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# CHANNEL SUBDIVISION AND BANK SELECTION IN OPEN CHANNELS

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There seems to be a great disparity in the selection of bank stations and the subdivision of channels in open channel flow analysis in natural channels. Because of this it was decided to attempt to put together some criteria that could be used. In general, most programs use methodology that utilizes the Manning's Equation to solve open channel flow problems. This equation: $Q = 1.486/n\ A\ R^{2/3}\ S^{1/2}$ is a slope conveyance equation. Where (conveyance) $K = 1.486/n\ A\ R^{2/3}$ and S = the energy slope. R = the hydraulic radius (A/Wp), n = the Manning's roughness coefficient, A = the area of the channel, and Wp = the wetted perimeter. This equation was designed for uniform steady state flow in trapezoidal channels. Needless to say, most natural channels are not uniform or trapezoidal. Thus, it is imperative that the Hydrologist or Engineer using the equation be aware of its shortcomings and use reasonable judgement to come up with the best results.

**Channel Subdivision:**

The largest shortcoming of the methodology when working with natural channels, is the change in roughness, n, across the channel. Because of this, some believe that they need to subdivide the channel at breaks in roughness. What this does, is greatly affect the computation of the hydraulic radius (R), thus, affecting the results of the equation. In most cases it is much better to determine an average roughness, n, for the main channel and allow the equation to solve a series of near rectangular or trapezoidal channels.

The United States Geological Survey's Report entitled "Estimating Manning's Roughness Coefficients for Stream Channels and Flood Plains in Maricopa County, Arizona", on page 10, makes the following statements. *"Sections with distinct changes in shape were subdivided into subsections, and n values were determined separately for each subsection. Subdivision location primarily was based on major breaks in cross-sectional geometry. Cross sections were subdivided if main channel depth was more than twice the depth of the stream edge of the overflow area". " Subdivision also was commonly made where the depth of the overflow at the stream edge is nearly half the depth of the main channel and the width of the overflow area is at least five times the depth of the overflow area."*

*"For sections or subsections with a nonuniform distribution of vegetation, a composite n was computed by using weighted values for segments having different roughness. Where sections were divided into segments of equal roughness, dividing lines were selected to parallel the general flow line and to represent the average contact between segments of different roughness. Composite n values were computed by using weighted values of either area (A) or wetted perimeter (P). Weighing was done by estimating area or wetted perimeter for each portion of channel and assigning weighing factors that were proportional to the total area or wetted perimeter. The general rule for deciding which weighing method to use is as follows. Use area weighing where vegetation is dense and occupies a distinct part of the cross section. Use wetted perimeter*

*weighing where the roughness factor for each segment is the result of low-lying boundary material."*

The above statements indicate that the values of Manning's n, that are commonly used for natural channels were developed for unit cross sections.

The United States Army Corps of Engineers, Hydraulic Engineering Center's report entitled "HEC-RAS River Analysis System, Hydraulic Reference Manual", Version 2.2, September 1998, page 2-6, makes the following statement. "*Flow in the* ***main channel*** *is not subdivided, except when the roughness coefficient is changed within the channel area.* ***HEC-RAS*** tests *the applicability of subdivision of roughness within the main channel portion of a cross section, and if it is not applicable, the program will compute a single composite n value for the entire main channel. The program determines if the main channel portion of the cross section can be subdivided or if a composite main channel n value will be utilized based on the following criterion: if a main channel side slope is steeper than* ***5H:1V*** *and the main channel has more than one n-value, a composite roughness* $n_c$ *will be computed [Equation 6-17, Chow, 1959]. The channel side slope used by* ***HEC-RAS*** *is defined as the horizontal distance between adjacent n-value stations within the main channel over the difference in elevation of these two stations."*

From this it can be seen that if a narrow section in the center of the channel has one n-value and the rest of the channel to the top of the banks has another n-value, the **5H/1V** used by the model might be a very artificial and misleading value. Thus, it would be better to manually compute the average channel n-value for the entire main channel.

The United States Geological Survey's Techniques of Water Resources Investigation Series, Book 3, Chapter A1, entitled, "General Field and Office Procedures for Indirect Discharge Measurements", page 28, makes the following statement. "*Cross sections may need to be subdivided for the computation of section properties because of changes in either shape or roughness. Values of n determined by verification studies have been derived for unit trapezoidal channels: that is, for main-channel sections include both the bed and banks. Therefore, do not subdivide trapezoidal channels at low-water's edge, in spite of difference between bed roughness and bank roughness. The dividing line between the main channel and an overflow portion, where the transverse slope of the bottom changes abruptly, is the proper point for subdivision. On an overflow plain of nearly uniform depths, make subdivisions where roughness changes.*"

The most comprehensive description of subdivision of channels is presented by the United States Geological Survey in their Techniques of Water Resources Investigation Series, Book 3,Chapter A15, entitled "Computation of Water-Surface Profiles in Open Channels", pages 20 – 26. In this report, they show an example of the affect of subdividing a trapezoidal channel based on roughness (Figure 1), ~~and~~ the affects of not subdividing a channel with a main trapezoidal channel and a shallow overflow section (a panhandle shaped channel) (Figure 2). In both cases the channel conveyance is greatly affected. The following statements on subdivision are made in the report.

1. *"Subdivisions should be done primarily for major breaks in cross-sectional geometry. Besides these, major changes in roughness may call for additional subdivisions. The roughness coefficients verified by the Geological Survey are based on unit cross sections that have complete or nearly complete wetted perimeters. Basic shapes that are approximately rectangular, trapezoidal, semicircular, or triangular are unit sections having complete wetted perimeters. Subdivisions for major breaks in geometry or for major changes in roughness should, therefore, maintain these basic shapes so that the distribution of flow or conveyance is nearly uniform in a subsection.*

   *The importance of proper subdivision, as well as the effects of improper subdivision, can be illustrated very dramatically. In figure 16* (Figure 1.), *a trapezoidal cross section having heavy brush and trees on the banks has been subdivided near the bottom of each bank because of the abrupt changes of roughness there. A large percent of the wetted perimeters (P) of the triangular subareas ($A_1$ and $A_3$) and possibly of the main channel ($A_2$) is eliminated. A smaller wetted perimeter abnormally increases the hydraulic radius ($R=A/P$), and this in turn results in a computed conveyance different from the conveyance determined for a section with a complete wetted perimeter. In figure 16* (Figure 1.), *a conveyance ($K_T$) has been computed for the cross section that would require a composite n value of 0.034. This is less than the n values of 0.035 and 0.10 that describe the roughness for the various parts of the basic trapezoidal shape. The basic shape should be left unsubdivided, and an effective value of n somewhat higher than 0.035 should be assigned to this cross section, to account for the additional drag imposed by the larger roughness on the banks."*

   If equation 6-17, from McGraw-Hill, Inc., by Ven Te Chow, entitled "Open Channel Hydraulics", $n = [(P_1n_1^{1.5} + P_2n_2^{1.5} + P_3n_3^{1.5}) / P]^{2/3}$, were used the composite n = 0.062. If the U.S. Geological Survey method of area weighting were used the composite n = 0.046 and if the method of wetted perimeter weighting were used the composite n = 0.058. The Engineer or Hydrologist needs to use their professional judgement to determine which method to use. Even with the difference between weighting methods, there is still a large difference in the composite n-value from n = 0.062, 0.046, or 0.058 for proper subdivision to n = 0.034 for improper subdivision.

