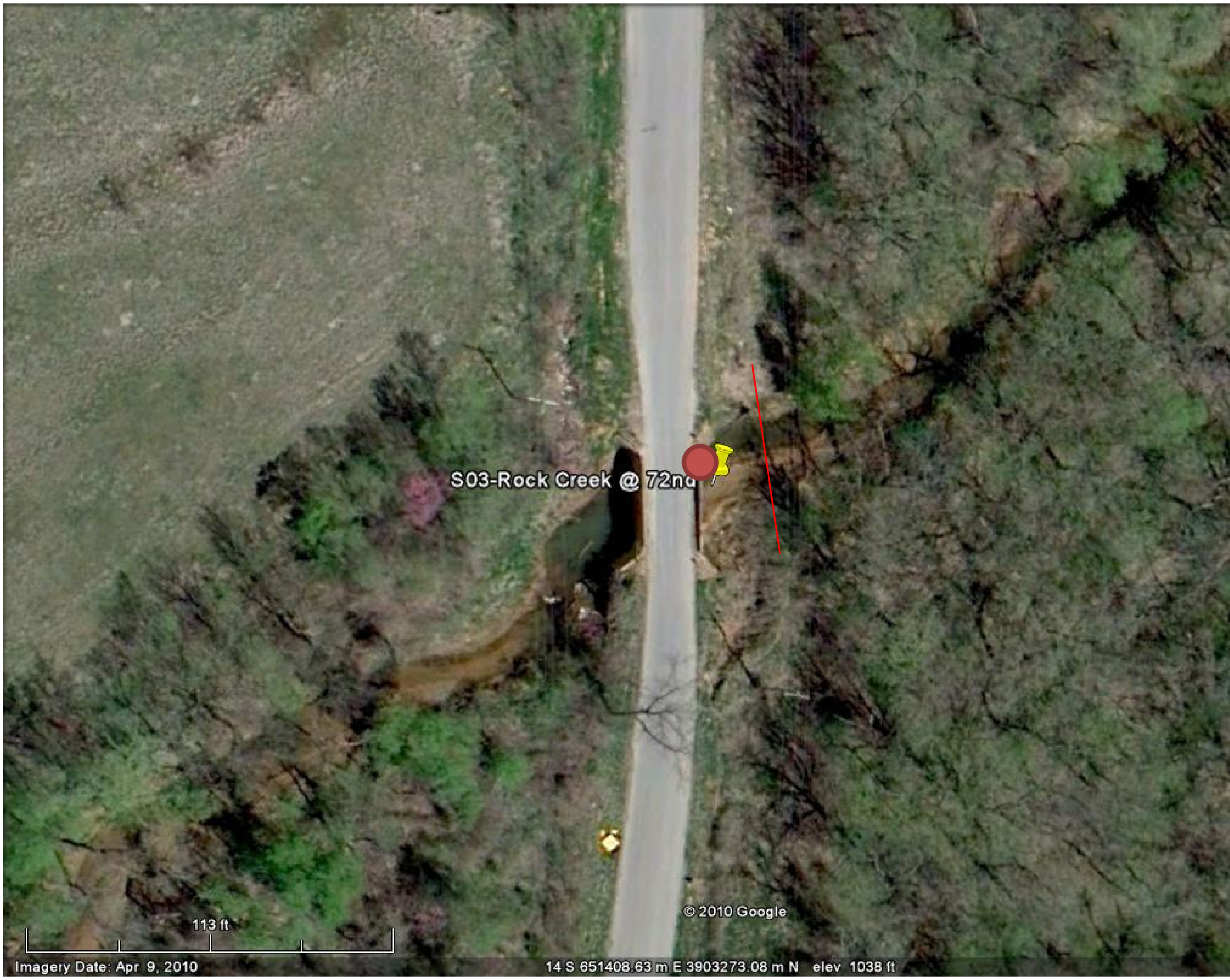
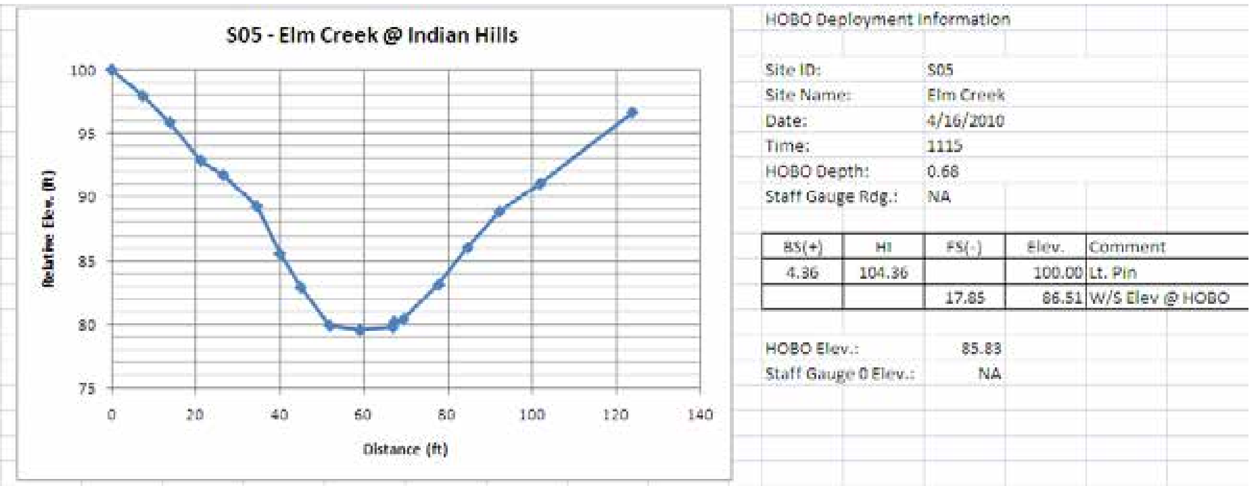


Figure D-4: Rating Curve Site Information – S04 – Rock Creek @ 72nd



HOBO Deployment Information

Site ID:	S05
Site Name:	Elm Creek
Date:	4/16/2010
Time:	1115
HOBO Depth:	0.68
Staff Gauge Rdg.:	NA

BS(+)	HI	FS(-)	Elev.	Comment
4.36	104.36		100.00	Lt. Pin
		17.85	86.51	W/S Elev @ HOBO

