Swan River Channel Stability and Geomorphic Assessment

Technical Memo

Submitted to the MPCA
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Introduction

The East Swan River, one of two major tributaries to the Swan River, is currently impaired for turbidity. In addition, several stream segments in the Swan River watershed were found to have biotic impairments by the MPCA in 2012 (East Swan Creek, Little Swan Creek, and the Swan River). In these segments and in the watershed more generally, elevated suspended sediment was a suspected stressor to aquatic life. In order to more fully understand the sources and causes of suspended sediment and its impact on biota, a HUC10 geomorphic study was conducted by the South St. Louis SWCD and MPCA partners between June 2012 and November 2014. This technical memo presents the methods, results, and conclusions of that study. Building upon the results from the *East Swan River Geomorphic Study* (Anderson 2011), this report attempts to further characterize the Swan River watershed and identify the location and causes of stream instability.

This HUC10 geomorphic study had several main objectives: 1) identify reaches that contribute high sediment loads, 2) characterize and establish permanent study reaches to monitor sediment loss and evaluate channel stability over time, 3) locate areas of erosion and calculate erosion rates over time. This technical memo also includes results from a gage station bankfull calibration and culvert/crossing assessments, both of which were conducted within the Swan River watershed but were not part of the HUC10 geomorphic study. Not included in this report are land-use and land-cover statistics for the watershed. Those statistics can be found in the previously mentioned *East Swan River Geomorphic Study.*

1. Suspended Sediment (SS) Monitoring

Methods

The *East Swan River Geomorphic Study* (Anderson, 2011) cites bank and bluff erosion as a major contributor of sediment inputs to the system. However, the source of these inputs was still relatively unknown. Anecdotal evidence suggested that Dempsey and Penobscot Creeks were contributing much of the suspended sediment to the system. This TSS monitoring study was undertaken to confirm suspicions and target locations of instability.

Longitudinal water samples were collected from 21 sites throughout the Swan River watershed. The sites are shown in Figure 2. Sites were chosen strategically in order to pinpoint, as much as possible, the reaches that are sediment contributors. For example, to accurately represent the suspended sediment contributions from the West Swan and East Swan River watersheds, water was sampled at road crossings nearest the mouths of the systems. We broke into two teams in order to sample the streams in a time period of approximately 3 hours. This was done to facilitate comparison of results. Actual procedures of sampling and testing followed standard MPCA QA/QC protocols, and will not be discussed here.

Results

Suspended sediment values from three events are shown below. The first, collected on June 28, 2012, was meant to capture the June 19-20 flood event that devastated parts of Northeast Minnesota. The Swan River watershed received between 2.5 and 3.5 inches of precipitation during this event (Climatology, 2012). However, it seems that the sampling occurred later in the recession limb of the hydrograph, and flows had already receded dramatically (see Figure 1). The Swan River gage at Highway 5 recorded a flow of 450cfs on this date, which is approximately 33% of bankfull flow (see Section 3 for bankfull discharge analysis). This event therefore was characterized as a medium flow event. The second sampling occurred on July 27, 2012. Flows were very low, with the Swan River gage recording a flow of 150cfs (~10% bankfull). This was characterized as a near base flow event. The third sampling was on April 30, 2013 during a snowmelt event. The gage at Highway 5 recorded an estimated flow of 2000cfs, or approximately 150% bankfull flow.

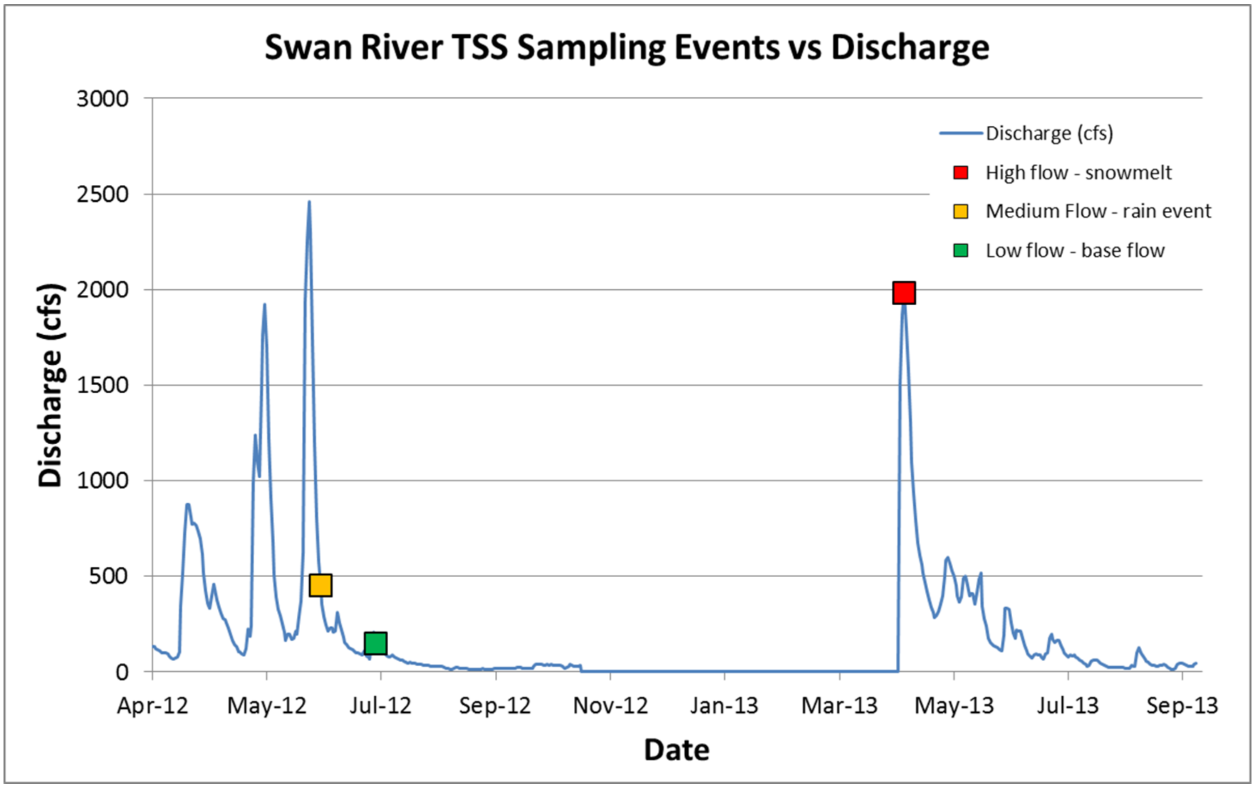


Figure 1: TSS sampling events plotted against 2012-2013 Swan River gage data

Suspended sediment (SS) values from June 28, 2012 vary considerably, from 0.4mg/L in the upper reaches of the West Swan River to 47.6mg/L in the middle reaches of the East Swan River. Generally, SS values were less than 5 mg/L in the small tributaries and the upper reaches of the larger tributaries. Two exceptions to this were Penobscot Creek (11.8mg/L) and Little Swan Creek (10.2mg/L). SS values are moderate in the lower reaches of Barber Creek, Dempsey Creek and West Swan River, ranging from 15mg/L to 21mg/L. Values in the main stem of the East Swan River and Swan River were generally around 40mg/L.

Suspended sediment values from July 27, 2012 were expectedly much lower. Generally, the SS results followed the same trend as the medium flow event, with the lowest values occurring in small tributaries and the upper reaches of the larger tributaries. The lower reach of the West Swan River had the highest SS value sampled (18.2mg/L).

The April 30, 2013 sampling provided proportionally similar results, although the values of suspended sediment were much higher. The Swan River sample from Oja Road contained a whopping 173 mg/L of sediment. Similar to the two other sampling efforts, the lowest concentrations of sediment were found in upper Dempsey and Barber Creeks, East Swan Creek, and the upper West Swan River. All TSS sampling results can be found in Appendix 1.

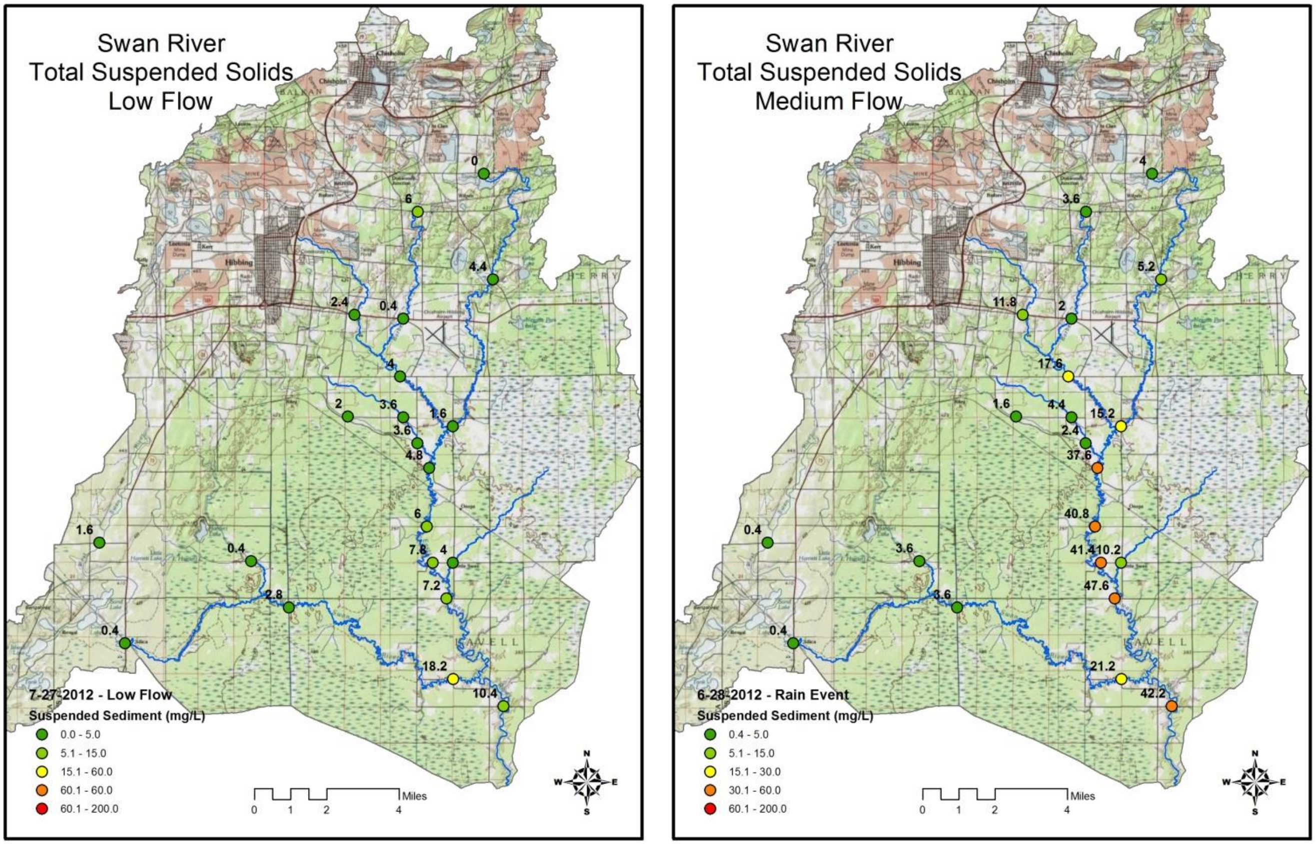


Figure 2: Results from low flow TSS sampling on July 27, 2012 and medium flow sampling on June 28, 2012.

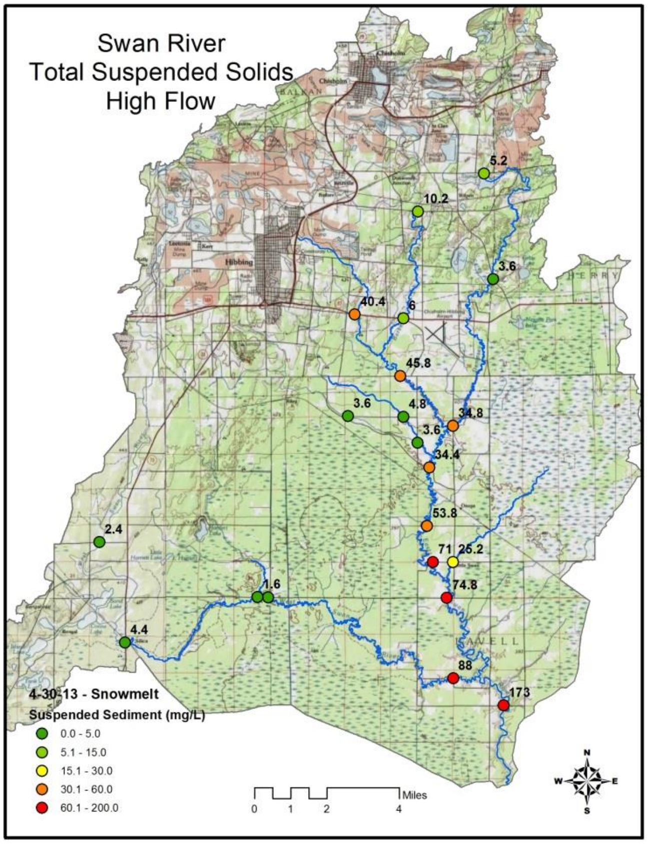


Figure 3: Results from high-flow TSS sampling on April 30, 2013.

Discussion

Analysis of synoptic suspended sediment data does not pinpoint specific bank or bluff instabilities, but it *can* identify problem areas where it appears that sediment is being sourced. By plotting the TSS value and drainage area of all the sites sampled, it is possible to determine which sub-watersheds are contributing disproportionate amounts of suspended sediment to the system. This was done for the April 30 snowmelt data and the results are shown in Figure 4.

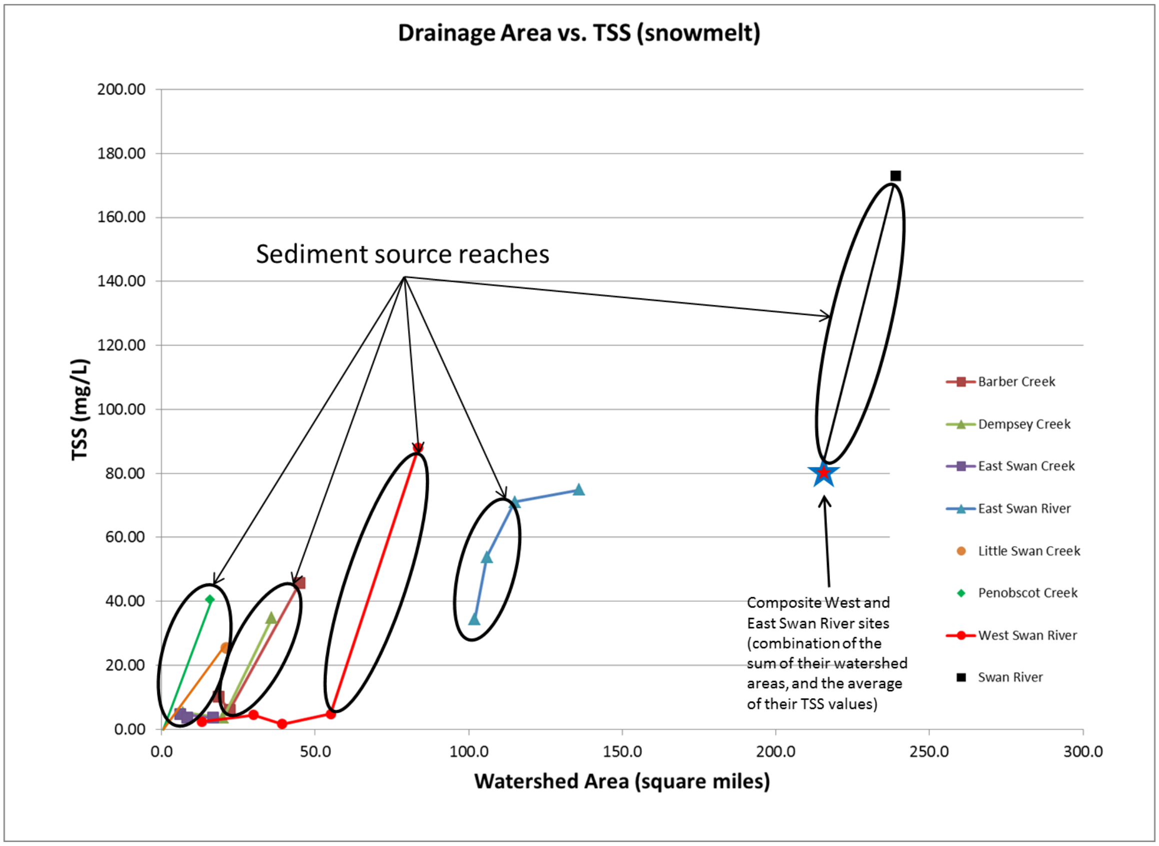


Figure 4: TSS vs. Drainage Area. High gradients suggest that sediment is being sourced in those reaches.

From Figure 4 t is immediately clear that there are high TSS contributions in several specific areas. The smaller watersheds of Penobscot and Little Swan Creek are contributing a large amount of suspended sediment relative to their drainage areas. Similarly, the reach of Barber Creek near its confluence with Penobscot Creek has a dramatic increase in suspended sediment. Just east of Barber Creek, there is a large increase in suspended sediment in Dempsey Creek downstream of Antonelli Road. The lower reaches of the West Swan River also appear to be contributing a good deal of suspended sediment; increasing from 1.6 mg/L at CR 442 to 88 mg/L at Hingely Road. Finally, almost the entire East Swan River (aside from the reach between Zim Road and CR 442) is contributing considerable sediment to the system. A spatial view of the possible sediment-source reaches in the watershed is shown in Figure 5, which assumes that the majority of the suspended sediment is coming from the channel bed and banks as opposed to overland sources.

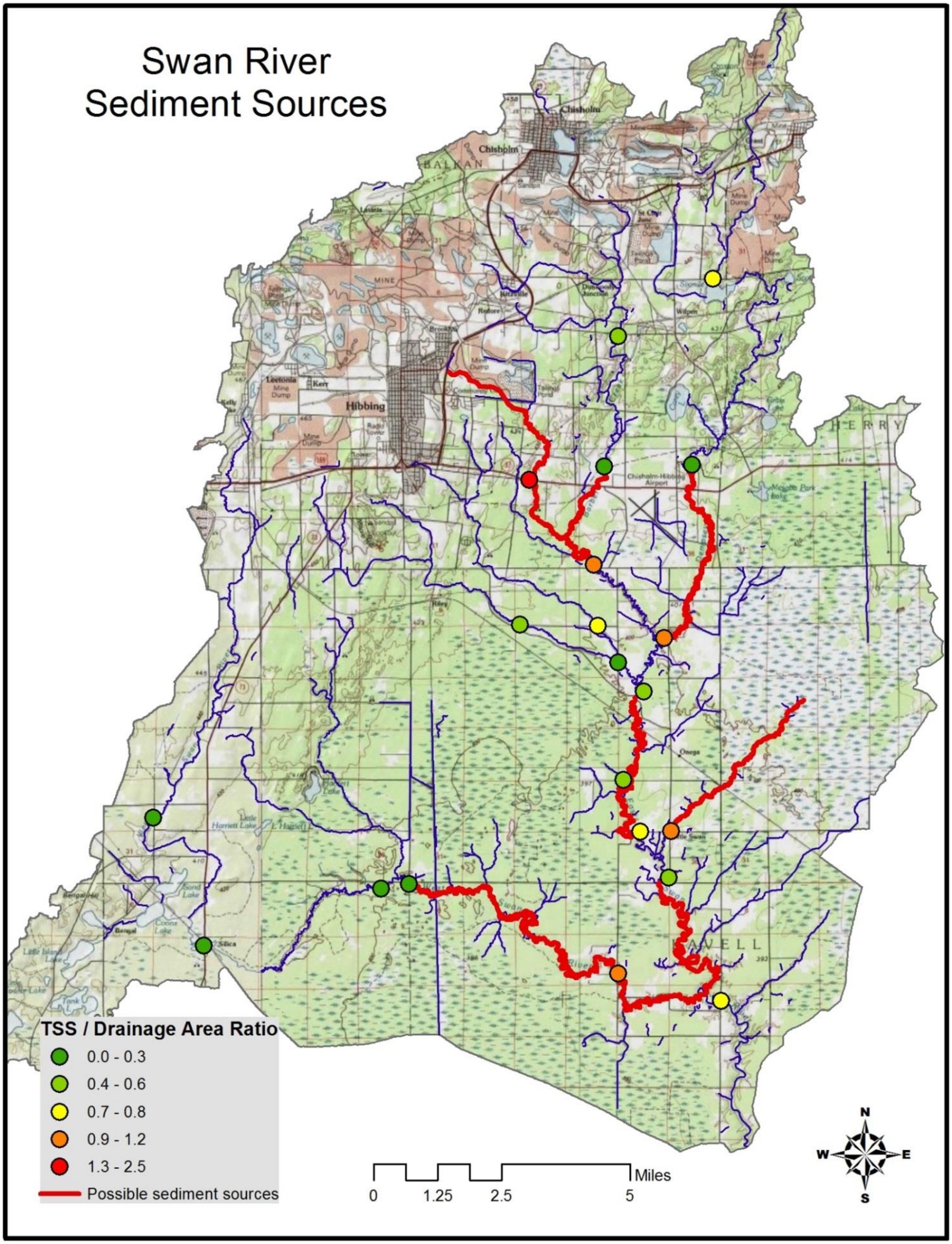


Figure 5: Spatial view of the possible sediment sources in the Swan River watershed (based on longitudinal TSS sampling during snowmelt)

2. Rapid Geomorphic Assessments

In order to paint a broad picture of the geomorphic characteristics of the Swan River watershed, methodology was established for conducting rapid geomorphic assessments. A number of sites were chosen by desktop reconnaissance. Criteria for choosing sites included accessibility, spatial distribution, and confluence proximity. These rapid assessments involved completing Pfankuch Channel Stability evaluations, surveying cross-sections and water surface slopes, and characterizing stream, valley and vegetation types. As with the TSS monitoring, a balance had to be struck between data collection and site inclusivity. The following is a brief discussion of the methods and results from these rapid geomorphic assessments. A complete list of all data collected is attached in Appendix 2.

Pfankuch Inventory

Pfankuch Stream Reach Inventory and Channel Stability Evaluation forms ((Pfankuch, 1975) were completed at 26 sites throughout the Swan River watershed. For each site, the upper banks, lower banks, and channel bottom were rated based on 15 characteristics. These include landform slope, mass wasting, debris jam potential, vegetative bank protection, channel capacity, bank rock content, obstructions, cutting, deposition, rock angularity, brightness, consolidation, bottom size distribution, scouring, and aquatic vegetation. Collectively these characteristics are used as an indicator of stream stability along with other metrics. Scoring is based on a quantitative system, where each characteristic is rated excellent, good fair, or poor, and given an associated score. Higher scores indicate higher instability.

Results from these Pfankuch assessments are shown in Figure 6 through Figure 8. Generally speaking, stream instability is increasing (Pfankuch scores increase) longitudinally down the watershed. An exception to this is the upper portion of Penobscot Creek which, due to the historic channelization of that reach, has very high instability scores.

The instability of most sites is manifested in very high lower bank and channel bottom scores. Commonly, these unstable reaches had continuous bank cutting (sometimes over 24” high), extensive deposits of fine particles, accelerated point bar development, low bank rock content, evidence of shifting channel substrate, and little to no aquatic vegetation. These characteristics are indicative of an incised system that is eroding its banks and depositing material on point bars. The extensive sediment deposits in the lower reaches of this watershed suggest that perhaps the incision process has ended and the channel is now widening, aggrading, and stabilizing within the incised system. Given the cohesive nature of the banks, however, this process may take decades and continue to contribute suspended sediment in the meantime.

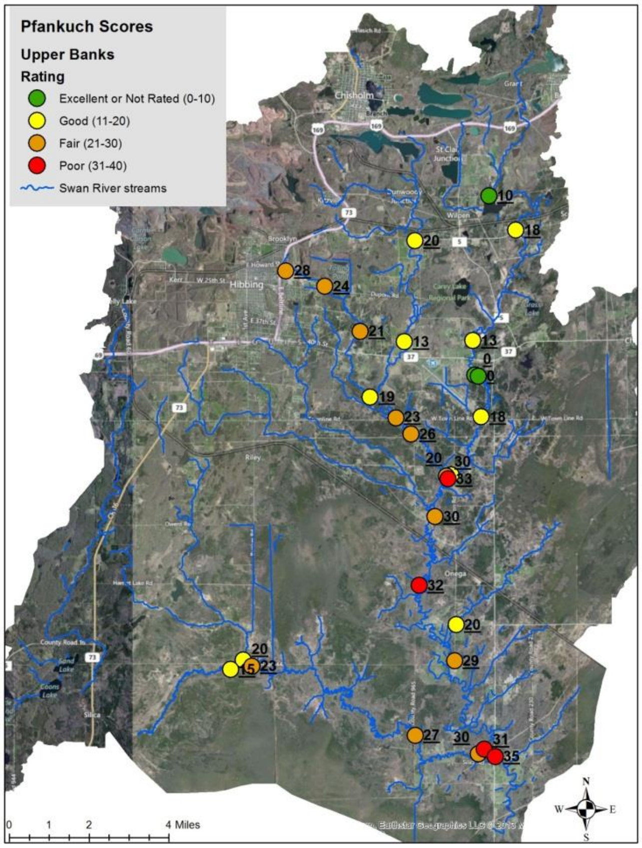


Figure 6: Pfankuch upper bank ratings.

