Geomorphic Assessment of the South Dry Sac River below Valley Water Mill

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Submitted to the Watershed Committee of the Ozarks on March 15, 2006

SCOPE AND OBJECTIVES

The Watershed Committee of the Ozarks is interested in evaluating and restoring stream channel and bank stability on the lands under its control around the Valley Water Mill Reservoir including the main stem and tributaries of the South Dry Sac River. It is planned that the managed and restored channel reaches will be used for demonstration and education purposes by the Watershed Committee of the Ozarks. This study involves the initial assessment and recommendation phase of the channel restoration plans for one stretch of the South Dry Sac River which begins at the USGS gage below the Valley Water Mill Reservoir and extends downstream for 0.62 miles or 1070 meters to where the land enters into private ownership.

This assessment project has three objectives:

1. Inventory and mapping of channel reaches negatively affected by bed and bank erosion and sedimentation along approximately 0.62 miles of channel length;

2. Measurement and classification of baseline channel conditions for “typical” channel reaches including geomorphic variables, sediment characteristics, bank conditions, and riparian conditions to support restoration plans and designs; and

3. Prioritize reaches based on stability and restoration needs and provide recommendations for bioengineering and natural restoration measures where possible.

The study area was visited by Pavlowsky and staff to collect data and interpret stream processes for three days in May 2005 and four days in February 2006.

STUDY AREA

A continuous flow gage operated by the USGS as gage number 6918493 and named the “South Dry Sac River near Springfield, MO” is located at the upper end of the study reach. This gage has a drainage area of 35.5 km^2 with an approximate bed elevation of 1,183 feet above sea level. The mean annual discharge for the discontinuous period of record from 1996 to present ranged from 0.25 to 0.51 m^3/s with its peak flow of record on July 12, 2000 measured at 37.4 m^3/s (Hauck and Nagel, 2002). This flow overtopped the banks of the stream and covered the adjacent valley floor to a depth of about 1 to 2 feet. About 16 meters below the gage, the Grandview tributary enters the rivers and adds another 5 km^2 of drainage area to the river and so drainage area represented by the entire study reach is really 40 km^2 or slightly greater as it picks up more area from the bluffs and surrounding pastureland and woodlands.

Land use of the watershed is about 11% urban, 72% pasture/grassland, and 17% forest above the study area (Horton, 2003). The south or left side of the river is dominated by a steep bluff with frequent bedrock exposures upon which residential development is occurring. The Grandview Tributary drains some of these areas and its watershed contains almost 50% urban area. The north or right side of the river is mainly pasture grassland over rolling and gently-sloped terraces and uplands. The forested riparian corridor typically ranges from 5 to 10 meters in width on the right side of the river, but is much wider on the left side due to the effects of the bluff in blocking access. There are two small grassed access points coming down from subdivisions to access the river on the left side, but these do not seem to coincide with channel instability problems (Picture 18).

The area around and immediately downstream of the Valley Water Mill Reservoir has a long history of human activity beginning as early as 1830 when the area was settled. A dam and grist mill was constructed just upstream of the study area near Sanders Spring sometimes during the period from 1850 to 1871 (Licher, 2003). Since that time and through the mid-1900s the area was used as a major public water supply and recreation area for Springfield residents. An old iron water pipe that used to bring water from the reservoir to the Fulbright Spring swallow hole located at tape distance (TD) 212 m is exposed along the left bank of the stream for 50 m before disappearing into the bank near the manhole to the spring (Picture 8). This pipe is buried by fill and alluvial deposits along the way with the root system of a very large Sycamore covering it and so giving testament to the time that has past since industrial human activities began to affect the area. The creation of the dam itself probably influenced the geomorphic processes of the stream with erosion and sedimentation during the construction phase and continued effects from the human disturbances attracted to the area by its presence. However, the dam may have also reduced some of the impacts of agricultural erosion and urban runoff on the study area due to its ongoing hydrologic control on the attenuation of moderate-sized floods and reduced bed sediment load from the Valley Water Mill tributary. The Valley Mill Tributary drains about 12 km^2 at the spillway dam or more than 25% of the drainage area of the study site.

METHODS.

The field methods used for this study are described in detail by Fitzpatrick et al. (1998) and Peck et al. (1998). A brief description of the sampling methods is provided below.

Spatial Control and Mapping

This study used high-resolution aerial photography shot in 2004 by the City of Springfield and Greene County as a base map to display geomorphic data. Historical aerial photography dating back to 1938 was used to identify the longer-term effects of land use and soil conservation practices on the study reach. A GPS was used to determine the specific locations of channel features, landmarks, and some survey points. Locations along the stream are described using a "river-mile" approach with the 0 (zero) stream meter point located at the USGS gage and distances increasing in meter increments in the downstream direction along the channel centerline to 1000 meters at the end of the study reach (Map 1). Negative stream meter distances refer to stream points located between the gage and the Valley Water Mill tributary confluence about 60 meters upstream. Thus in this study, longitudinal locations are quantified by tape line measurements which are reproducible to +/- 2 meters. The lack of major channel location changes since 1938 infers that the channel centerline location has been relatively unchanged for 60 years and so tape distance measurements, along with GPS coordinate checks, are suitable for longer-term spatial controls for future studies as well as the present one (Map 2).

Longitudinal and Channel Surveys

Two types of topographic surveys are used in this study to understand the geomorphology of the South Dry Sac River: longitudinal surveys and cross-section surveys. The longitudinal survey involves measuring the elevation of the channel bed at its deepest point along the thalweg tape distance with a Topcon autolevel and stadia rod. Surveying points were collected at every riffle and pool location with additional points in between as needed. Water level was also recorded at most points. Longitudinal trends are useful for defining channel slope, riffle-pool spacing, and bar forms.

Cross-section surveys were completed using a hand-level with stadia rod readings along a meter tape pulled tight across the channel from high bank to high bank with 0 on the left bank looking downstream. Stadia rod readings were collected at slope-breaks and points in-between as needed. All cross-sections are located at a riffle crest or within 5 meters upstream of the crest along the channel glide (Map 1). Geomorphic data collected at these locations best describes channel size and shape for hydraulic analysis. In addition, elevations of alluvial surfaces or deposits indicative of channel behavior were also measured. Two channels are identified for analysis in this study: bankfull and total channel. The top stage of the “bankfull” channel is identified as the highest elevation of bed load or gravel transport in the channel and indicates the minimum elevation of the active floodplain surface which typically conveys the 1 to 2 year flood. There are very few locations where an active floodplain is found in the study reach so bankfull stage determinations were made based on bar heights, bank scour breaks, and exposed root lines. The “total” channel represents the stage at which the channel will overflow its high banks and spread out over the valley floor; usually this surface is called the low terrace. Geomorphic measures of width, mean depth, and area were made at each cross-section and combined with local slope measurements over a three riffle distance from the longitudinal survey to evaluate channel flow capacity.

Bed Material Evaluation

Bed material size is evaluated for bars and riffles. Bar counts of 20 pebbles were done by the zig-zag method on mobile bars associated with adjacent riffle crest locations in order to determine the sizes of the bed material most often transported during floods by the stream. Riffle counts measure the five largest clasts along or near the riffle crest to determine the maximum size of bed material transported in the channel. Only large clasts that were potentially-mobile were measured so they had to appear to have been moved recently showing abrasion marks or imbrication and be representative of the largest materials found in the riffle.

Gravel Bar Distribution

Four basic types of gravel bars were identified in the field and the location of each recorded. Alternate bars are deposited along alternating sides of the channel in the downstream direction and indicate a sinuous flow path of the thalweg in an otherwise straight channel. Point bars form on the inside of meander bends where flow separation occurs as the main current is directed towards the opposite bank. Mid-channel bars form when channels become relative wide and the thalweg divides into two locations nearer to the banks. These types of bars may be migrating downstream and be only temporary, however, they may also indicate a situation where channel instability will develop and bank erosion will occur to produce channel widening. Mid-channel bars represent a potential problem in this usage. Mega-bars are relative large mid-channel bars that form barriers to flow with a high riffle crest with a steep cascading run below it. These bars effectively clog or fill the channel causing flood waters to spread out and attack the banks, sometimes eroding one or more chute channels into the flanking floodplain or low terrace. Mega-bars are sometimes referred to as "sediment waves" since they are much larger than typical bar forms and may migrate downstream over periods of decades to centuries. Thus, they also indicate distinct disturbance reaches along the stream.

Additional GIS Resources

Additional GIS data layers that are available on-line were used to evaluate the study reach including topographic maps, 100-year floodplains, and soil series. Several survey bench marks, tape distance points, and other land marks were located with a GPS receiver (Table 6).

Hydraulic and Sediment Mobility Equations

Discharge and velocity calculations are based on the application of the Darcy-Weisbach Equation and empirical estimation of channel roughness using a friction factor (f) equation which is mathematically related to the "Manning n" roughness coefficient. Sediment transport analyses are based on the bed shear stress equation. Shear stress values are used to estimate the critical size of sediment that can be transported by the channel using the Rosgen relationship. The critical size values are then compared to bed material sample statistics (i.e. D50 and D84) in order to evaluate the competence of the flow at each sampled cross-section.

Stream Log Pictorial

Extensive notes on disturbance features, landmarks, stream bank erosion conditions, and channel landforms were collected in the field. A description of the study reach was documented at the time of investigation by the collection of a digital photograph series showing the general channel and bank condition and important land forms along the study reach (Pictures 1-30).

RESULTS

Historical Channel Instability and Recovery

Evidence from1938 historical photography indicates that runoff volume, soil erosion rates, and bed sediment loads have largely decreased over the past 65 years since 2004 (Map 2). Indicators of poorer conditions on the 1938 photographs include wider and gravel-choked streams, abundant row cropping with fewer trees, and severe soil erosion and gullying on adjacent hillslopes and these features are absent in 2004. Soil conservation practices involving pond construction, riparian management, and pasture cropping are obvious in 2004 and were probably responsible for much of the improvement. While it is safe to say that conditions have improved for geomorphic stream stability along the South Dry Sac study reach since World War II, it is not clear how the stream is responding to reduced fine-grained sediment loads and the reworking of excess bed sediment stored in the historical bed, bar, and floodplain deposits of the river since then. For example, it is highly probable that the stream will continue to show signs of bed and bank erosion and gravel transport as the river attempts to remove the excess stored sediment and reach a new balance with present conditions. This recovery period seems to take a long time in Ozark streams and can last for 50 to 100 years or more. Thus observations of some bed and bank erosion should be expected as the channel becomes more stable and sediment-balanced though time during the recovery process.

Historical and Present Channel Instability

There are two reaches where there were observable shifts in channel locations between 1938 and 2004 (Map 3). The first reach runs from TD 90 to 170 meters just below several disturbance factors including the reservoir, roads, and Grandview tributary confluence. The channel locations overlap again when the river flows up against the southern bluff line at TD 175 meters where the ability to erode laterally is limited by bedrock-control. The second reach runs from TD 720 to 800 meters where the channel is relatively far away from the bluff and the confining influence of bedrock-control. In addition to historical evidence of channel change at this site, there is also evidence of pre-1938 age channel fills and cutoffs on the valley floor along the south side of the channel (Picture 19). These reaches represent about 15 percent of the study area and indicate locations where the channel may be predicted to erode laterally given its past behavior, however at present it is relatively stable.