HOBO Elev.:	85.83
Staff Gauge 0 Elev.:	NA

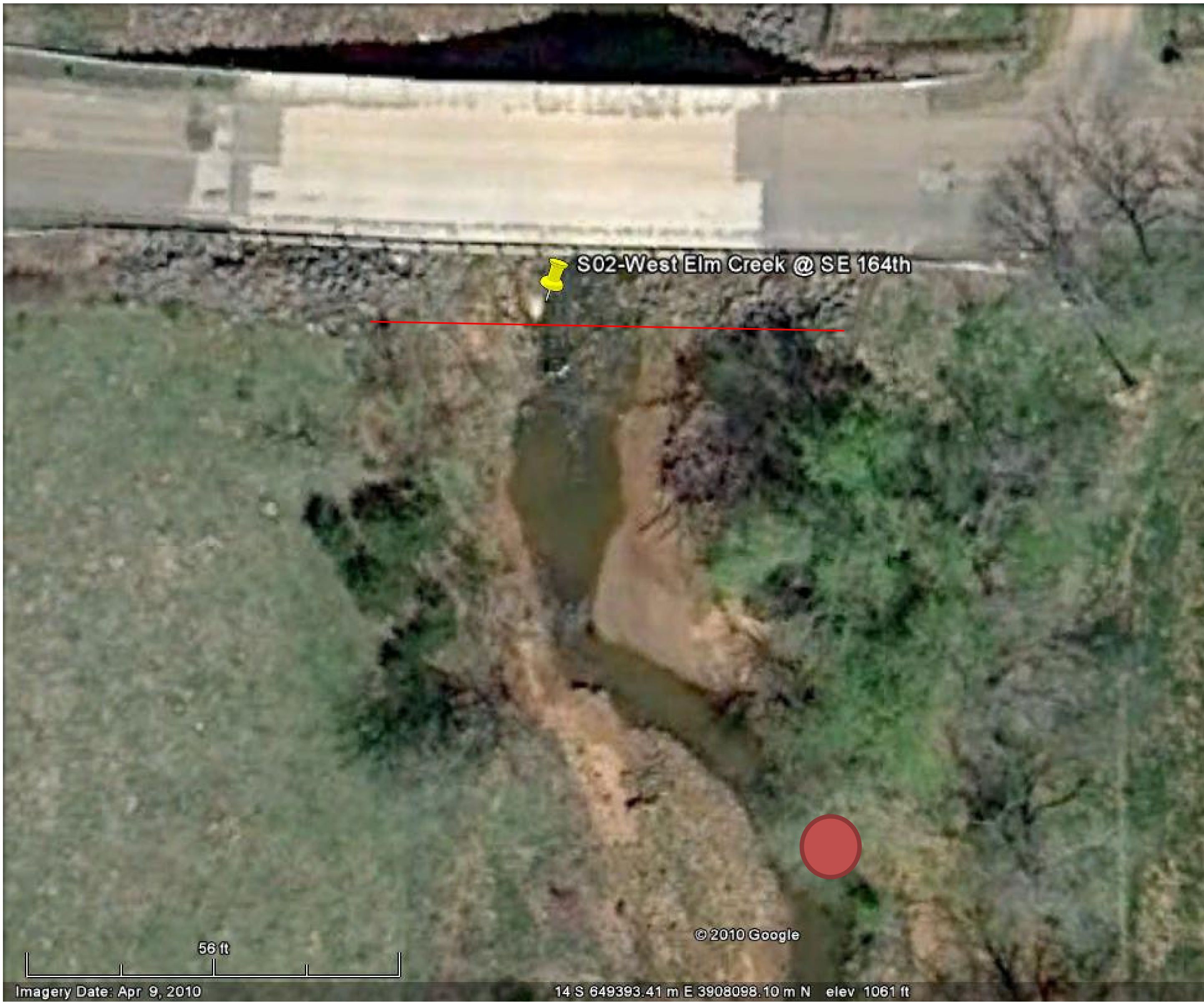
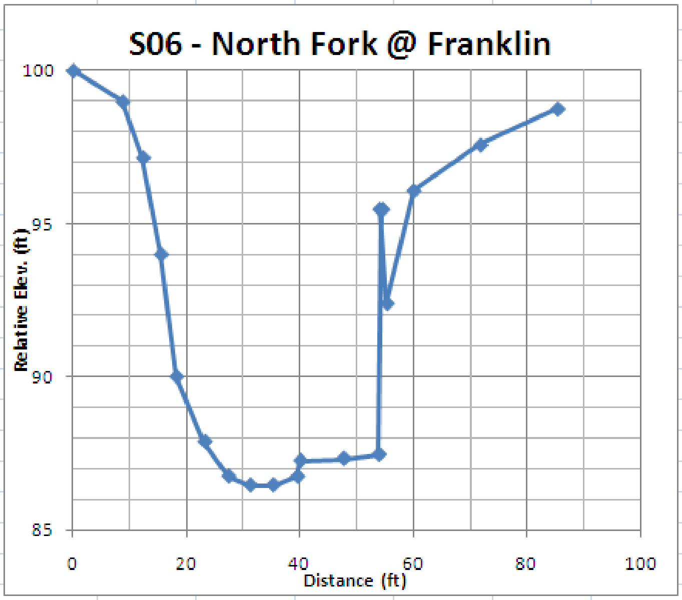


Figure D-5: Rating Curve Site Information – S05 – Elm Creek @ Indian Hills



HOBO Deployment Information

Site ID:	S06
Site Name:	North Fork @ Franklin
Date:	3/29/2010
Time:	
HOBO Depth:	0.77
Staff Gauge Rdg.:	NA

BS(+)	HI	FS(-)	Elev.	Comment
2.47	102.47		100.00	Lt. Pin
		18.73	83.74	W/S Elev @ HOBO

HOBO Elev.:	82.97
Staff Gauge 0 Elev.:	NA

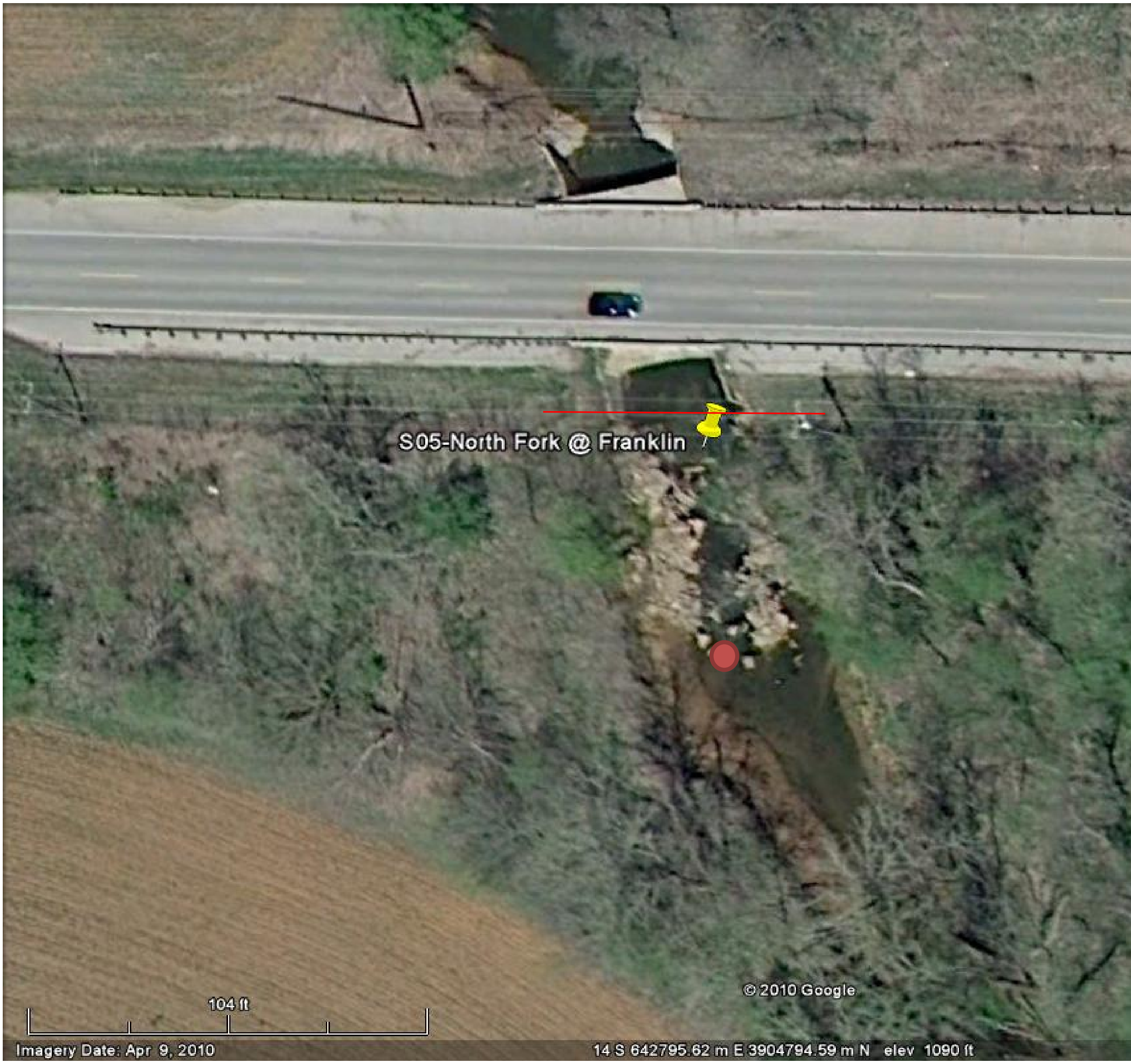
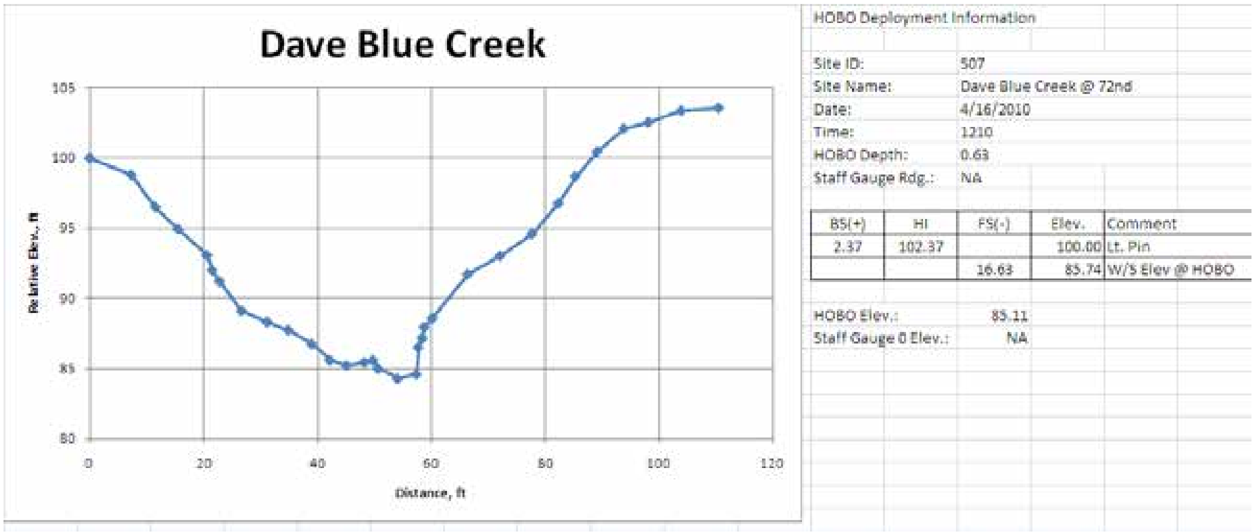