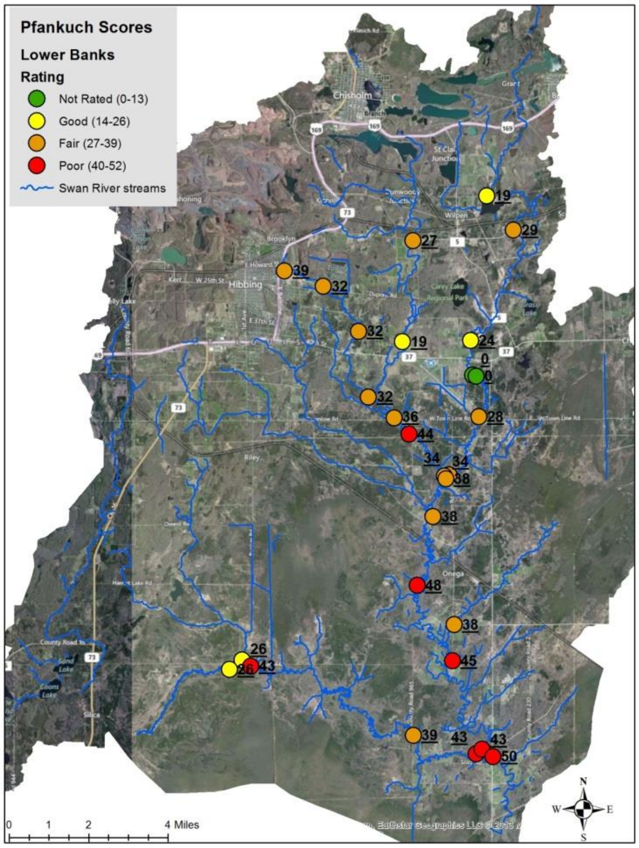


Figure 7: Pfankuch lower bank ratings.

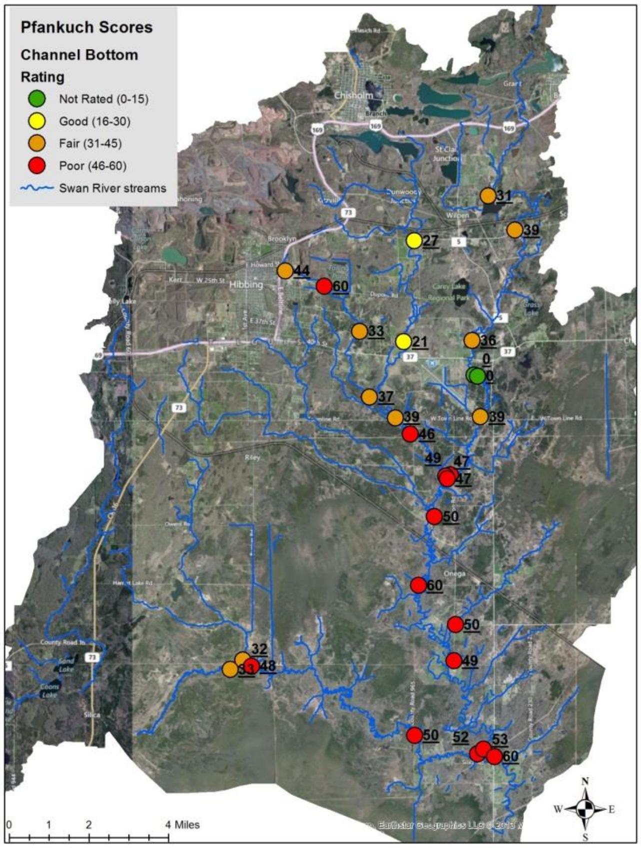


Figure 8: Pfankuch channel bottom ratings.

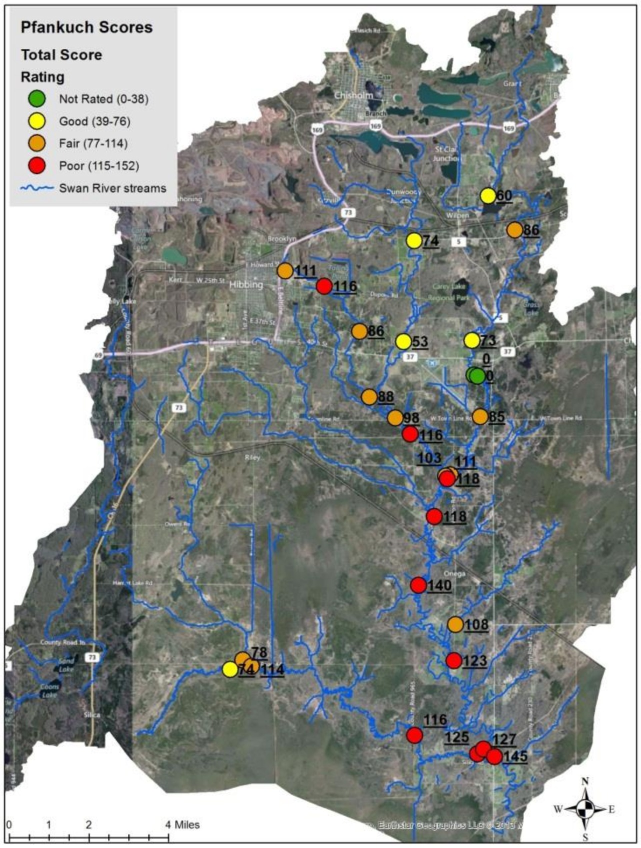


Figure 9: Pfankuch total score ratings.

Channel Cross sections

Cross-sections and water surface slopes were surveyed at 28 sites using a Trimble S3 Total Station and R10 survey-grade GPS. These sites were established as permanent study reaches, and all control points were tied-in to the NAD 83 UTM Feet, Zone 15N coordinate system with sub-inch horizontal and vertical errors. When sites were located at road crossings, the cross-section was surveyed at least 300 feet away from the road to minimize the influence of the crossing on the results of the survey. Cross-sections were chosen at the narrowest riffle available. Water surfaces were surveyed from head-of-riffle to head-of-riffle. Cross section data and graphs are included in Appendix 2a. Field reconnaissance reports for each site, detailing the overall reach condition and important findings, are included in Appendix 2b.

Swan River Mini Regional Curve

There was a high degree of incision and a lack of bankfull indicators in many of the rapid assessment sites. Thus, before any geomorphic analysis could be completed it was essential to derive a relationship between drainage area (DA) and bankfull parameters for just the Swan River watershed (i.e. a mini regional curve). USGS StreamStats was used to determine drainage area for survey sites. Bankfull dimensions were plotted for the sites that were not incised and that had reliable bankfull indicators and well-developed floodplains. The results for bankfull cross-sectional area, width, and mean depth are shown in Figure 10 and Figure 11. It is immediately apparent that there is a strong correlation between drainage area and bankfull area (R^2 of 0.98). The relationship between DA and bankfull width is not as strong (R^2 of 0.89), and even less so for DA and bankfull mean depth (R^2 of 0.55). This is most likely due to the wide variation of width and depth between different stream types.

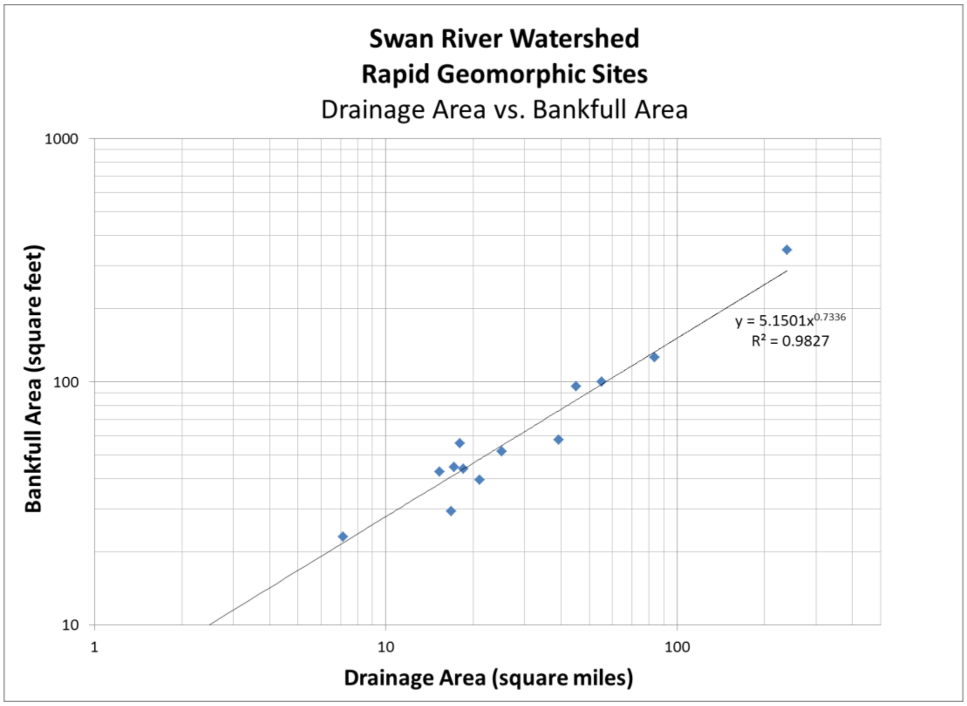


Figure 10: Drainage area vs. bankfull cross-sectional area at rapid assessment sites.

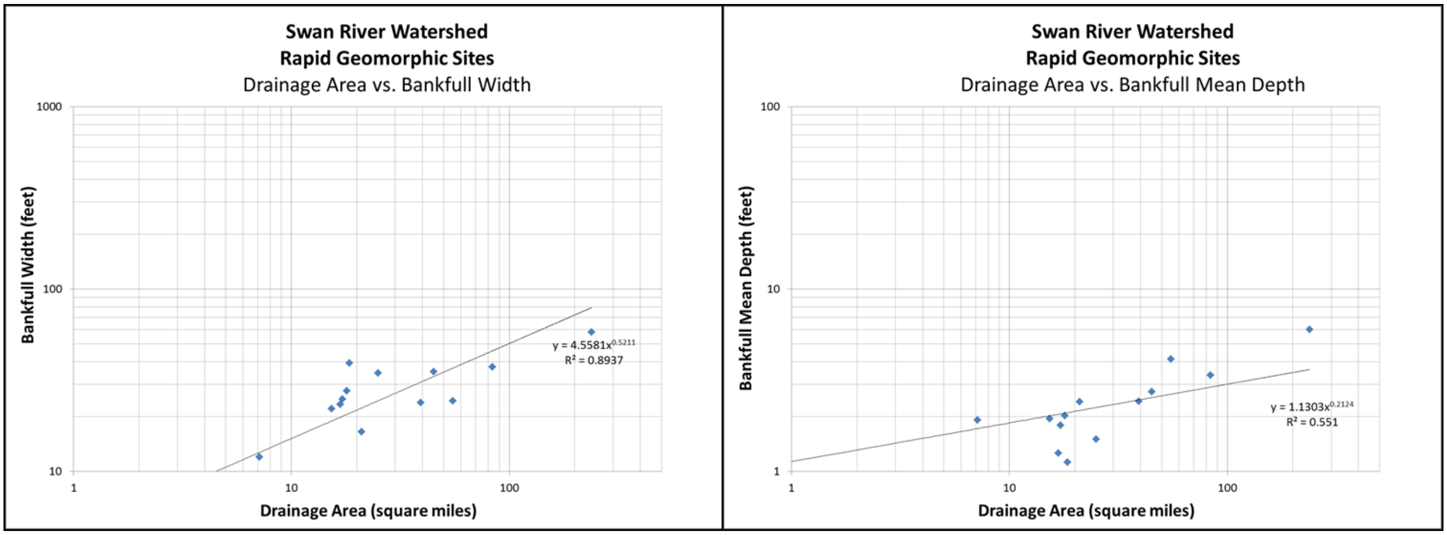


Figure 11: Drainage area vs. bankfull width and depth at rapid assessment sites

The empirically-derived relationship between DA and cross-sectional area in the Swan River watershed is $Y=5.1501X^{0.7336}$, where X is the drainage area and Y is bankfull cross-sectional area at any particular site. This formula was used to approximate the bankfull elevation at incised sites and to determine the degree of incision (i.e. incision ratio). The following several images are some examples of incised cross-sections where the mini regional curve was used to estimate the bankfull elevation. In almost all of them there was no bankfull bench, but there *was* a slope inflection that indicates that the stream is trying to recreate its floodplain at the lower elevation.

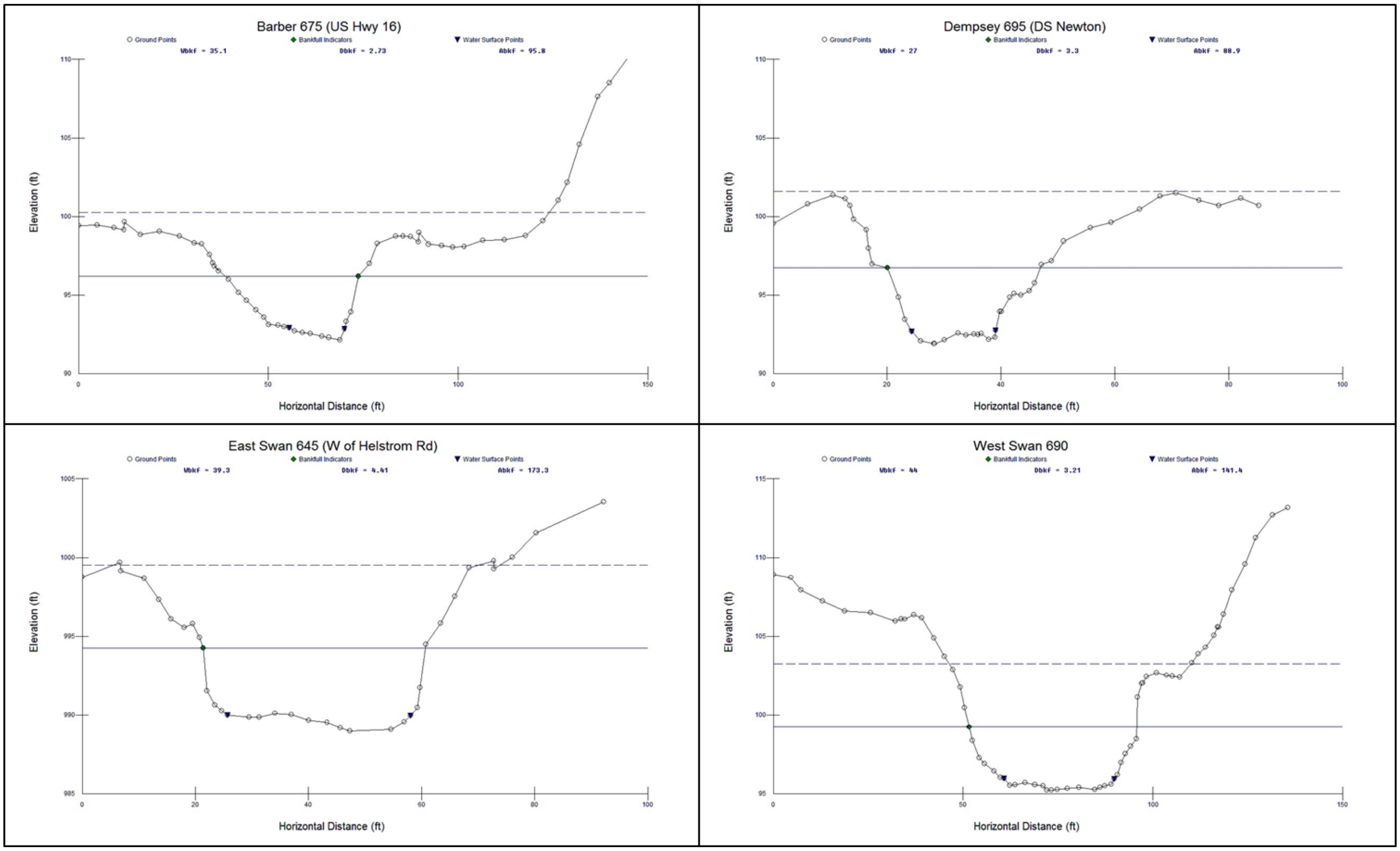


Figure 12: Examples of incised cross-sections where a mini regional curve was needed to approximate bankfull elevation

Incision, Entrenchment, and Width/Depth Ratios

A RiverMorph analysis (Appendix 2a) was conducted for all 28 surveys, which revealed the degree of incision and entrenchment for each reach. The results are shown in Figure 13.

Channel incision is the process of downcutting and flood plain abandonment. It is calculated by dividing the low bank height by the maximum bankfull depth. In reaches where the low bank *is* the bankfull depositional surface, the ratio is 1. A channel with an incision ratio of 1.0-1.1 is considered to be stable. Incision ratios between 1.1 and 1.3 are slightly incised, ratios of 1.3 to 1.5 are moderately incised, and ratios of over 1.5 are deeply incised (Rosgen, 2008). Incised channels tend to be unstable because higher flows do not have floodplain connection to dissipate energy anymore. This results in increased shear stress on the channel bed and banks and large increases in sediment supply.

In the upper reaches of the watershed, channels generally have well-developed bankfull depositional surfaces and are connected to their floodplains. In the Dempsey and Barber systems, channel incision seems to start increasing south of Hwy 37. North of Hwy 37, incision ratios are 1.0, except in the channelized reaches of Penobscot Creek. Those reaches have moderately incised ratios of 1.4 and 1.3. Descending south of Hwy 37, incision ratings range between slightly and deeply incised. The West Swan River has good flood-plain connection in the upstream half of the watershed, but somewhere between CR 442 and Hingeley Road the channel downcuts. The Hingeley Road site has an incision ratio of 1.5 and the site just before the confluence with the East Swan River has an incision ratio of 1.9.

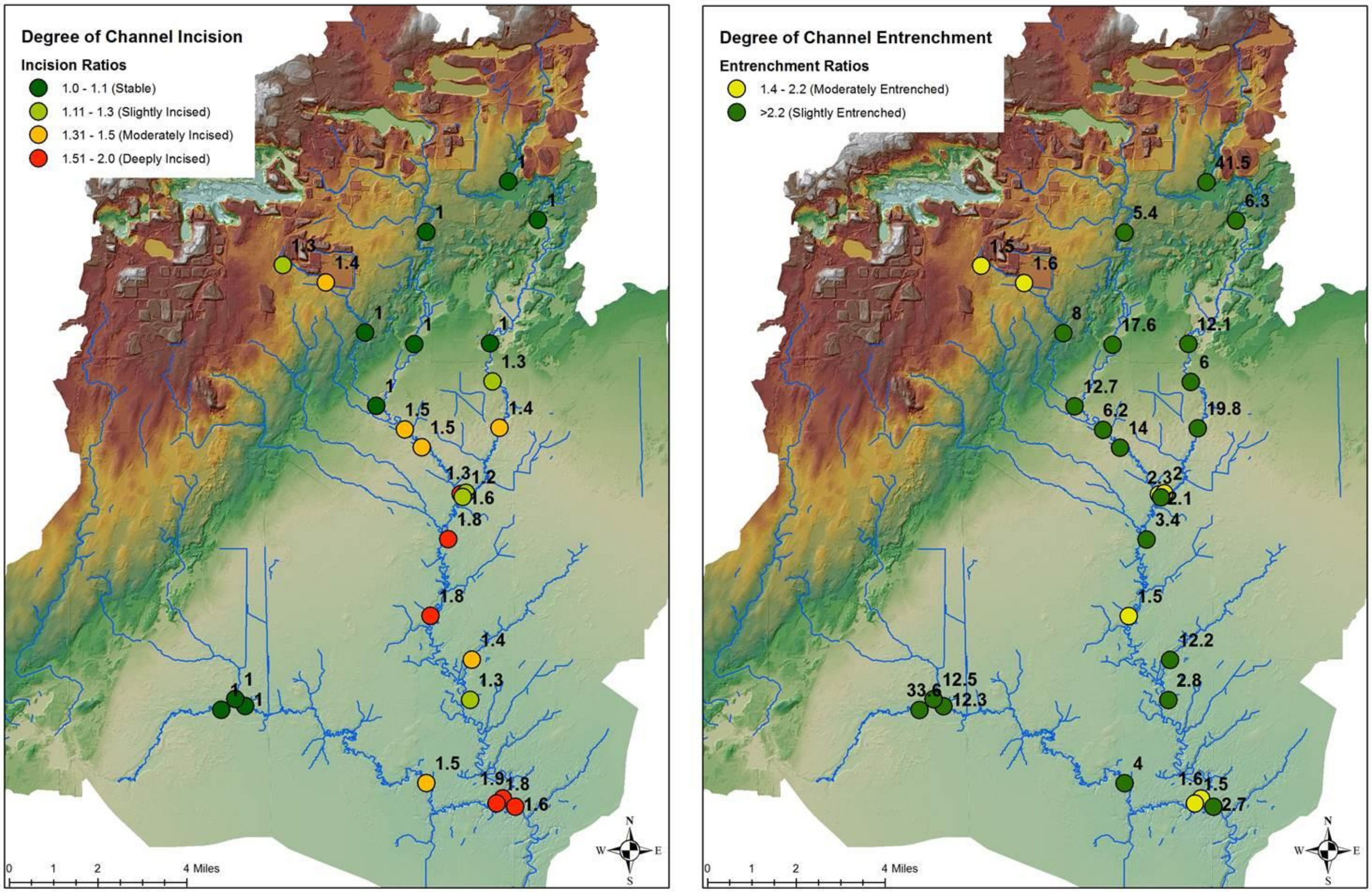


Figure 13: Incision and entrenchment ratios for rapid assessment sites in the Swan River watershed

Entrenchment is the horizontal containment of a channel, and is defined as the flood-prone width divided by the bankfull width. Entrenchment ratios help determine stream types, as “A”, “G”, “F”, and “B” channels do not have extensive floodplains and are considered “entrenched.” “E”, “C”, and “D” channels, conversely, have wide floodplains and are generally not entrenched. Entrenchment ratios of less than 1.4 are considered “entrenched”. Ratios between 1.4 and 2.2 are “moderately entrenched,” and a ratio above 2.2 is “slightly entrenched”. Entrenchment is not necessarily an indication of instability, but rather needs to be examined in conjunction with stream type and valley type at any particular site. For example, “B” channels often flow within narrow valleys and are thus moderately entrenched to entrenched, but they are seldom unstable. “E” channels, on the other hand, are commonly very sinuous and flow across wide flat valleys; hence the flood prone width is many times more than the bankfull width. This is usually the stable state of an “E” channel. If the entrenchment ratio of an “E” channel is reduced to “moderately entrenched” or “entrenched”, that may be a sign of incision and floodplain abandonment.

Looking at the entrenchment ratios of the 28 surveyed reaches, the upper reaches of the West Swan River and the reaches north of Hwy 37 are only slightly entrenched. Entrenchment ratios decrease longitudinally down the system, although the relationship between entrenchment and longitudinal location is not as strong as with incision. Most of the sites classify as “slightly entrenched”, although the ratios are much lower than would be expected for the stream and valley types found there. For example, the site on the East Swan River upstream of CR 442 has an entrenchment ratio of 2.8 (technically “slightly entrenched”). However, that is not painting the whole picture. The bankfull width is approximately 40 feet, and the valley width is around 400 feet. Thus the entrenchment ratio *should* be around 10. However, the flood prone area is much narrower than the valley (110 feet), indicating a downcut channel. The incision ratio of 1.3 at that site is further evidence of that.

The same areas (Penobscot Creek, Barber/Dempsey confluence, East Swan River, and lower West Swan) that have high incision ratios also have relatively low entrenchment ratios, suggesting that those reaches have downcut to the point that the flood-prone area is not much wider than the bankfull channel. This scenario describes an “F” channel, and is one of the most unstable stream types in the alluvial or lacustrine valleys that dominate this watershed.

There is a general trend of decreasing W/D ratios longitudinally down the watershed. Two notable exceptions are 1) Penobscot Creek @ Hwy 73 (W/D of 9) due to channelization and 2) West Swan River at the East Swan confluence (W/D of 14) due to widening after incision.

Generally, W/D ratios of less than 12 are associated with slightly entrenched “E” channels and entrenched “G” channels. W/D ratios between 12 and 40 are associated with slightly entrenched “C” channels, moderately entrenched “B” channels, and entrenched “F” channels. Because width/depth ratios are dependent on stream type, it is difficult to make any conclusions about stream stability and sediment supply based solely on W/D ratios. Assuming the same dominant substrate, low W/D “G” channels are less stable and will produce much more sediment than low W/D “E” channels. Similarly, high W/D “F” channels will produce more sediment than high W/D “C” channels (Rosgen, Applied River Morphology, 1996).