The location of sedimentary bars also indicate areas where present channel conditions are disturbed (i.e. mega bars) or potentially unstable (i.e. middle bars). Mega-bars are found in the study area at TD 260 to 329 meters (Pictures 9-10) and TD 800 to 870 meters (Pictures 21-25) (Map 3, Map 4). These are sub-reaches of major instability and change which form by the excessive deposition of relatively coarse bedload materials in composite bar and riffle forms. Since they effectively clog the channel and force the flow against and out over the banks, evidence for chute channel incision and/or avulsion on flanking floodplains is also found at each of these sites. Both of these disturbance reaches are located at a bend downstream of a relatively long straight reach along the bluff line where there is an ample supply of large clasts from bedrock and colluvium sources.

Although historical settlement and agricultural impacts on the river have abated, it is not clear how recent trends in urbanization and suburbanization have influenced the reach and how this influence may be affecting the historical recovery process. In general, urban areas increase the volume and/or duration of runoff to adjacent streams and either of these hydrologic effects can increase bed and bank erosion rates. Field observations indicate that the Grandview Tributary is undergoing extensive bed and bank instability due to development pressure that has probably resulted in forming a relatively large deposit of bed material below its confluence at TD 15 meters to 50 meters that is blocking the left side of the channel and forcing the flow to erode the banks on the right side (Pictures 1 and 2). However, large scour hole and bar formation is typically found below bridges and so in this case it is hard to distinctly separate the influence of urban stream instability and bridge hydraulic interference on the local bed and bank disturbances observed. Rip-rap extends along both banks from TD 0 to 12 meters to protect the bridge from undermining here too. To compound matters, there is a slight bend of the stream to the left at TD 45 which would also cause “natural” bank erosion on the outside bank as is typical to meandering rivers. Nevertheless, the area along the stream extending from the bridge to 60 meters and even slightly further downstream is an area of potential instability that needs to be monitored (Pictures 1-4).

Planform Controls and Stability

The planform (or channel pattern) of the study area is relatively stable and, as discussed above, has been relatively unchanging for some time with only a few exceptions. With bedrock close to the surface in the area and the channel forced over to the bluff-side of the valley, it is very difficult for the channel to migrate laterally with much freedom (Pictures 15, 26-28). The channels probably are superimposed over existing fracture patterns or local weaknesses in the bedrock and have a difficult time moving out of location either by eroding though bluff outcrops and lower confining bedrock straths or though alluviation and the rising of bed elevation above bedrock obstacles. Thus, the South Dry Sac River is largely bedrock-controlled with little ability to adjust by changing its depth though scour and/or to adjust its slope through meandering. Most of the mainstem and tributary channels within the river system have sinuosity values less than 1.05 and only very few reach 1.10 (Horton, 2003). These types of channels tend to be classified as sinuous or straight channels--not as meandering channels--by geomorphologists. Even though bank erosion occurs at stream bends in the study area, most (not all) of these bends are not moving laterally at any appreciable rate so the stream can recover through sedimentation and other channel adjustments.

Longitudinal Profile

The longitudinal profile of the stream tends to step down over short distances at 200 to 400 meter intervals indicating the effects of bedrock control (Figure 1). Bank heights and longitudinal slopes are fairly consistent among the four geomorphic surfaces evaluated in this study: low terrace, bankfull, riffle crest, and deepest pool point (Figure 2). However, riffle crest slope does vary by sub-reach with zones of very high and very low channel slopes occurring within the study area (Figure 3). Lower slopes tend to occur upstream of mega-bars or in “step” zones between relatively steep reaches. The highest slopes are found downstream of mega-bars (Figure 1).

The bedform profile in the study area usually is composed of riffle crests, riffle/runs, and pools. The average riffle crest-crest spacing in the study area is 33 m +or– 15 m and residual pool depths (at the deepest point relative to the downstream riffle crest) average 0.33 m +or– 0.26 m (Table 1). Longer riffle spacing is found between TD 400 and 550 meters and TD 800 and 900 meters (Figure 4b, Map 3). The deepest pools are found in sub-reaches extending from TM 50 to 280 meters and TM 700 to 880 meters with some other large pools around TD 300 and TD 400 meters (Figure 4, Map 3). A relatively long reach of very shallow pools is found between TD 480 to 700 meters where the channel flows up against a bluff (Figure 4a).

Channel Cross-section Morphology

Channel dimensions vary in the downstream direction due to local factors such as at mega-bar scour zones (TM 300), bend location (TM 900 m), and bluff influence (TM 600-700 m) (Table 2; Figures 5 and 6). The bankfull channel has average dimensions as follows: width at 11 m +or- 1.3 m; mean depth at 0.54 m +or- 0.11 m; area at 5.9 m^2 +or- 1.4 m^2; and width/depth ratio at 21 +or- 5 (Table 2). The total channel (at maximum channel capacity before it floods over the low terrace bank) has average dimensions as follows: width at 15 m +or- 2 m; mean depth at 1.2 m +or- 0.2 m; area at 18.3 m^2 +or- 2.6 m^2; and width/depth ratio at 13 +or- 3 (Table 2).

Applying the cross-section and riffle slope data to hydraulic equations, flow information relating to the flow mechanics and discharge of the study area can be evaluated (Table 5; Figure 7). Channel roughness values of Mannings n tend to range from 0.03 to 0.045 with slightly lower values for the deeper total channel flows (Figure 7a). Mean channel velocity averages 1 m/s +or- 0.3 m/s for the bankfull discharge of 6.1 m^3/s +or- 2.9 m^3/s (Figure 7). The total channel has an average velocity of 1.7 m/s +or- 0.5 m/s and discharge of 31.5 m^3/s +or- 10.5 m^3/s (Table 5). Although methods for adequately calibrating flow frequency relationships may not be available for this karst area, it is believed that the total channel can contain the 2 to 10 year flood, while the bankfull flood has a recurrence interval of 1-year or less in the South Dry Sac River system (Horton, 2003). Further, the 2000 flood of record (37 m^3/s), with an estimated recurrence interval of 25 to 50 years, could have been contained by only about one third of the cross-sections examined. Thus, given the moderate degree of flooding along the study reach observed in 2000, the total channel capacity estimates in this report seem reasonable.

Bed Material and Sediment Transport

The diameter of bed material is largely controlled by the proximity to bed rock and colluvial clasts along bluff lines where cut banks have formed against bedrock outcrops such as along TD 200-300 m, TD 500-600 m, and TD 800-1,000 m (Figure 8, Map 4). The average maximum riffle clast size for the study area is 218 mm +or- 69 mm and the sub-reach containing the largest bed sediment occurs from TD 882 to 1,000 meters where the bedrock supply of large >300 mm clasts is very high (Table 3, Figure 8, Pictures 26-30). The size of gravel sediment in bar features tends to follow the same patterns as maximum clast size (Figure 8). The median or D50 of the bar pebble counts average 29 mm +or- 13 mm and the D84 averages 54 mm +or- 21 mm for the study area (Table 4, Picture 17).

Bed shear stress values for the study reach average 0.37 lbs/ft^2 +or- 0.2 lbs/ft^2 for the bankfull stage and 0.78 lbs/ft^2 +or- 0.41 lbs/ft^2 for the total channel stage (Table 5). Using the shear stress values to estimate the critical size of sediment capable of being transported at the given force, the bankfull flow is approximately competent to transport the D50 bar size and the total channel flow is competent to transport the D84 (Figure 9). This relationship suggests that channel capacity and bed sediment transport are balanced so that both deposition and sedimentation can occur in the channel. Thus, the stream can adjust to external changes though sediment transport processes and bedform deposition and erosion.

Bank Conditions

Bank stability was assessed visually by observing upper bank angle, bank height, vegetation cover, and evidence of erosion such as exposed tree roots or recent bank collapse. As mentioned before, channel location has been relatively stable over time so few severely eroding banks were found in the study area. The banks showing the most consistent extent of erosion are located on the floodplain/terrace features on the right side of the stream in locations where flood flows are forced to converge and increase in erosive force as they enter a bluff-lined reach (Map 4). Additional locations for bank erosion occur at relatively tight bends or any bend along a steep reach. Finally, bank erosion is also noticeable at a slight bend being affected by the Grandview tributary and the depositional bar below it (TD 45 m) (Picture 2).

Most of the bank erosion observed seems to relate to geologic control and systemic flow/sediment transport problems that are difficult to identify. In addition, although evidence for steep and potentially eroding banks can be found in the study area (Picture 14), the rate of bank erosion is relatively slow in most instances and is being off-set by resistance from bedrock bluff-lines and dense tree roots (or other vegetation) (Pictures 4, 11-12). In many places where tree roots are obviously exposed, the roots have “barked over” suggesting that the rate of bank erosion is very slow or stopped or it is possible that the bank has recovered in the near past but is now beginning to erode again (Pictures 7, 13, 16). The worst bank erosion problem found in the study area is located just below mega-bar #2 where the rivers bends sharply to the left (Pictures 23-25). This bank is eroding relatively quickly and is very high partially because it is composed of old fill material that seems to have been dumped or stored there.

RECCOMENDATIONS

For the most part, the study reach has been relatively stable in terms of very low channel migration rates and slow bank erosion rates. Aerial photographs from 1938 indicate that channel locations have not changed much at all compared to 2004 conditions and that soil conservation practices have improved watershed conditions. However, the influence of recent urban growth on runoff and instability in the channel is difficult to assess at the moment. These stream channels tend to respond and recover slowly (in a geomorphic sense) probably due to a combination of factors including karst hydrology, bedrock influence, resistant bank soils, low sediment loads, and vegetation. Some areas of instability and future concern were observed along the South Dry Sac River and form the basis for the following recommendations:

1. **Disturbance reach or mega-bar monitoring**. The excessive accumulations of bed sediment in the two disturbance reaches containing mega-bars need to be monitored. In other Ozark streams these features are believed to formed as a response to past poor land management and the introduction of gravel via soil erosion to the channel system. Unstable conditions such as eroding banks, mid-channel bars, scouring pools, and chute channel erosion are associated with these areas in the study area. There are no simple restoration fixes for these types of areas since they deal more with sediment transport and supply problems at the segment or watershed-scale rather than bed or bank resistance at the sub-reach scale that can be managed on-site.

2. **Pool enhancement along the TD 500-700 Sub-reach.** This area has very shallow, almost absent, pool forms and thus lacks the hydraulic and habitat values they provide. This area might offer a good location to try and restore riffle and pool habitats with vanes and weir structures. The concept here would be to improve aquatic habitat diversity with restoration measures that stand up to sediment transport and flashy flows. This area also remains flowing through out the year, so aquatic life will not be limiting by dry bed conditions and a variety of vegetation stabilization options would be possible.

3. **Possible bank stabilization sub-reaches:**

    a. Generally speaking, maintain the vegetation resistance on all banks, but particularly those that are located at entry zones to bluff-constricted areas and those opposite bed-rock bluff outcrops.

    b. The bend at TD 400 m seems to be undergoing a recent episode of erosion where exposed roots have a fresh appearance and mid channel gravel bars are slowly advancing downstream toward it. This reach should be examined for stabilization and restoration action—at the least it needs to be monitored.

    c. The bend below mega-bar #2 and TD 800 is very unstable. Bank regrading, stabilization, and toe-protection is needed to stabilize this area. Some of the excess energy could be directed around this bend by expanding the chute channel on the low floodplain on the left side of the channel to direct floodwater around it.