Figure D-6: Rating Curve Site Information – S06 – North Fork @ Franklin



HOBO Deployment Information

Site ID:	507
Site Name:	Dave Blue Creek @ 72nd
Date:	4/16/2010
Time:	1210
HOBO Depth:	0.63
Staff Gauge Rdg.:	NA

BS(+)	HI	FS(-)	Elev.	Comment
2.37	102.37		100.00	Lt. Pin
		16.63	85.74	W/S Elev @ HOBO

HOBO Elev.:	85.11
Staff Gauge 0 Elev.:	NA

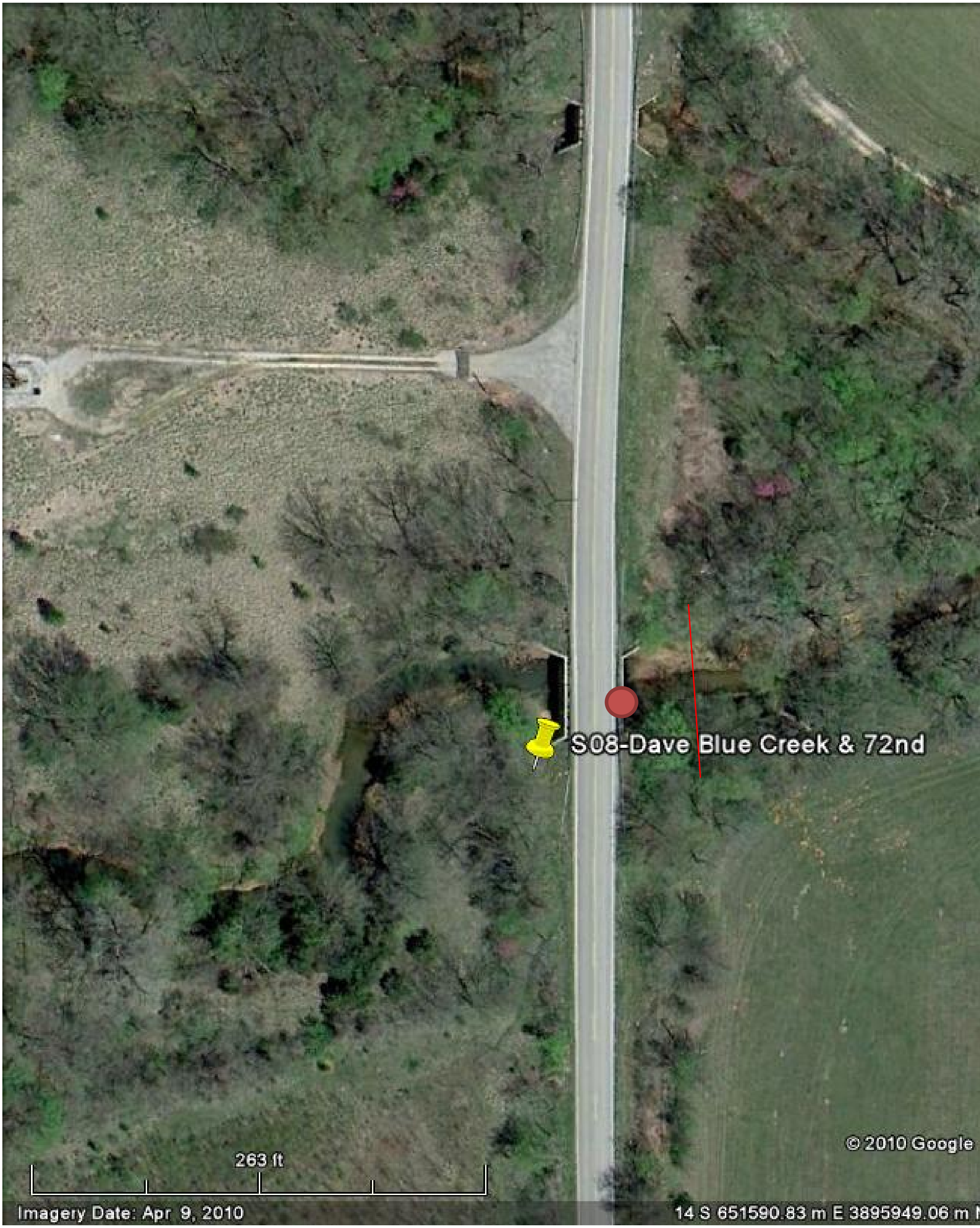

S08-Dave Blue Creek & 72nd
© 2010 Google
263 ft
Imagery Date: Apr 9, 2010
14 S 651590.83 m E 3895949.06 m N