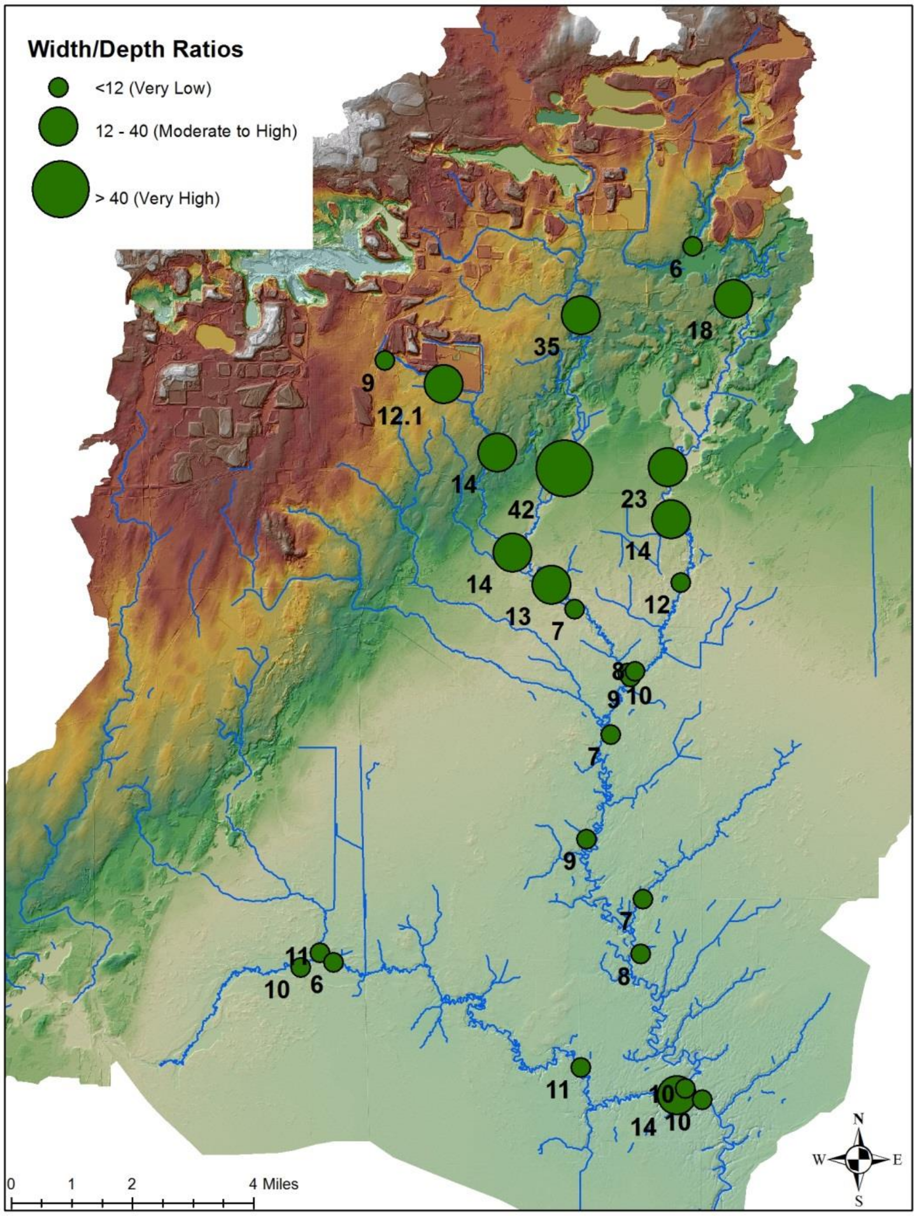


Figure 14: Measured width/depth ratios at rapid assessment sites.

Valley and Stream Types

Valley and stream typing followed the Rosgen classification system. Figures detailing the three valley types found in the Swan River watershed as well as a key to the Rosgen stream type classification are shown below. Valley types 10 (lacustrine) and 8c (alluvial) dominated the watershed with the exception of the channelized portion of Penobscot Creek, where the berms have been built so high that the valley most closely resembles a confined colluvial valley. “C”, “E”, “DA” and “B_C” streams are the stable stream types associated with the 8 and 10 valley types.

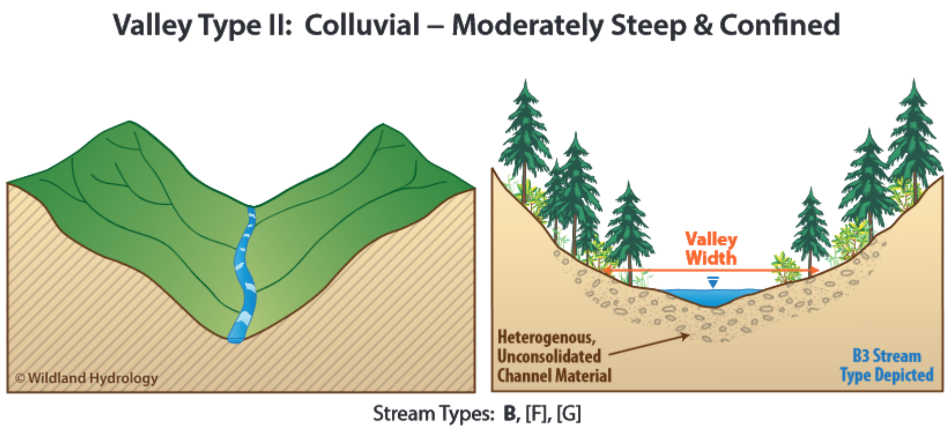


Figure 15: Type 2 colluvial valley, only found in the channelized reaches of Penobscot Creek

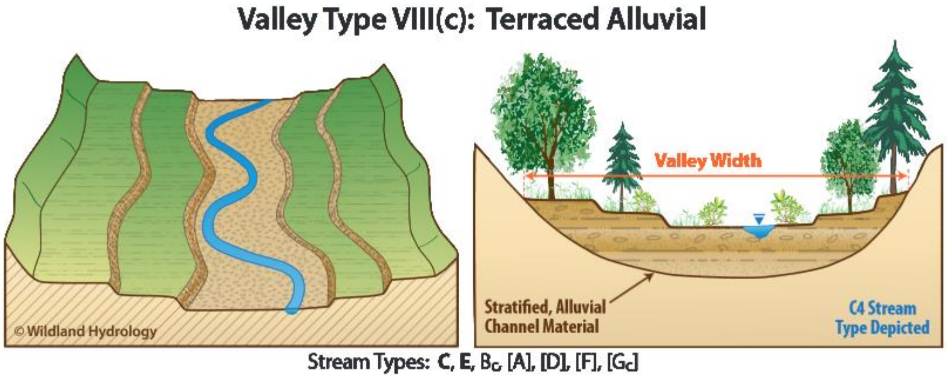


Figure 16: Type 8 alluvial valley, found in the lower half of the watershed where the channel has cut down into glacial lake sediments

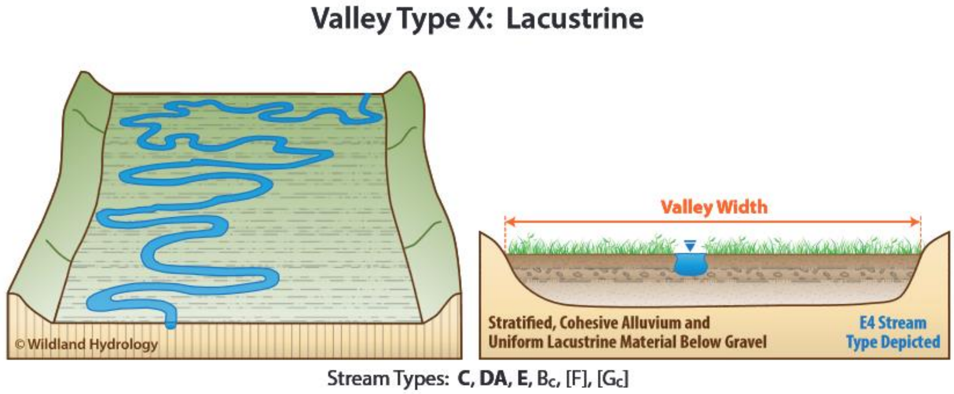


Figure 17: Type 10 lacustrine valley, found mainly in the upper reaches of the Barber, Dempsey, and West Swan River systems

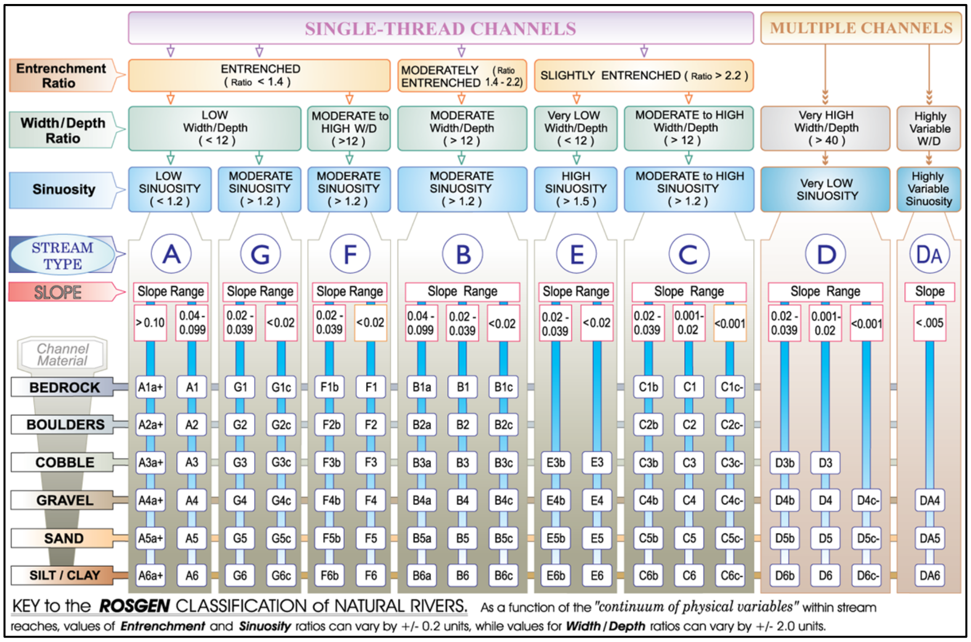


Figure 18: Key to the Rosgen stream classification system based on entrenchment, W/D ratio, sinuosity, and slope (Rosgen, 1996)

Using field observations, slope, W/D ratios, and entrenchment ratios, stream and valley types were determined for all 28 sites (Figure 19). Narrow, deep and sinuous "E" channels were most common and dominated the lower reaches of the watershed. As stated before, many of the sites are moderately to deeply incised in the lower stretches of the Dempsey, Barber, East Swan and West Swan systems. Some of those sites are incised enough to type out as low-gradient "G" channels (highly unstable streams in lacustrine or alluvial valleys). Additionally, an unstable "F" channel was found just upstream of the West Swan River mouth – most likely this stream is widening and was previously a narrower "G" channel. Wider, less sinuous "C" channels were present in slightly higher-gradient reaches, and occurred north of Highway 16. Photo examples of each of the four stream types documented in the Swan River watershed are shown in Figure 20. It is worth noting that the "E" channels in the lower reaches were on the verge of typing out as G or F channels, and were either lacking the required incision or entrenchment ratios to properly classify as those unstable stream types. Nevertheless, the E channels in the lower half of the watershed are in poor condition, as evidenced by the Pfankuch ratings and increased levels of suspended sediment. Many of them require almost a 50-year flood event to access their floodplains.

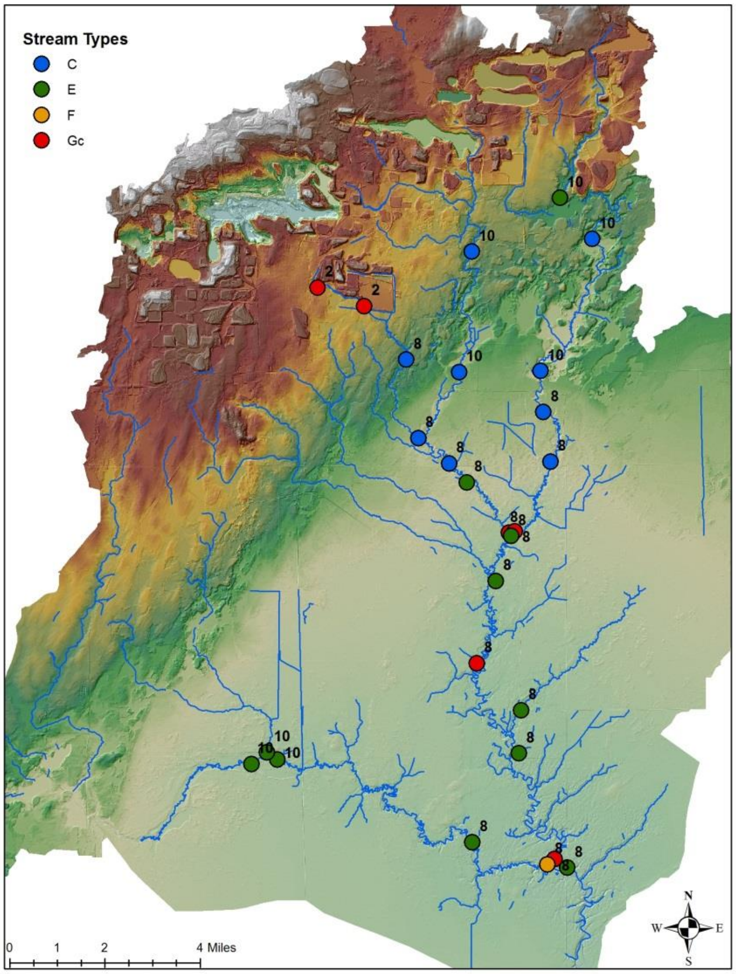


Figure 19: Stream and valley types in the Swan River watershed. Stream types are color-coded and valley types are labeled.

Figure 20: Examples of each of the four stream types documented in the Swan River watershed

3. Level II Stream Survey

Methods

To properly classify the Swan River system and to help determine the stability departure of survey sites, a Level II stream survey was conducted at the Swan River gage station at Hwy 5 near Toivola, MN. The gage station ID is H03-084-001, with coordinates of 47° 15’ 00.7” N and 92° 48’ 37.7” W. The gage was installed in 2010 by MPCA but was also operated from 1952 to 1961. Thus 13 years of flow data could be used to perform a peak flow frequency analysis.

To complete the Level II assessment, a longitudinal profile and two cross-sections were surveyed, as well as reach-level and riffle pebble counts. The longitudinal profile (shown in Figure 21) included water-surface, thalweg, and observed bankfull indicators for almost 1000’ of stream. Cross sections were taken at two observed riffles, and are shown in Figure 22 and Figure 23. In the cross section figures the solid blue line represents the bankfull elevation and the dashed line represents the flood-prone elevation. The longitudinal locations of each cross section are shown on the longitudinal profile. The Level II survey results are found in Appendix 3.

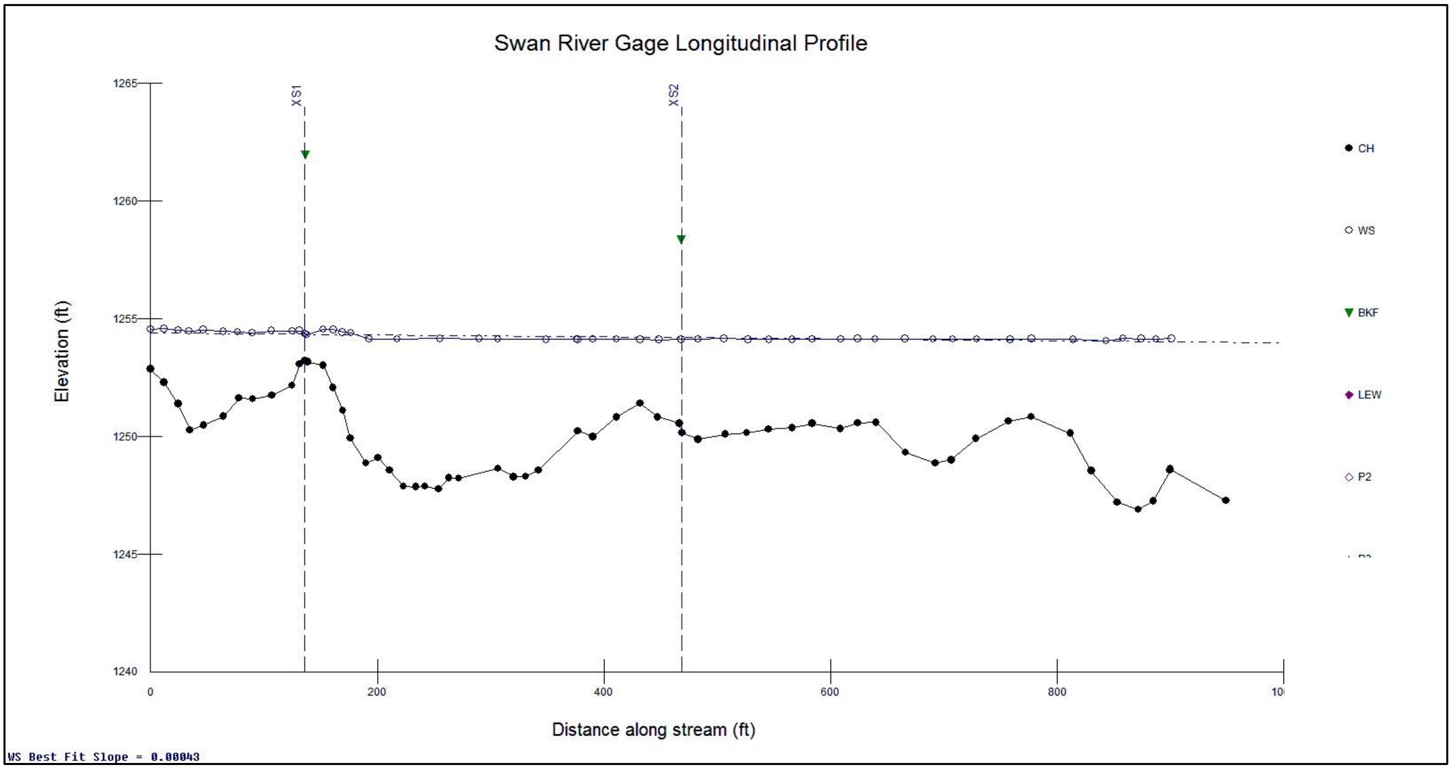


Figure 21: Longitudinal profile of Swan River Level II survey site. Both cross-sections are taken at riffles.

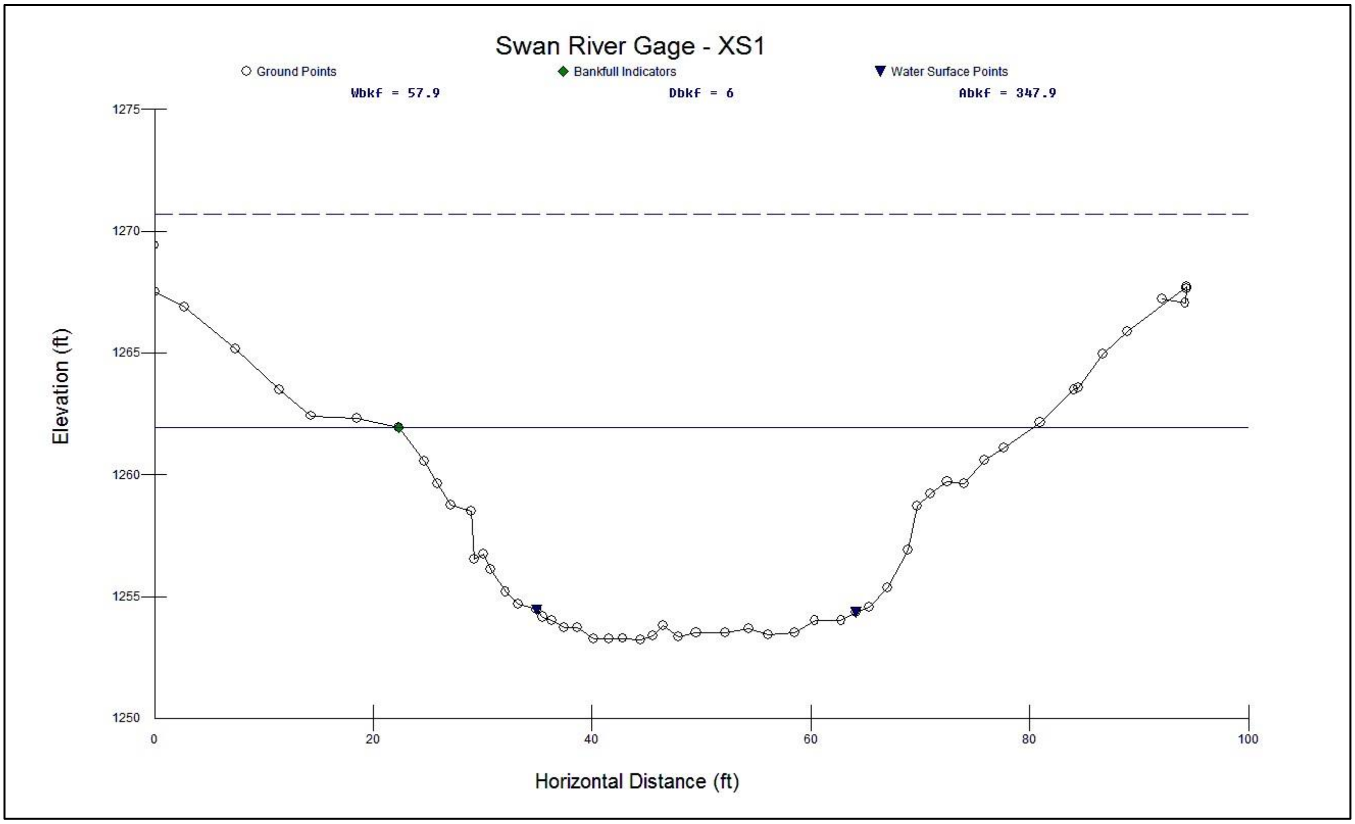


Figure 22: XS1, taken at STA 1+36, just downstream of the stream gage.

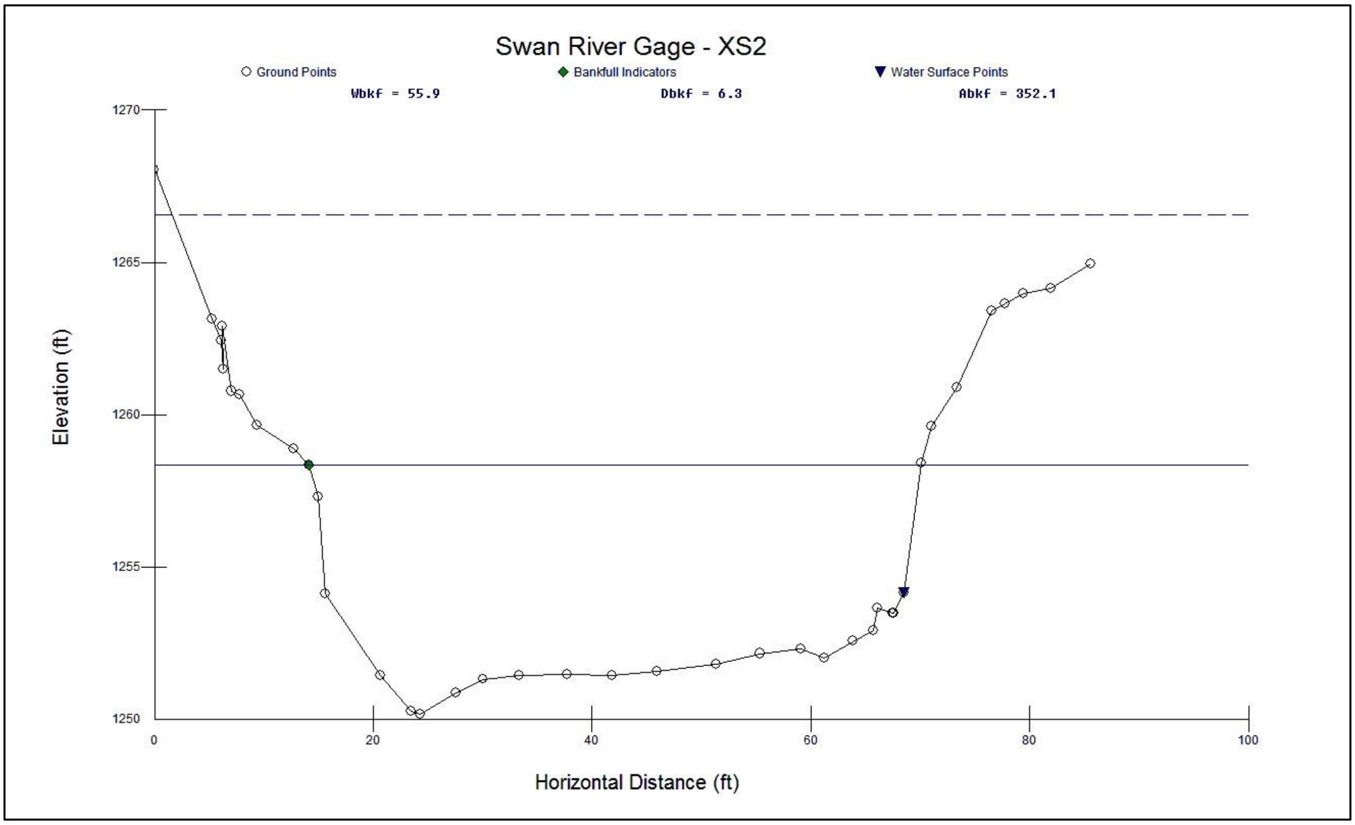


Figure 23: Cross section 2, taken at STA 4+69.