4. **Monitor, and maybe stabilize, the Grandview Tributary Confluence sub-reach from TD 12 m to 60 m.** This area is receiving stormwater and sediment from Grandview Tributary that is affected by urbanization. Restoration activities and stormwater BMP implementation should continue in the watershed to decrease the influence on the South Dry Sac River. Controlling sediment clogging of the channel and stabilizing the right bank may also help reduce the instability of this reach. The instability of this reach could possibly lead to downstream instability that may reactivate or remobilize mega-bar #1. Monitoring activities should extend down to TD 100 m to watch for these downstream progressing effects.

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Table 1: Inventory of Pools and Riffles

Pools					**Riffles**			
ID No.	Tape (m)	Elev (m)	Spacing (m)	Max res d (m)	ID No.	Tape (m)	Elev (m)	Spacing (m)
					"00"	-72	8.63	
"00"	-39	7.77		0.475	0	-24	8.245	48
0	-5	7.745	34	0.43	1	19	8.175	43
1	38	7.985	43	0.055	2	44	8.04	25
2	60	7.25	22	0.73	3	89	7.98	45
3	120	7.5	60	0.3	4	128	7.8	39
4	138	7.58	18	0.14	5	162	7.72	34
5	167	7.35	29	0.33	6	191	7.68	29
6	215	7.09	48	0.33	7	230	7.42	39
7	246	6.88	31	0.65	8	269	7.53	39
8	297	6.76	51	0.22	9	305	6.98	36
9	310	6.24	13	0.8	10	328	7.04	23
10	337	6.89	27	0.13	11	356	7.02	28
11	363	6.87	26	0.07	12	368	6.94	12
12	420	5.74	57	0.76	13	428	6.5	60
13	437	6.29	17	0.215	14	447	6.505	19
14	463	6.24	26	0.12	15	472	6.36	25
15	538	5.915	75	0.265	16	540	6.18	68
16	549	5.97	11	0.18	17	560	6.15	20
17	580	5.985	31	0.125	18	586	6.11	26
18	600	5.94	20	0.06	19	612	6	26
19	630	5.77	30	0.18	20	634	5.95	22
20	640	5.88	10	0.04	21	646	5.92	12
21	654	5.73	14	0.15	22	668	5.88	22
22	674	5.67	20	0.13	23	700	5.8	32
23	710	5.33	36	0.33	24	727	5.66	27
24	758	4.76	48	0.86	25	773	5.62	46
25	780	5.09	22	0.57	26	817	5.66	44
26	858	4.51	78	0.75	27	882	5.26	65
27	889	5	31	0.11	28	890	5.25	8
28	911	4.75	23	0.25	29	918	5	28
29	940	4.1	29	0.63	30	959	4.73	41
		mean=	**32.6**	**0.33**				**33.3**
		s=	17.7	0.26				14.7
		Cv%=	54.3	78.5				44.1

Table 2:Cross-section Data

Date	**CS ID**	**Riffle**	**Active Bed**			**Bankfull**						
	Tape-m	#	Elevation (m)	Slope (m/m)	width (m)	width (m)	depth max (m)	depth mean (m)	area (m2)	Hydraulic Radius (m)	w/d	Elevation (m)
May-05	41	2	8.03	0.0026	6.5	9.25	0.69	0.62	5.70	0.54	15.0	8.72
May-05	89	3	7.98	0.0028	7.9	11.5	0.60	0.41	4.70	0.38	28.1	8.58
May-05	128	4	7.8	0.0036	8.4	9.6	0.85	0.70	6.67	0.61	13.8	8.65
May-05	164	5	7.72	0.0019	10.0	10.6	0.79	0.48	5.13	0.44	21.9	8.51
May-05	186	6	7.66	0.0045	7.4	11.3	0.62	0.43	4.85	0.40	26.3	8.28
May-05	229	7	7.42	0.0018	9.0	10.9	0.79	0.51	5.58	0.47	21.3	8.21
May-05	269	8	7.53	0.0037	11.8	12.75	0.48	0.44	5.57	0.41	29.2	8.01
Feb-06	128	4	7.8	0.0019	8.1	10.6	0.9	0.57	6.08	0.52	18.5	8.7
Feb-06	186	6	7.66	0.0045	8.1	9.6	0.62	0.36	3.43	0.33	26.9	8.28
Feb-06	264	8	7.47	0.0037	11.3	13.8	0.73	0.48	6.64	0.45	28.7	8.2
Feb-06	348	11	7	0.0022	7.2	10.9	0.8	0.52	5.69	0.48	20.9	7.8
Feb-06	379	12	6.86	0.0073	8	11.4	0.55	0.49	5.56	0.45	23.4	7.41
Feb-06	478	15	6.36	0.0033	7.1	10.1	0.7	0.44	4.39	0.40	23.2	7.06
Feb-06	559	17	6.15	0.0015	7	10.2	0.88	0.60	6.16	0.54	16.9	7.03
Feb-06	586	18	6.11	0.0029	8.4	10.4	0.88	0.75	7.79	0.65	13.9	6.99
Feb-06	612	19	6	0.0034	8.1	10.8	1	0.81	8.74	0.70	13.3	7
Feb-06	661	22	5.83	0.0022	9.6	10.8	0.75	0.55	5.94	0.50	19.6	6.58
Feb-06	702	23	5.77	0.0037	8.3	11.4	0.7	0.48	5.49	0.44	23.7	6.47
Feb-06	775	25	5.62	0.0023	9	9.4	0.85	0.57	5.33	0.51	16.6	6.47
Feb-06	812	26	5.58	0.0037	9.3	11.4	0.6	0.40	4.61	0.38	28.2	6.18
Feb-06	884	27	5.22	0.0063	8.7	14.1	0.85	0.65	9.19	0.60	21.6	6.07
Feb-06	917	29	5	0.0075	6.9	11.5	0.8	0.63	7.22	0.57	18.3	5.8
Feb-06	961	30	4.7	0.0075	6.6	10	0.65	0.53	5.28	0.48	18.9	5.35
			Mean=	**0.0037**	**8.38**	**10.97**	**0.74**	**0.54**	**5.90**	**0.49**	**21.23**	**7.41**
			s=	0.0018	1.37	1.25	0.13	0.11	1.35	0.09	5.06	1.04
			Cv%=	50	16	11	17	21	23	19	24	14

Date	**CS-ID**	**Riffle**	**Total**						
	Tape-m	#	width (m)	depth max (m)	depth mean (m)	Area (m2)	Hydraulic Radius (m)	w/d	Elevation (m)
May-05	41	2	15.8	1.28	0.94	14.79	0.84	16.9	9.31
May-05	89	3	13.2	1.28	0.99	13.11	0.86	13.3	9.26
May-05	128	4	17.3	1.56	1.03	17.85	0.92	16.8	9.36
May-05	164	5	13.1	1.84	1.33	17.36	1.10	9.9	9.56
May-05	186	6	14.9	1.34	0.97	14.41	0.86	15.4	9.00
May-05	229	7	15.3	1.96	1.19	18.24	1.03	12.8	9.38
May-05	269	8	16.3	1.35	1.15	18.66	1.00	14.2	8.88
Feb-06	128	4	18.6	1.65	1.06	19.75	0.95	17.5	9.45
Feb-06	186	6	16.4	1.87	1.17	19.19	1.02	14.0	9.53
Feb-06	264	8	18.3	1.6	1.25	22.78	1.10	14.7	9.07
Feb-06	348	11	18	1.9	1.12	20.16	1.00	16.1	8.9
Feb-06	379	12	14.9	1.65	1.39	20.65	1.17	10.8	8.51
Feb-06	478	15	16.6	1.7	1.07	17.75	0.95	15.5	8.06
Feb-06	559	17	12.4	1.9	1.43	17.68	1.16	8.7	8.05
Feb-06	586	18	12.9	1.8	1.43	18.41	1.17	9.0	7.91
Feb-06	612	19	13.5	2	1.55	20.88	1.26	8.7	8
Feb-06	661	22	15.6	2.2	1.55	24.12	1.29	10.1	8.03
Feb-06	702	23	16.6	1.8	1.26	20.92	1.09	13.2	7.57
Feb-06	775	25	14	1.85	1.22	17.04	1.04	11.5	7.47
Feb-06	812	26	15.7	1.35	0.94	14.77	0.84	16.7	6.93
Feb-06	884	27	16.8	1.4	1.05	17.71	0.94	15.9	6.62
Feb-06	917	29	15.1	1.6	1.18	17.86	1.02	12.8	6.6
Feb-06	961	30	13.8	1.7	1.29	17.77	1.09	10.7	6.4
		Mean=	**15.44**	**1.68**	**1.20**	**18.34**	**1.03**	**13.27**	**8.34**
		s=	1.78	0.25	0.18	2.62	0.13	2.86	1.03
		Cv%=	12	15	15	14	12	22	12

Table 3: Riffle Maximum Clast Size (n=5)

Date	Riffle Number	Crest Dis (m)	Sample Dis (m)	B-Diameter (mm)					Median (mm)	Mean (mm)	Stdev (mm)	Cv%	Max (mm)
				1	2	3	4	5					
5/24/2005	00	-72		240	190	160	228	218	218	207	32.2	15.5	240
5/24/2005	0	-24		234	217	257	210	208	217	225	20.5	9.1	257
5/20/2005	1	18.6	24	185	119	130	155	142	142	146	25.5	17.4	185
5/20/2005	2	44	44	138	152	183	178	158	158	162	18.6	11.5	183
5/20/2005	3	89	92	108	154	188	159	168	159	155	29.5	19.0	188
2/23/2006	3	89	89	128	169	180	180	160	169	163	21.5	13.2	180
2/23/2006	4	128	128	280	185	187	170	168	185	198	46.6	23.6	280
5/20/2005	4	128.3	131	214	178	173	171	212	178	190	21.5	11.4	214
5/24/2005	5	162	163	207	218	240	190	148	207	201	34.6	17.2	240
5/20/2005	6	190.6	189	196	232	210	223	179	210	208	21.2	10.2	232
2/23/2006	6	191	185.5	520	330	350	500	270	350	394	110.1	28.0	520
5/24/2005	7	230.3	228	186	227	290	300	244	244	249	46.8	18.8	300
5/20/2005	8	269	270	176	164	226	157	229	176	190	34.6	18.2	229
2/23/2006	8	269	264	300	370	290	220	210	290	278	65.3	23.5	370
2/23/2006	11	356	348	240	190	195	280	170	195	215	44.4	20.7	280
2/23/2006	12	368	379	140	165	180	150	190	165	165	20.6	12.5	190
2/23/2006	15	472	478	170	140	205	135	190	170	168	30.5	18.2	205
2/23/2006	17	560	559	400	420	220	315	235	315	318	91.7	28.8	420
2/23/2006	18	586	586	370	250	275	280	305	280	296	45.7	15.5	370
2/23/2006	19	612	612	140	205	205	200	180	200	186	27.7	14.9	205
2/23/2006	22	668	661	134	243	145	133	106	134	152	52.8	34.7	243
2/23/2006	23	700	702	168	153	170	248	160	168	180	38.7	21.5	248
2/23/2006	25	773	775	107	142	120	163	117	120	130	22.5	17.4	163
2/23/2006	26	817	812	275	245	183	275	185	245	233	46.0	19.8	275
2/23/2006	27	882	883	390	278	240	210	260	260	276	68.8	24.9	390
2/23/2006	29	918	917	334	220	110	150	215	215	206	85.2	41.4	334
2/23/2006	30	959	961	330	380	320	520	425	380	395	81.5	20.6	520
								mean=	**213**	**218**	**44**	**20**	**276**
								s=	64.9	69.1	24.8	7.4	98.3
								Cv%=	30	32	57	38	36