2. *"At the other extreme, the panhandle section in figure17* (Figure 2.), *having a main channel and an overflow plain, must be subdivided into two parts having nearly complete wetted perimeters. The value of n is 0.040 throughout the section. If the section is not subdivided, the increase in wetted perimeter of the flood plain is relatively large with respect to the increase in area. The hydraulic radius is abnormally reduced, therefore, and a fictitious, lower value of 0.028 is needed to obtain the conveyance equivalent to that of a unit section. It is clear that irregular cross sections such as that in figure 17* (Figure 2.) *should be subdivided to create individual basic shapes."*

Again, the large discrepancy in composite n-value can be seen by improper subdivision.

3. "*R. H. Tice, has suggested criteria which are generally quite satisfactory for subdivision of bench panhandle shapes. He recommends subdivision if the value of the ratio L/y* (width/depth) *is 5 or greater (see figure 18)* (Figure 3.).

4. *"For L/y equal to 20 or greater, Tice recommends several subdivisions".*

5. *"Another shape criterion for subdivision has been proposed by Matthai and is shown in figure 19* (Figure 4.). *If the main-channel depth is more than twice the depth at the stream edge of the overbank area, Matthai recommends subdivision. Subdivision on the basis of geometry should be coordinated with the expected range in depths. For example, the cross section of figure 20* (Figure 5) *should be subdivided differently for different stages, as shown in the figure."*

**Channel Bank Selection:**

The channel bank, in most analysis, is intended to be the dividing line between the main channel and any overflow areas. See Figure 6 for an example of two different cross sections, one with a very bad channel bank location and the other with a good channel bank location. See Figure 7 for an example of the channel bank location for the same cross section, the first shows a bad location and the second shows a much-improved condition. In natural channels the channel bank stationing varies based upon the depth of flow being analyzed. Thus, the first criteria in the selection of bank stations for the cross section should be based on the criteria described in the section above on channel subdivision and the channel banks as they relate to the flow event being analyzed (100-year discharge if a floodplain is being studied). See Figure's 1 - 5.

Because many of us use the step-backwater methodology, which uses the Manning's equation for the delineation of floodplain and floodway boundaries, the channel bank station is a point within which the HEC-RAS and HEC-2 models will not delineate a floodway. Therefore, the channel banks can be used in the analysis to assure that development can not occur within certain areas along the main channel. Depending on the condition, the efficiency of the analysis may be improved or hindered. Any inaccuracies in the analysis may be justified by the ability to control development in highly flood prone areas. Particularly in light of the fact that the inaccuracies in the analysis may be less than the inaccuracies in the magnitude of the 100-year discharge that is being used in the analysis. Figure 8 shows an example where changing the bank station location, not only improves the conditions hydraulically, but also would limit development of the steep bank.

The Arizona State Standard for Supercritical Flow for Floodplain Regulations, dated November 1994 gives guidelines for five special cases of supercritical floodway problems in the section "Special Cases of Supercritical Flow", on page 2.

1. *"**Bank Station Designation.** In some cases, the location of the channel bank stations may not be obvious. Because floodways may not encroach within the channel banks of a stream accurate definition of the channel stations is important for floodway modeling."*

2. *"**High-Velocity, Near-Critical Flow.** HEC-2 may become computationally unstable at depths near critical depth, and default to critical depth, even where critical or supercritical depth do not occur."*

3. *"**Channelized Supercritical Flow.** Where supercritical flow is confined within the designated channel banks, the floodway and floodplain widths are identical."*

4. *"**Composite Flow.** Composite flow occurs where both supercritical flow and subcritical flow are present within a single cross section."*

5. *"**Braided Flow.** Supercritical flow on braided streams is usually a special case of composite flow, or a case of floodway delineation around islands."*

The Arizona State Standard for Supercritical Flow also makes the following statement in the section "Channel Bank Design", on page 4.

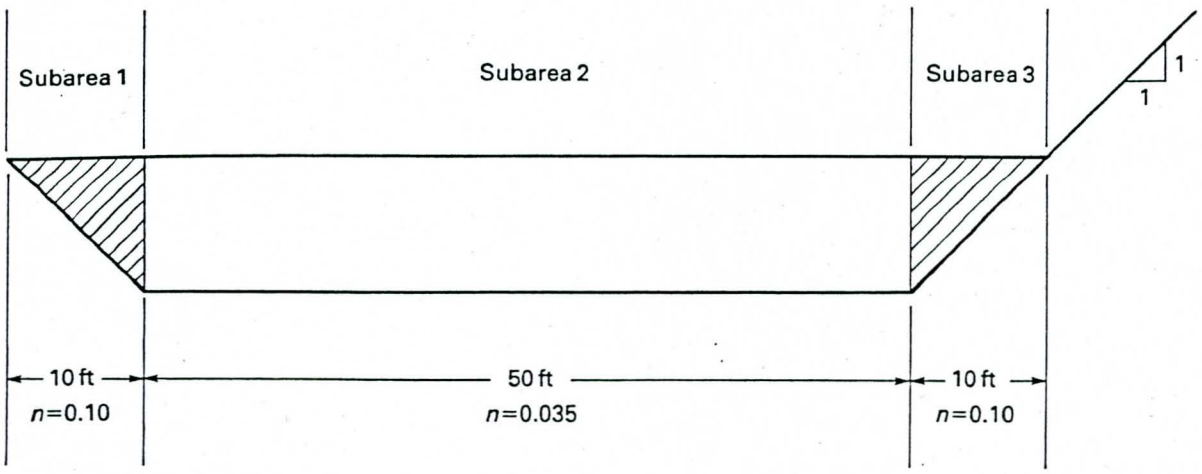
*"In many cases. It is obvious where channel bank stations should be located. Key indicators include the grade break between the bank slope and overbank floodplain, the change in vegetation between the channel bed and riparian area, or geomorphic characteristics of the stream. Where channel banks cannot readily be identified from topographic and other data, the Corps of Engineers (1988) definition of channel banks[4] should be used. The Corps defines the channel banks (or the beginning of the overbank area) as the point where depths become less than 3 feet and velocities become less than 3 feet per second. This bank definition may also be used as the starting point for floodway encroachment modeling. It is necessary to perform an initial HEC-2 run to obtain a velocity distribution in order to apply the Corps bank station definition. Subsequent runs will be necessary to refine floodway limits."*

[4] *Channel bank definition is intended only for floodway delineation purposes.*

Another criteria that should be observed, is the need for uniformity between cross sections. That is, if the main-channel bottom is so irregular that it may look like more than one channel, at several cross sections, we need to use our best judgement in placing the channel bank stations, (see Figure 9), making sure that we are consistent between sections (see Figure 10). If this is not done, the main channel will become a series of large cross-sectional area to small cross-sectional area and vice-versa. This will cause the analysis to compute a large contraction and/or expansion between cross sections, as well as impact the length of over-bank and the center of mass calculations. This again will have a significant affect on the results of the analysis.