Results

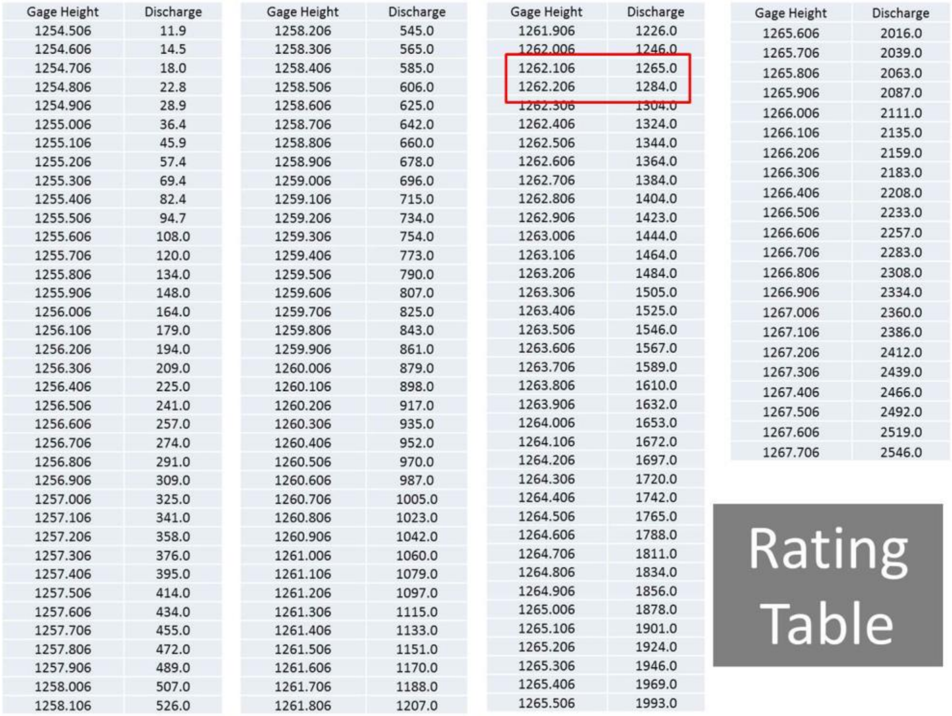
Results from the longitudinal profile and riffle pebble count yielded a water surface slope of .043% and a D84 of 148.8mm. The D50 from the reach pebble count was 0.05mm. RiverMorph analysis of the survey data showed that the stream type was E6, which was the same as the field determination.

Bankfull Discharge Calibration

XS2 at STA 4+69 did not have a reliable bankfull indicator due to incision; therefore XS1 at STA 1+36 was used to determine the hydraulic relations for the reach. The observed bankfull elevation at XS1 was 1261.96 ft. The water surface at XS1 was measured to be 0.19 ft below the water surface at the gage station. Therefore, in order to relate the bankfull elevation at XS1 to the gage records, 0.19 ft was added for a gage bankfull elevation of 1262.15 ft. Using the rating table obtained from MN DNR (Table 1), the water surface elevation of 1262.15 ft corresponds to a discharge (Q) of between 1265 and 1284 cfs.

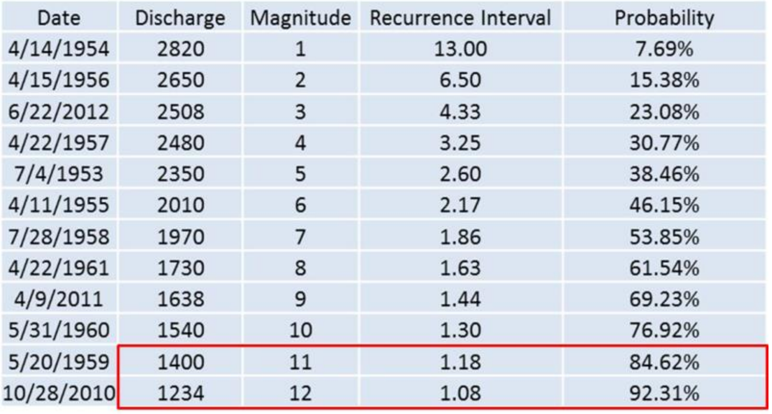
In order to verify that this Q lies within the normal recurrence interval for a bankfull event (every 1.1 - 1.5 years), a flood frequency analysis was performed using the peak discharge record for the gage (see Table 2). That exercise revealed a recurrence interval of between 1.1 and 1.2 years for the bankfull discharge of ~1275 cfs. Using the channel dimensions, slope and discharge, a Manning's "n" value of 0.046 was calculated. The finalized hydraulic relationships for this gage station are shown in Table 3.

Table 1: Rating table for stream gage H03084001.



Gage Height	Discharge
1254.506	11.9
1254.606	14.5
1254.706	18.0
1254.806	22.8
1254.906	28.9
1255.006	36.4
1255.106	45.9
1255.206	57.4
1255.306	69.4
1255.406	82.4
1255.506	94.7
1255.606	108.0
1255.706	120.0
1255.806	134.0
1255.906	148.0
1256.006	164.0
1256.106	179.0
1256.206	194.0
1256.306	209.0
1256.406	225.0
1256.506	241.0
1256.606	257.0
1256.706	274.0
1256.806	291.0
1256.906	309.0
1257.006	325.0
1257.106	341.0
1257.206	358.0
1257.306	376.0
1257.406	395.0
1257.506	414.0
1257.606	434.0
1257.706	455.0
1257.806	472.0
1257.906	489.0
1258.006	507.0
1258.106	526.0
1258.206	545.0
1258.306	565.0
1258.406	585.0
1258.506	606.0
1258.606	625.0
1258.706	642.0
1258.806	660.0
1258.906	678.0
1259.006	696.0
1259.106	715.0
1259.206	734.0
1259.306	754.0
1259.406	773.0
1259.506	790.0
1259.606	807.0
1259.706	825.0
1259.806	843.0
1259.906	861.0
1260.006	879.0
1260.106	898.0
1260.206	917.0
1260.306	935.0
1260.406	952.0
1260.506	970.0
1260.606	987.0
1260.706	1005.0
1260.806	1023.0
1260.906	1042.0
1261.006	1060.0
1261.106	1079.0
1261.206	1097.0
1261.306	1115.0
1261.406	1133.0
1261.506	1151.0
1261.606	1170.0
1261.706	1188.0
1261.806	1207.0
1261.906	1226.0
1262.006	1246.0
1262.106	1265.0
1262.206	1284.0
1262.306	1304.0
1262.406	1324.0
1262.506	1344.0
1262.606	1364.0
1262.706	1384.0
1262.806	1404.0
1262.906	1423.0
1263.006	1444.0
1263.106	1464.0
1263.206	1484.0
1263.306	1505.0
1263.406	1525.0
1263.506	1546.0
1263.606	1567.0
1263.706	1589.0
1263.806	1610.0
1263.906	1632.0
1264.006	1653.0
1264.106	1672.0
1264.206	1697.0
1264.306	1720.0
1264.406	1742.0
1264.506	1765.0
1264.606	1788.0
1264.706	1811.0
1264.806	1834.0
1264.906	1856.0
1265.006	1878.0
1265.106	1901.0
1265.206	1924.0
1265.306	1946.0
1265.406	1969.0
1265.506	1993.0
1265.606	2016.0
1265.706	2039.0
1265.806	2063.0
1265.906	2087.0
1266.006	2111.0
1266.106	2135.0
1266.206	2159.0
1266.306	2183.0
1266.406	2208.0
1266.506	2233.0
1266.606	2257.0
1266.706	2283.0
1266.806	2308.0
1266.906	2334.0
1267.006	2360.0
1267.106	2386.0
1267.206	2412.0
1267.306	2439.0
1267.406	2466.0
1267.506	2492.0
1267.606	2519.0
1267.706	2546.0

Table 2: Flood frequency and recurrence analysis



Date	Discharge	Magnitude	Recurrence Interval	Probability
4/14/1954	2820	1	13.00	7.69%
4/15/1956	2650	2	6.50	15.38%
6/22/2012	2508	3	4.33	23.08%
4/22/1957	2480	4	3.25	30.77%
7/4/1953	2350	5	2.60	38.46%
4/11/1955	2010	6	2.17	46.15%
7/28/1958	1970	7	1.86	53.85%
4/22/1961	1730	8	1.63	61.54%
4/9/2011	1638	9	1.44	69.23%
5/31/1960	1540	10	1.30	76.92%
5/20/1959	1400	11	1.18	84.62%
10/28/2010	1234	12	1.08	92.31%

Table 3: Final hydraulic relations from Swan River gage station.

Gage Station: Swan River @ Hwy 5 near Toivola, MN						Gage Station #: H03084001						
1	2	3a	3b	3c	3d	4	5	6	7	8	9	10
Drainage Area (sq mi)	Bankfull Discharge (cfs)	Bankfull Width (ft)	Bankfull Mean Depth (ft)	Bankfull Area (sq ft)	Bankfull Velocity (ft/s)	Ave. Water Surface Slope (ft/ft)	D84 (mm)	Stream Type	Mannings "n"	Relative Roughness R/D84	Shear Velocity u* (ft/s)	Friction Factor
239	1275	57.95	6	347.9	3.7	0.0012	148.8	E6	0.046	0.040	0.477	7.749

Discussion

The calculated recurrence interval of between 1.1 and 1.2 years for a bankfull event at this gage station is unexpected. Values in the 1.1 – 1.3 range are more common in flashy systems with bedrock-controlled or urbanized runoff regimes (Rosgen, 1996). Some of the hydro-physiographic characteristics of the Swan River watershed, such as the prevalence of bogs and other wetlands, would suggest bankfull recurrence intervals of 1.5 years or more. However, it is entirely possible that the prevalent ditch network in the watershed, combined with agricultural, mining and urban areas, have increased the flashiness of the watershed and lowered the recurrence interval to around 1.2 years.

This was not an ideal location for a Level II gage survey for a couple reasons. First, this reach is incised and did not have readily apparent bankfull surfaces. There were no bankfull surfaces immediately upstream of the gage. This presents somewhat of a problem since flow calibrations at gage stations rely on confident bankfull determinations on a longitudinal profile that is surveyed through the gage site. Second, the gage data is not continuous. Historical flow records from the mid-20th century, while utilized for this analysis, may not accurately represent the current flow regime within the Swan River watershed. Land-use and climate may have been altered in the intervening decades. Channel-forming discharge in this system may have changed enough to disqualify the historic data from current analyses.

In order to accurately relate bankfull dimensions to discharge, additional gage station calibrations are recommended. Unfortunately, there are not many gage station candidates in the area that: 1) have current or recent discharge data, 2) have an adequate period of record, and 3) have reliable bankfull indicators at the gage site. Consequently, meticulous field reconnaissance and evaluation of historic gage data should be performed to determine the suitability of each site *prior* to the Level II survey.

4. Culvert Inventory

Methods

In order to assess the impact of road crossings on stream stability and fish passage, 66 culverts were inventoried within the Swan River watershed. Using desktop reconnaissance, the crossings were located and chosen mostly based on whether or not they lay on the main stems of the West and East Swan River, Dempsey, Barber, Penobscot, Little Swan, and East Swan Creeks. Smaller tributaries, ditches, and intermittent streams were largely ignored in this assessment.

Data was collected during the month of November 2012 using a Trimble Juno SB hand-held GPS unit with Terrasync software and a custom data dictionary. Culvert and bankfull measurements were made with a 100’ field tape, and flood prone widths were measured either in the field with a range finder or by using LiDAR data. Geo-tagged photos were taken of the culvert’s inlet, outlet, inside, and the stream itself. A list of measurements and information collected at each crossing is shown in Table 4.

For the most part, bankfull widths and other stream morphology parameters were measured at least 300 feet upstream or downstream to avoid the influence of the crossing on the actual morphology of the stream. As a convention and where possible, the upstream location was given preference.

Table 4: List of data collected at road crossings.

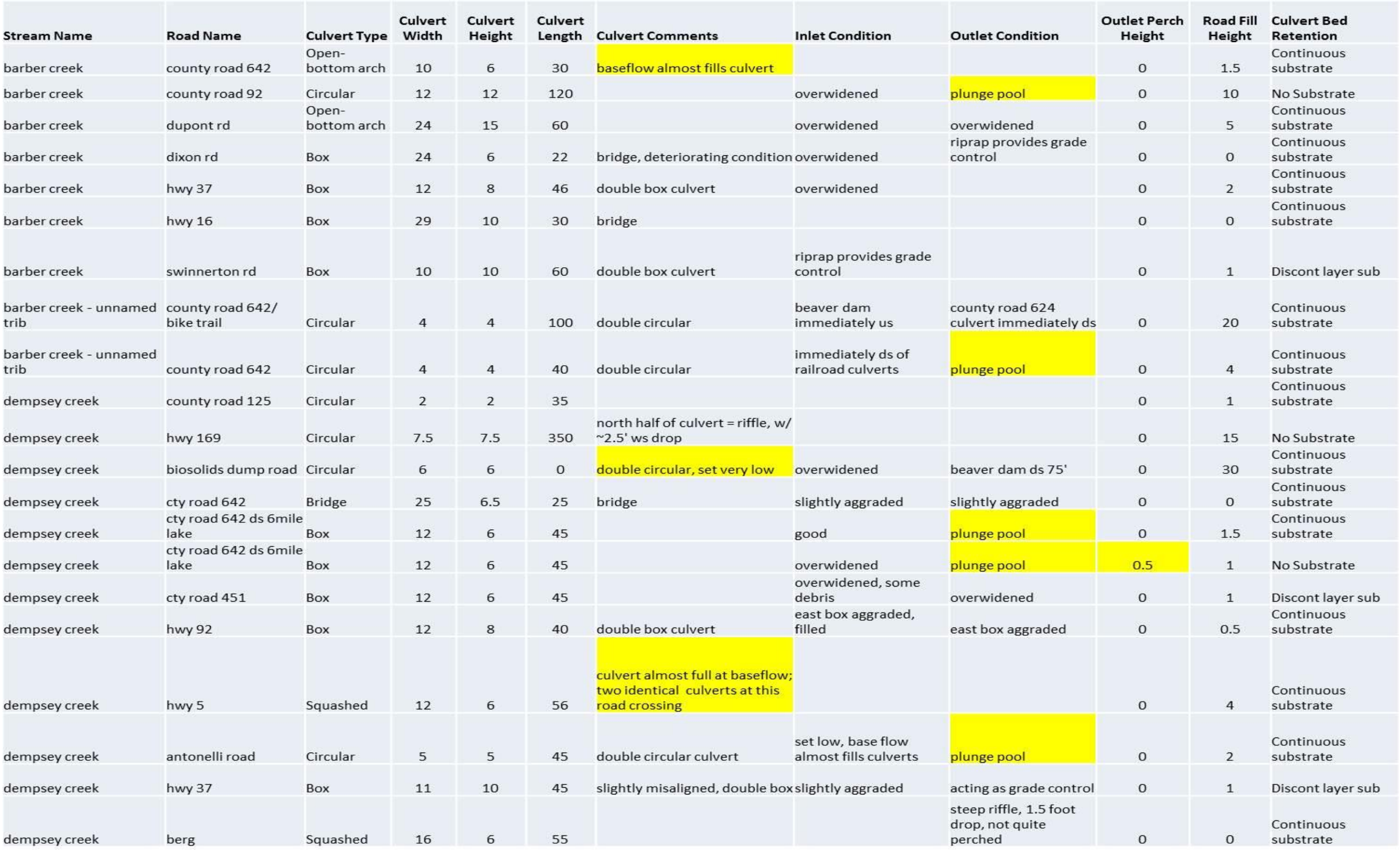
Stream Name
Longitudinal Location
Road Name/Number
Date
Time
Surveyor 1
Surveyor 2
Crossing Information
Culvert Type
Culvert Material
Inner Structures
Culvert Width
Culvert Height
Culvert Length
Culvert Rustline
Culvert Comments
Culvert Inside Picture
Inlet Projecting?
Inlet Mitered?
Inlet Wingwall?
Inlet Headwall?
Inlet Apron?
Inlet Trashrack?
Inlet Comments
Inlet Picture
Outlet Projecting?
Outlet Mitered?
Outlet Wingwall?
Outlet Headwall?
Outlet Apron?
Outlet Comments
Outlet Perch Distance
Outlet Picture
Road Condition
Road Fill Height
Stream Morphology
Culvert Bed Retention
Bankfull to Water Surface
Bankfull Width 1
Bankfull Width 2
Flood Prone Width
Stream Picture

Results

Complete culvert data and results are attached in Appendix 4. Some of the items that may have impacts on stream stability and biota are highlighted in Table 5 - Table 7. In many sites, scour pools had formed, indicating high water velocities through a too-narrow culvert during flood events. Another observed hydrologic issue was the low placement of many wetland culverts, which most likely increase head at high flows and greatly increase velocities. Some connectivity problems were also noticed, including perched culverts, beaver dams located at crossings, and subsurface stream flow through cobbles placed in the channel at road crossings. Examples of some of these issues are shown in the photos in Figure 24 and Figure 25.

Out of 66 culverts, 12 had significant scour pools, 5 were almost full at baseflow, 10 had noticeable aggradation, and 3 were perched.

Table 5: Culvert assessment results (1)



Stream Name	Road Name	Culvert Type	Culvert Width	Culvert Height	Culvert Length	Culvert Comments	Inlet Condition	Outlet Condition	Outlet Perch Height	Road Fill Height	Culvert Bed Retention
barber creek	county road 642	Open-bottom arch	10	6	30	baseflow almost fills culvert			0	1.5	Continuous substrate
barber creek	county road 92	Circular	12	12	120		overwidened	plunge pool	0	10	No Substrate
barber creek	dupont rd	Open-bottom arch	24	15	60		overwidened	overwidened	0	5	Continuous substrate
barber creek	dixon rd	Box	24	6	22	bridge, deteriorating condition	overwidened	riprap provides grade control	0	0	Continuous substrate
barber creek	hwy 37	Box	12	8	46	double box culvert	overwidened		0	2	Continuous substrate
barber creek	hwy 16	Box	29	10	30	bridge			0	0	Continuous substrate
barber creek	swinnerton rd	Box	10	10	60	double box culvert	riprap provides grade control		0	1	Discont layer sub
barber creek - unnamed trib	county road 642/ bike trail	Circular	4	4	100	double circular	beaver dam immediately us	county road 624 culvert immediately ds	0	20	Continuous substrate
barber creek - unnamed trib	county road 642	Circular	4	4	40	double circular	immediately ds of railroad culverts	plunge pool	0	4	Continuous substrate
dempsey creek	county road 125	Circular	2	2	35				0	1	Continuous substrate
dempsey creek	hwy 169	Circular	7.5	7.5	350	north half of culvert = riffle, w/ ~2.5' ws drop			0	15	No Substrate
dempsey creek	biosolids dump road	Circular	6	6	0	double circular, set very low	overwidened	beaver dam ds 75'	0	30	Continuous substrate
dempsey creek	cty road 642	Bridge	25	6.5	25	bridge	slightly aggraded	slightly aggraded	0	0	Continuous substrate
dempsey creek	cty road 642 ds 6mile lake	Box	12	6	45		good	plunge pool	0	1.5	Continuous substrate
dempsey creek	cty road 642 ds 6mile lake	Box	12	6	45		overwidened	plunge pool	0.5	1	No Substrate
dempsey creek	cty road 451	Box	12	6	45		overwidened, some debris	overwidened	0	1	Discont layer sub
dempsey creek	hwy 92	Box	12	8	40	double box culvert	east box aggraded, filled	east box aggraded	0	0.5	Continuous substrate
dempsey creek	hwy 5	Squashed	12	6	56	culvert almost full at baseflow; two identical culverts at this road crossing			0	4	Continuous substrate
dempsey creek	antonelli road	Circular	5	5	45	double circular culvert	set low, base flow almost fills culverts	plunge pool	0	2	Continuous substrate
dempsey creek	hwy 37	Box	11	10	45	slightly misaligned, double box	slightly aggraded	acting as grade control	0	1	Discont layer sub
dempsey creek	berg	Squashed	16	6	55			steep riffle, 1.5 foot drop, not quite perched	0	0	Continuous substrate

Table 6: Culvert assessment results (2)

Stream Name	Road Name	Culvert Type	Culvert Width	Culvert Height	Culvert Length	Culvert Comments	Inlet Condition	Outlet Condition	Outlet Perch Height	Road Fill Height	Culvert Bed Retention
dempsey creek	wegener rd	Squashed	15	10	46	heavily aggraded			0	2.5	Continuous substrate
dempsey creek	hwy 16	Squashed	16	9	41		slight debris jam		0	2	Discont layer sub
dempsey creek	mestek	Squashed	16	9	46		debris jam potential	culvert cut off meander	0	1	Continuous substrate
dempsey creek	foss	Squashed	16	12	55		beaver dam causing 3.5 ft drop in ws	culvert cut off meander	0	2.5	Continuous substrate
dempsey creek	newton	Box	10	8	60	double box			0	4	Continuous substrate
east swan creek	swinnerton	Bridge	40	10	30	bridge	bridge riprap causing slight grade control	plunge pool	0	0	Continuous substrate
east swan creek - north	east 41st street	Circular	3	3	60	double circular culvert, one has no flow	additional abandoned 4 ft circular culvert	plunge pool, perched 2nd culvert	0	6.5	No Substrate
east swan creek - north	hwy 16	Box	14	6	55				0	3	Continuous substrate
east swan creek - north	koivu rd	Squashed	10	6.5	61	triple culvert	misaligned with stream	overwidened	0	1.5	Discont layer sub
east swan creek - south	hwy 16	Box	8	5	88	double culvert, one is raised to bankfull	ditched	water in culvert, no flow in stream	0	4	No Substrate
east swan creek - south	county road 57	Circular	5.5	5.5	78	triple culvert	aggraded	water in culverts, no flow in stream	0	4.5	Discont layer sub
east swan creek - south	hwy 16	Box	10	10	60	double culvert, one is raised	no flow	no flow in stream	0	3.5	Discont layer sub
east swan creek - south	county road 444	Bridge	25	10	25	bridge	overwidened	overwidened	0	0	Continuous substrate
east swan creek - south	koivu rd	Open-bottom arch	12	6.5	31				0	1	Continuous substrate
east swan river	county road 444	Bridge	82	15	35	bridge			0	0	Continuous substrate
east swan river	zim road	Bridge	35	15	20	bridge			0	0	Continuous substrate
east swan river	county road 442	Bridge	90	15	30	bridge		riprap provides grade control, steep riffle	0	0	Continuous substrate
east swan river - unnamed trib	county road 442	Circular	6	6	62	woody debris caught in trashrack	beaver dam 60' us, 3.5' drop in ws	plunge pool, overwidened	0	2.5	Continuous substrate
east swan river - unnamed trib	county road 444	Circular	4	4	60	double circular culvert	north culvert inlet aggraded	north culvert outlet aggraded	0	2	No Substrate
east swan river - unnamed trib	hwy 5	Box	10	10	37	aggraded large cobbles	aggraded	aggraded	0	3	Continuous substrate
little swan creek	hacky road	Circular	10	10	55	double circular culvert	overwidened, beaver dam recently removed	plunge pool, baseflow almost fills culvert	0	2	Continuous substrate

Table 7: Culvert assessment results (3)

Stream Name	Road Name	Culvert Type	Culvert Width	Culvert Height	Culvert Length	Culvert Comments	Inlet Condition	Outlet Condition	Outlet Perch Height	Road Fill Height	Culvert Bed Retention
little swan creek	hwy 5	Box	10	8	40	double box culvert	north culvert aggraded	plunge pool	0	1	Continuous substrate
little swan creek	county road 444	Bridge	25	10	25	bridge		steep riffle into plunge pool	0	0	Continuous substrate
little swan creek	zim road	Bridge	25	10	25	bridge		riffle into plunge pool, aggradation under bridge	0	0	Continuous substrate
penobscot creek	hyw 73	Circular	10	10	999		not found		0	5	Discont layer sub
penobscot creek	howard street	Circular	10	10	100		channelized	riffle provides grade control	0	13	No Substrate
penobscot creek	dupont	Squashed	12	8	115		beaver dam removed recently	much debris	0	8	Continuous substrate
penobscot creek	tamminen	Squashed	16	10	50		not aligned with stream pattern	much debris	0	1.5	Discont layer sub
penobscot creek	hwy 37	Squashed	14	8	135				0	15	Continuous substrate
swan river	hwy 5	Bridge	160	20	30	bridge		riprap provides grade control	0	0	Continuous substrate
swan river	oja road	Bridge	160	20	30	bridge			0	0	Continuous substrate
swan river - unnamed trib	county road 230	Box	12	8	45				0	0	Discont layer sub
west swan river	stuart road	Bridge	20	8	20	bridge	flooded, possible beaver dam ds		0	0	Continuous substrate
west swan river	stuart road	Bridge	20	8	20	bridge	cut off meander		0	0	Continuous substrate
west swan river	hwy 73	Bridge	75	10	35	bridge		wetland, overwidened	0	0	Continuous substrate
west swan river	county road 442	Bridge	30	7	25	bridge	overwidened	overwidened	0	0	Continuous substrate
west swan river	hwy 73	Bridge	75	10	35	bridge	overwidened, several riffles 100' upstream	appears to be more incised than us of bridge	0	0	Continuous substrate
west swan river	hwy 73	Bridge	100	10	35	bridge			0	0	Continuous substrate
west swan river	county road 442	Bridge	50	8	25	bridge	half of bridge filled with sediment		0	0	Continuous substrate
west swan river	county road 442	Bridge	50	8	25	bridge	overwidened	half of bridge filled with sediment	0	0	Continuous substrate
west swan river	hingeley road	Bridge	53	15	20	bridge		riprap provides grade control	0	0	Continuous substrate
west swan river	county road 927	Bridge	70	12	26	bridge			0	0	Continuous substrate
west swan river	county road 444	Bridge	120	18	26	bridge		riffle provides grade control	0	0	Continuous substrate
west swan river - unnamed trib	county road 442	Circular	1.5	1.5	45	double circular culvert, set at different heights		both culverts perched, 1.1' and 2.5'	1.8	3	No Substrate
west swan river - unnamed trib	county road 442	Circular	6	6	53	double circular culvert, deteriorating condition	bankfull bench obstructs flow in west culvert	overwidened, west culvert perched .25'	0.3	2.5	No Substrate

Figure 24: Examples of inadequate capacity (above right, above left, and bottom left) and a scour pool caused by an overly narrow culvert

Figure 25: Examples of connectivity barriers. Pictured are a 4' high beaver dam built at a crossing (top left), slightly perched culvert with a very shallow low flow water depth (top center), >1 foot perched culvert (top right), and low flow disappearing in cobbles (bottom three photos)

Discussion

The headwaters of this watershed are not incised or entrenched, which indicates that perhaps the incision process was stopped or slowed somehow. Commonly this occurs at road crossings or bedrock grade control, where a headcut cannot continue its rapid progress. Given the lack of bedrock control in this watershed (surface geology is mostly glacial lakebed and deposits) it is unlikely that bedrock is slowing a headcut advance. Given the breadth of incision ratios in this system, we expected to find headcuts that had moved up the watershed, only to stop at a culvert - forming a perched culvert. Therefore we would expect to see many perched culverts. This wasn’t the case however. Due to channel substrate or some other geological control, it may be that the headcuts are manifesting themselves as long, drawn-out riffles. An analysis of LiDAR data might be able to pinpoint such riffles (next section).