Table 4: Bar Sediment Diameter using the Zig-Zag method

Date	Nearest	Particle measurements (B-Diameter in mm)																				Min	D16	D50	D84	Max	Mean	Stdev	Cv%
	Riffle	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(%)
5/20/2005	16	1	10	13	14	17	18	19	20	21	21	25	28	32	33	34	37	37	42	46	63	1	15	23	39	63	27	14.3	54
5/20/2005	42	3	6	12	14	15	17	19	20	23	24	25	25	26	28	34	36	41	59	66	70	3	14	25	45	70	28	18.5	66
5/20/2005	75	1	3	3	4	5	5	6	6	7	8	9	9	11	11	11	14	18	24	31	42	1	4	9	19	42	11	10.3	90
2/23/2006	89	11	16	20	20	25	30	35	37	37	39	40	45	48	60	62	63	70	85	87	140	11	22	40	73	140	49	30.6	63
5/20/2005	117	6	7	14	19	19	22	26	26	34	39	39	42	48	48	62	64	69	79	133	170	6	17	39	71	170	48	41.2	85
2/23/2006	128	14	15	15	16	18	19	24	30	33	35	37	38	40	40	45	50	55	59	60	70	14	16	36	55	70	36	17.0	48
5/20/2005	142	3	6	12	15	16	19	23	26	31	34	34	38	39	39	41	43	47	48	68	78	3	14	34	46	78	33	19.1	58
5/20/2005	174	6	7	15	18	19	19	29	32	38	38	40	40	47	52	56	58	59	71	73	79	6	17	39	63	79	40	21.9	55
2/23/2006	186	18	24	25	28	29	34	35	35	35	40	42	42	45	46	48	55	60	65	70	83	18	27	41	60	83	43	16.7	39
5/20/2005	225	2	5	7	12	14	14	16	19	20	21	23	27	27	29	32	49	59	60	66	83	2	11	22	56	83	29	22.4	77
5/20/2005	244	3	4	7	9	9	9	9	11	11	11	12	13	14	15	22	25	28	29	50	84	3	8	12	27	84	19	18.9	101
5/20/2005	263	1	5	6	7	8	8	11	14	16	17	17	19	22	22	23	27	30	32	44	46	1	7	17	30	46	19	12.4	66
2/23/2006	264	8	12	15	25	28	34	40	56	60	60	64	70	70	75	90	100	105	110	110	125	8	23	62	105	125	63	35.8	57
5/20/2005	287	9	9	10	10	11	13	14	15	24	24	26	26	26	36	43	44	47	51	58	67	9	10	25	47	67	28	18.0	64
2/23/2006	348	6	10	12	12	15	15	15	19	20	20	20	24	24	25	25	30	30	35	40	55	6	13	20	32	55	23	11.5	51
2/23/2006	379	3	4	9	10	10	12	12	14	14	15	19	19	20	20	29	29	34	40	40	50	3	10	17	34	50	20	12.9	64
2/23/2006	478	10	14	18	20	23	25	28	29	32	37	39	41	43	50	51	63	65	77	80	85	10	20	38	68	85	42	22.5	54
2/23/2006	559	5	10	11	13	14	15	17	18	20	24	25	26	26	27	29	42	50	54	58	94	5	13	25	49	94	29	21.3	74
2/23/2006	586	6	7	7	8	11	15	21	24	25	28	29	35	39	40	40	42	58	70	74	78	6	9	29	57	78	33	22.7	69
2/23/2006	612	12	15	15	15	18	19	20	20	21	22	22	23	23	24	37	43	48	50	60	72	12	16	22	47	72	29	16.8	58
2/24/2006	661	10	12	13	15	16	16	21	22	22	23	23	23	25	27	30	31	32	32	33	38	10	15	23	32	38	23	7.9	34
2/24/2006	702	8	10	11	15	16	17	18	22	23	27	27	33	36	43	53	56	74	78	98	132	8	14	27	69	132	40	33.1	83
2/24/2006	775	4	4	5	7	10	11	12	16	17	18	19	23	24	27	32	38	43	44	53	55	4	7	19	42	55	23	16.1	70
2/24/2006	812	14	21	25	25	26	28	30	30	38	49	66	72	73	73	75	82	87	115	115	125	14	25	58	95	125	58	34.7	59
2/24/2006	883	5	7	10	10	12	15	18	22	32	38	42	48	53	59	70	76	83	95	101	185	5	11	40	85	185	49	44.2	90
2/24/2006	917	8	8	9	9	10	11	14	17	17	17	19	19	21	23	30	38	38	48	65	82	8	9	18	41	82	25	20.1	80
2/24/2006	961	8	9	10	13	14	15	16	21	21	24	27	33	48	56	58	62	78	82	108	134	8	12	26	74	134	42	35.8	86
																			mean=			**7**	**14**	**29**	**54**	**88**	**34**	**22**	**66**
																			s=			4.4	5.7	12.7	21.1	38.2	12.6	9.7	16.2
																			Cv%=			64	41	44	39	43	38	44	24

Table 5: Hydraulic Data for each Cross-section

Date	CS	Riffle #	Bankfull Channel				Total Channel			
			Mean v m/s	Discharge m3/s	Shear Stress Lbs/ft2	Critical Size mm	Mean v m/s	Discharge m3/s	Shear Stress Lbs/ft2	Critical Size mm
May-05	41	2	0.96	5.45	0.29	15	1.29	19.15	0.45	28
May-05	89	3	0.99	4.67	0.22	12	1.71	22.40	0.50	30
May-05	128	4	1.07	7.16	0.45	28	1.45	25.92	0.68	41
May-05	164	5	0.72	3.69	0.17	10	1.36	23.55	0.43	23
May-05	186	6	0.93	4.49	0.37	19	1.61	23.22	0.79	48
May-05	229	7	0.70	3.90	0.17	10	1.22	22.23	0.38	18
May-05	269	8	1.07	5.99	0.31	16	1.98	36.91	0.76	47
Feb-06	128	4	0.76	4.62	0.20	11	1.17	23.11	0.37	17
Feb-06	186	6	0.88	3.02	0.31	15	1.96	37.55	0.94	75
Feb-06	264	8	0.78	5.20	0.34	18	1.53	34.78	0.83	60
Feb-06	348	11	0.91	5.20	0.21	12	1.51	30.38	0.45	28
Feb-06	379	12	1.53	8.49	0.67	42	2.93	60.59	1.75	200
Feb-06	478	15	0.75	3.31	0.27	14	1.41	25.11	0.64	38
Feb-06	559	17	0.75	4.65	0.17	9	1.28	22.57	0.36	20
Feb-06	586	18	1.14	8.89	0.39	20	1.70	31.38	0.69	42
Feb-06	612	19	1.32	11.49	0.49	28	1.96	40.99	0.88	62
Feb-06	661	22	0.92	5.44	0.22	13	1.74	42.06	0.58	35
Feb-06	702	23	0.86	4.75	0.34	17	1.66	34.78	0.83	55
Feb-06	775	25	0.86	4.58	0.24	13	1.42	24.15	0.49	30
Feb-06	812	26	0.70	3.21	0.29	15	1.28	18.88	0.64	39
Feb-06	884	27	1.37	12.61	0.77	45	1.90	33.72	1.21	120
Feb-06	917	29	1.76	12.70	0.87	60	2.64	47.16	1.57	180
Feb-06	961	30	1.38	7.30	0.73	43	2.48	44.12	1.67	190
	Mean=		**1.01**	**6.12**	**0.37**	**21.09**	**1.70**	**31.51**	**0.78**	**62**
	s=		0.29	2.88	0.20	13.66	0.46	10.52	0.41	55
	Cv%=		29	47	55	65	27	33	53	89

Table 6. GPS Positions for Selected Locations

UTM Easting	UTM Northing	Description	Relative Elevation (m)	Tape Dist. (m)	Notes
4124427.03617512	477926.43419827	End of spillway	na	-64	Start of survey
4124454.56158479	477869.90608696	Benchmark 1	na	0	Support for USGS gage at FR 171 bridge
4124459.57972461	477772.41299604	Tape line stake	na	100	Stake on north bank
4124461.51361210	477716.29287139	Benchmark 3	8.925	166	Pin on top of large rock in channel
4124476.48372006	477682.08653840	Tape line stake	na	200	Stake on north bank
4124495.03299881	477644.08524138	Benchmark 4	8.885	243.5	Pin on top of large rock in channel
4124506.98885300	477624.13998738	Tape line stake	na	300	Stake on north bank
4124532.05042038	477599.47379891	Benchmark 5	8.72	308.5	Pin on tree root on left bank looking downstream
4124598.85982751	477541.14987730	Tape line stake	na	400	Stake on north bank
4124606.62215506	477531.65790086	Benchmark 6	8.09	407	Pin on tree root on right bank looking downstream
4124630.70313311	477428.98685813	Tape line stake	na	500	Stake on north bank
4124686.17353668	477383.00023749	Benchmark 8	6.94	582	Pin on tree root on left bank looking downstream
4124698.68487553	477377.80196433	Tape line stake	na	600	Stake on north bank
4124744.65684745	477323.22913583	Benchmark 9	6.64	673	Pipe on left bank looking downstream
4124771.47214894	477310.45978354	Tape line stake	na	700	Stake on north bank
4124833.68466209	477192.67532454	Benchmark 10	6.28	858	Rock in tree on left bank looking downstream
4124840.73016462	477227.88956044	Tape line stake	na	800	Stake on north bank
4124869.49360712	477155.19894259	Tape line stake	na	900	Stake on north bank
4124893.39993084	477118.16563469	Benchmark 11	6.02	940	Rock in tree root on left bank looking downstream
4124932.75694253	477089.26059568	Tape line stake	na	1000	Stake on north bank
4124505.74573487	477868.61359481	City benchmark	na	na	City benchmark 451 north of FR 171