For braided flow conditions, we may not want to allow development within the series of braided channels. Figure 11 shows a map of an area of braided channels. Two possible sets of channel bank locations are shown. The set represented by the dots would be to regulate only the main channel, while the set represented by the X's would represent a set where development was not wanted within the system of braided channels. Thus, Figure 12 shows an example of one of the cross sections where channel banks are placed to regulate the one main channel and an example of the same cross section where channel banks are placed to regulate the entire system. With the second example the floodway would contain all of the area between the channel banks, thus restricting development within the entire braided channel system.

As was stated above, the Manning's equation was intended for the analysis of steady state uniform flow conditions, which we very seldom achieve in natural channels. Amazingly, the method works very well when the Engineer or Hydrologist considers all of the problems that may be encountered and uses good judgement in the analysis.




$A_1 = A_3 = 50$
$P_1 = P_3 = 14.14$
$R_1 = R_3 = 3.54$
$K_1 = K_3 = 1730$

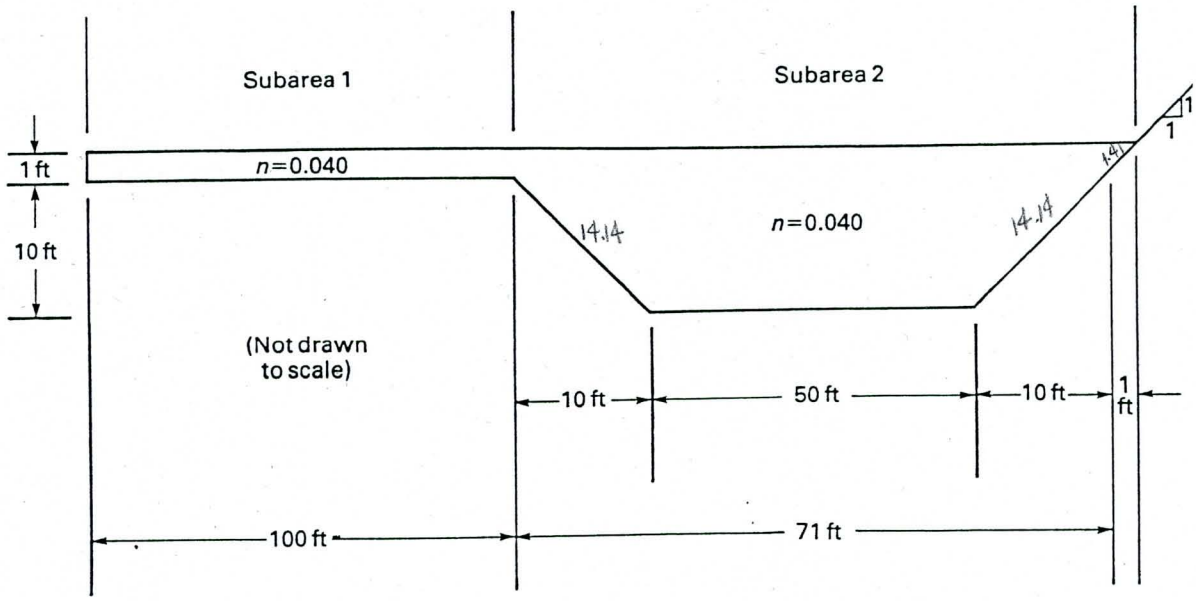
$A_2 = 500$
$P_2 = 50$
$R_2 = 10$
$K_2 = 98{,}500$

$K_T = K_1 + K_2 + K_3$
$= 102{,}000$

Composite solution: $A_c = 600$
$P_c = 78.3$
$R_c = 7.66$

$$n_c = \frac{1.486\, A_c R_c^{2/3}}{K_T} = 0.034$$

Figure 1 (Figure 16 from USGS, Book 3, Chapter A15). – Effects of subdivision on a trapezoidal channel.




$A_1 = 100$
$P_1 = 101$
$R_1 = 0.990$
$K_1 = 3700$

$A_2 = 670.5$
$P_2 = 79.7$
$R_2 = 8.41$
$K_2 = 103{,}000$

$K_T = K_1 + K_2$
$= 107{,}000$

Composite solution: $A_c = 770.5$
$P_c = \cancel{108}\ 180.7$
$R_c = 4.26$ ✓

$$n_c = \frac{1.486\, A_c R_c^{2/3}}{K_T} = 0.028$$

Figure 2 (Figure 17 from USGS, Book 3, Chapter A15). – Effects of subdivision on a panhandle section.

$\boxed{K = 75{,}221}$ using $n = 0.040$

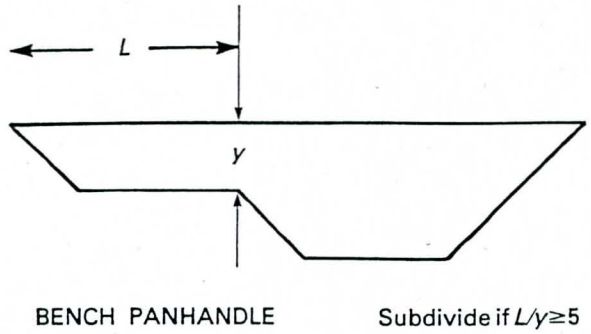



Figure 3 (Figure 18 from USGS, Book 3, Chapter A15). – Subdivision criterion of Tice.