Figure D-7: Rating Curve Site Information – S07 – Dave Blue Creek @ 72nd

Appendix E – HOBO Stage Plots

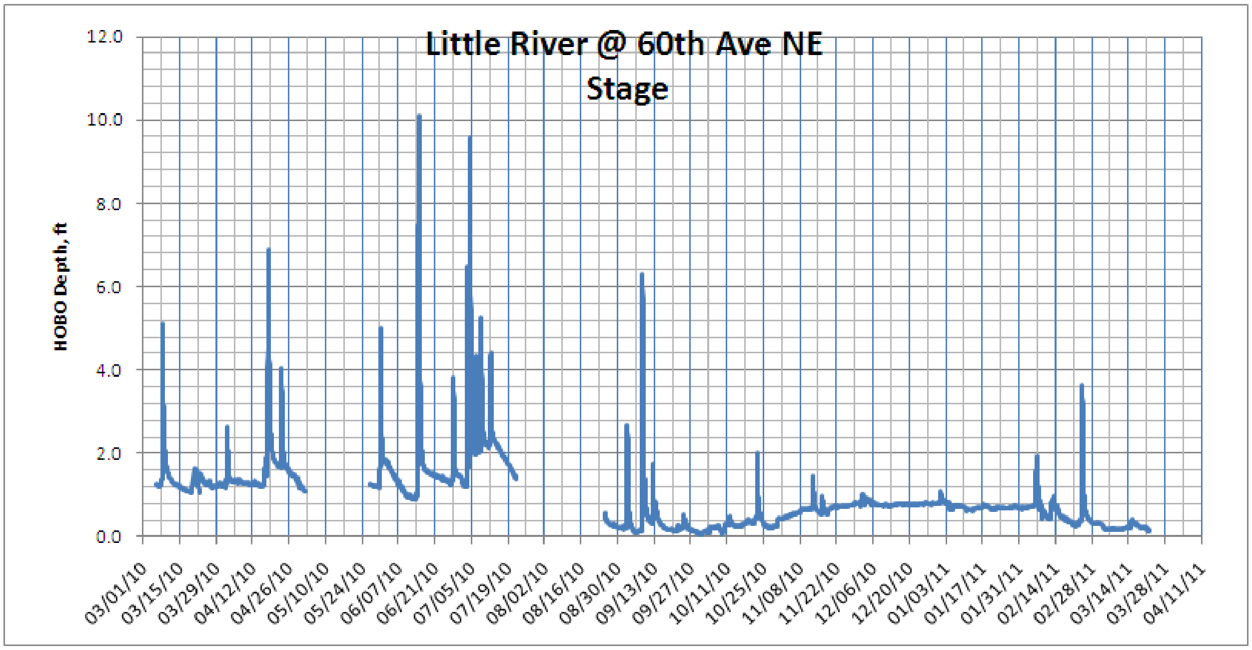


Figure E-1: Stage Record – Site S01 – Little River @ 60th

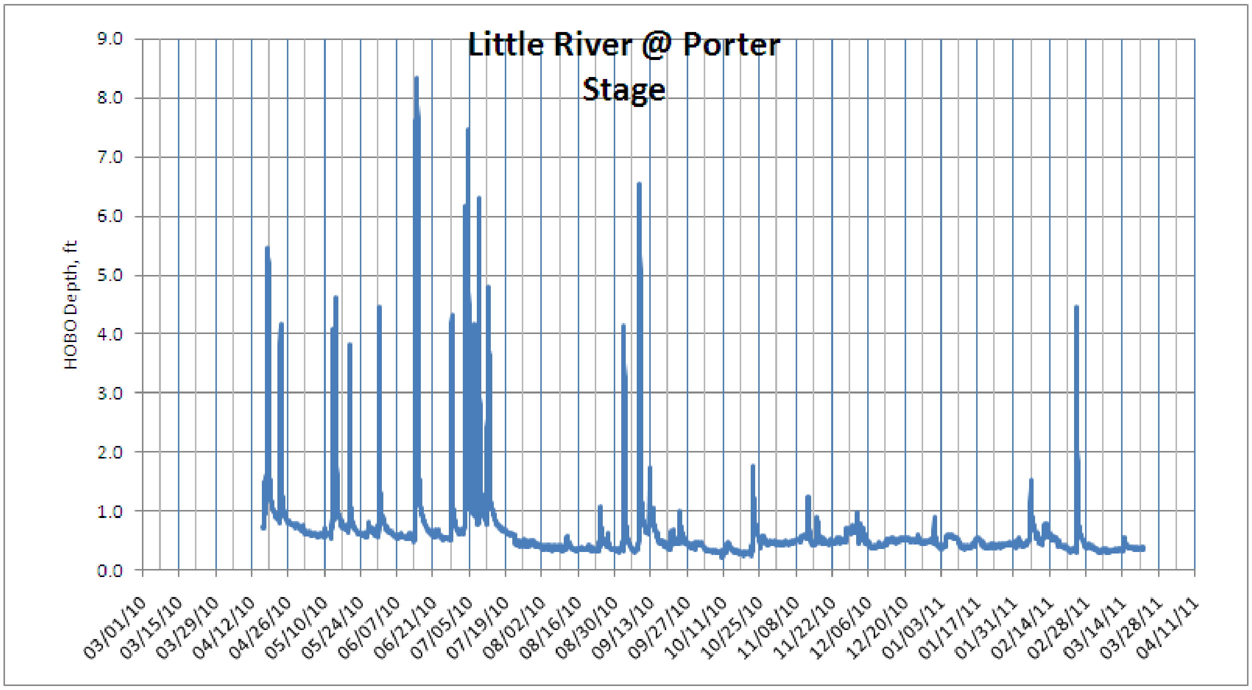


Figure E-2: Stage Record – Site S02 – Little River @ Porter