Figure 1: Longitudinal Survey

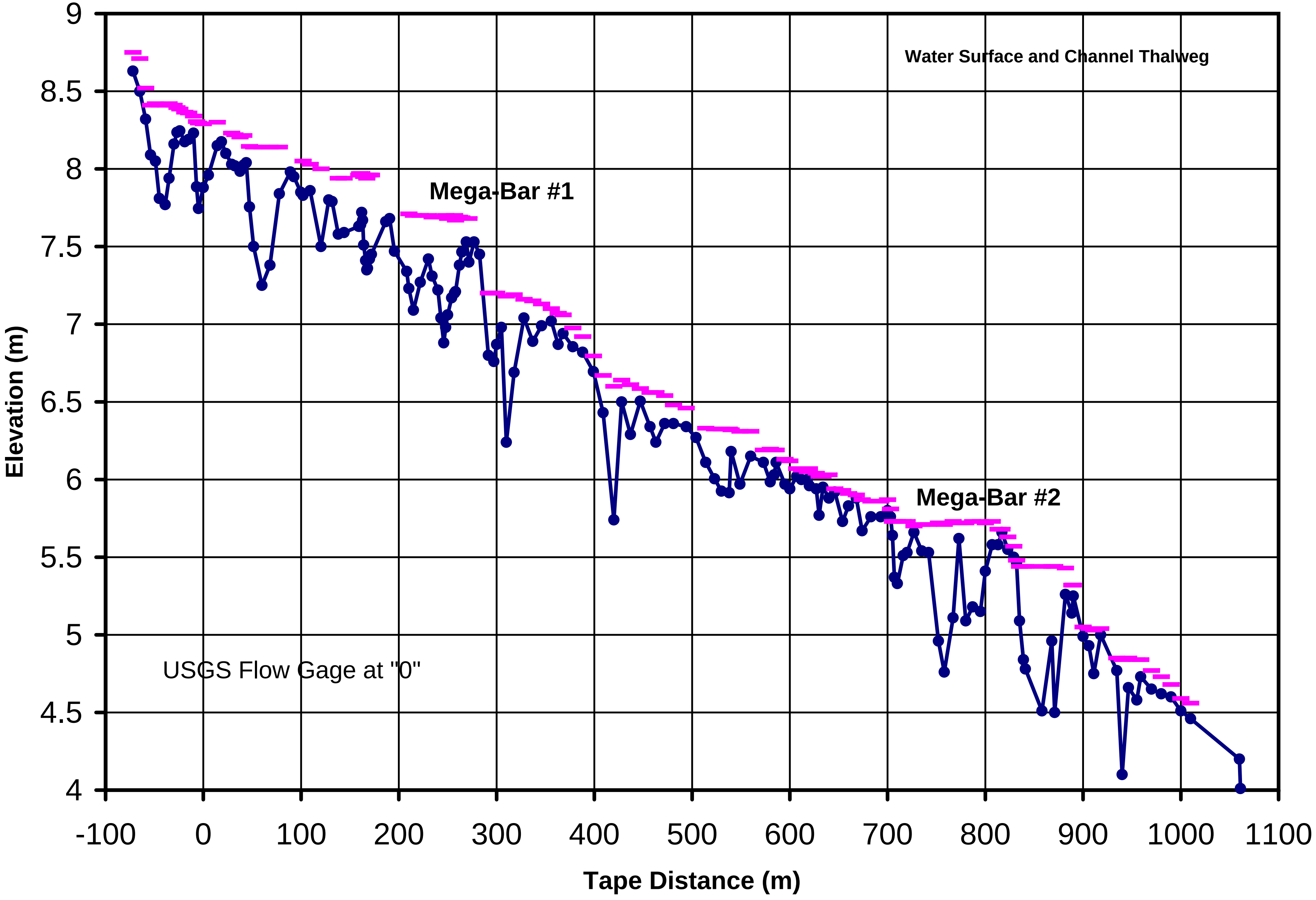


Figure 2: Channel, Floodplain, and Terrace Slope Trends

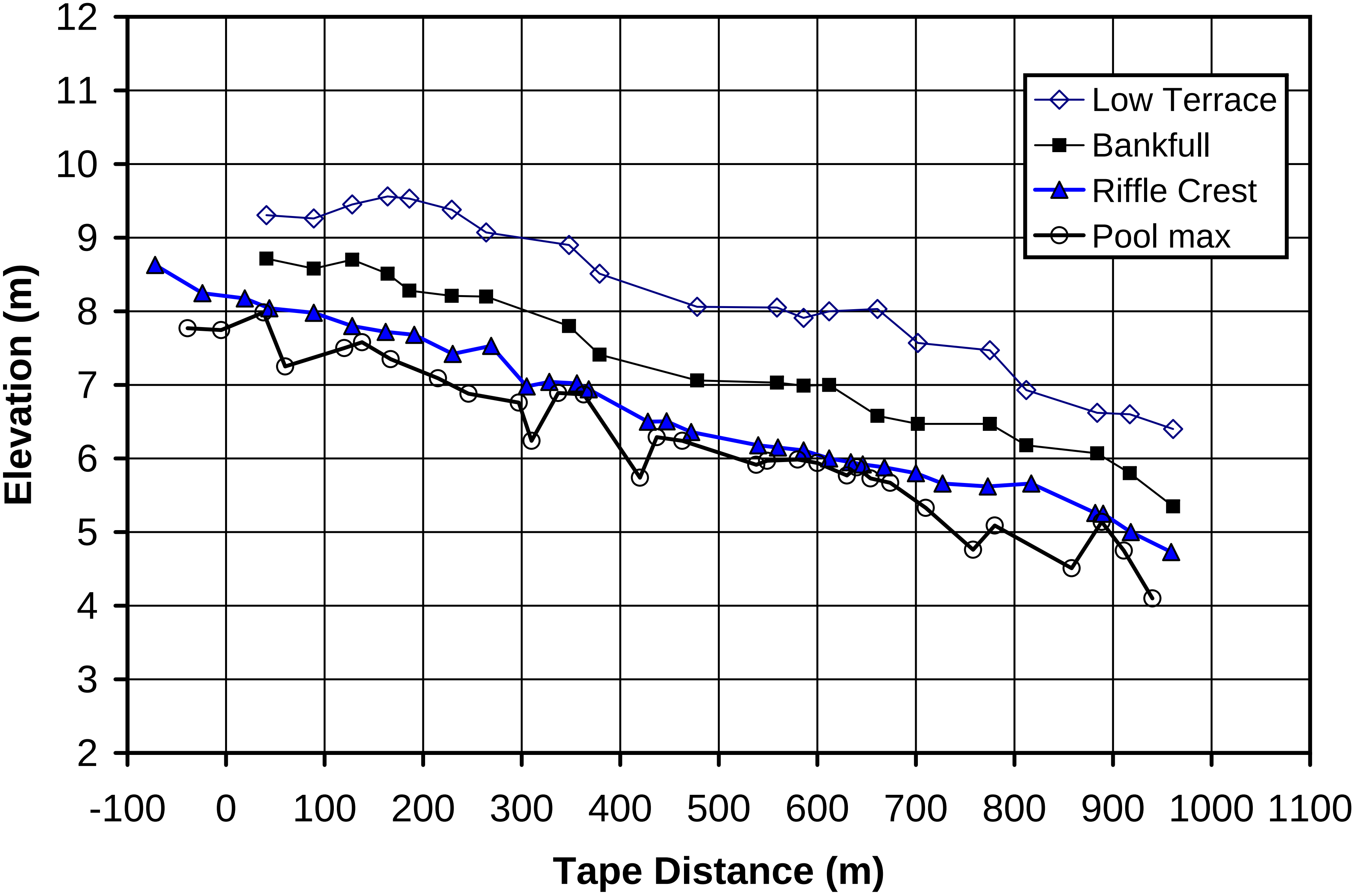


Figure 3: Sub-reach Slope Classification

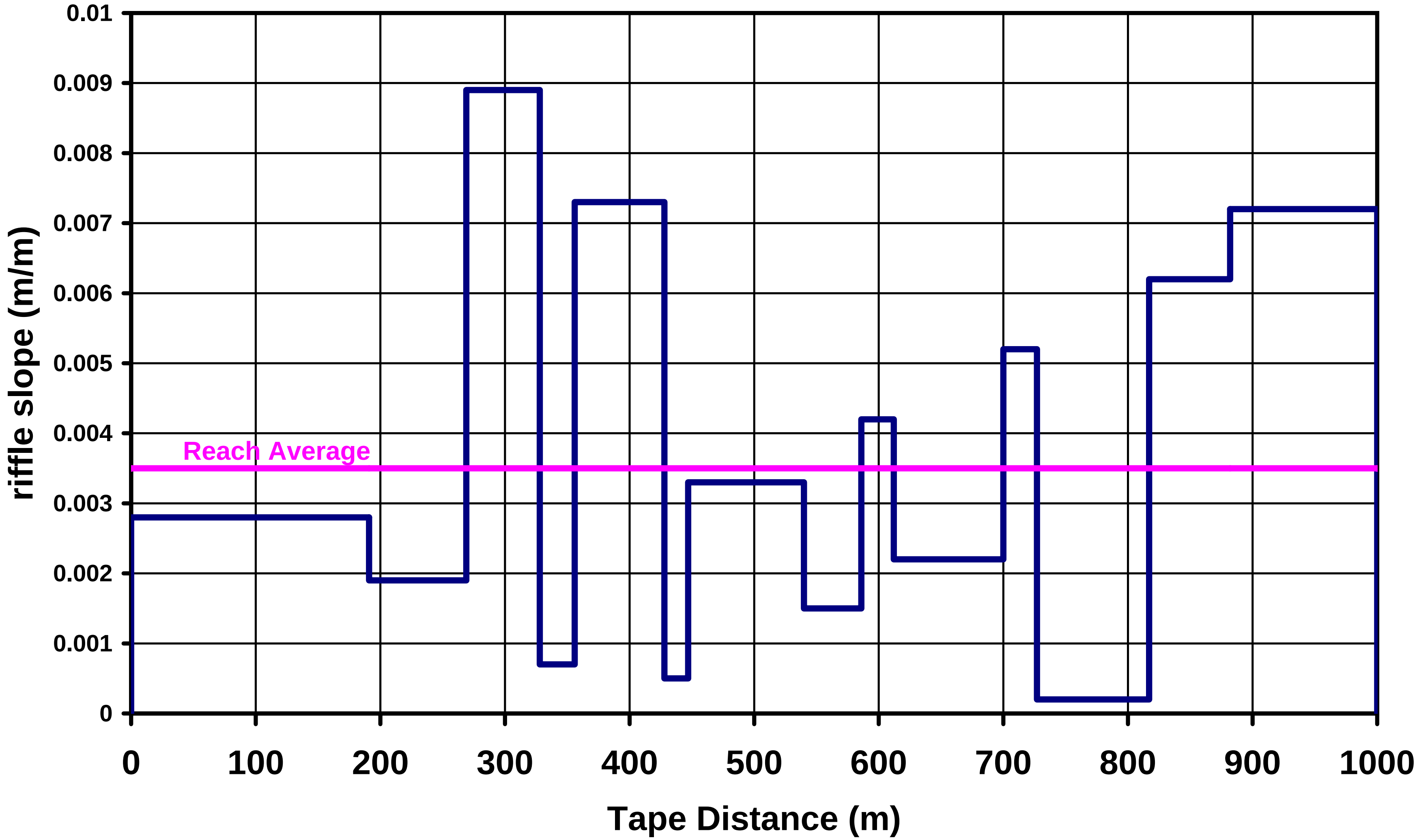
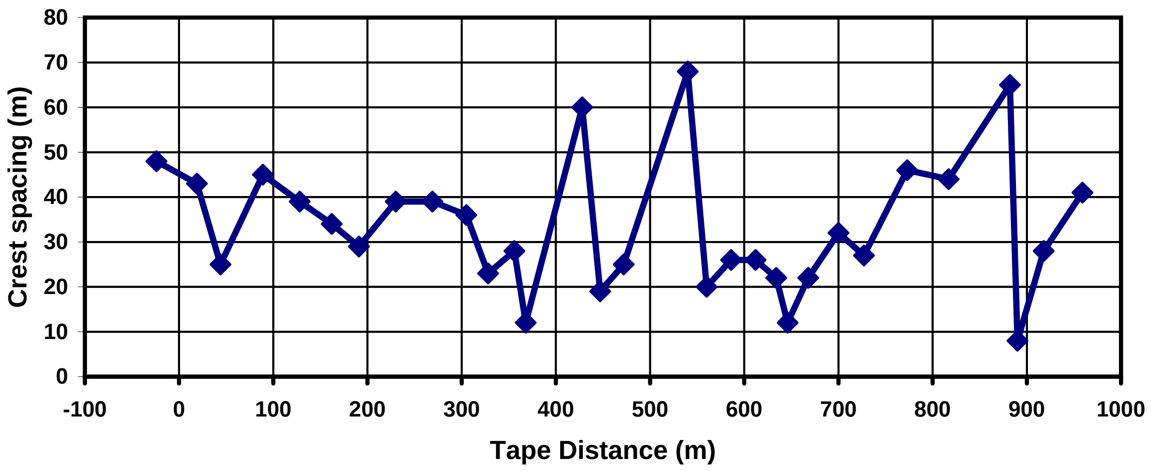