The most pervasive issue with the crossings in this watershed is inadequate culvert width. Properly-sized culverts should be comparable in width to the bankfull width of the stream. Crossings that had bankfull width / culvert width ratios of between 0.8 and 1.2 were considered to be adequate.

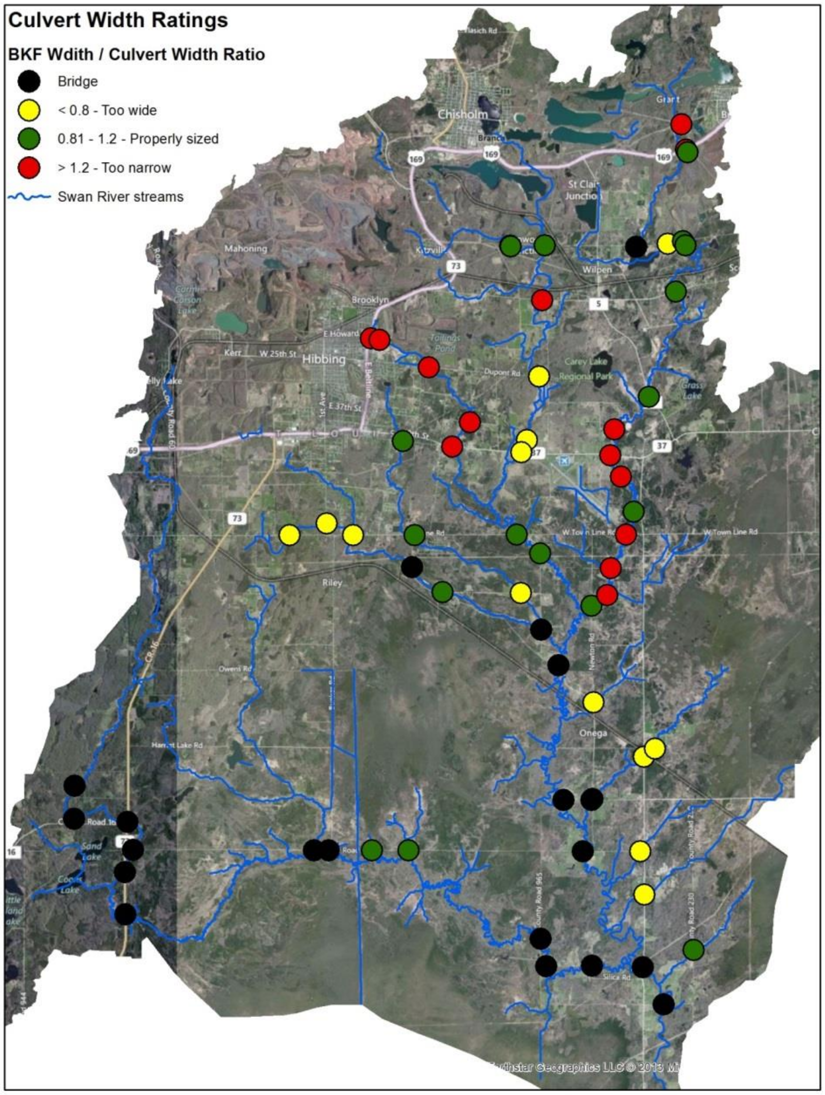


Figure 26: Assessment of bankfull widths / culvert widths. Ratios between 0.8 and 1.2 are not considered to negatively impact stream health.

Crossings with a ratio less than 0.8 are potentially causing stream impacts or fish passage problems. These culverts are overly wide, causing flow to become too shallow during dry periods. Excessively shallow water can create a fish passage concern, especially if culverts are long. Also, velocity and shear-stress decrease as width and area increase, leading to deposition and aggradation within culverts that are wider than bankfull.

Crossings with a ratio greater than 1.2 can also have stream impacts to stream stability. When culverts are significantly narrower than bankfull, flow constriction occurs during bankfull (and higher) flow events. This has several negative impacts on stream stability and the ability of the stream to move sediment. First, water velocities and shear stresses increase within the culvert and immediately downstream, causing erosion of banks and channel degradation leading to incision. Increased velocities within the crossing make it difficult for some species of fish to traverse. Upstream of the crossing, velocities are decreased due to backwater effects. This causes deposition and aggradation, filling in pools and destroying habitat. Lastly, narrow culverts have an increased risk of trapping debris, creating dams and the potential for road-overtop and massive failure.

Of the 66 crossings assessed, 14 were considered too narrow, 33 were too wide, and 19 were properly sized (Figure 26). All of the culverts that are rated “too narrow” occurred on Dempsey, Barber, and Penobscot Creeks. It appears that there is a correlation between these narrow culverts and the increase in TSS values in Penobscot Creek and the Dempsey/Barber confluence area. Narrow culverts could certainly add to suspended sediment values, as they increase water velocities and shear stresses allowing more sediment to be entrained.

Of the 33 crossings considered “too wide”, 19 were bridges and do not fall in the same category as culverts that are overly wide. Bridges generally have floodplain or bankfull capacity within the bridge structure and they do not have bottoms (water depth does not become an issue for fish passage). All of the crossings on the main stems of the West Swan and East Swan River are bridges. This means that any incision that was migrating upstream would have had no barriers to overcome.

Recommendations

A priority list of culverts needing additional study and potentially replace was made as a result of this study, and will be included in a separate report.

5. LiDAR profiles

Methods

Detailed stream profiles and cross-sections were developed using LiDAR datasets and the 3D Analyst extension for ArcMap. In order to gain an understanding of the error associated with LiDAR, cross-sections were generated at a subset of the 28 permanent study reaches. The generated cross-sections were then calibrated to the surveyed cross-sections. Figure 27 shows the similarity between the surveyed cross-sections and the LiDAR-derived cross-sections. Horizontal and vertical accuracies are sub-foot. Minor landscape details, such as small floodplain depressions (see Figure 27) are represented in the LiDAR profile. This exercise gave a high level of confidence to the rest of the LiDAR analyses.

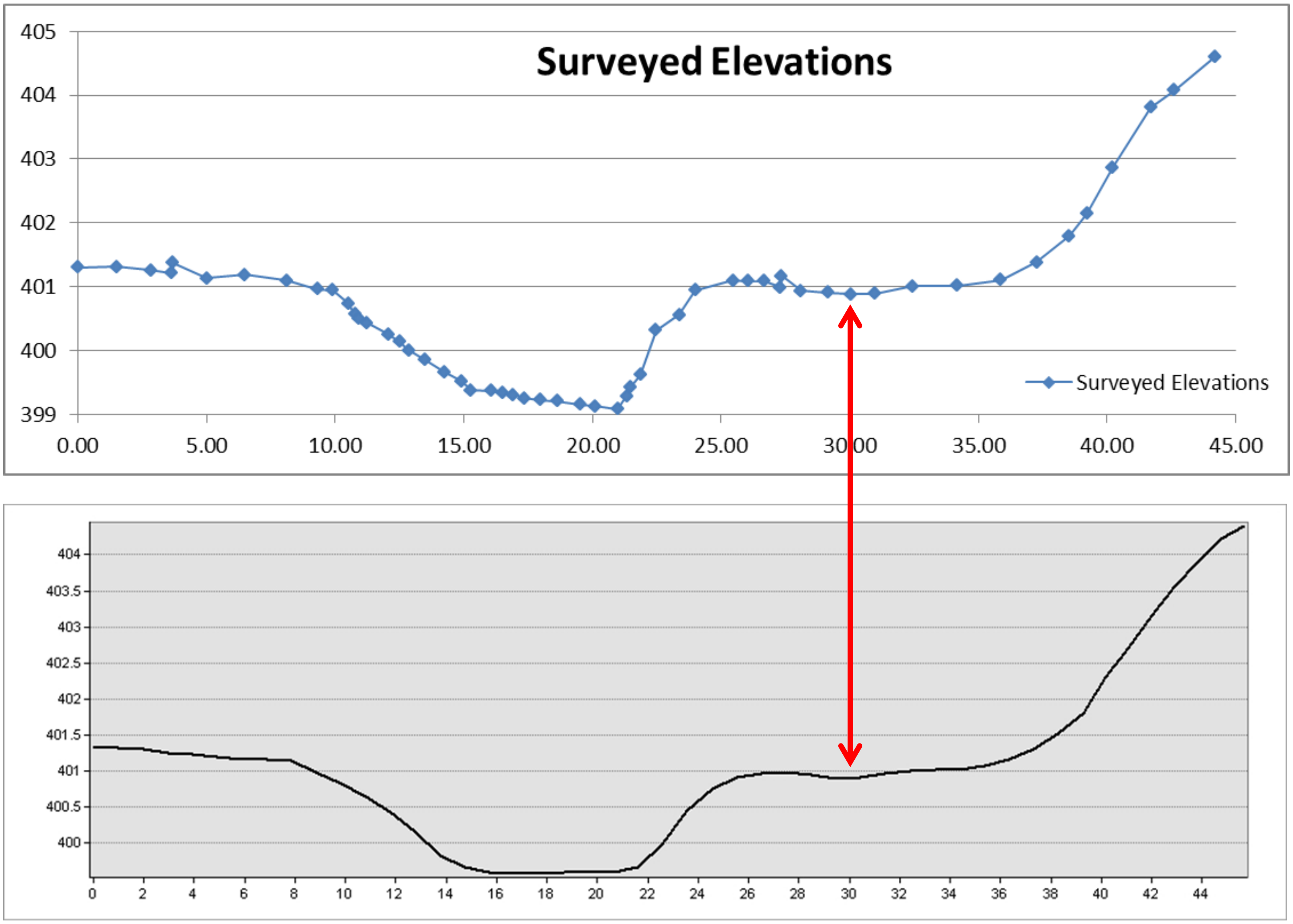


Figure 27: Surveyed and LiDAR-derived cross-sections taken on Barber Creek just upstream of Highway 16. Units for both are meters. Note the similarity between the two, both even showing a small sub-foot depression on the floodplain.

Longitudinal Profiles

Using 3D Analyst, interpolated lines were carefully drawn in ArcMap, following the centerline of the streams as closely as possible. Derived longitudinal profiles represented only water surface profiles and did not contain thalweg profiles. The goal in this exercise was *not* to gain slope data for specific reaches, but to gain a broad understanding of larger stream slope characteristics and to pinpoint headcuts (also referred to as knickpoints) that may be leading to stream instability.

Profile data was collected in ArcMap and exported as an Excel spreadsheet. Results are shown in Figure 28 - Figure 33. Figure 34 is a composite profile of all streams in the watershed. All data collected in this effort is located in Appendix 5.

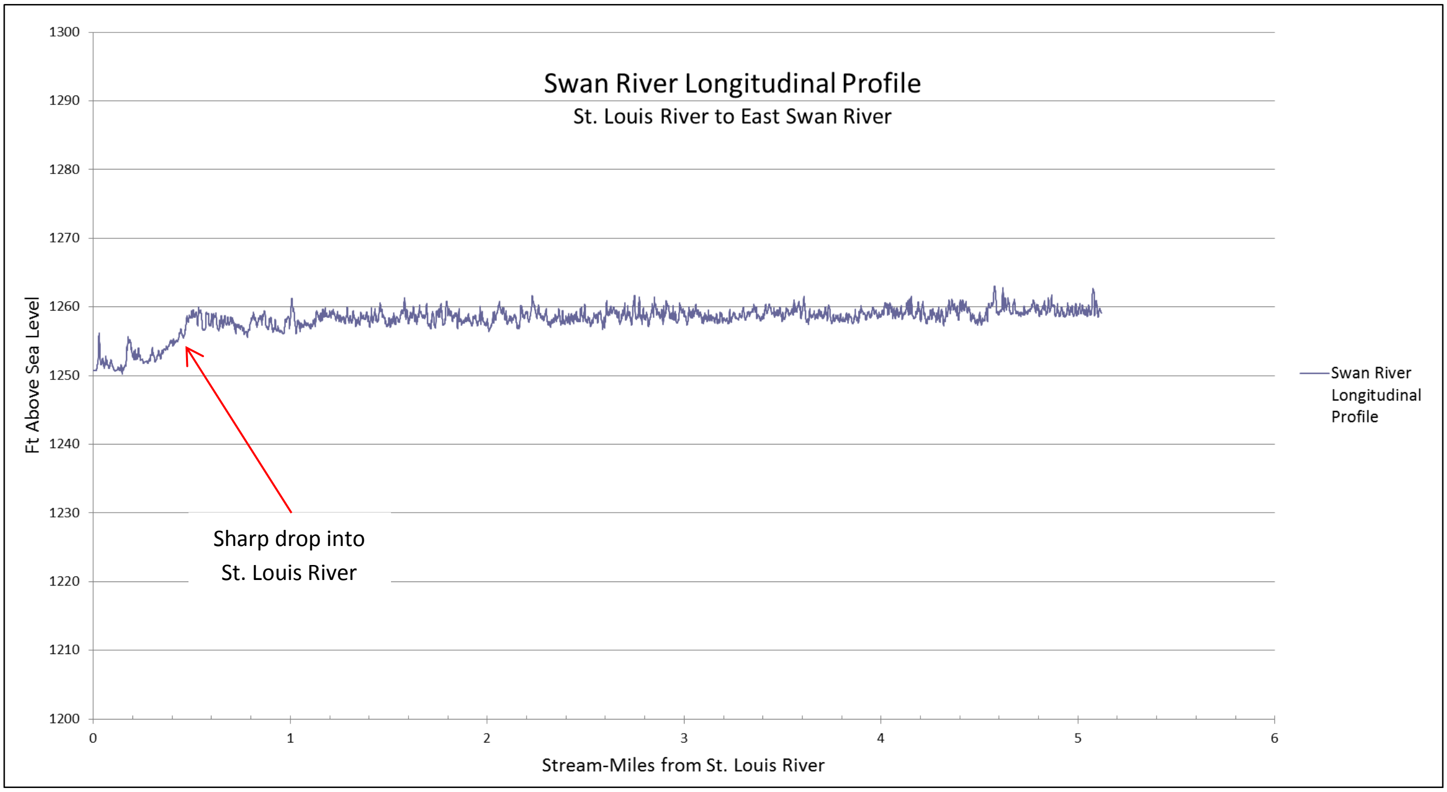


Figure 28: Swan River longitudinal profile from St. Louis River to East/West Swan River.

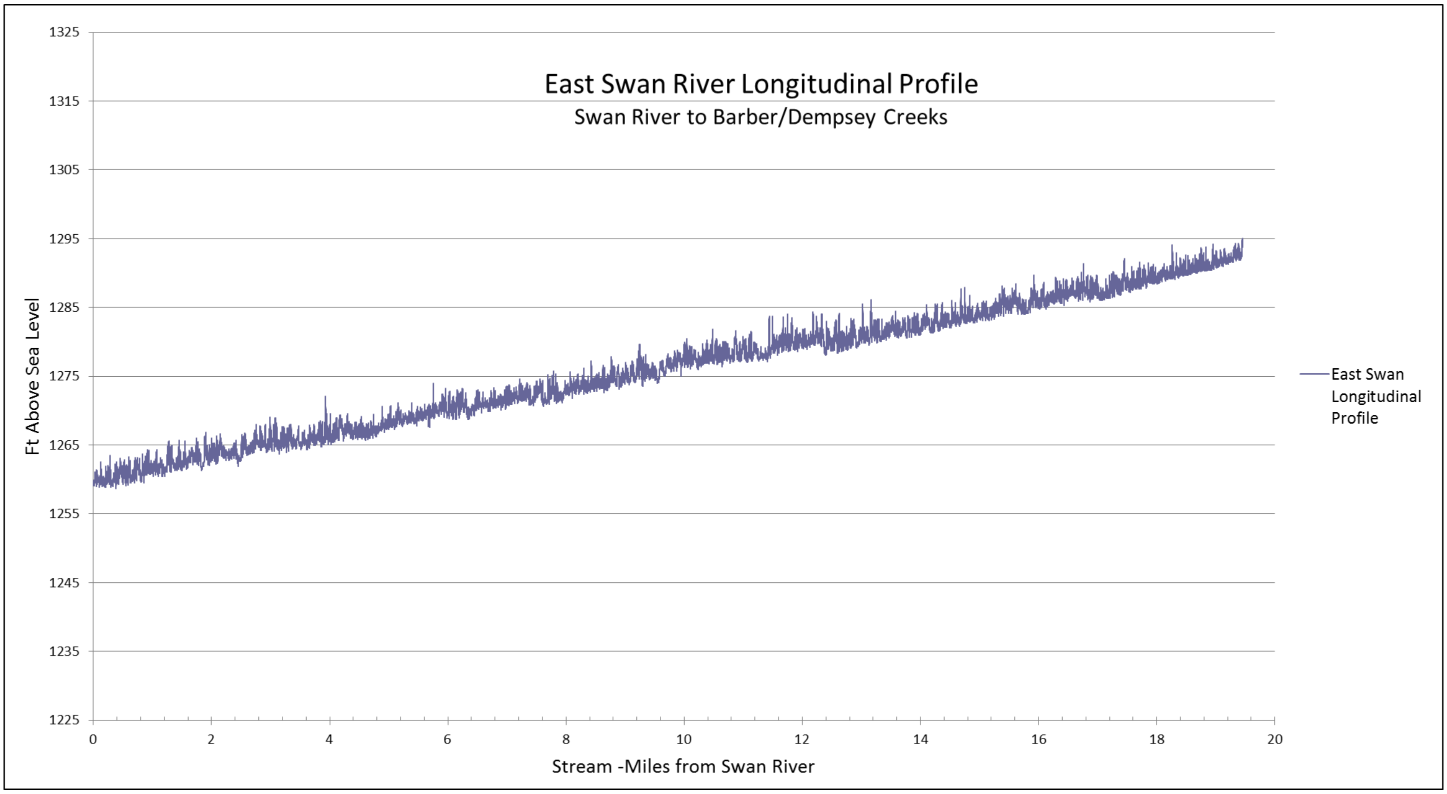


Figure 29: East Swan River longitudinal profile from Swan River to Dempsey/Barber confluence.

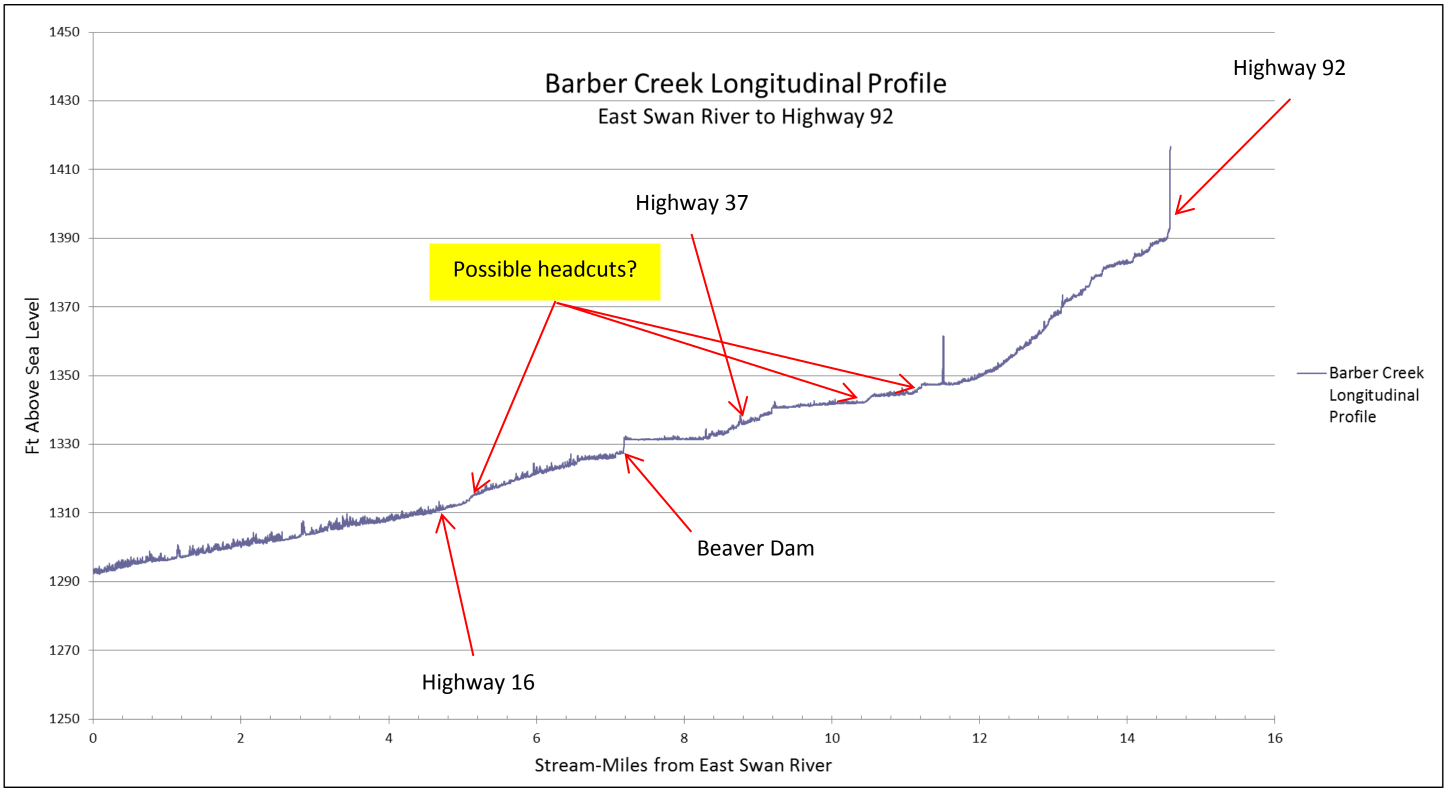


Figure 30: Barber Creek longitudinal profile from East Swan River to Highway 92.