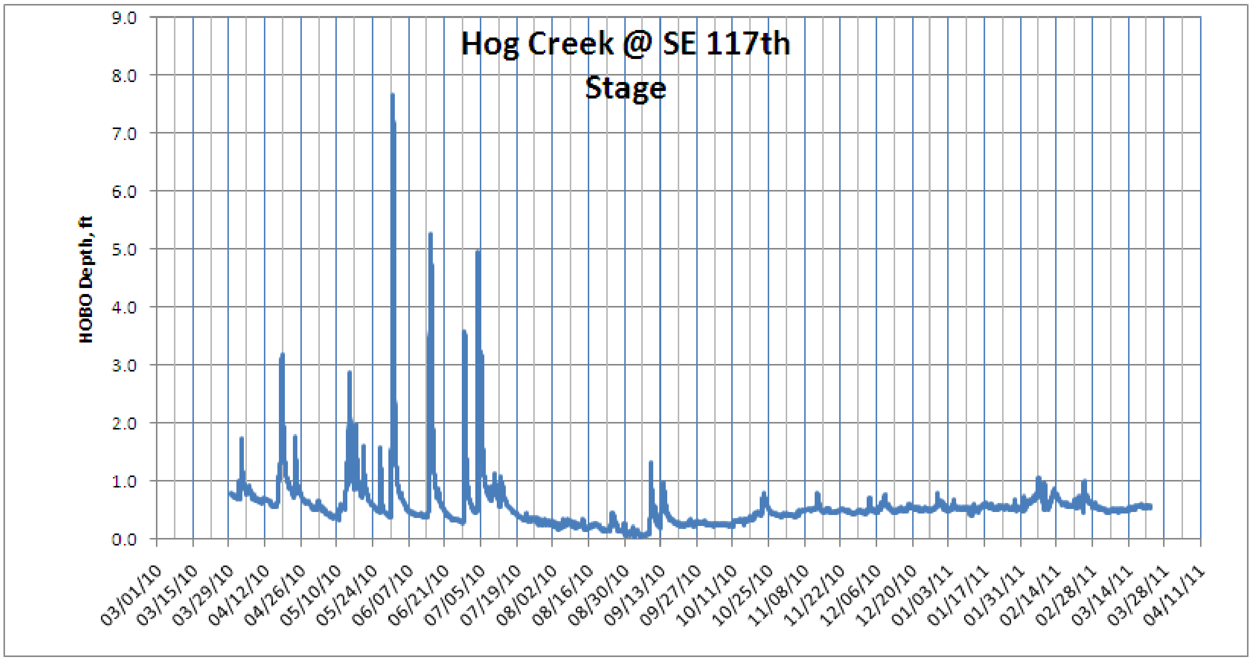


Figure E-3: Stage Record – Site S03 – Hog Creek @ 117th

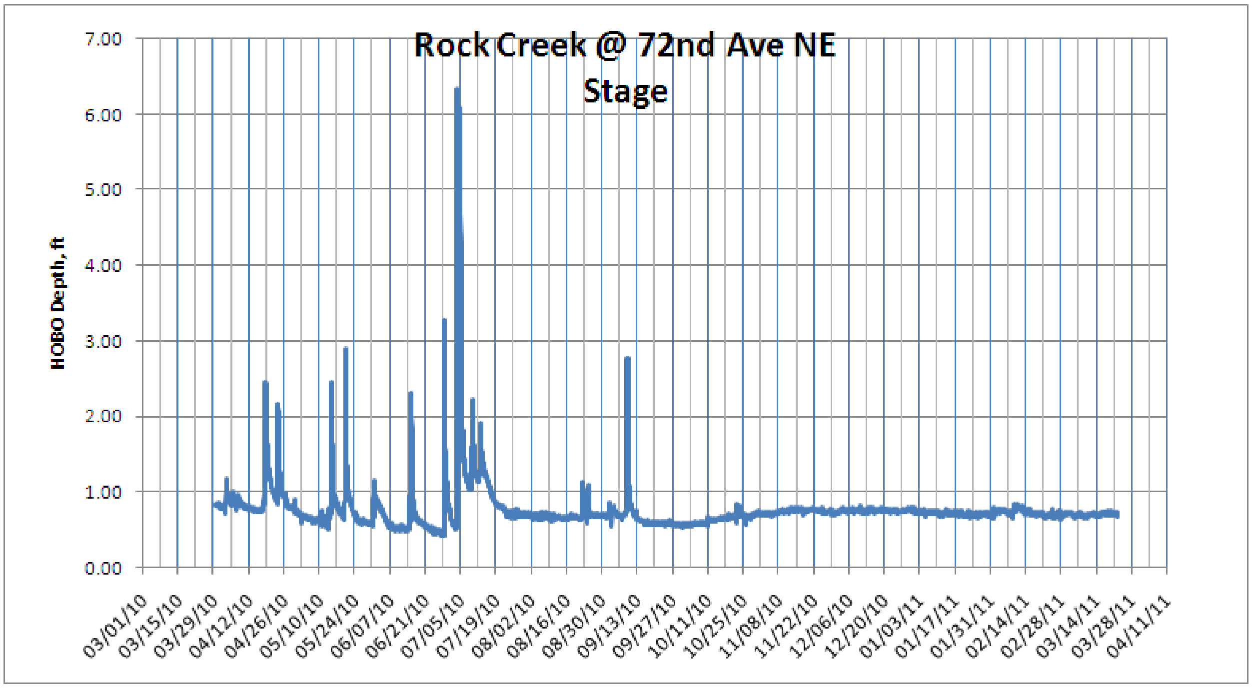


Figure E-4: Stage Record – Site S04 – Rock Creek @ 72nd

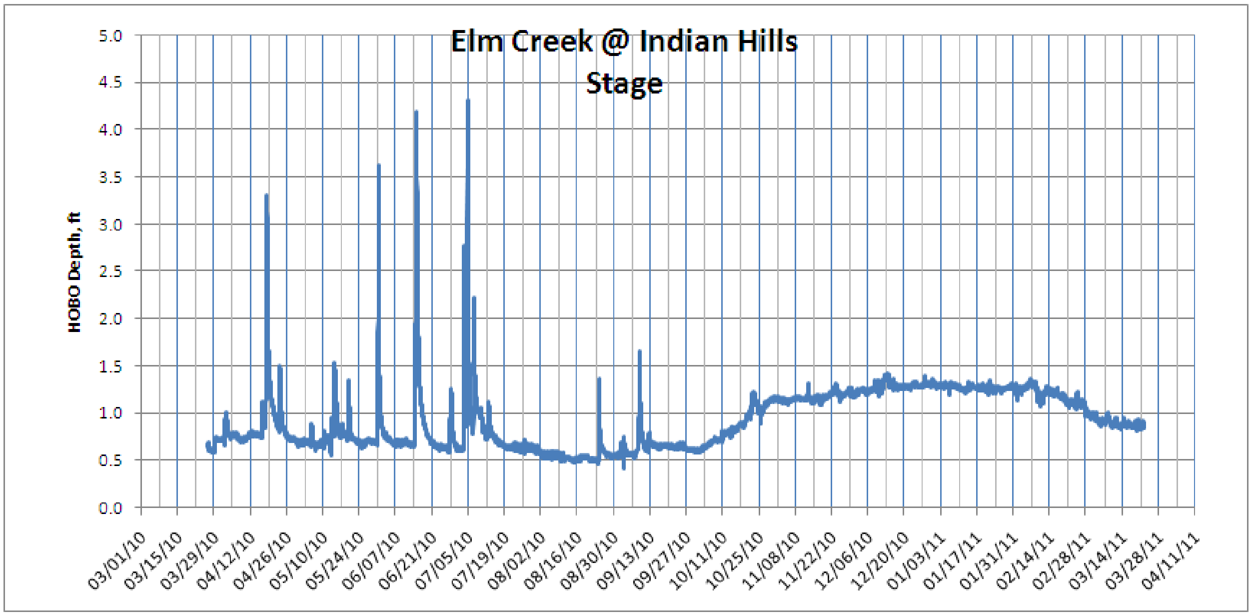


Figure E-5: Stage Record – Site S05 – Elm Creek @ Indian Hills