Figure 4: Riffle Spacing and Pool Depth

B. Riffle Spacing



A. Residual Pool Depth

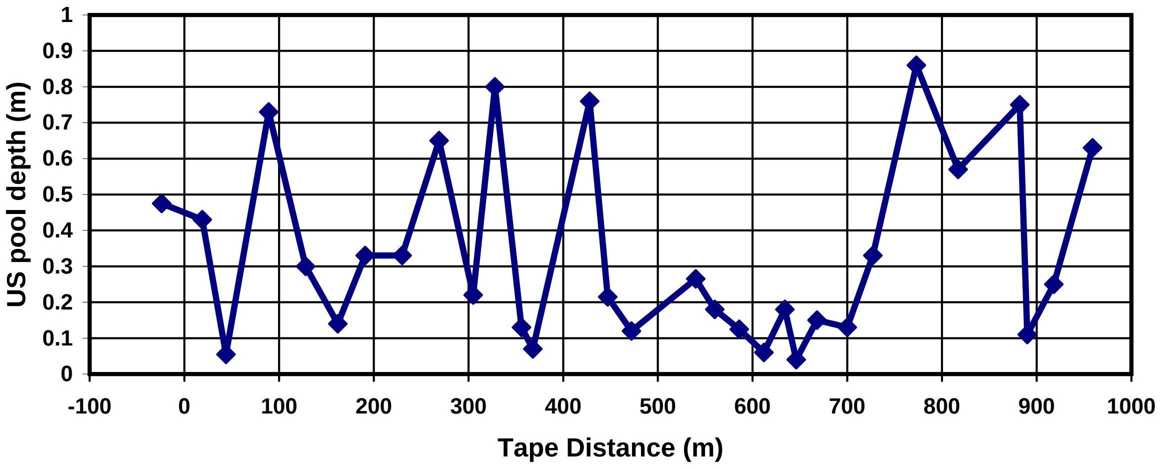


Figure 5: Channel Width and Depth

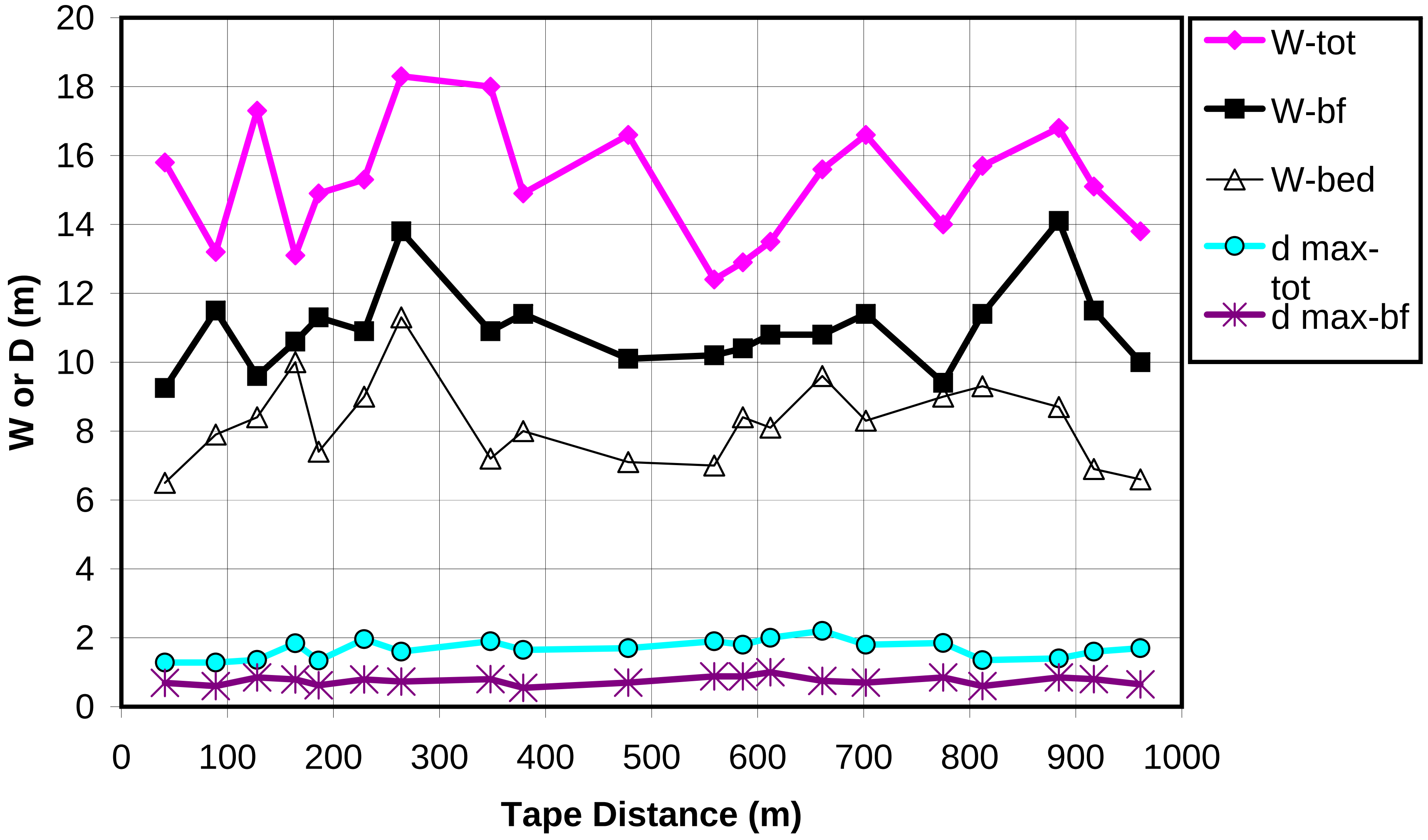


Figure 6: Cross-section Area

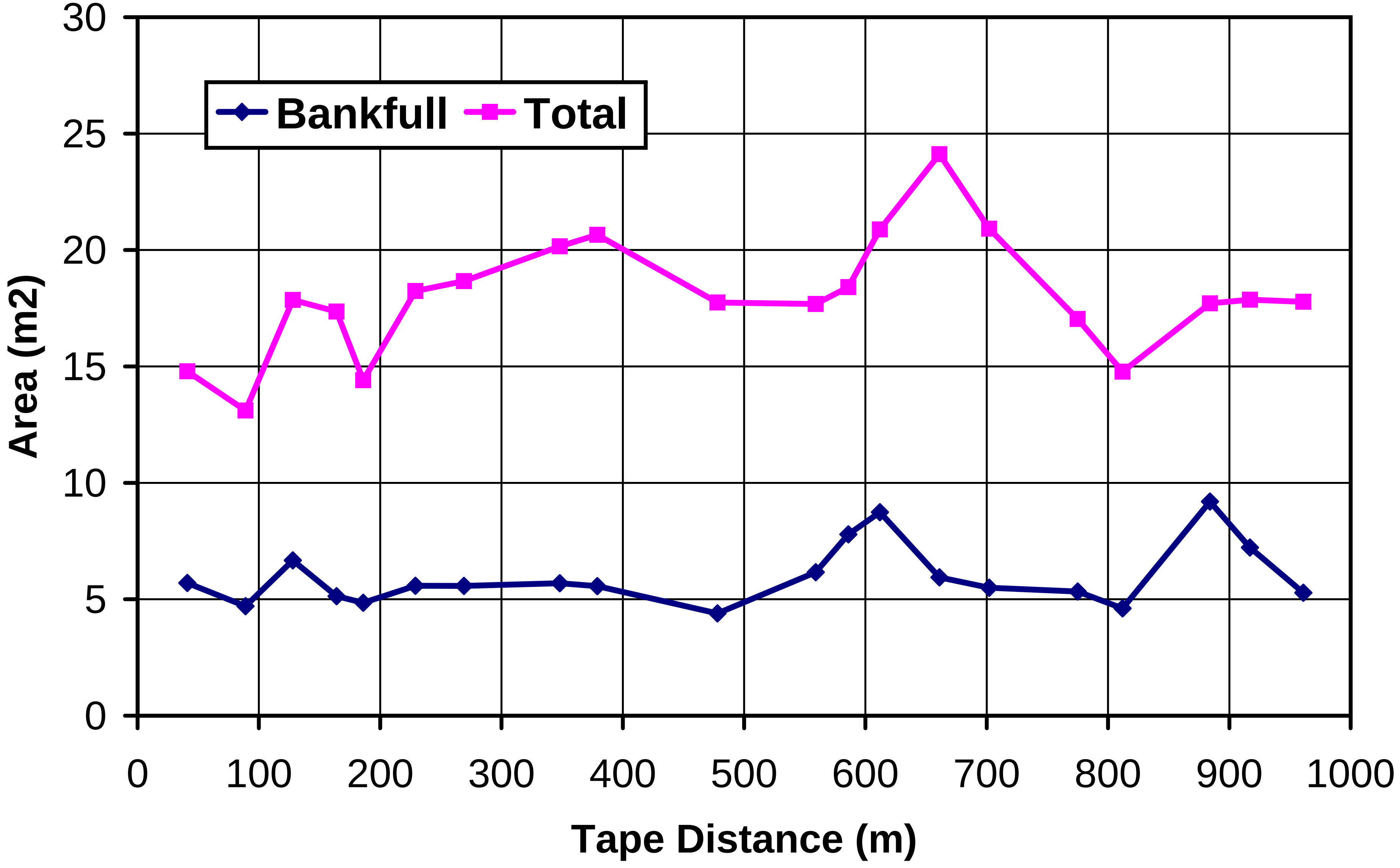
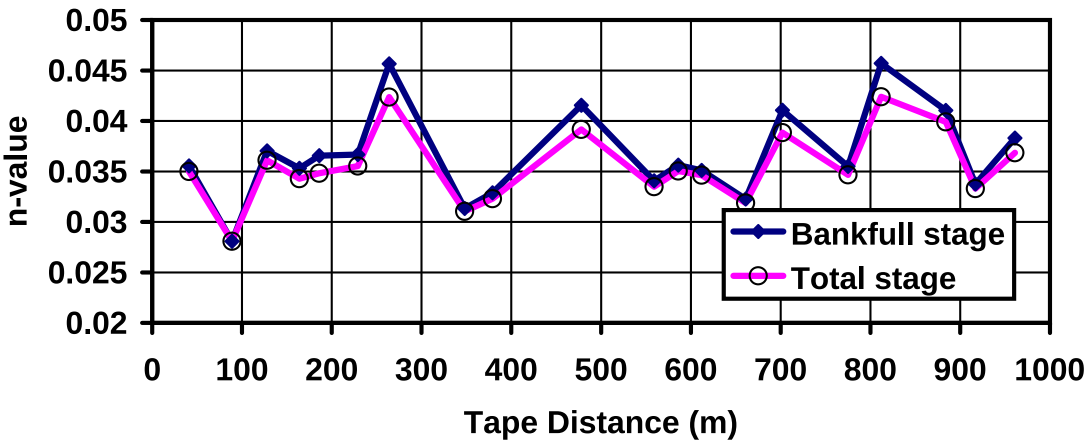