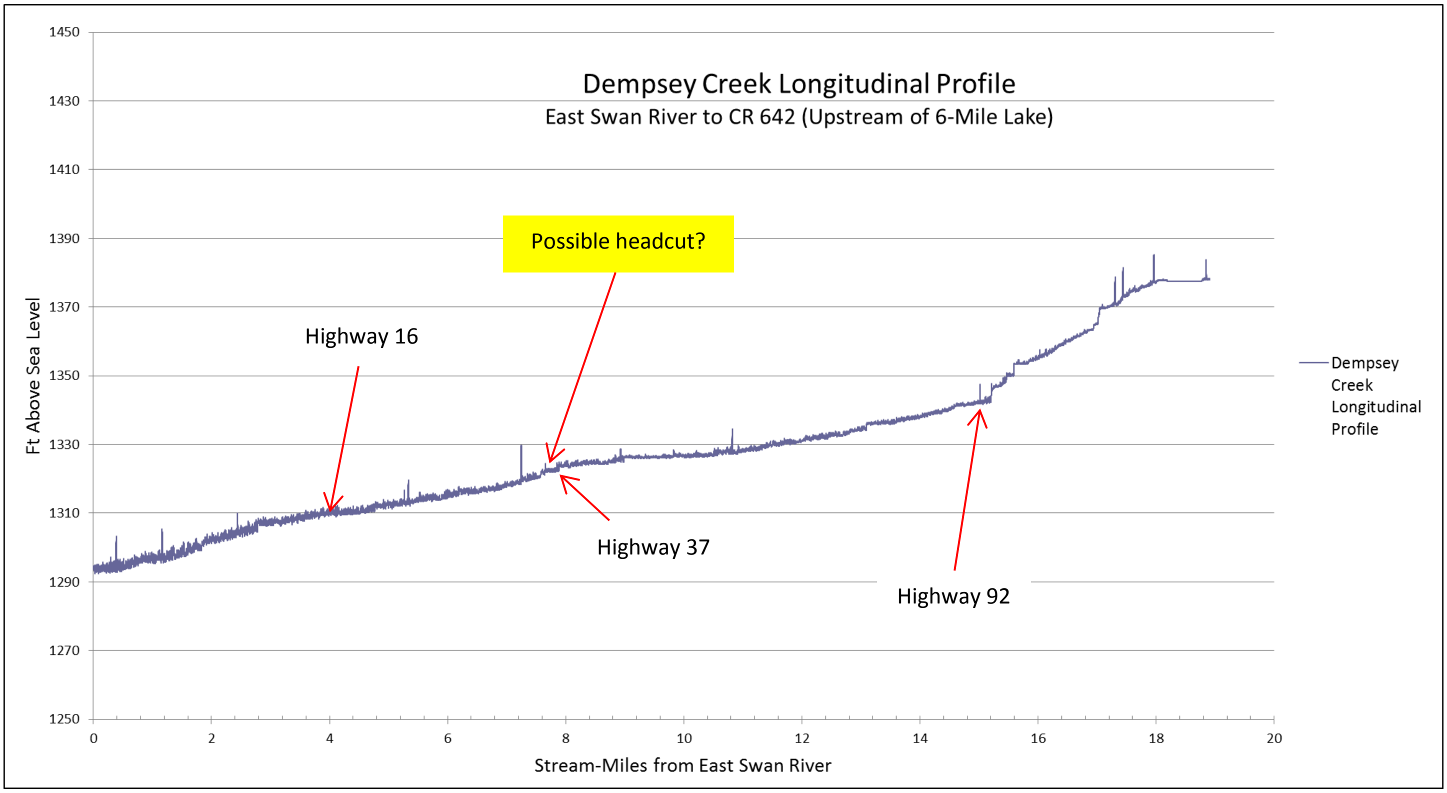


Figure 31: Dempsey Creek longitudinal profile from East Swan River to County Road 642 upstream of Six-Mile Lake.

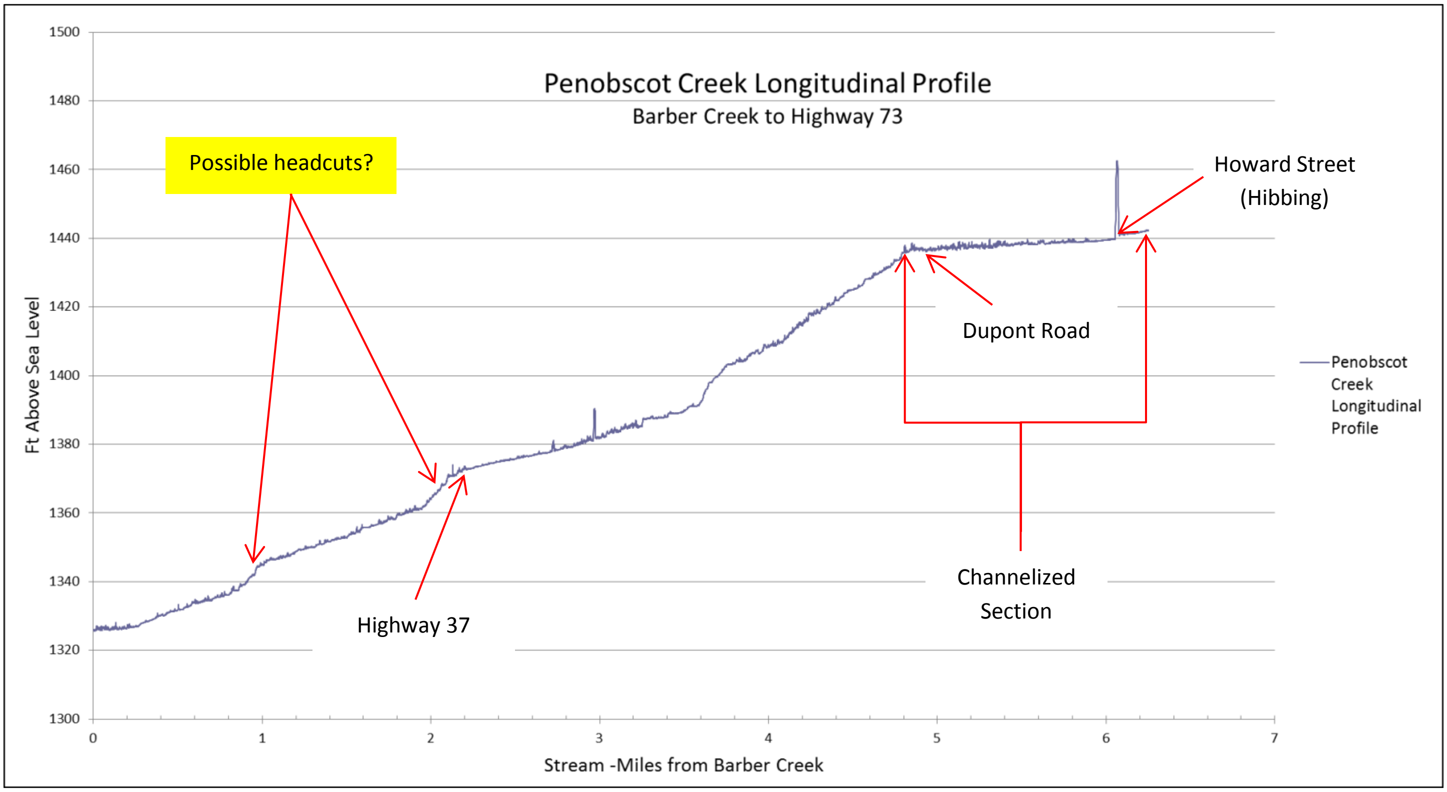


Figure 32: Penobscot Creek longitudinal profile from Barber Creek to Highway 72 in Hibbing.

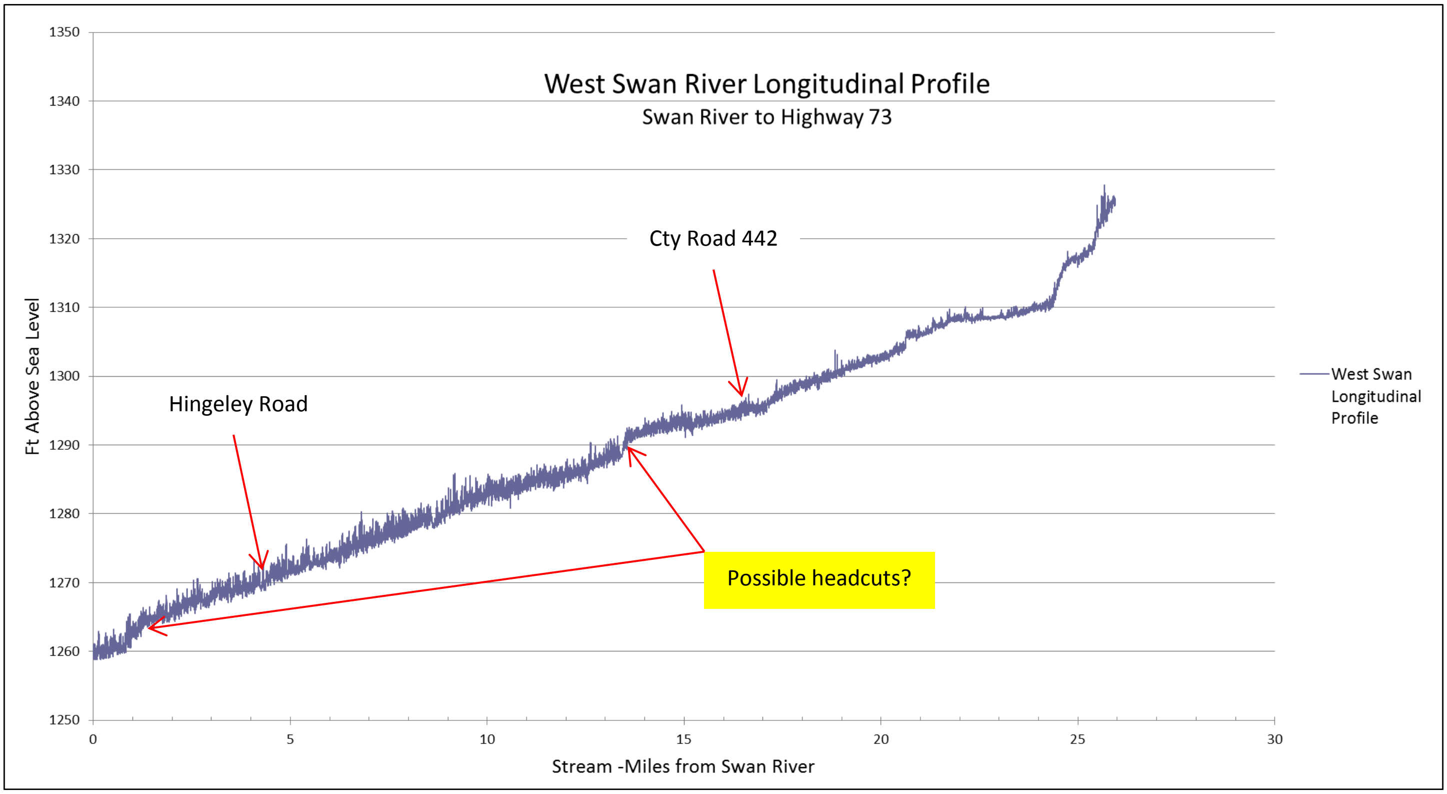


Figure 33: West Swan River longitudinal profile from Swan River to Highway 73.

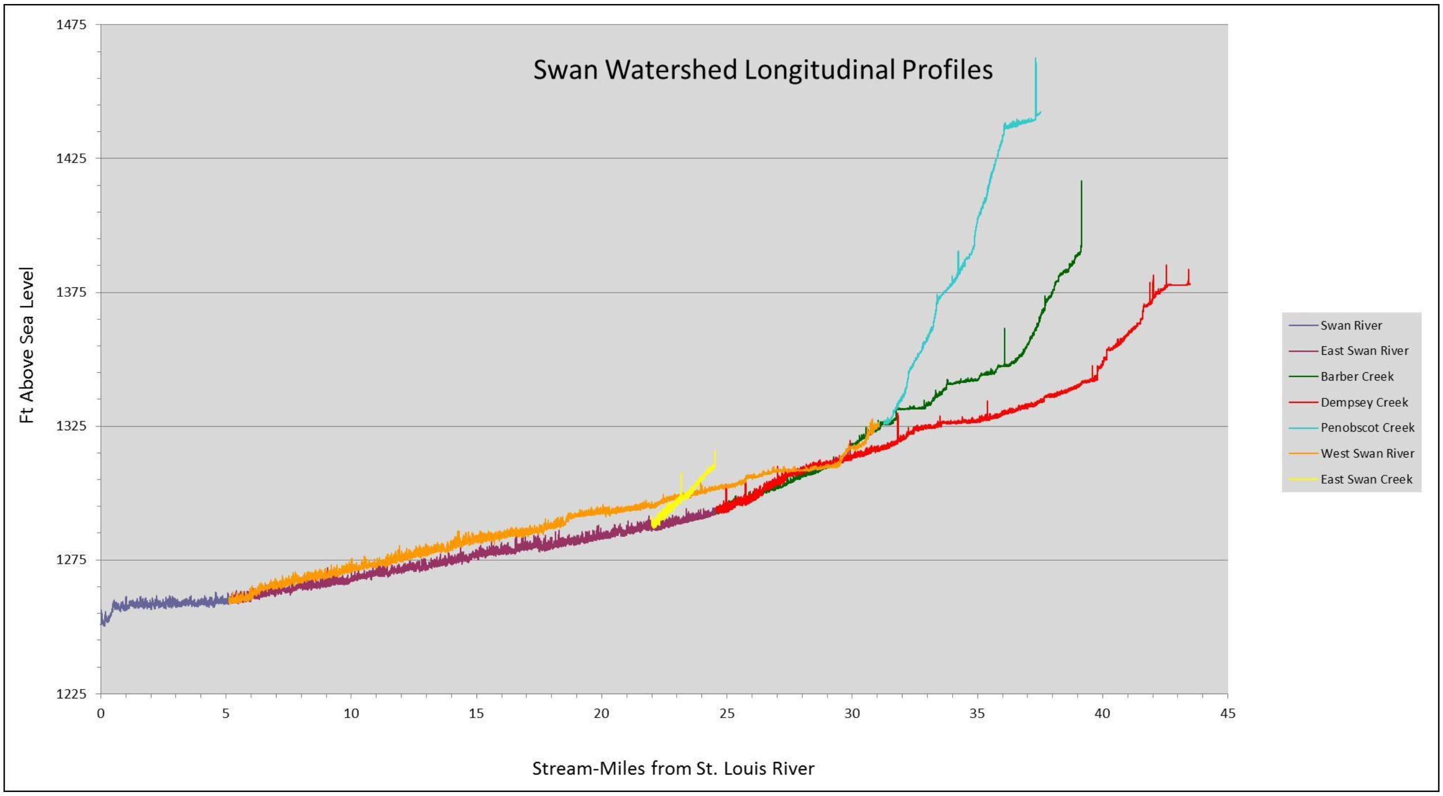


Figure 34: Combined longitudinal profile of main trunk and large tributaries in the Swan River watershed.

Discussion

Possible headcuts were located within the longitudinal profiles of Barber, Dempsey, and Penobscot Creeks and the West Swan River. To determine their connection to stream stability, it is crucial to validate whether or not these headcuts are mobile or fixed (stable).

Fixed or stable headcuts will be generated where rivers flow over resistant lithology or where plentiful coarse sediment supply prevents degradation and erosion (Crosby, 2012). The best evidence for a stable headcut in this watershed would most likely be found right at the headcut location in the form of an increase in substrate size.

Mobile headcuts, on the other hand, are usually initiated from some downstream base-level drop and propagate upstream. This type of headcut causes incision leading to increased bank height and near-bank shear stress. It can initiate channel evolution, turning a stable “C” or “E” channel into a “G” and later “F” channel, greatly increasing suspended sediment in a stream (Rosgen, 2006). The best evidence for a mobile headcut is an abandoned terrace or set of terraces that project from the headcut downstream (Crosby, 2012). If the headcut is propagating faster than the downstream reach can re-form bankfull depositional surfaces, the stream channel will also be incised immediately below the headcut. The headcut would not be contained only to main trunk channels but also propagate into smaller tributaries. Thus, another supporting clue for mobile headcuts is the presence of headcuts of similar height in downstream tributaries.

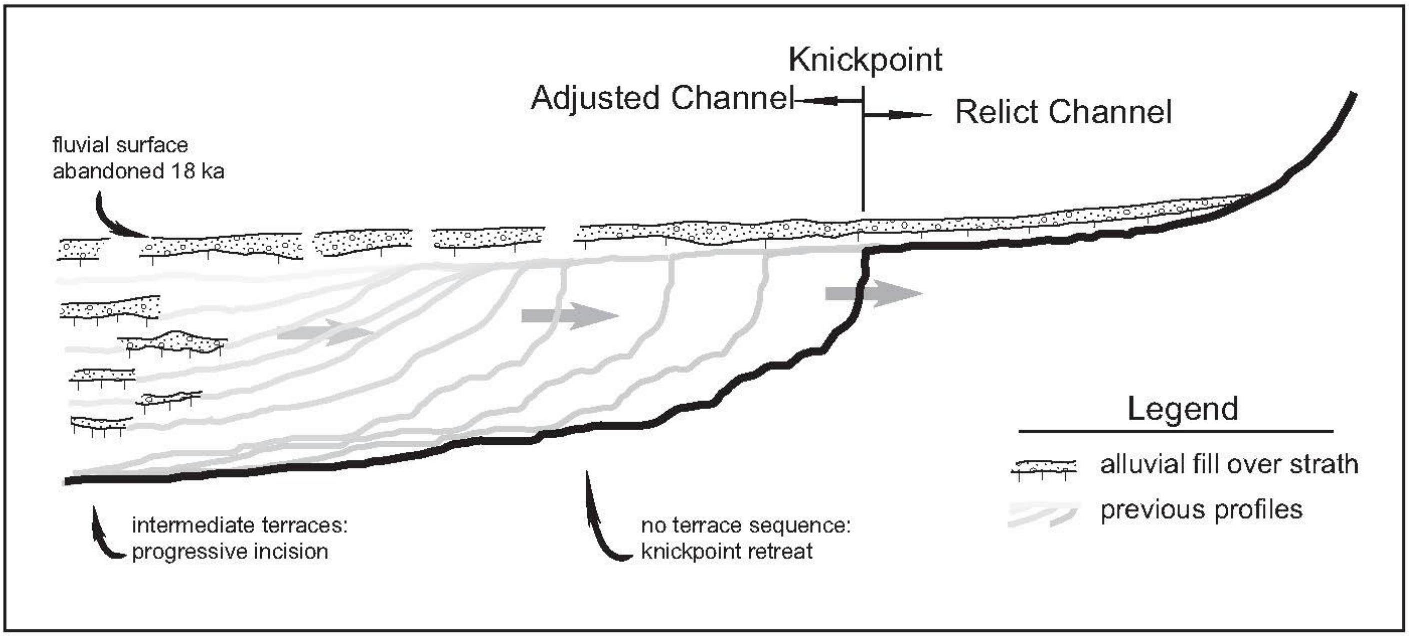


Figure 35: Longitudinal profile of a typical headcut (knickpoint) showing upstream propagation. Abandoned fluvial surfaces can be traced upstream to the location of the knickpoint.

The exact spatial locations of several potential mobile headcuts were determined using LiDAR data and the longitudinal profiles shown above. One such location on Barber Creek is shown in Figure 36. To find out whether or not these headcuts were mobile, cross-sections of the stream channel and valley were drawn with 3D Analyst at points above and below the headcut (Figure 37). If the headcut was indeed propagating upstream, the cross-section below the headcut would show an incised channel with a lack of bankfull depositional surfaces and would show abandoned terraces at similar elevations to the upstream cross-section bankfull surface.

This turned out to be the case in at least six headcuts. Examples of headcuts on Barber Creek and the West Swan River that were determined to be mobile are shown in Figure 37 and Figure 39 . In these cases, the bankfull surfaces in the upstream cross-section line up with the low terrace in the downstream cross-section. There is a lack of bankfull surfaces in both downstream cross-sections, indicating that the headcut moved through too recently for new bankfull surfaces to form. The Barber Creek headcut contained another clue – the presence of a similarly-sized headcut in a downstream tributary (see Figure 36 and Figure 38).

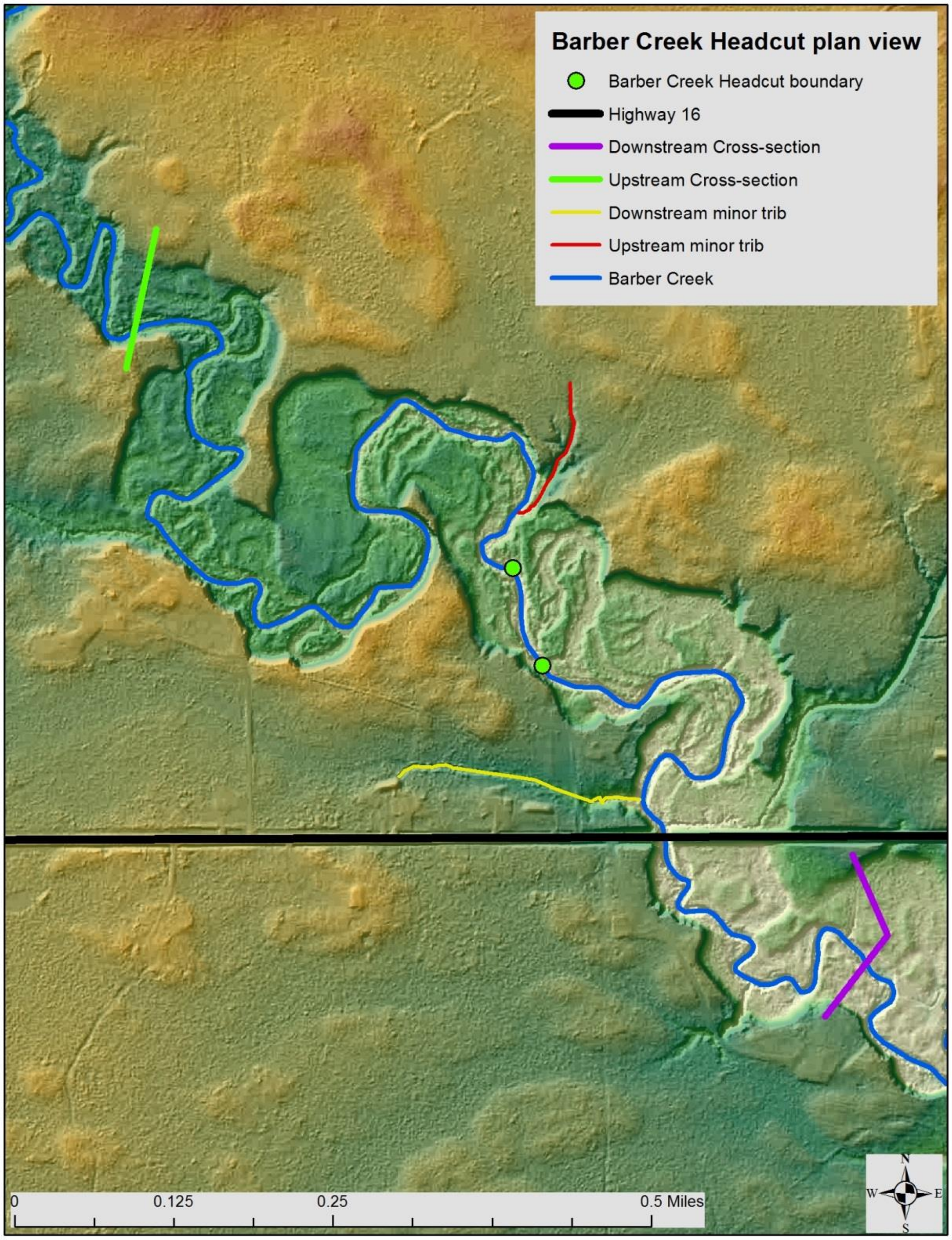


Figure 36: Plan view of headcut location on Barber Creek, just upstream of Highway 16

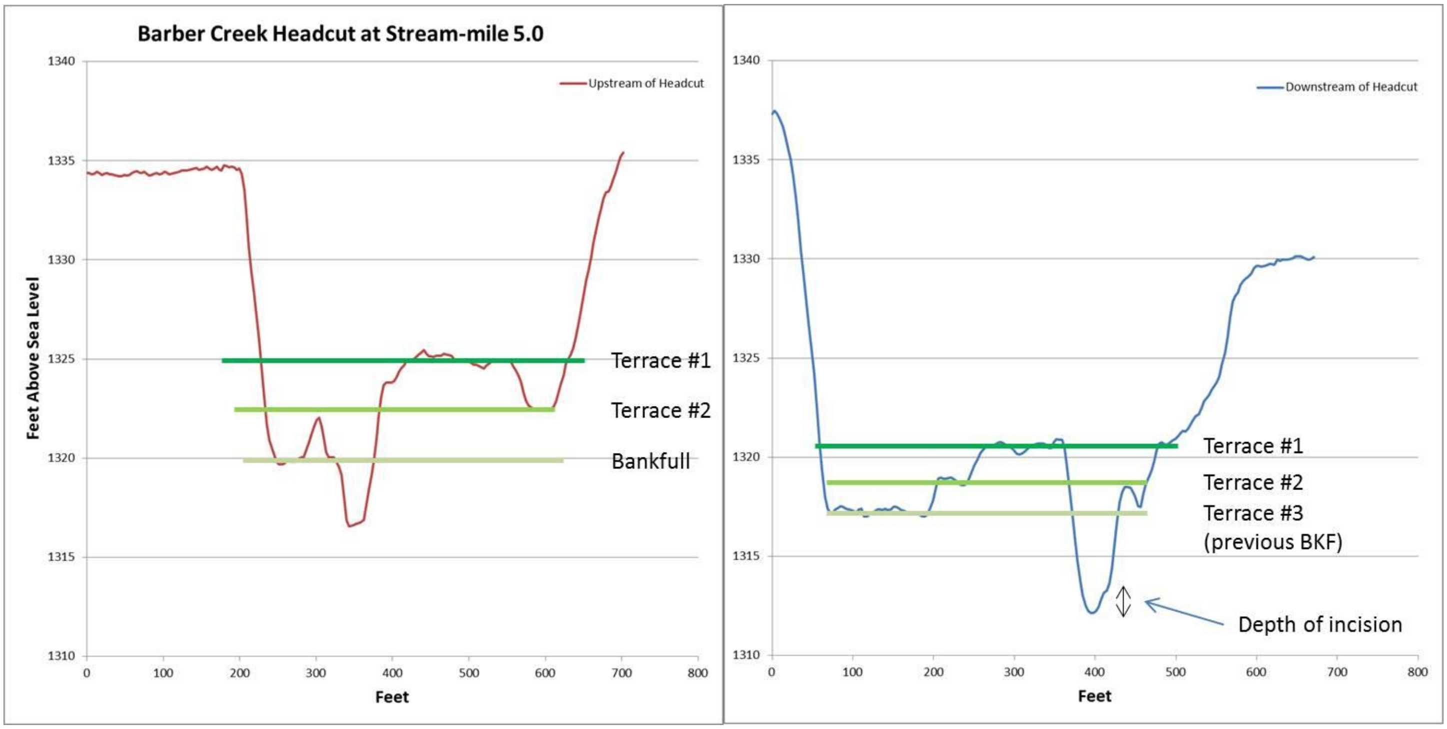


Figure 37: Cross-sections of Barber Creek, located above and below a suspected headcut.