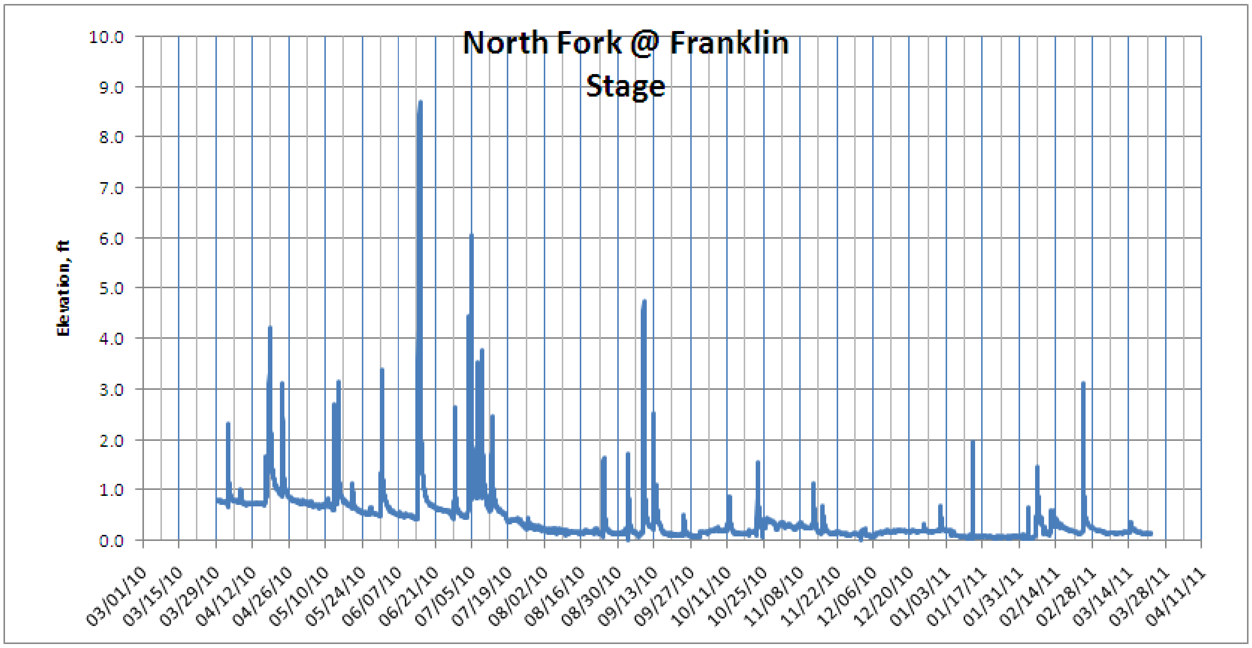


Figure E-6: Stage Record – Site S06 – North Fork @ Franklin

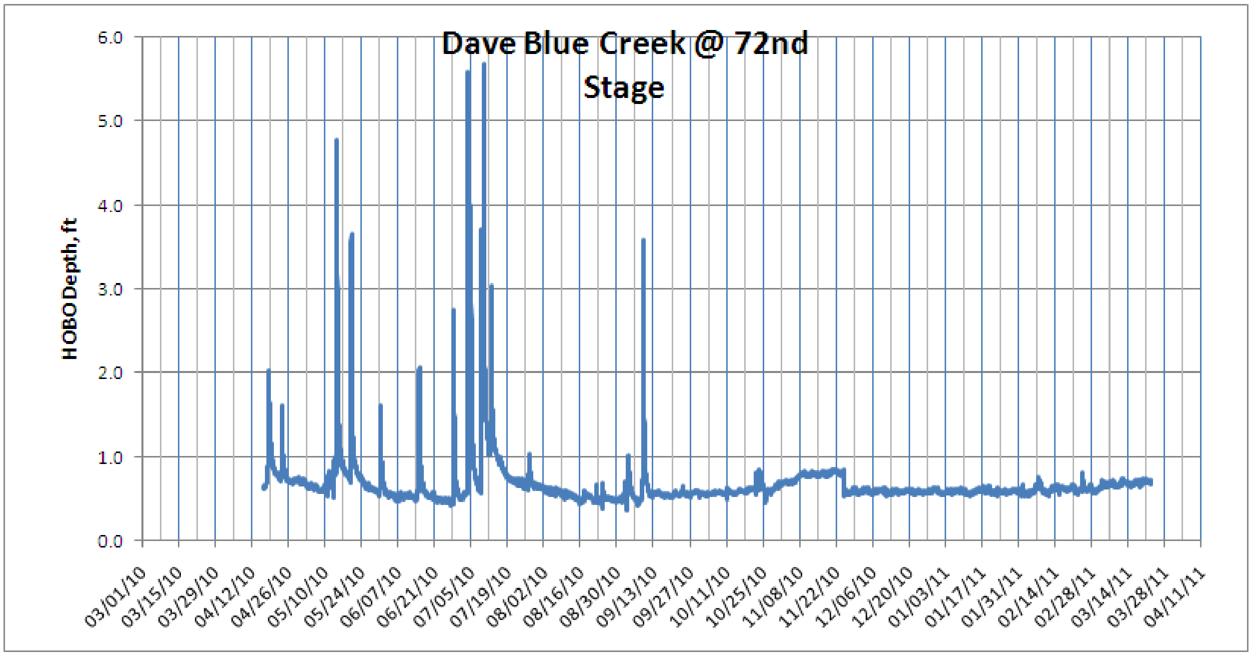


*Figure E-7: Stage Record – Site S07 – Dave Blue Creek @ 72^nd^*

Appendix F –Stage-Discharge Plots

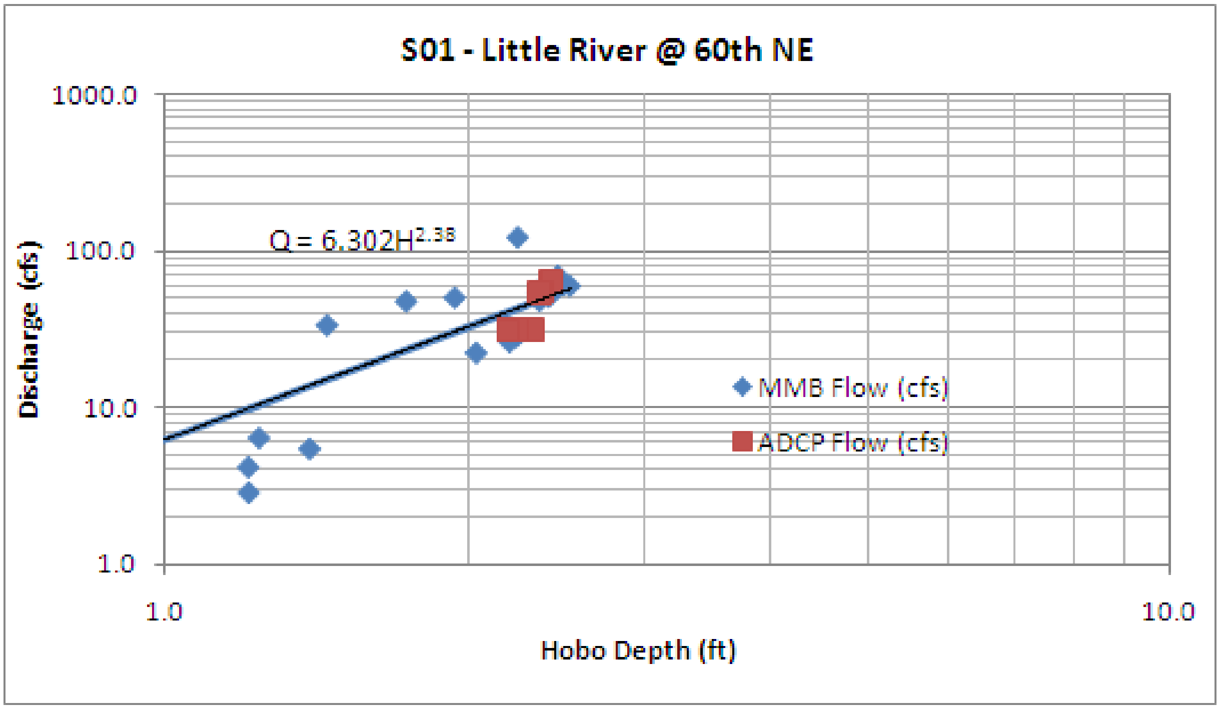