Figure 7: Channel Roughness and Velocity

A. Channel Roughness (Manning n)



B. Velocity

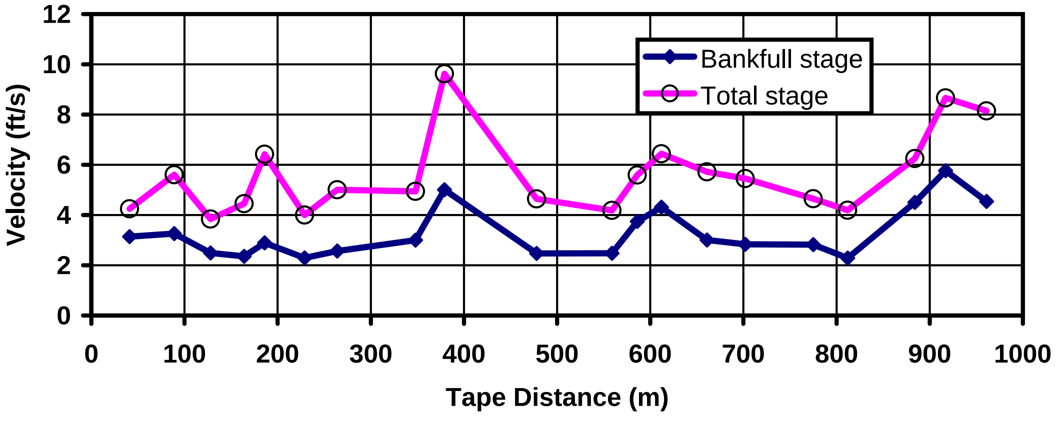


Figure 8: Bed Material Size Trends

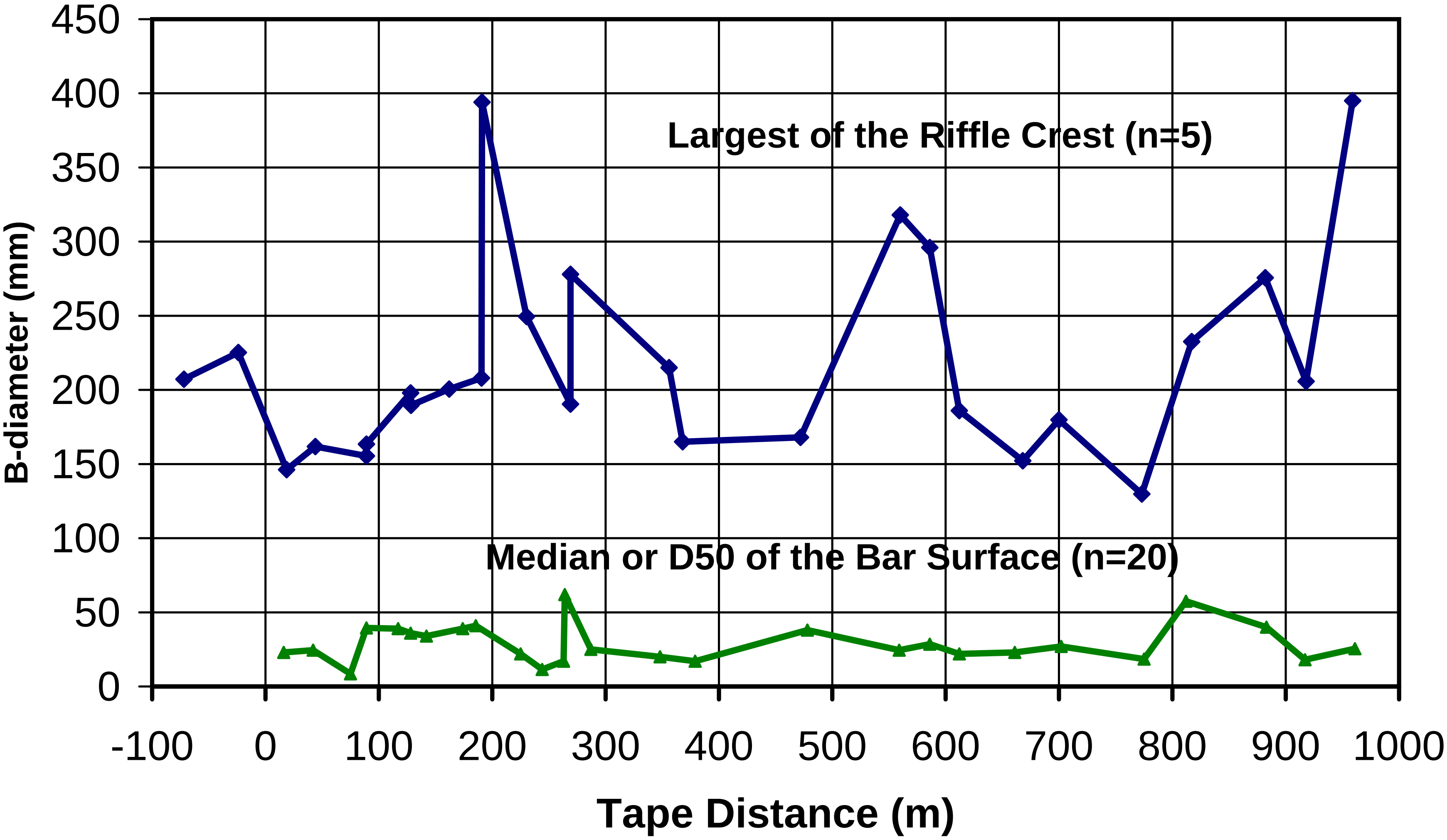
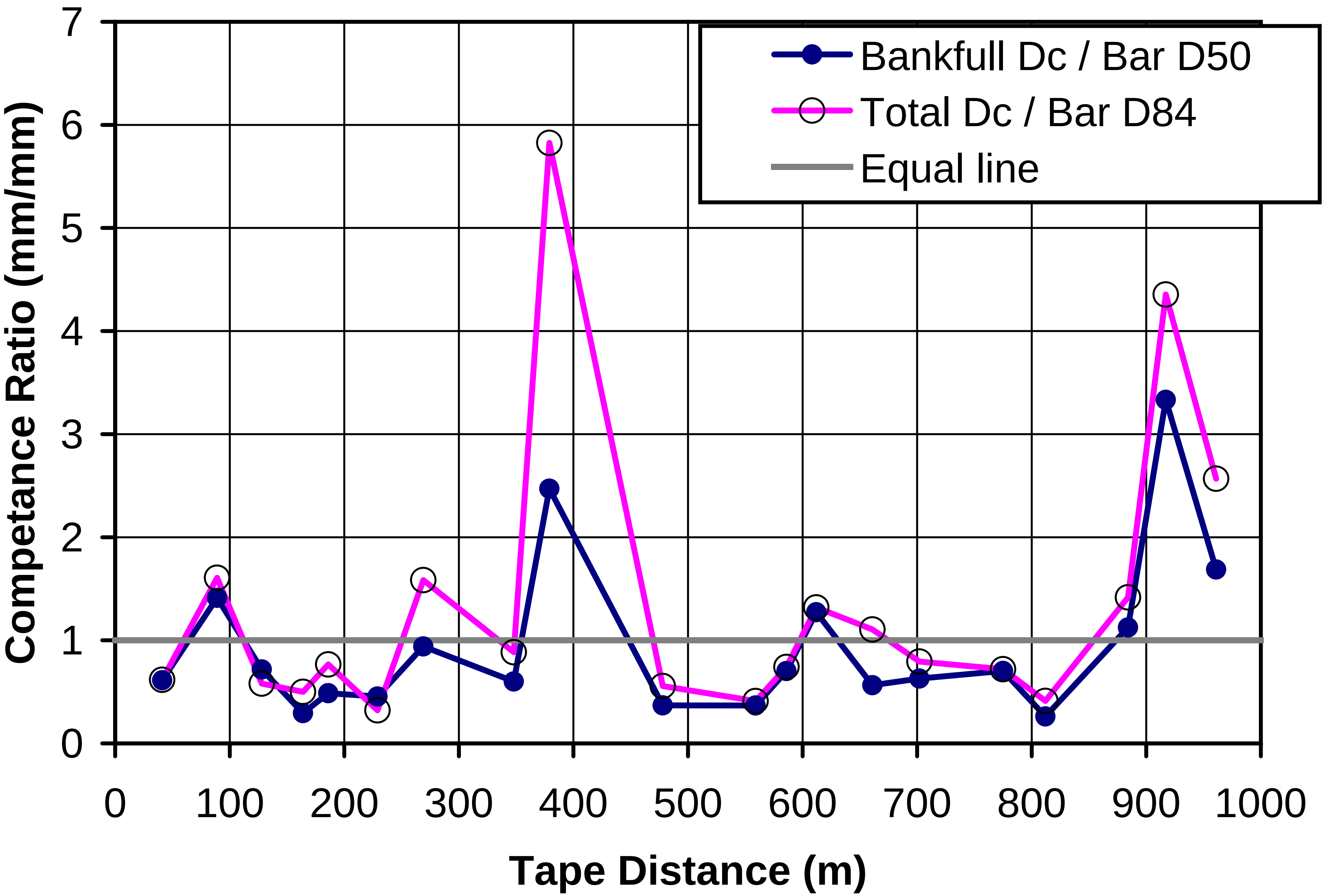
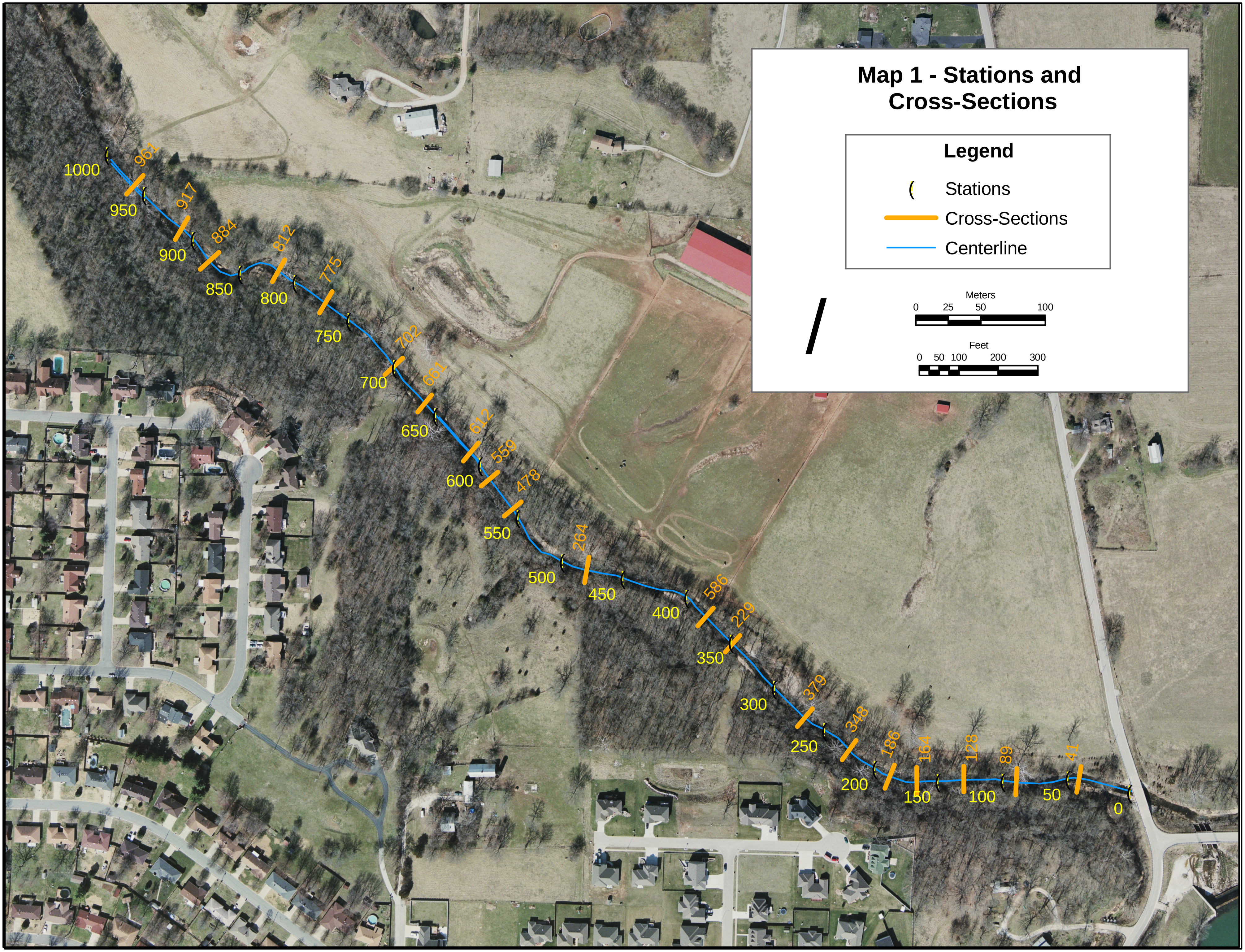