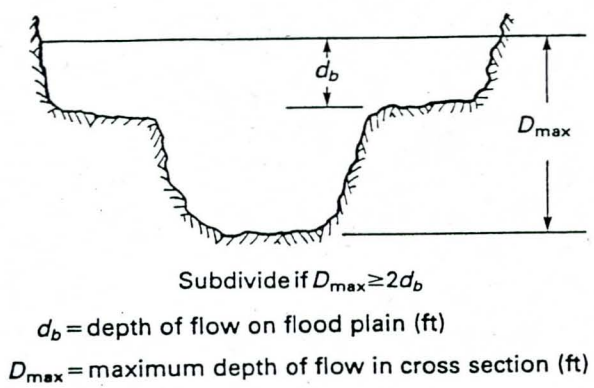
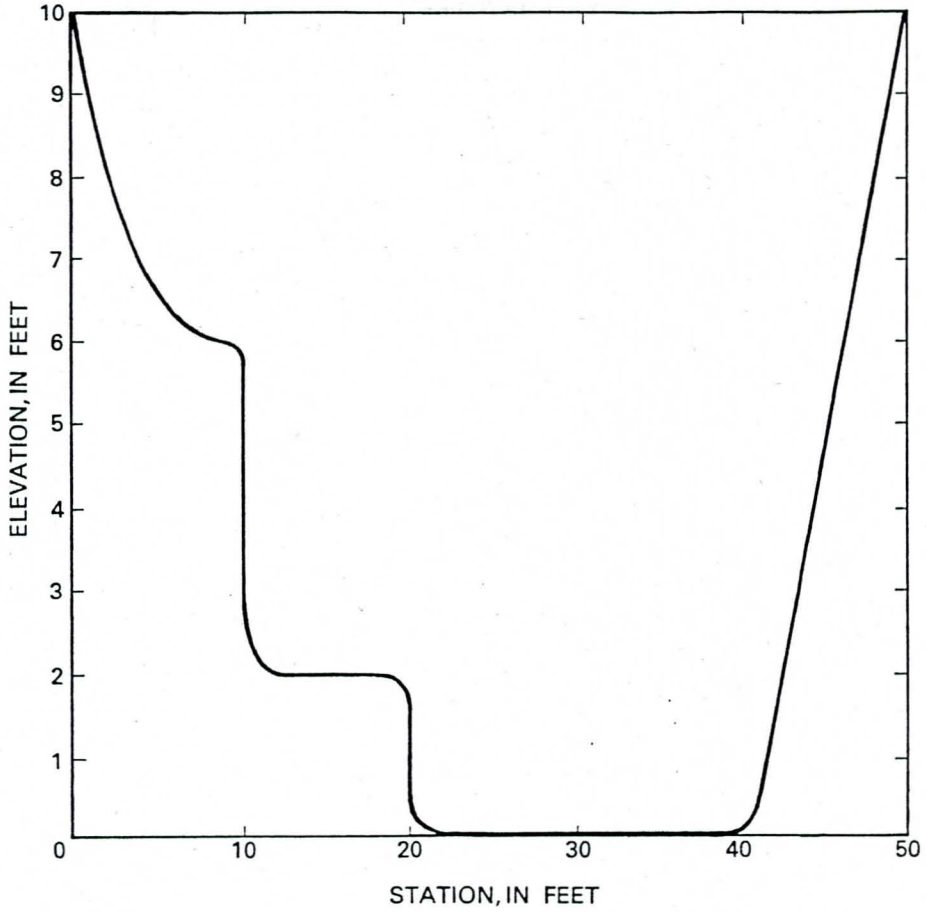
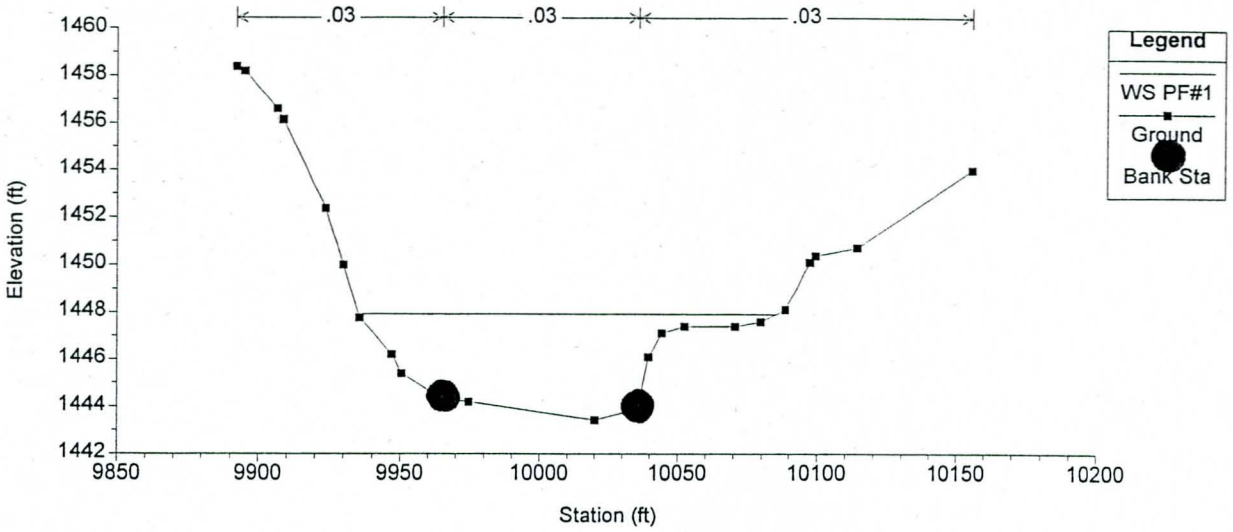



Figure 4 (Figure 19 from USGS, Book 3, Chapter A15). – Subdivision criterion of Matthai.

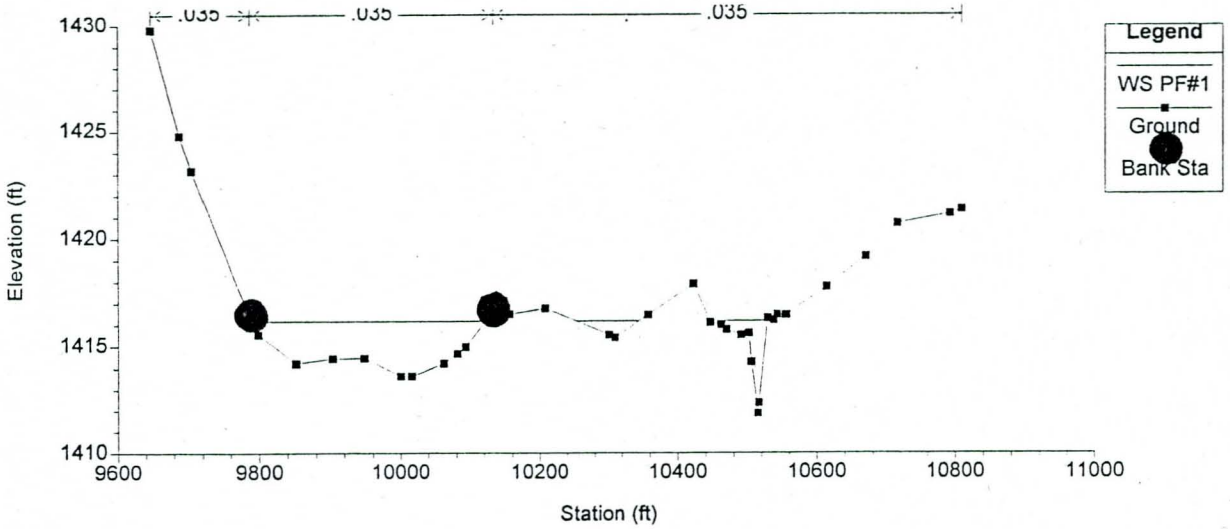



| Range of water-surface elevation, in feet | Substation | |
|---|---|---|
| | Station 20 | Station 10 |
| 0–2 | No | — |
| 2–4 | Yes | — |
| 4–6 | No | — |
| 6–8 | No | Yes |
| 8–10 | No | No |

Figure 5 (Figure 20 from USGS book 3, chapter A15). – Cross section in which subdivision could be dependent on expected elevations of water surface.