Figure F-1: Stage-Discharge Plot – S01 - Little River @ 60^{th}

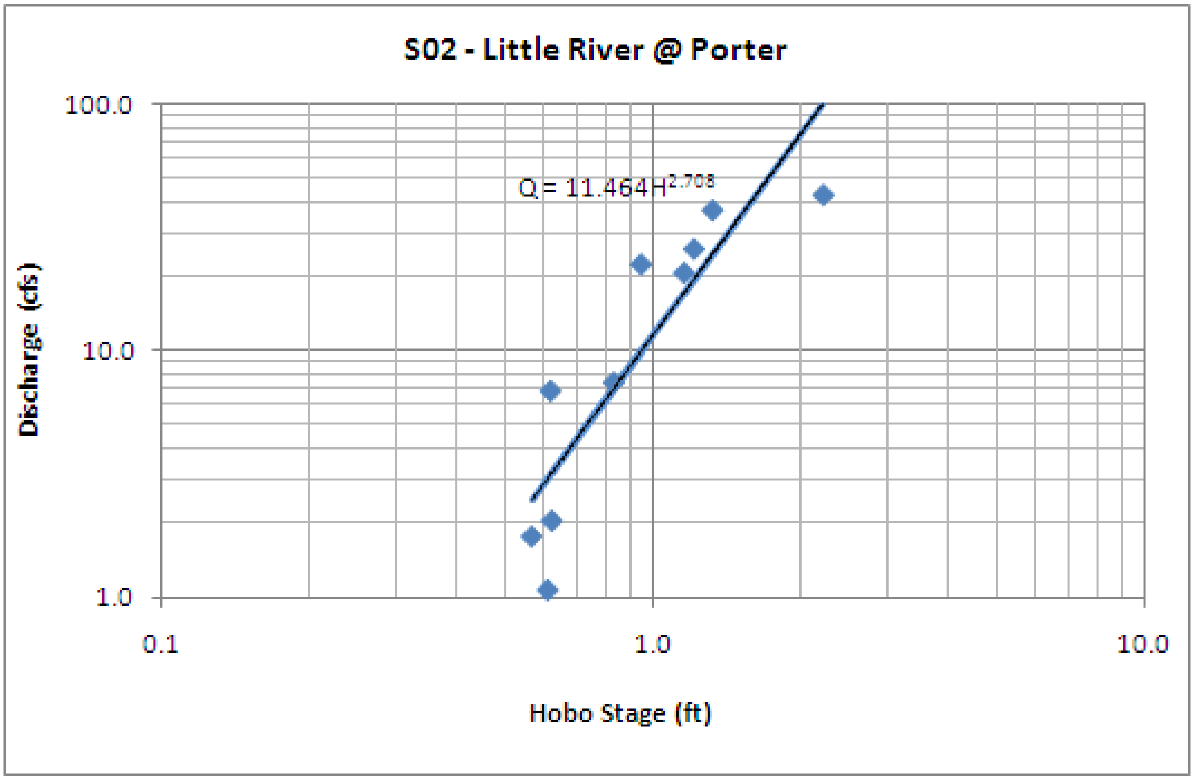


Figure F-2: Stage-Discharge Plot – S02 - Little River @ Porter

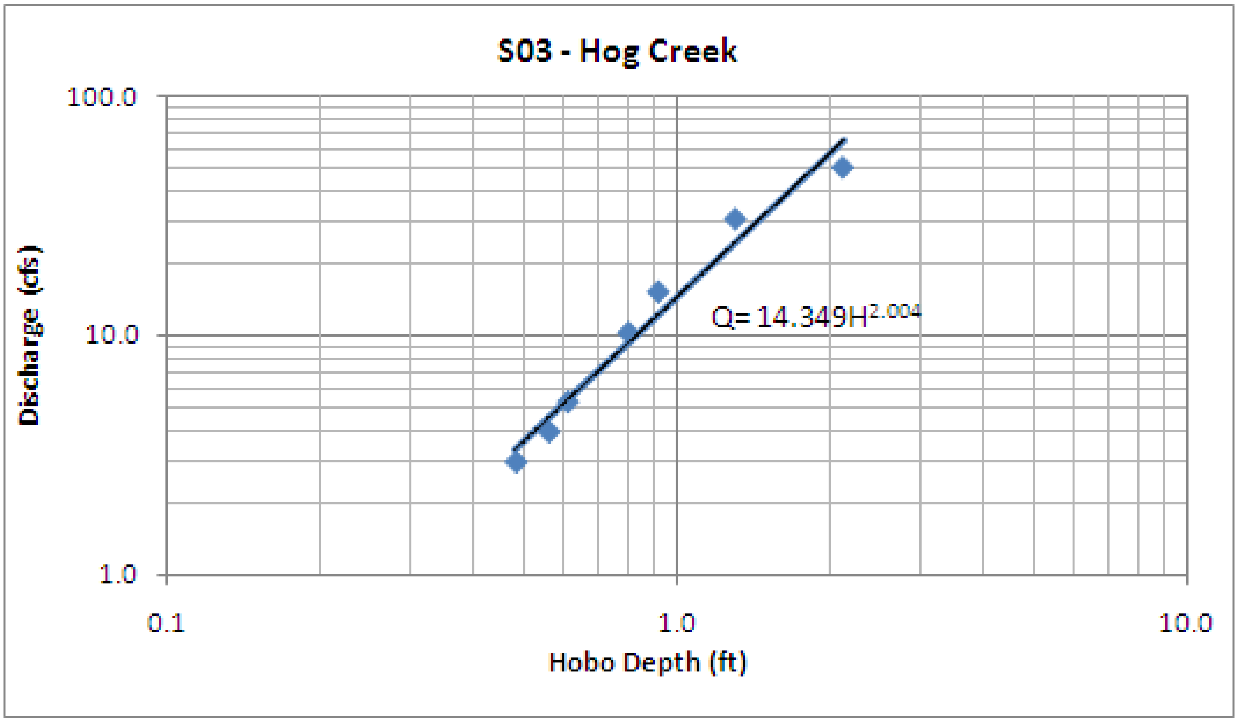


Figure F-3: Stage-Discharge Plot – S03 – Hog Creek

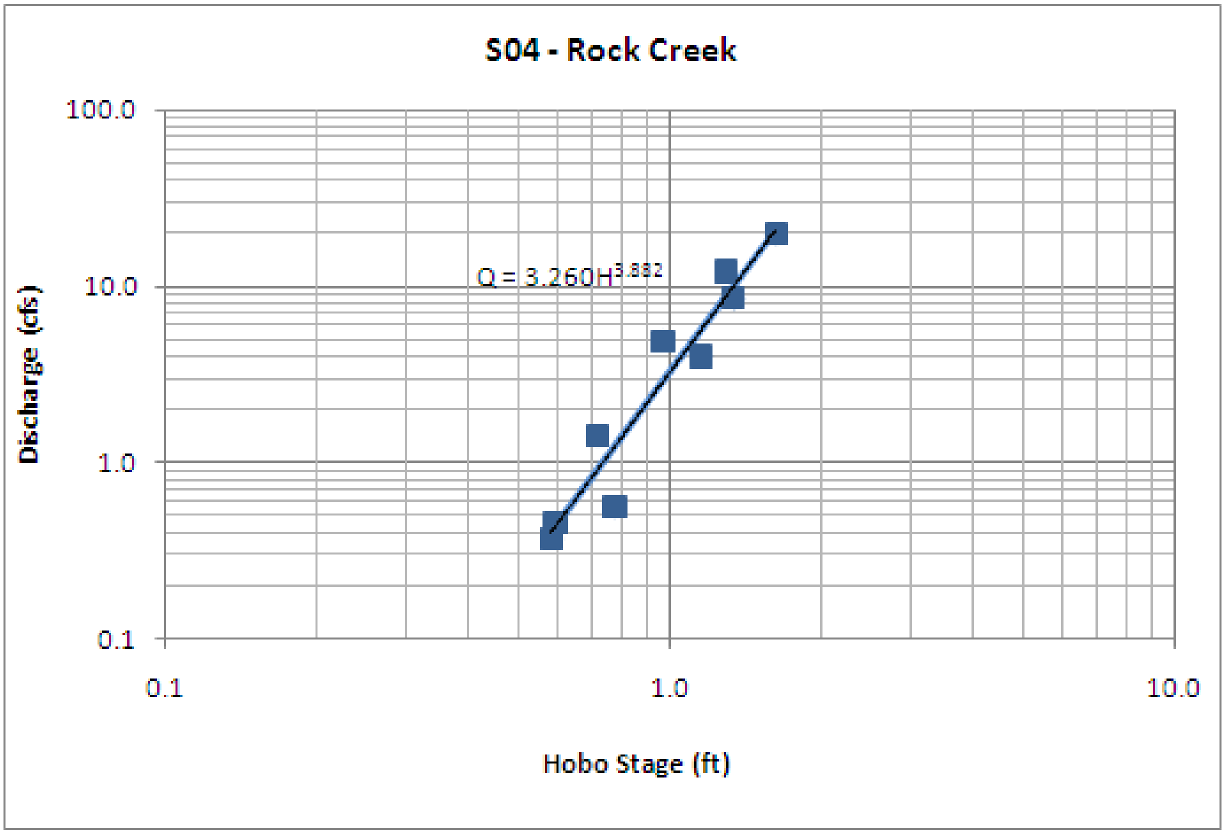


Figure F-4: Stage-Discharge Plot – S04 – Rock Creek