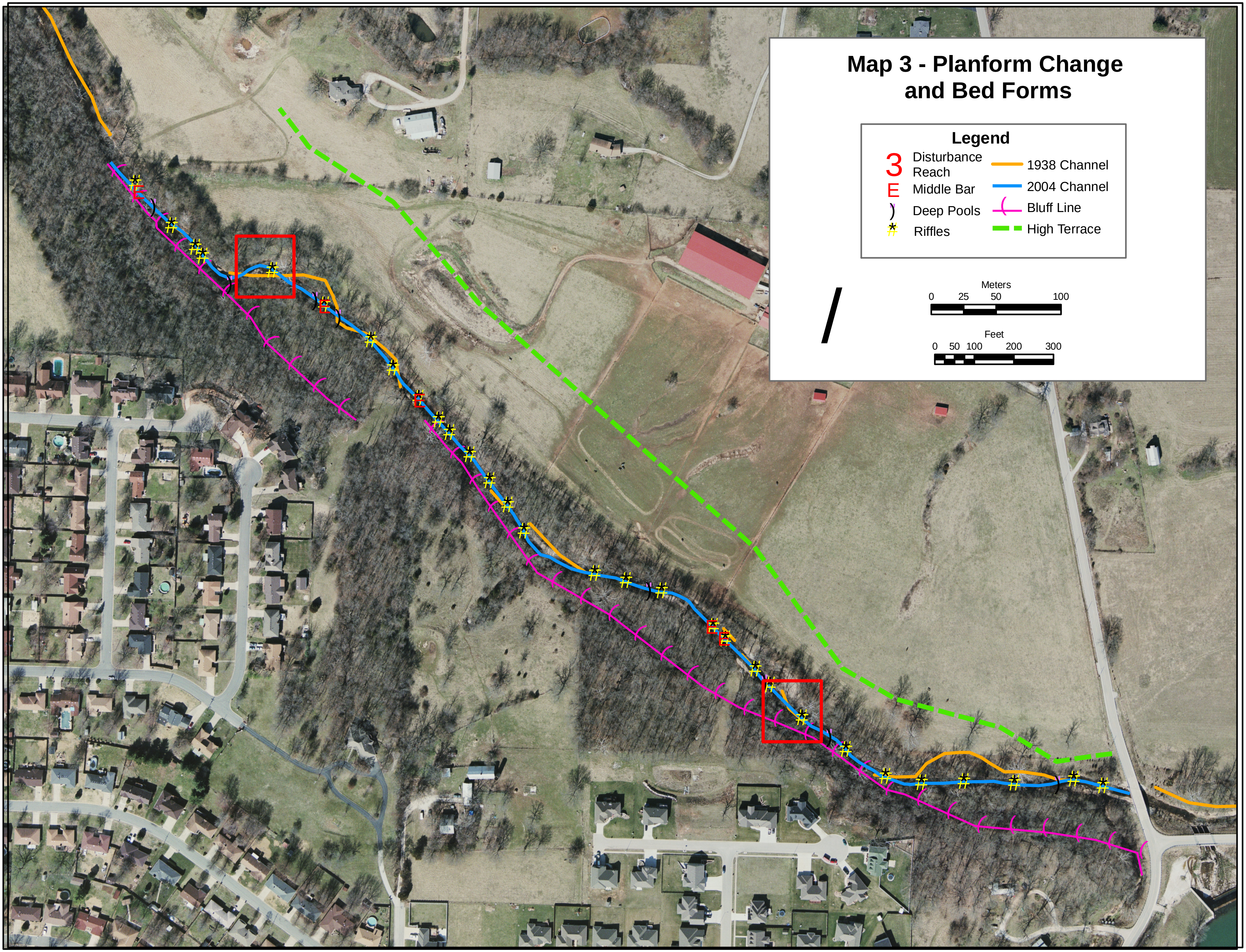
Figure 9: Flow Competence



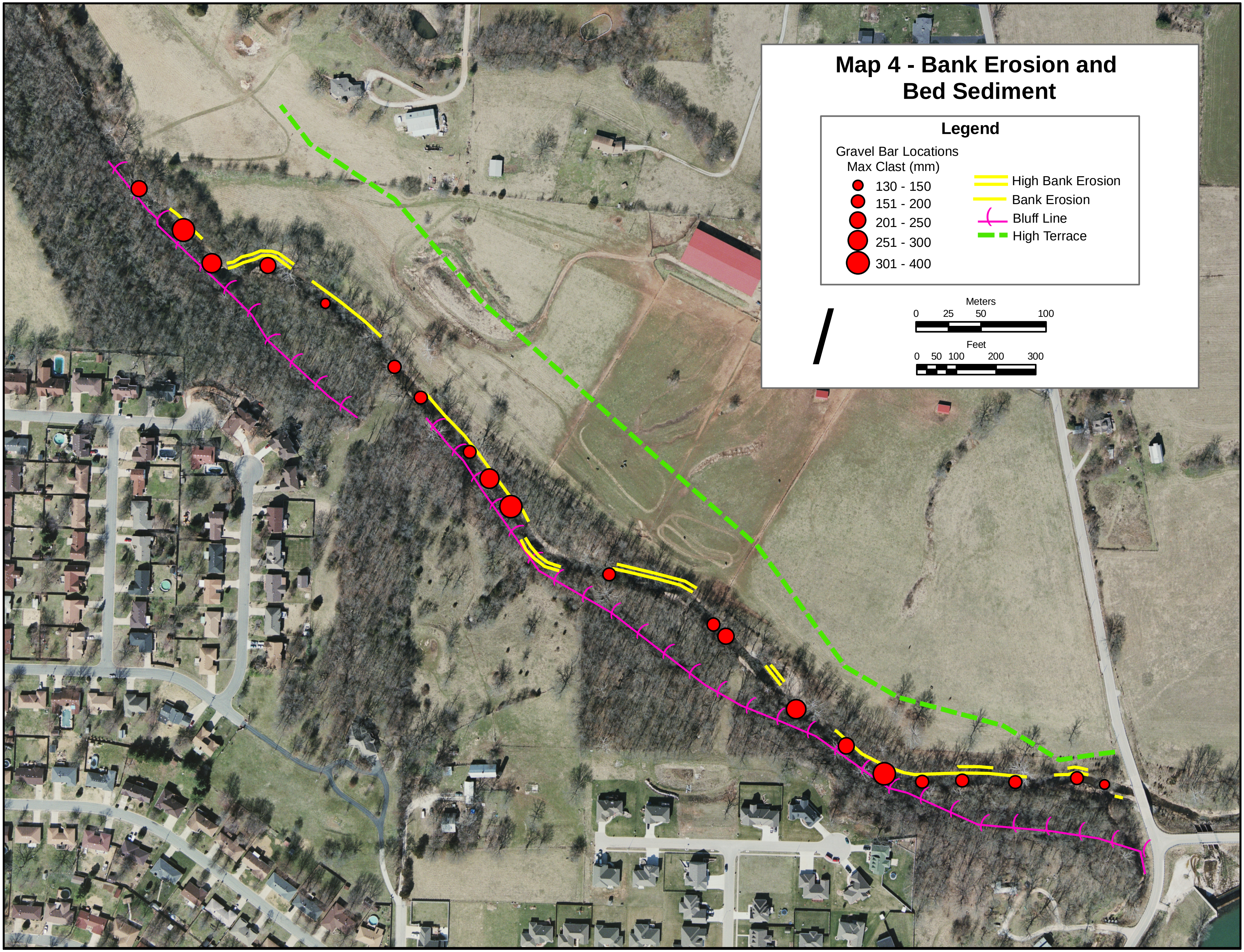
Map 1 - Stations and Cross-Sections



Map 2 Historical Air Photo Comparison



Map 3 - Planform Change and Bed Forms



Map 4 - Bank Erosion and Bed Sediment

Picture 1. Gravel Bar at Grandview Tributary DS of Farm Road 171 bridge (0 m)

Picture 2. Cutbank at 50 m

Picture 3. Flood debris jam at high bank level (100 m)

Picture 4. North bank vegetation Spring 2005 (150 m)

Picture 5. Alluvial fan on south bank (150 m)

Picture 6. Colluvial block in pool at 160 m looking upstream

Picture 7. Exposed roots with bark (170 m)

Picture 8. Riffle and exposed pipe at 180 m looking upstream

Picture 9. Riffle at disturbance reach looking downstream (280 m)

Picture 10. Pool at disturbance reach looking downstream (280 m)


Picture 11. Exposed roots along eroding bank looking downstream (400 m)


Picture 12. Alluvial fan tributary (south bank) and point bar (500 m)

Picture 13. Exposed root with bark cover (500 m)

Picture 14. Cutbank at 500 m


Picture 15. Bluff controlled reach looking downstream (550 m)


Picture 16. Exposed roots with bark along north bank looking downstream (600 m)

Picture 17. Mobile bar sediment at 600 m

Picture 18. Utility crossing and subdivision along south bank (670 m)

Picture 19. Paleomeander along south bank at 700 m

Picture 20. Mid channel bar looking downstream at 700 m

Picture 21. End of mid channel bar at 750 m

Picture 22. Upstream of disturbance reach riffle at 800 m looking downstream


Picture 23. Disturbance reach riffle looking downstream (800 m)


Picture 24. Disturbance reach pool looking downstream (800 m)

Picture 25. Disturbance reach cutbank (800 m)

Picture 26. Bedrock bluff and colluvium along south bank (860 m)

Picture 27. Bluff controlled riffle-pool sequence (880 m)

Picture 28. Steep bluff controlled reach looking downstream (950 m)

Picture 29. Large bed sediment at 960 m

Picture 30. Imbricated bed at 965 m