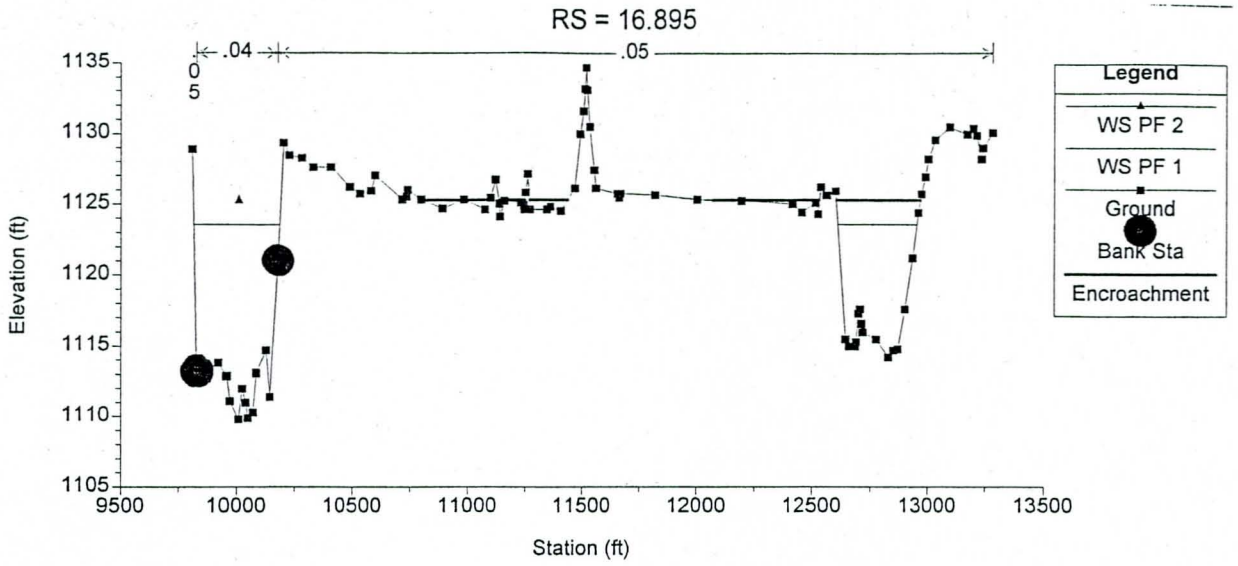



Bad Channel Bank Location

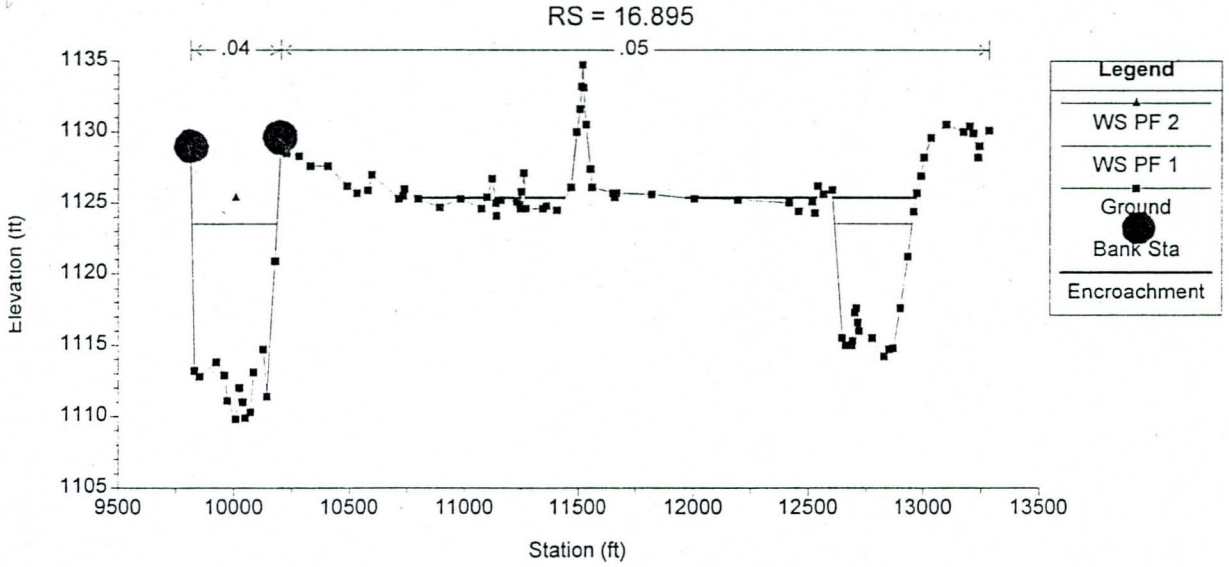



Good Channel Bank Location

Figure 6 – Example of a bad and a good channel bank location.