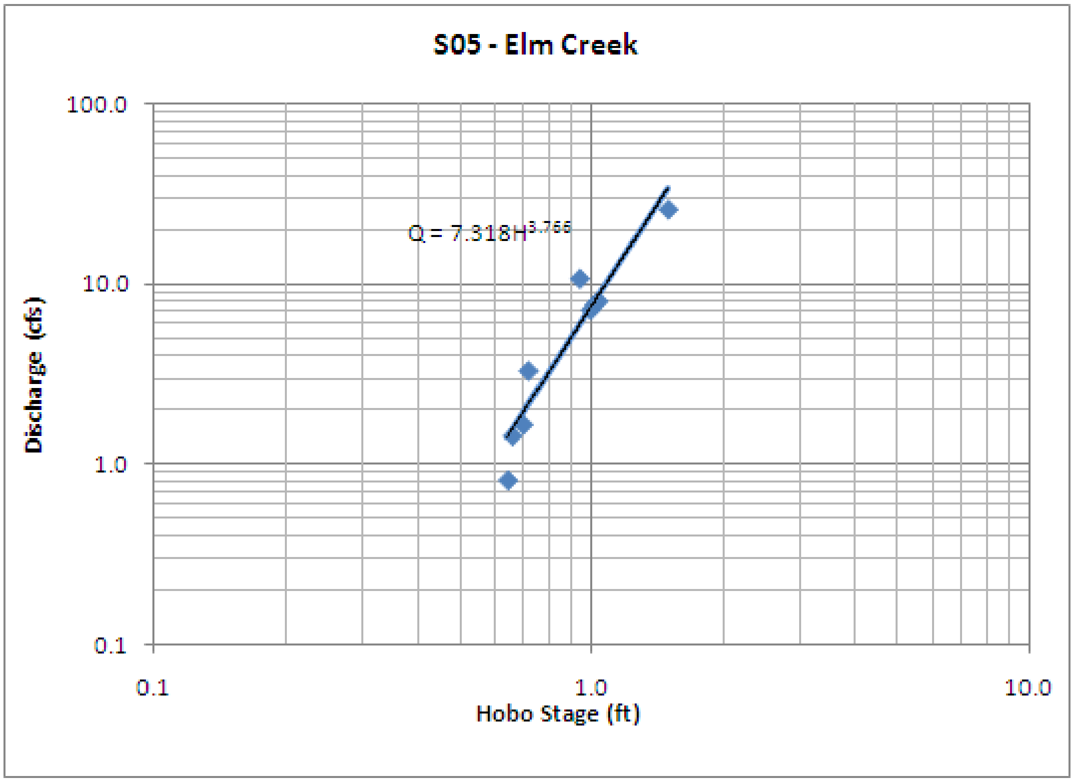


Figure F-5: Stage-Discharge Plot – S05 – Elm Creek

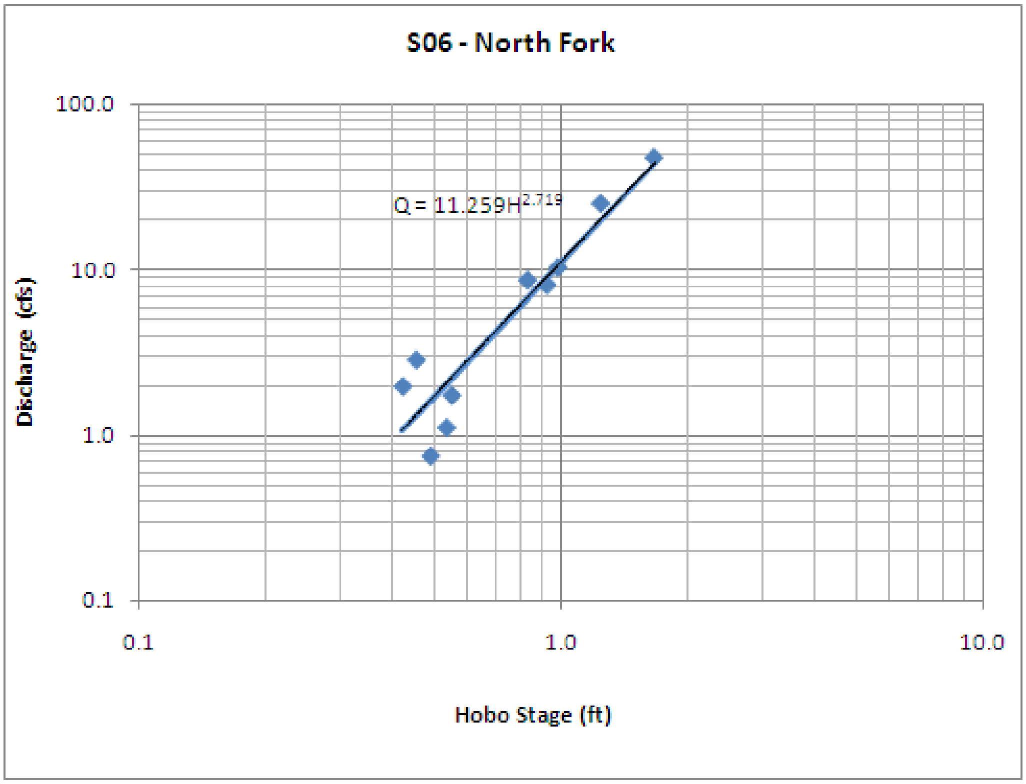


Figure F-6: Stage-Discharge Plot – S06 – North Fork

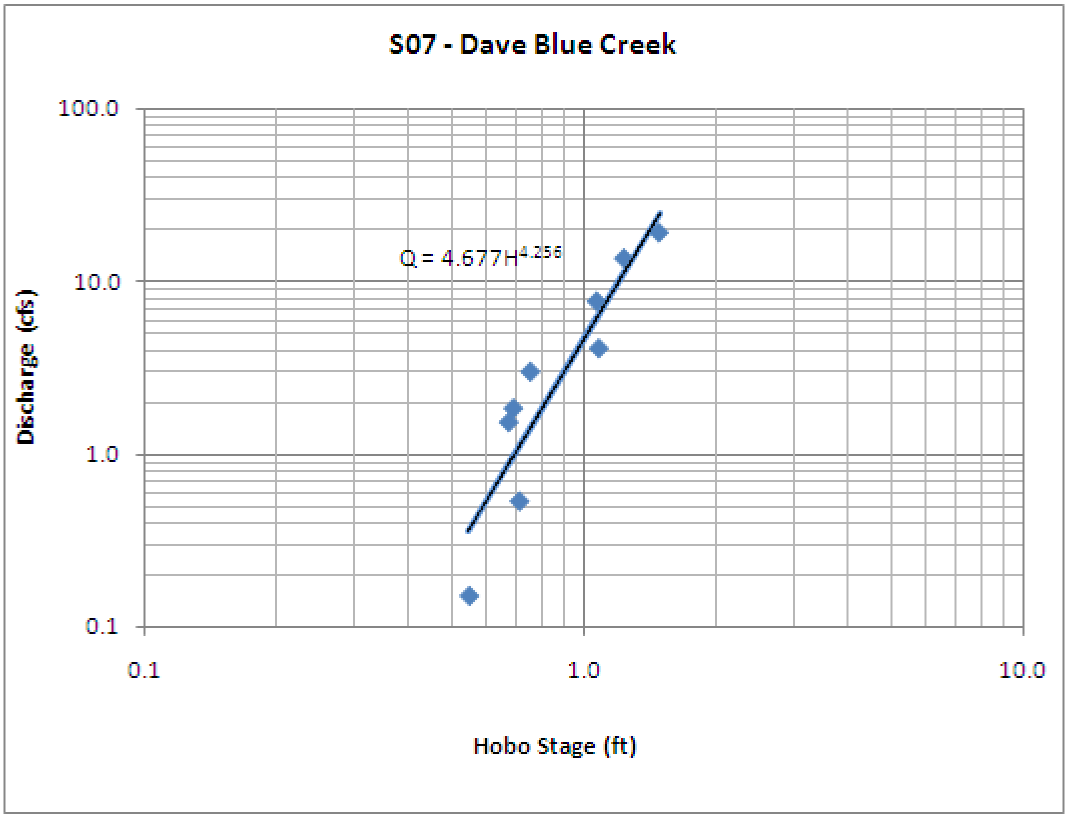


Figure F-7: Stage-Discharge Plot – S07 – Dave Blue Creek