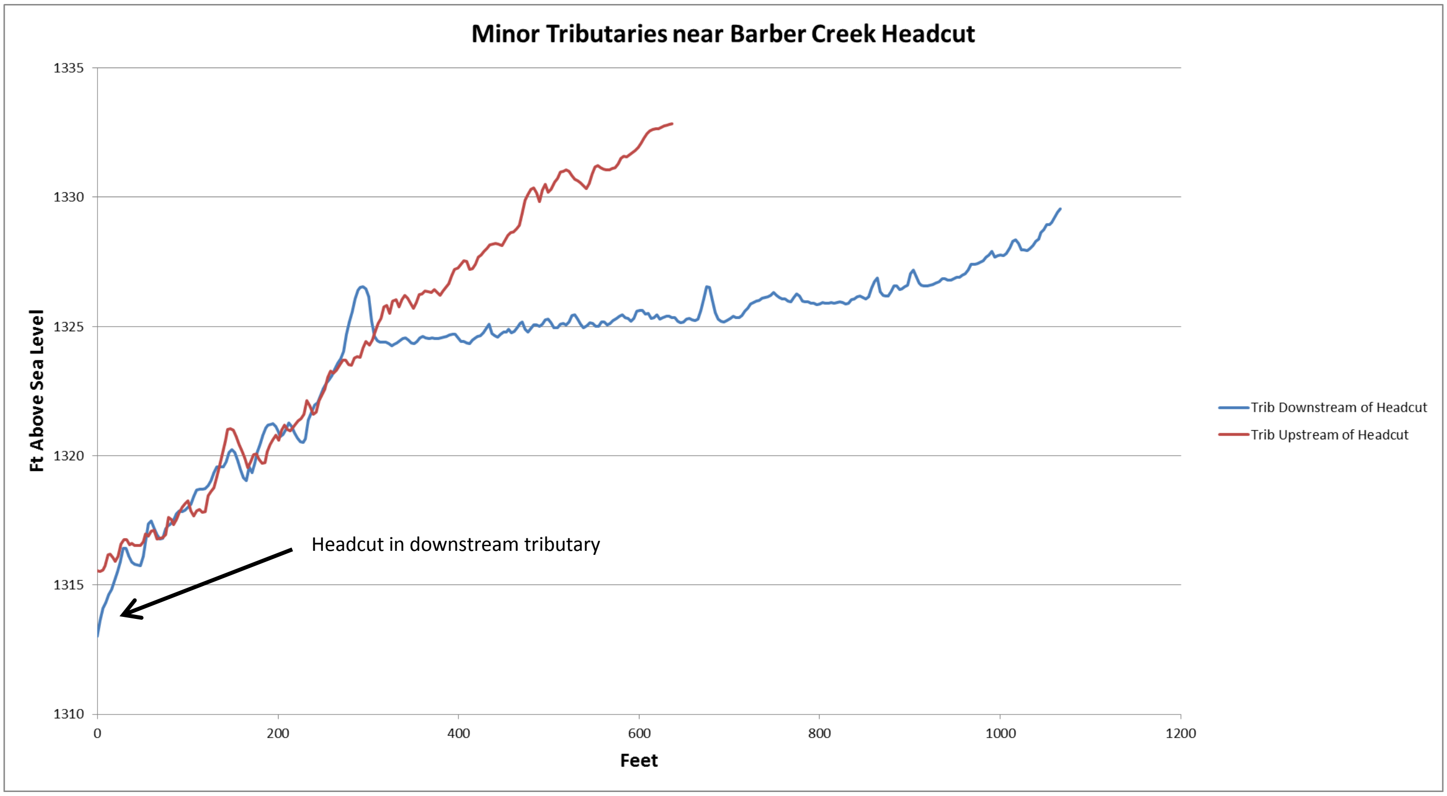


Figure 38: Longitudinal profiles of two minor tributaries to Barber Creek, located above and below a suspected headcut.

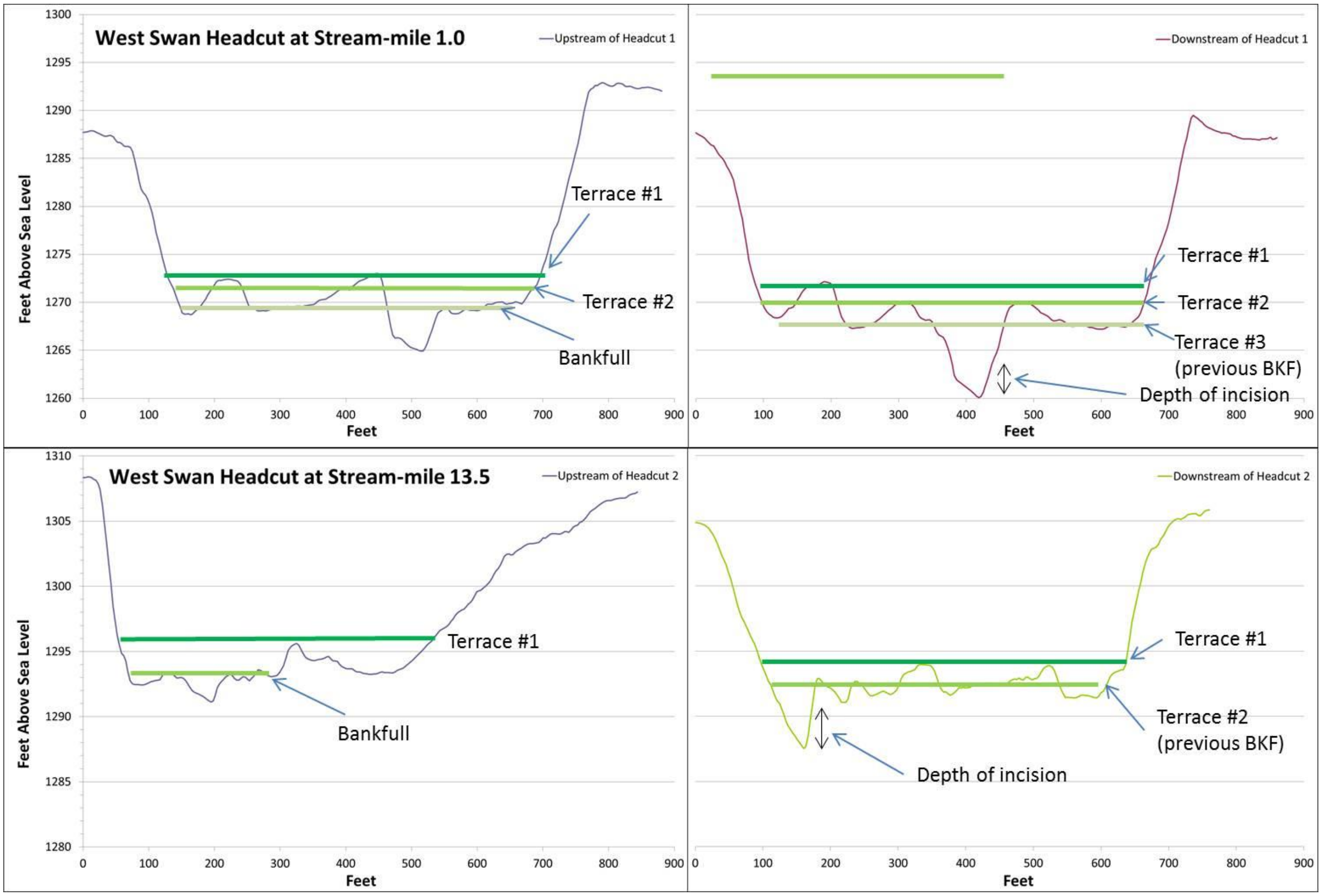


Figure 39: Cross-sections above and below two suspected headcuts on the West Swan River.

A map of all potential mobile headcuts is shown in Figure 40. The “mobile” headcuts are entirely contained within the glacial lakebed that encompasses the lower half of the watershed. The fine lacustrine deposits associated with that lakebed are probably not significantly impeding headcut progression. It is important to note two caveats that accompany this analysis. First, no attempt was made to determine the propagation rate of headcuts in this system. Such an attempt would require field data and long-term monitoring of the site. Second, labeling a headcut “mobile” at this point is not a guarantee. Although desktop reconnaissance is useful for narrowing the scope and focus of field forays, nothing can replace actual field reconnaissance and data collection. The authors recommend long term monitoring of these sites to validate the analysis made here.

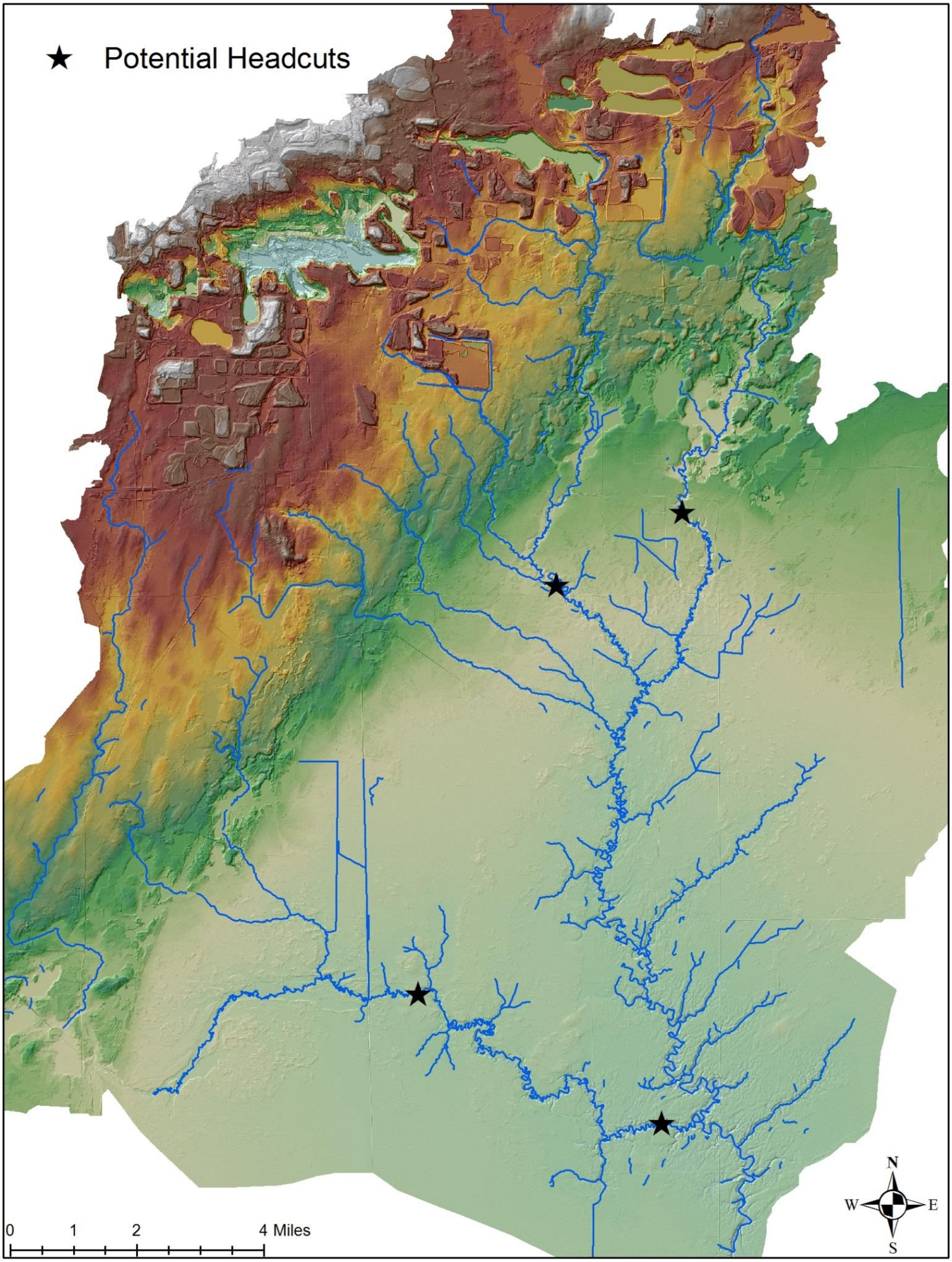


Figure 40: Map of all potential headcuts contributing to stream instability in the Swan River watershed.

6. Historical Photo Analysis

Methods

Historical photos from the DNR Historic Airphoto Index were analyzed to approximate bank and meander migration rates. The photos used in this analysis were all from 1939 – the earliest photos available in that area. Photos were imported as .jpegs into ArcMap, then geo-referenced using the geo-referencing tool. At least five control points were placed for each airphoto to limit error. Control points were placed on structures or landmarks that have not changed their position since 1939, such as old farmsteads and the centers of road intersections. Even so, the match was not perfect, and each control point had an associated RMS error.

Truly analyzing the meander migration and bank erosion in these systems since 1939 would be a very time-consuming process, involving thousands of measurements of bank advance along the entire stretch in question. Needless to say, that was not attempted here. As a substitute, ten banks on each stream located on outside bends were randomly chosen for analysis. Using the measurement tool in ArcMap, the spatial difference between the 1939 bank and the 2011 bank (the Bing Maps base layer uses 2011 imagery) was measured and recorded, along with the associated error of the closest geo-referencing control point (see Table 8 and Table 9).

Discussion

Using the measured bank change and the geo-referencing error, a maximum and minimum change for each bend was determined, as well as maximum and minimum yearly rates. An average yearly rate is shown graphically in Figure 41. As we can see, erosion rates of 0.5 feet/year are common, especially within the Penobscot system and in Barber Creek south of Hwy 16. Three bends had yearly erosion rates of 0.96, 0.98, and 0.95 feet/year. Using these rates, sediment yields can be estimated.

In order to determine whether or not these migration rates are abnormally high and are causing some of the high TSS values (discussed in Section 1), further historic photo analyses should be undertaken for other eras and areas of the Swan River watershed.

Table 8: Results from historical photo analysis.

River Name	LAT	LONG	Measured Bank Change (ft)	Error (ft)	Maximum Change	Minimum Change	Aveage Yearly Rate	Rate/ 10 Years
Dempsey	512614	5244273	16.31	0.00000074	16.31	16.31	0.23	2.27
Dempsey	513105	5244467	6.08	0.00000022	6.08	6.08	0.08	0.84
Dempsey	513435	5244888	14.14	0.00000022	14.14	14.14	0.20	1.96
Dempsey	513473	5245509	4.05	0.00000007	4.05	4.05	0.06	0.56
Dempsey	513658	5246164	34.01	0.00000005	34.01	34.01	0.47	4.72
Dempsey	513791	5246342	17.46	0.00000005	17.46	17.46	0.24	2.43
Dempsey	514113	5247034	23.02	0.00000011	23.02	23.02	0.32	3.20
Dempsey	514111	5247735	11.26	0.00000011	11.26	11.26	0.16	1.56
Dempsey	513712	5248214	21.53	0.00000004	21.53	21.53	0.30	2.99
Dempsey	513415	5248745	11.07	6.98818898	18.06	4.08	0.15	1.54
Dempsey	513418	5249476	19	5.47900262	24.48	13.52	0.26	2.64
Dempsey	514438	5250655	19.07	6.52887139	25.60	12.54	0.26	2.65
Dempsey	514853	5252086	18.84	6.16797900	25.01	12.67	0.26	2.62
Dempsey	515357	5253238	20.74	11.08923885	31.83	9.65	0.29	2.88
Dempsey	515355	5253935	13.18	11.08923885	24.27	2.09	0.18	1.83
Dempsey	516090	5255112	7.47	11.08923885	18.56	-3.62	0.10	1.04
Dempsey	515171	5255731	16.59	0.00000075	16.59	16.59	0.23	2.30
Dempsey	514131	5255567	6.09	0.00000071	6.09	6.09	0.08	0.85
Dempsey	514329	5255836	11.97	0.00000071	11.97	11.97	0.17	1.66
Dempsey	514934	5257414	11.08	0.00000047	11.08	11.08	0.15	1.54
Barber	512440	5244249	47.18	0.00000074	47.18	47.18	0.66	6.55
Barber	512219	5244556	22.05	0.00000019	22.05	22.05	0.31	3.06
Barber	511948	5245050	37.69	0.00000019	37.69	37.69	0.52	5.23
Barber	511872	5245201	69.32	0.00000015	69.32	69.32	0.96	9.63
Barber	511313	5245797	12.3	0.00000015	12.30	12.30	0.17	1.71
Barber	510945	5246003	70.91	25.49212598	96.40	45.42	0.98	9.85
Barber	510783	5246234	43.95	8.69422572	52.64	35.26	0.61	6.10
Barber	510519	5246673	15.21	0.00000004	15.21	15.21	0.21	2.11
Barber	509640	5247272	17.88	0.00000002	17.88	17.88	0.25	2.48
Barber	510299	5248798	29.09	0.00000005	29.09	29.09	0.40	4.04
Barber	510829	5249298	6.27	0.49212598	6.76	5.78	0.09	0.87
Barber	511073	5251073	7.31	0.19685039	7.51	7.11	0.10	1.02
Barber	511139	5252403	19.56	2.39501312	21.96	17.16	0.27	2.72
Barber	511044	5253776	11.13	4.95406824	16.08	6.18	0.15	1.55
Barber	511194	5254646	23.07	5.24934383	28.32	17.82	0.32	3.20

Table 9: Results from historical photo analysis (continued)

River Name	LAT	LONG	Measured Bank Change (ft)	Error (ft)	Maximum Change	Minimum Change	Aveage Yearly Rate	Rate/ 10 Years
Penobscot	508931	5247788	42.46	0.45931759	42.92	42.00	0.59	5.90
Penobscot	508617	5248030	29.53	0.98425197	30.51	28.55	0.41	4.10
Penobscot	508648	5248599	22.13	0.98425197	23.11	21.15	0.31	3.07
Penobscot	508615	5249002	7.82	4.92125984	12.74	2.90	0.11	1.09
Penobscot	508473	5249313	26	4.92125984	30.92	21.08	0.36	3.61
Penobscot	508713	5249781	31.49	0.78740157	32.28	30.70	0.44	4.37
Penobscot	508911	5250247	56.33	0.78740157	57.12	55.54	0.78	7.82
Penobscot	508549	5250784	45.08	1.14829396	46.23	43.93	0.63	6.26
Penobscot	508310	5251381	68.36	0.32152231	68.68	68.04	0.95	9.49
Penobscot	506206	5252611	19.31	0.25918635	19.57	19.05	0.27	2.68
East Swan River	513908	5233375	25.16	0.00000001	25.16	25.16	0.35	3.49
East Swan River	513665	5234309	20.03	0.00000001	20.03	20.03	0.28	2.78
East Swan River	512930	5236032	15.68	6.66010499	22.34	9.02	0.22	2.18
East Swan River	512319	5237346	17.19	5.90551181	23.10	11.28	0.24	2.39
East Swan River	511395	5238423	27.1	0.95144357	28.05	26.15	0.38	3.76
East Swan River	511499	5239909	14.65	0.82020997	15.47	13.83	0.20	2.03
East Swan River	512034	5240946	12.38	0.00000008	12.38	12.38	0.17	1.72
East Swan River	511814	5242665	14.8	4.23228346	19.03	10.57	0.21	2.06
East Swan River	512247	5243642	19.75	0.00000010	19.75	19.75	0.27	2.74
East Swan River	512497	5244007	49.68	0.00000010	49.68	49.68	0.69	6.90
Swan River	515034	5231626	16.32	2.36220472	18.68	13.96	0.23	2.27
Swan River	514956	5232149	27.49	2.36220472	29.85	25.13	0.38	3.82
West Swan River	513128	5233086	16.11	4.95406824	21.06	11.16	0.22	2.24
West Swan River	512262	5232903	22.48	4.95406824	27.43	17.53	0.31	3.12
West Swan River	511215	5233571	28.38	2.06692913	30.45	26.31	0.39	3.94
West Swan River	510519	5233949	25.01	1.64041995	26.65	23.37	0.35	3.47
West Swan River	509169	5234721	41.63	11.08923885	52.72	30.54	0.58	5.78
West Swan River	508249	5235232	16.18	14.40288714	30.58	1.78	0.22	2.25
West Swan River	507559	5235588	20.74	14.40288714	35.14	6.34	0.29	2.88
West Swan River	506044	5236278	25.53	6.92257218	32.45	18.61	0.35	3.55
West Swan River	505357	5236253	28.06	8.89107612	36.95	19.17	0.39	3.90
West Swan River	504639	5236559	37.75	6.59448819	44.34	31.16	0.52	5.24

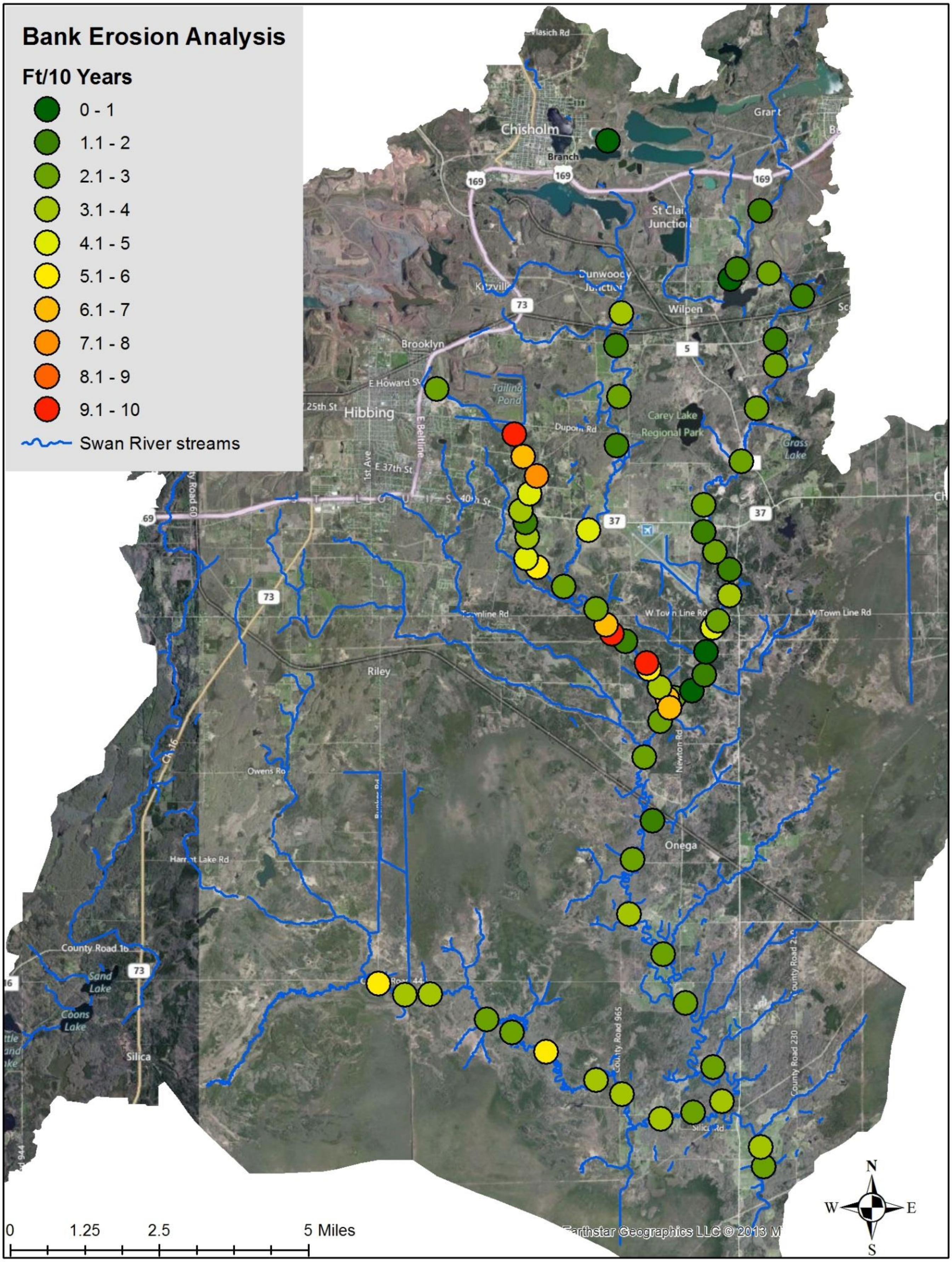


Figure 41: Measured erosion rates on outer bends in the Swan River watershed.