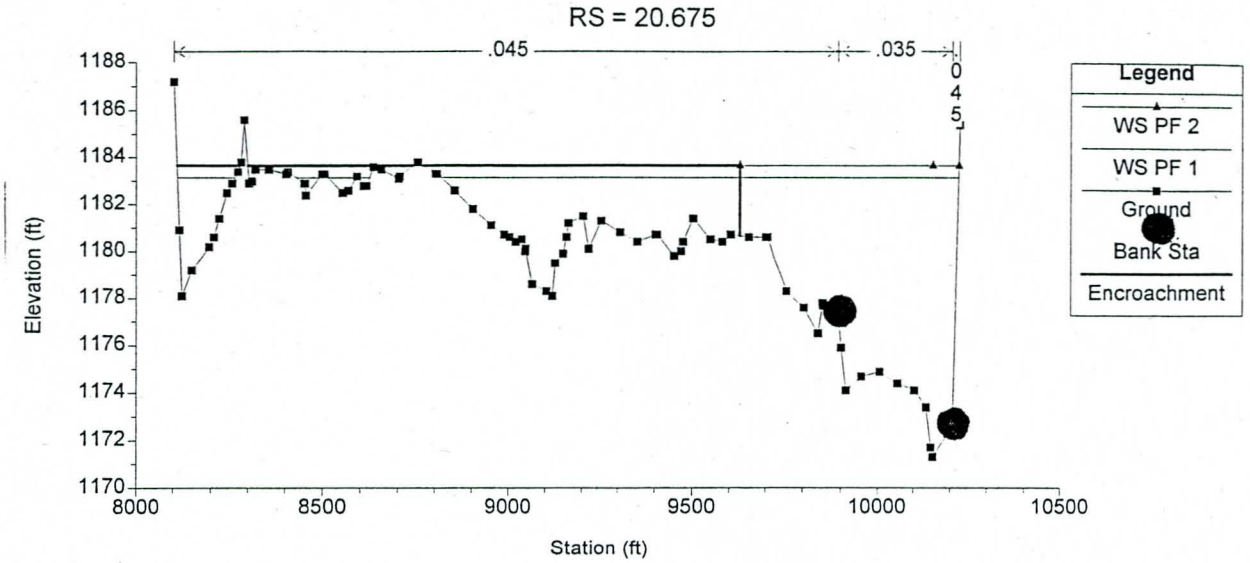



Bad Channel Bank Location

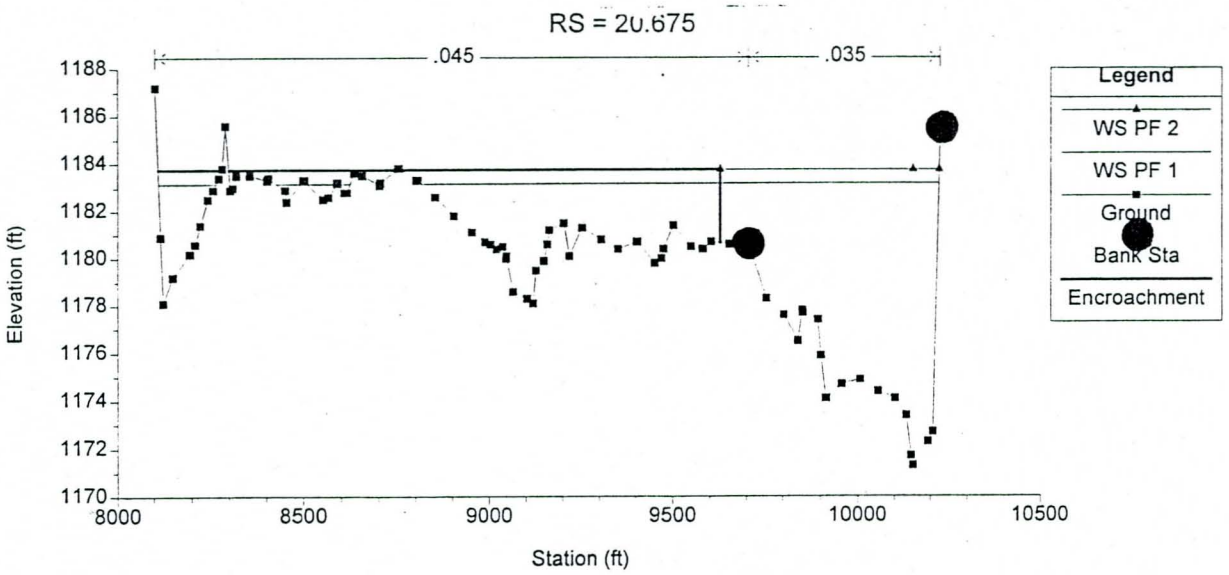



Good Channel Bank Location

Figure 7 – Example of a cross section with bad channel bank location modified to show good channel bank location.

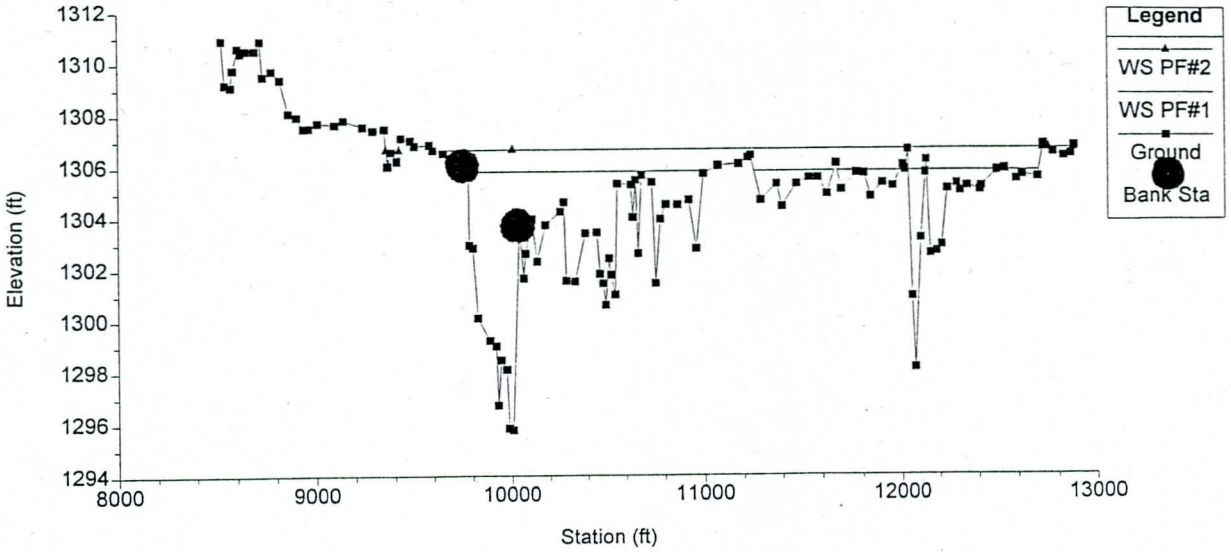



Bad Channel Bank Location

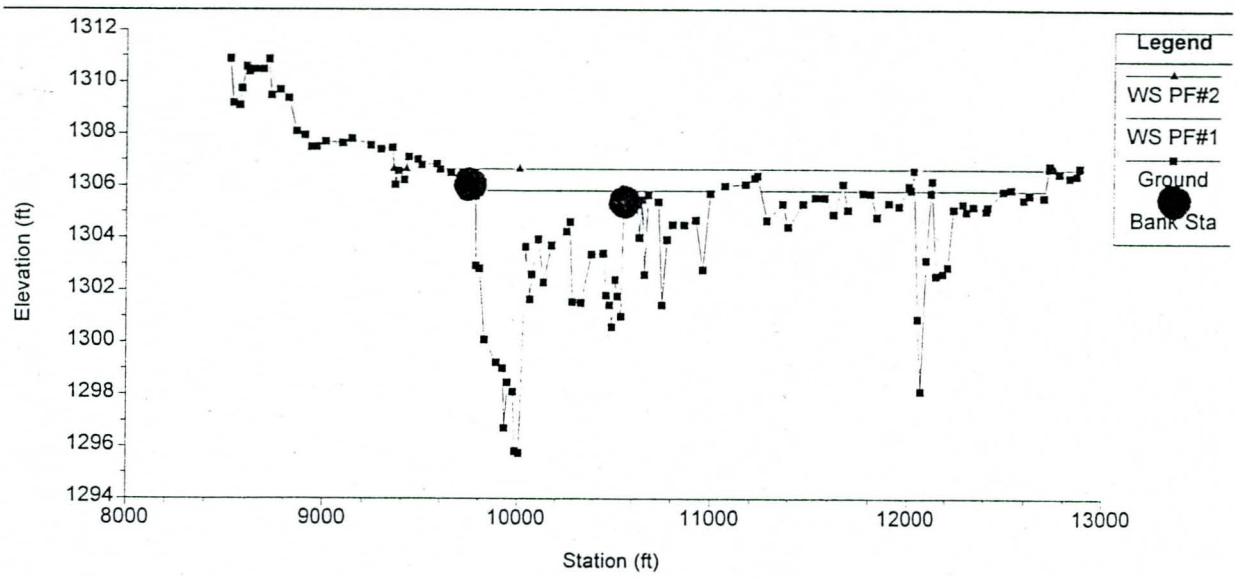



Good Channel Bank Location

Figure 8 – Example of a cross section with bad channel bank location modified to show channel bank location which is not only better hydraulically but, it also will limit any development along the steep bank.




Channel Bank Locations for one Channel




Channel Bank Locations including more than one channel

Figure 9 – Example of a cross section with channel bank locations for one channel only or modified to show channel bank locations which include more than one channel.

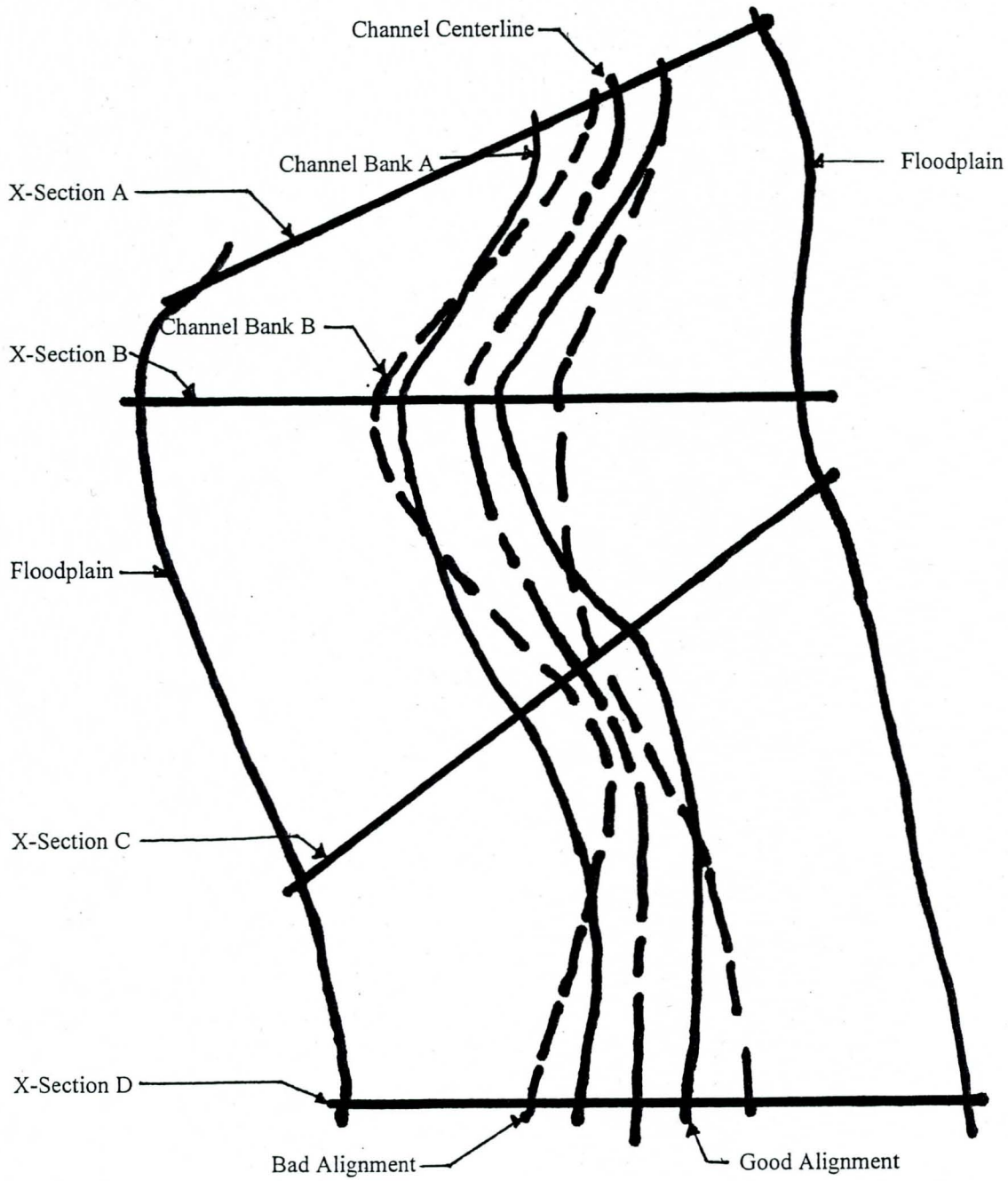



Figure 10. - A sketch showing two possible channel bank alignments.