7. Summary

Conclusions

Historic or prehistoric headcut propagation through lacustrine deposits has caused channels in the Swan River watershed to become unstable. Similar to the *East Swan River Geomorphic Study,* this report concludes that significant channel instability is occurring in the lower reaches of the Barber and Dempsey Creek systems. This conclusion is confirmed and quantified by TSS results, geomorphic assessments, culvert evaluations, LiDAR profiles, and historic photo analysis. However, these data also point to several other areas of channel instability where suspended sediment is a probable stressor to aquatic life. The following is a list of problem areas where channel instability is occurring and the data-based rationale for listing:

1. Barber Creek, between Hwy 37 and Hwy 16.
    a. A large increase in suspended sediment occurred in this reach during the 2013 snowmelt sampling event (from 6 mg/L to 46 mg/L).
    b. Pfankuch stability ratings are moderately unstable to unstable.
    c. Incision ratios in this reach increase from stable at the upstream end to moderately incised at Hwy 16.
    d. LiDAR analysis revealed the possibility of a mobile headcut within this reach.
    e. Bank erosion rates were very high, with an average of 6ft every 10 years.
2. Dempsey Creek, between Hwy 37 and the Barber/Dempsey confluence.
    a. Suspended sediment values during snow melt increased from 3.6 mg/L north of Hwy 37 to 35 mg/L just upstream of the Barber confluence.
    b. Pfankuch stability ratings are moderately unstable to unstable.
    c. Channel incision increases from stable north of Hwy 37 to slightly or moderately incised downstream (incision ratios of 1.3, 1.4, and 1.3 were recorded).
    d. The channel is moderately entrenched just upstream of the mouth, with an entrenchment ratio of 2.0.
    e. The reach just upstream of the Dempsey Creek mouth is classified as a low gradient G channel, with low width/depth ratio and high entrenchment. High sediment yields are expected from this type of channel.
    f. All but one road crossing downstream of Hwy 37 are too narrow, having Bkf W/Culvert W ratios greater than 1.2.
    g. LiDAR analysis revealed the possibility of a mobile headcut within this reach.
    h. Bank erosion rates are moderate, with an average of 3.4 ft every 10 years.
3. The entirety of Penobscot Creek, from the outlet of the stormwater pipe at Hwy 73 to Barber Creek.
    a. Relatively high suspended sediment values were sampled in 2013 (40.4 mg/L) compared to Penobscot's drainage area. In fact, this site had the highest TSS/Drainage Area ratio in the watershed.
    b. Pfankuch stability scores are unstable in the channelized reaches of Penobscot Creek.
    c. Moderate channel incision ratios are seen in the channelized reaches upstream of Dupont Road. (1.3 and 1.4).
    d. The channel is moderately entrenched through the channelized portion, with ratios of 1.5 and 1.6.
    e. Low gradient G channel types were documented in the channelized portion of Penobscot Creek upstream of Dupont Road. These are both unstable channels and high sediment yields can be expected.
    f. All road crossings located on the Penobscot main trunk have Bkf W/Culvert W ratios greater than 1.2.
    g. Bank erosion rates are high, with an average of 5.1ft every 10 years.
4. West Swan River, between County Road 442 and the East/West Swan confluence.

    a. Suspended sediment values increase dramatically, from 1.6mg/L near CR 422 to 88 mg/L just upstream of the West Swan River mouth.
    b. Pfankuch stability ratings are unstable.
    c. Channel incision increases from stable at County Road 442 to moderately incised at Hingely Road to deeply incised (ratio of 1.8) at the West Swan River mouth.
    d. The channel is highly entrenched just upstream of the mouth, with a ratio of 1.5
    e. The reach upstream of the West Swan River mouth is typed as an "F" channel, with high width/depth and entrenchment. High sediment yields are expected from this channel type.
    f. LiDAR analysis revealed the possibility of two mobile headcuts within this reach.
5. Little Swan Creek, upstream of CR 444.
    a. Suspended sediment values during snowmelt are relatively high for the drainage area (25.2 mg/L)
    b. Pfankuch stability rating at the rapid assessment site at CR 444 is unstable.
    c. The reach at CR 444 is moderately incised, with a bank height ratio of 1.4.
6. East Swan River between County Road 444 and Zim Road.
    a. Suspended sediment values during snowmelt more than doubled, increasing from 34.4 mg/L to 71 mg/L
    b. Pfankuch stability ratings in this reach are unstable.
    c. The channel is deeply incised in this reach, with bank height ratios of 1.8 at CR 444 and Helstrom Road.
    d. The channel is moderately entrenched at Helstrom Road, with a ratio of 1.5.
    e. The site at Helstrom Road typed out as a low gradient G channel, with low width/depth ratio and high entrenchment. High sediment yields are expected from this type of channel.
7. East Swan River and Swan River, between County Road 442 and Oja Road.
    a. Suspended sediment values during snowmelt increased from 74.8 mg/L to 173 mg/L
    b. Pfankuch stability ratings in this reach are unstable.
    c. Channel incision increases from slightly incised at County Road 442 to deeply incised at the East Swan River mouth (bank height ratio of 1.9) and the Swan River at Hwy 5 (ratio of 1.6).
    d. Entrenchment near the East Swan/Swan River confluence is moderate (ratio of 1.6).
    e. The site near the mouth of the East Swan River is classified as a low gradient G channel, with low width/depth ratio and high entrenchment. High sediment yields are expected from this type of channel.

The long-term stability of these reaches relates directly to the channel evolution model that each reach is currently undergoing. This study has determined that most unstable reaches started as stable "E" channels in low-gradient alluvial valleys, then experienced incision as a result of increased sediment-carrying capacity (from either increased slope from headcut propagation and/or increased peak flows from watershed development). Due to that, and the fact that there are not many "G" or "F" channels (except in the lower reaches of the system), it is theorized that the evolutionary stage for most of these unstable reaches is somewhere between steps 1 and 3 in the stream evolution model in Figure 42. In this scenario, the streams widen after the initial downcutting event to recreate a floodplain at a lower base elevation.

In these scenarios, the initial instability leads to degradation and incision. This report concludes that headcut propagation is the cause of instability in all the reaches except Penobscot Creek, which is unstable due to historic channelization. Propagating headcuts trigger incision, leading to higher shear stress on the banks and poorer condition of the channel, and then manifested in increase suspended sediment values. Figure 43 clearly shows this correlation in the Swan River watershed.

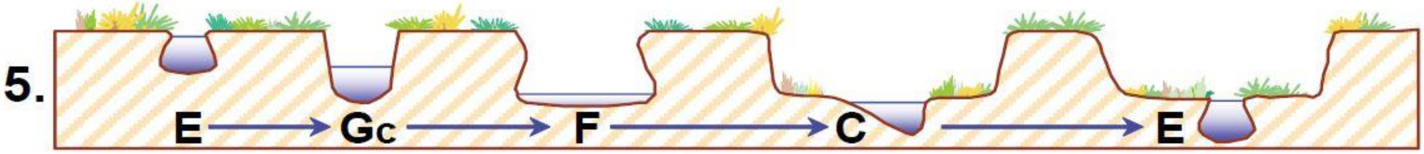


Figure 42: Hypothesized channel evolution model (presented by Dave Rosgen and others) in the Swan River watershed, where the channel cuts down into its bed, then erodes its banks before finally recreating a new floodplain at a lower elevation. Many reaches in the lower West and East Swan Rivers are farther along in the evolutionary process and have probably succeeded to "F" channels.

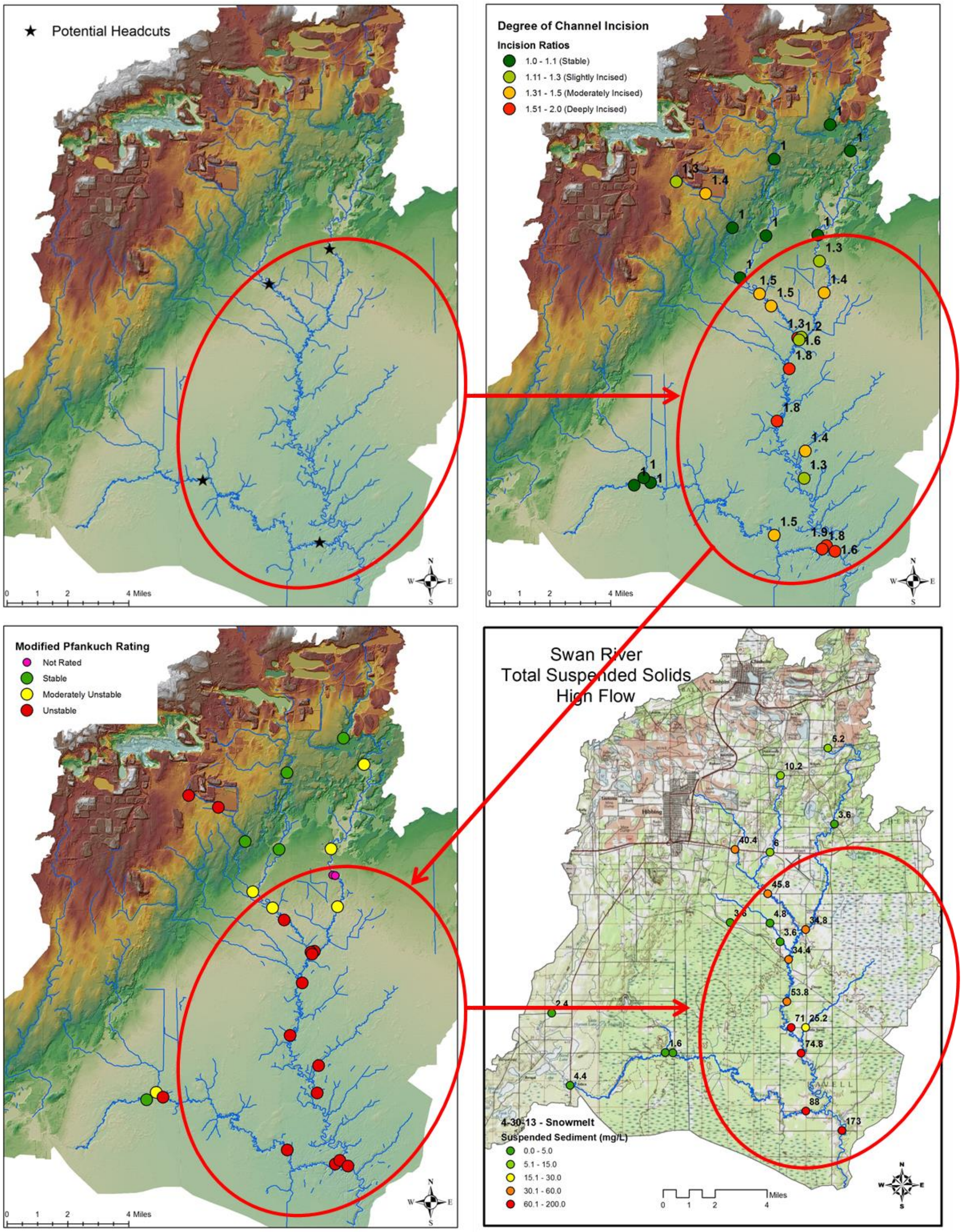


Figure 43: Headcut locations, compared with channel incision, Pfankuch stability, and suspended sediment results.

Recommendations

There are basically two options with any unstable channel in need of restoration. The first is the “do nothing” option. Given enough time (and no further land use or climatic changes), these downcut channels will eventually widen and form new flood plains at a lower elevation. This scenario is shown in evolution Models #1 and #5 (Figure 42). This option costs nothing in terms of project dollars; rather the cost would be realized in untold amounts of entrained sediment while the channel re-equilibrates. Aquatic life will continue to suffer as eroded sediment degrades habitat. Structures and other property could be threatened as banks erode and fail. Additionally, the lowering of the water table could be very detrimental to floodplain plant communities, which generally consist of species that have adapted to shallow water tables and frequent inundation.

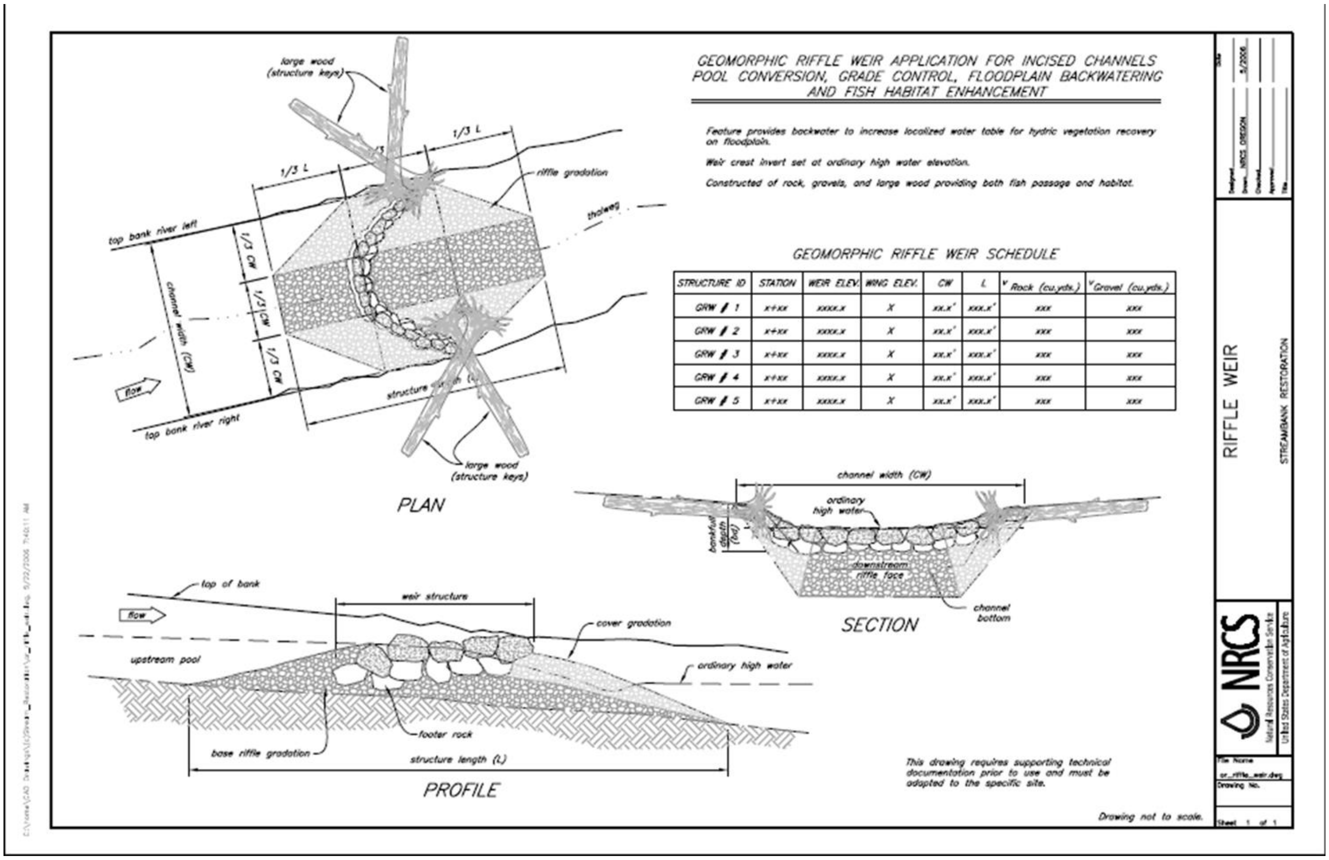
The second option is to attempt to hinder, reverse, or accelerate channel succession. For example, in the case of channel evolution Model #5, installing grade control (Figure 44) above a headcut would prevent headcut propagation. In essence this would hinder channel succession, preventing the evolution of an “E” channel into a “G”. Installing flood-plain culverts (Figure 45) would improve flow conditions and hinder channel degradation and succession, but ultimately would not address the problem of headcut advancement. Installation of stormwater retention BMPs (Best Management Practices) throughout the watershed would also hinder channel succession by attenuating peak flows and reducing shear stresses on channel banks.

Channel succession could also be reversed by installing grade control in an incised reach, and then converting the upstream “G” or “F” channel back to a stable “E” at the previous channel elevation (Figure 46). Due to the vast amount of fill material required, this scenario would probably not be cost-effective. It would, however, have the advantage of benefiting aquatic life and floodplain vegetation by raising the water table.

The final option would be to construct bankfull benches and floodplains at the new bankfull elevation in incised reaches (Figure 47). This essentially accelerates the succession model past the unstable stages.

Table 10: Summary of the costs and benefits of restoration options listed above.

Options to address channel instability and high suspended sediment		
Hinder Channel Succession	**Benefits**	**Costs**
1. Grade control above headcut	Relatively inexpensive	Does not address downstream issues
	Proven to work if designed correctly	
	Locations can be determined by field verification	
2. Flood-plain culverts	Relatively inexpensive, depending on the crossing	Does not address headcut advancement
	Can decrease downstream degradation	Can meet resistance with transportation officials
	Floodplain connectivity is improved	
	Improves aquatic habitat	
3. Stormwater retention BMP’s	Can be targeted to impervious areas	Does not *directly* address instabilities
	Can be inexpensive	
	Not in-stream	
	Immediate effect	
4. Filling incised reaches	Restores flood-plain connectivity	May lead to flooding issues
	Keeps water table at original elevation	Relatively expensive
		Sourcing the fill may be problematic
5. Construct new floodplain	Restores flood-plain connectivity	Relatively expensive
	May have more public support	Does not raise the water table



GEOMORPHIC RIFFLE WEIR APPLICATION FOR INCISED CHANNELS POOL CONVERSION, GRADE CONTROL, FLOODPLAIN BACKWATERING AND FISH HABITAT ENHANCEMENT

Feature provides backwater to increase localized water table for hydric vegetation recovery on floodplain.

Weir crest invert set at ordinary high water elevation.

Constructed of rock, gravels, and large wood providing both fish passage and habitat.

GEOMORPHIC RIFFLE WEIR SCHEDULE

STRUCTURE ID	STATION	WEIR ELEV.	WING ELEV.	CW	L	V Rock (cu.yds.)	V Gravel (cu.yds.)
GRW # 1	x+xx	xxxx.x	X	xx.x'	xxx.x'	xxx	xxx
GRW # 2	x+xx	xxxx.x	X	xx.x'	xxx.x'	xxx	xxx
GRW # 3	x+xx	xxxx.x	X	xx.x'	xxx.x'	xxx	xxx
GRW # 4	x+xx	xxxx.x	X	xx.x'	xxx.x'	xxx	xxx
GRW # 5	x+xx	xxxx.x	X	xx.x'	xxx.x'	xxx	xxx

This drawing requires supporting technical documentation prior to use and must be adapted to the specific site.

Drawing not to scale.

Figure 44: Example of grade control structure to halt headcut advancement.

Figure 45: Floodplain culverts improve flow conditions, decreasing downstream degradation and upstream aggradation.

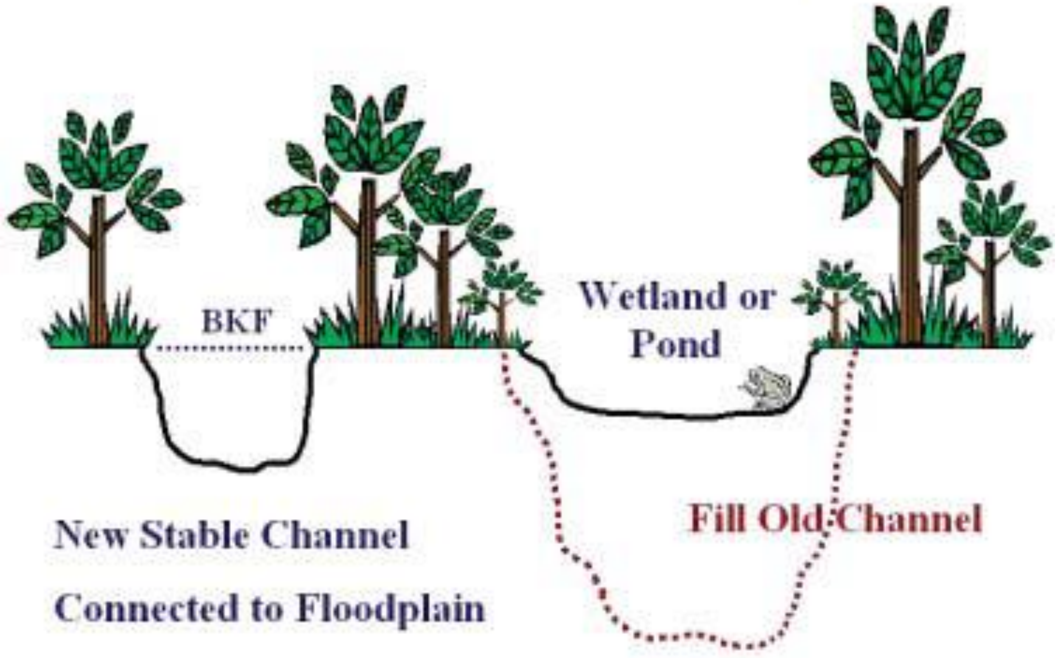


Figure 46: Channel succession can be reversed by filling in an incised reach.

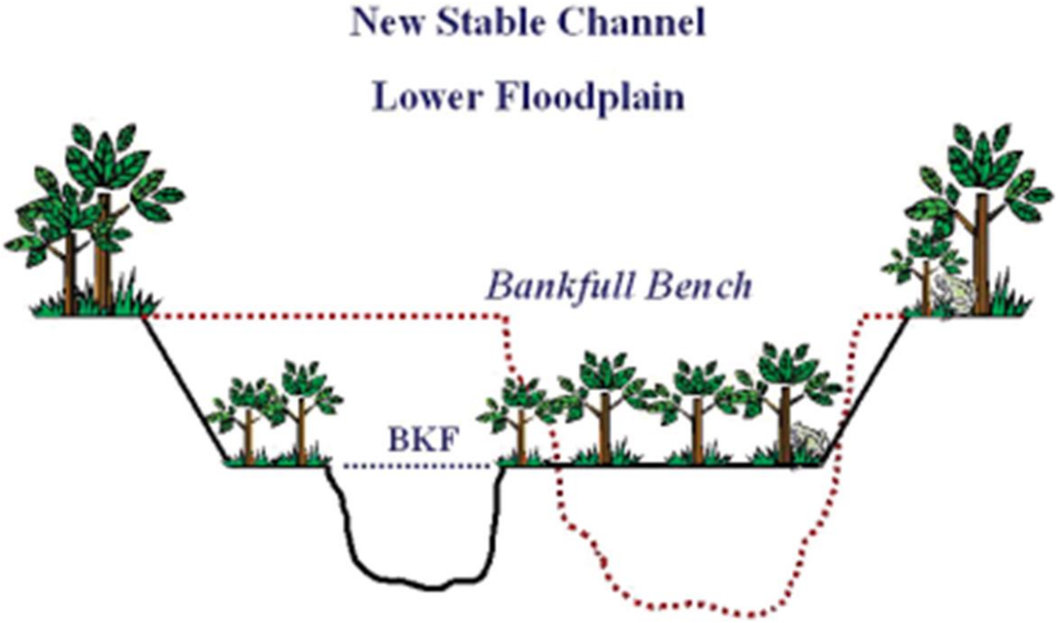


Figure 47: Channel succession can be accelerated by constructing a new channel and "jumping" to the stable end-point of the channel succession model.

Further Study

The following is a preliminary list of additional information or studies that are needed to more fully understand the source and causes of suspended sediment in this system:

1. Higher density of TSS measurements, especially within the problem areas listed above.
2. Establish permanent survey cross sections above and below “mobile” headcuts.
3. Install toe and bank pins at worst bank erosion locations.
4. Perform more gage station surveys to add to the Eastern MN regional curve.
5. Collect Bank Erosion Hazard Index (BEHI) data.
6. Install scour chains to track the movement on the channel bottom.
7. Investigate ravines and gullies for stability indices.
8. Investigate the possible causes of downcutting in the watershed.
9. Historic airphoto analysis in the rest of the Swan watershed.
10. Analysis of airphotos from other eras – not just 1939.
11. Investigate any historic changes in land use, climate, or hydrology.
12. Bed-load sampling.
13. Analyze the effect of mine pit dewatering on base and bankfull flows.
14. Build a sediment transport model with empirical data.
15. Work to further identify biological barriers.

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