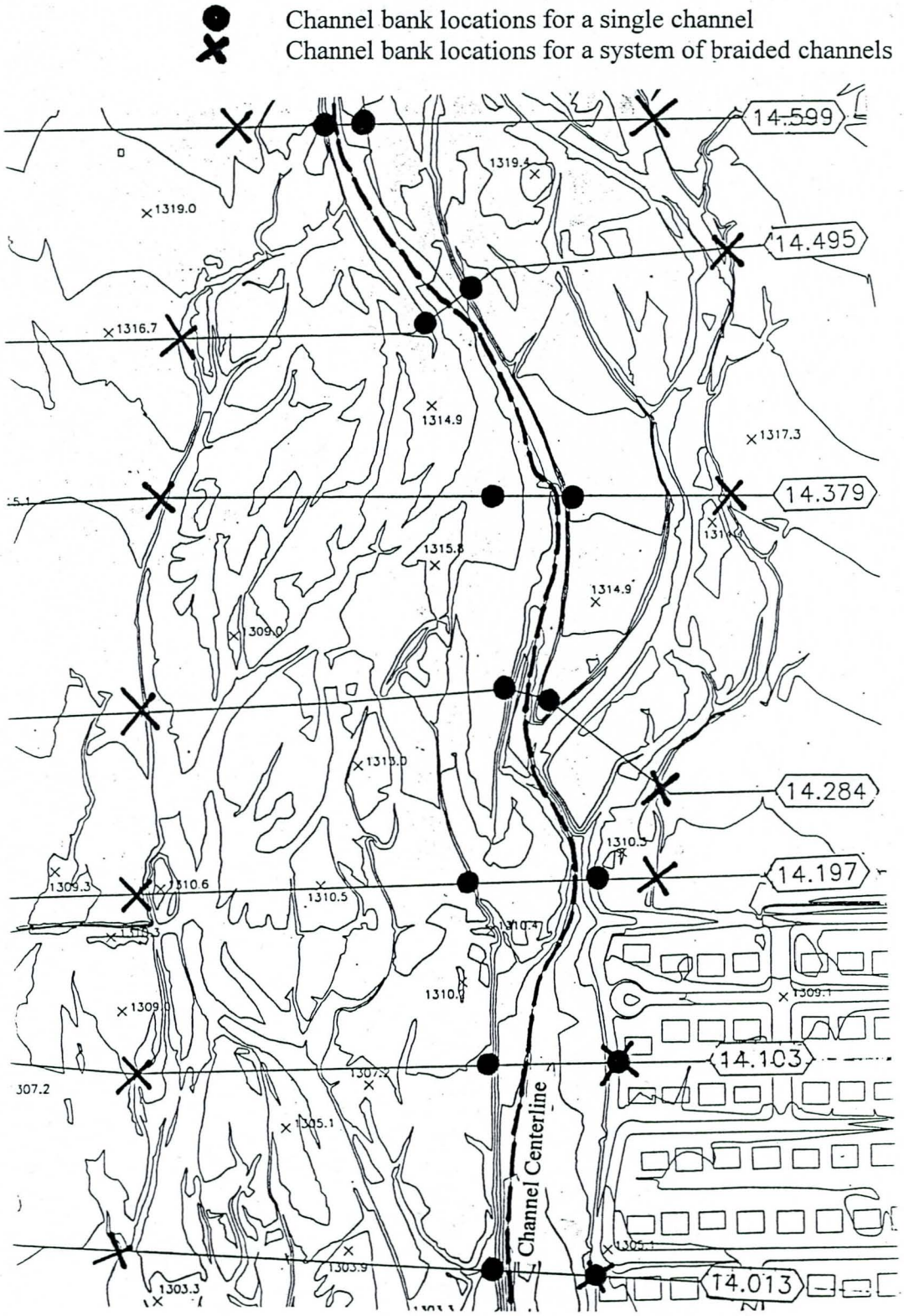
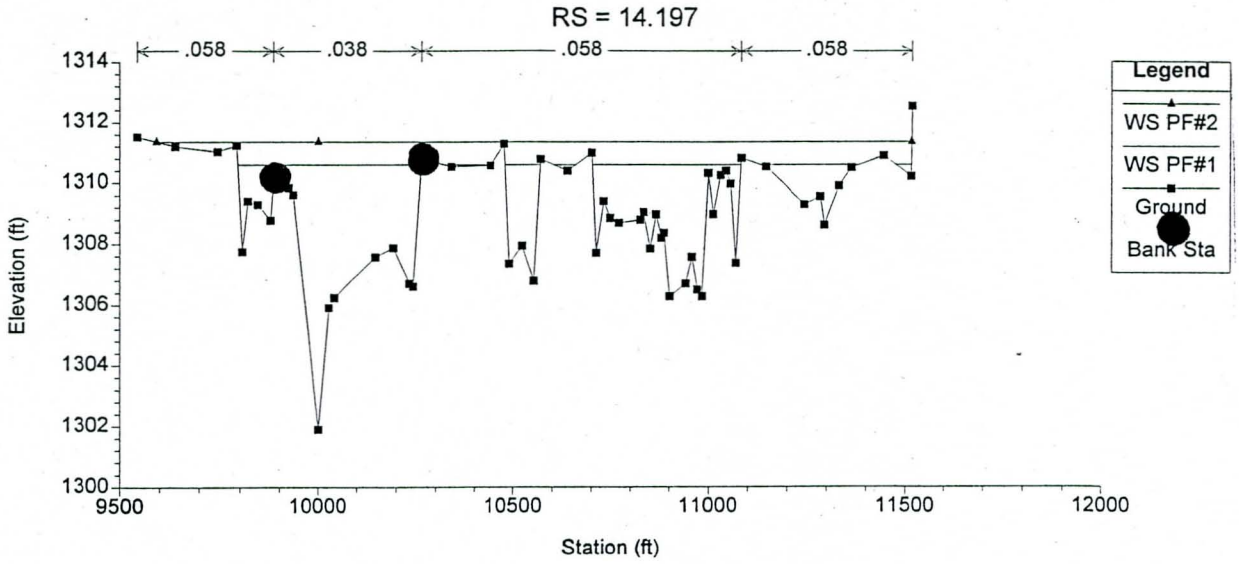
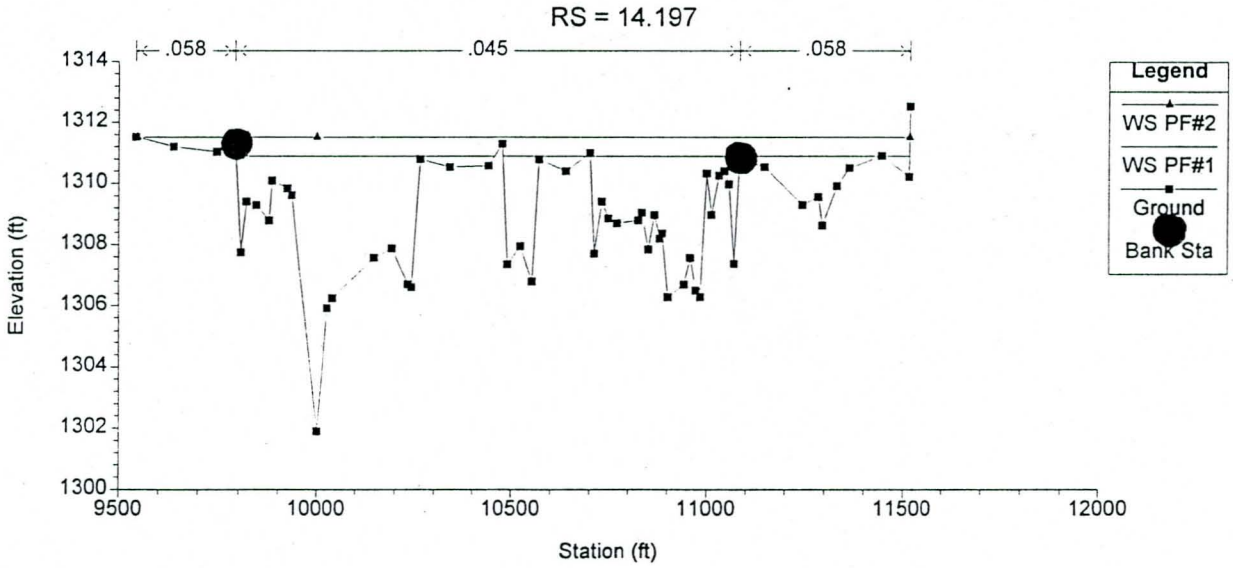



Figure 11 – A map showing a system of braided channels with Examples of channel bank locations for one main channel or locations to show possible regulation control for the system of braided channels.




Channel Bank Locations for one Channel




Possible Channel Bank Locations for a series of Braided Channels

Figure 12 – Example of a cross section with channel bank locations for one channel only or modified to show possible channel bank locations for a series of braided channels.