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• Geotechnical Engineering • Geology • Engineering Geophysics

May 9, 2000

Ms. Laverne Ivie
Yellowstone Conservation District
1371 Rimtop Drive
Billings, MT 59105

Re: Report of Yellowstone River Geomorphic Analysis.

Dear Laverne:

In cooperation with Aquoneering, we are pleased to present this report of our analysis of the geomorphology of the Yellowstone River from upstream of Laurel to downstream of Billings. The report quantifies channel training structures and changes to river form between 1957 and 1999.

We are grateful for the opportunity to provide this service.

Respectfully submitted,

Ray Womack

Ray Womack, P.E., P.G.
enc

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YELLOWSTONE RIVER GEOMORPHIC ANALYSIS YELLOWSTONE COUNTY, MONTANA

PREPARED FOR

YELLOWSTONE CONSERVATION DISTRICT
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MAY 9, 2000

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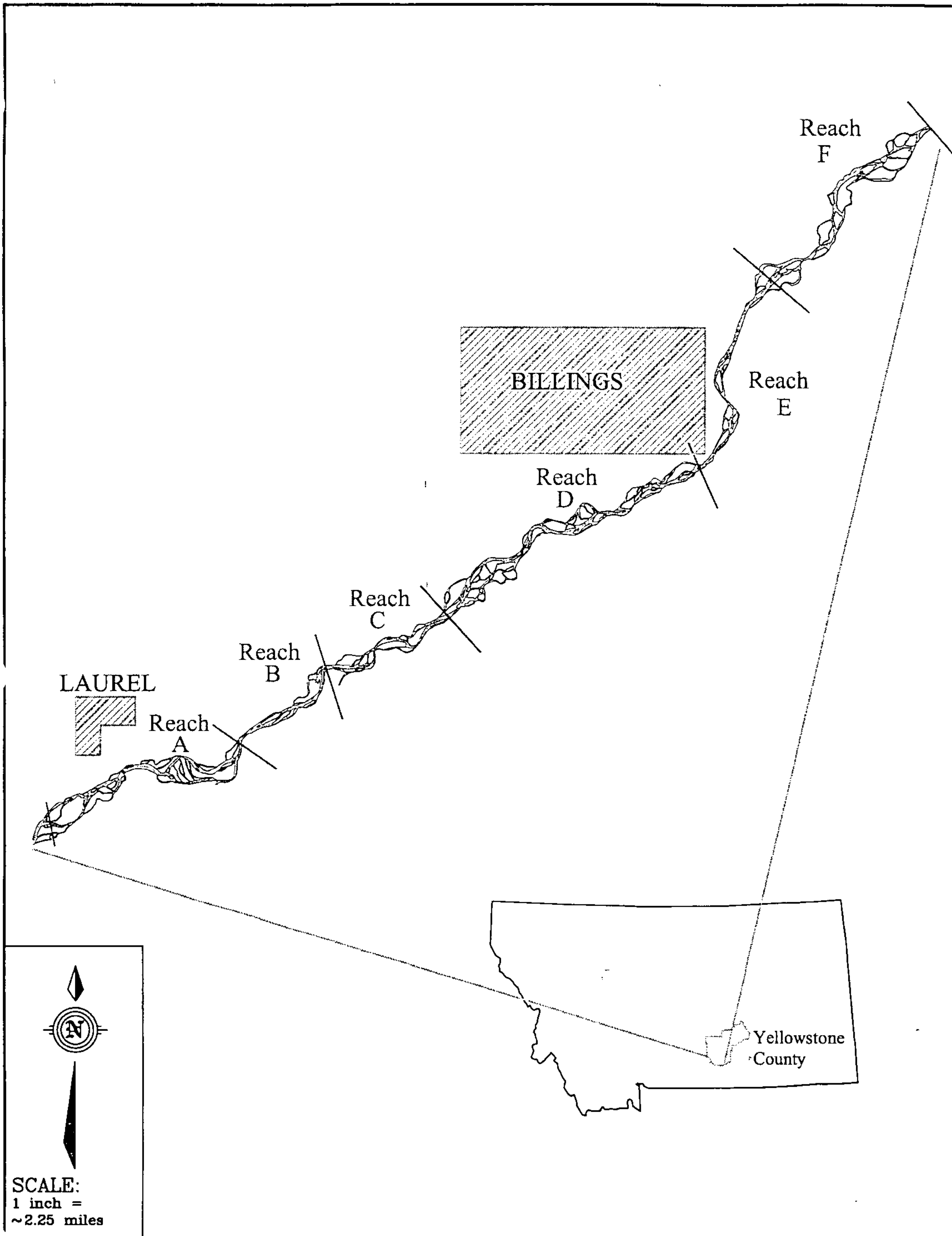
1.0 INTRODUCTION

The Yellowstone River is the longest undammed river in the United States. Because development of this region has lagged behind most of the rest of the country, the river has largely escaped the comprehensive channel training that has affected most other major rivers. In recent years, however, partly as a result of two large consecutive floods and partly due to increased development adjacent to the river, there has been a substantial increase in the number and size of channel training projects, particularly near population centers such as Billings. This trend has been controversial for several reasons. The visual esthetic impacts are obvious. Concrete rubble, stone riprap, and other assorted materials now cover large reaches of the river banks. Some interest groups are concerned that wildlife habitat, particularly the fishery, is being negatively impacted. River armoring tends to have a cumulative effect; i.e., piecemeal armoring of some reaches may trigger accelerated erosion of unprotected banks. Also, reduction of sediment load resulting from armoring has caused some rivers to undergo changes in geometry that affected flood elevations, among other things. This report will address apparent changes to the Yellowstone River over the past 40 years in the Laurel-Billings area of Yellowstone County (Location map, Figure 1), and will quantify the extent and effects of channel training.

The report will attempt to answer several fundamental questions. How much of the river has been armored? Has there been a measurable loss of stream channel habitat? More fundamentally, is the river stable in a geomorphic sense? That is, does it have the same general geometry that it had 40 years ago? Answers to these questions will allow river managers and other stakeholders to evaluate the effects of current training and permitting practices.

It should be emphasized that the purpose of this work has been to identify and quantify the extent and effects of channel training, and not to present value judgements. It is our hope that the information in this report will enhance the management of a valuable and beautiful resource and be of benefit to those who live and work along the river.

This work has been done at the request of the Yellowstone Conservation District (YCD) and funded by YCD with assistance from the Montana Department of Natural Resources and Conservation (DNRC). Womack & Associates, Inc. (WAI), and Aquoneering have worked together to collect data and prepare this report. Although there was a high level of cooperation and joint effort between the two firms, in general WAI has been responsible for the geomorphic analysis, and Aquoneering has been responsible for surveying, description of channel geometry, and hydraulic analysis.



Yellowstone River Geomorphic Analysis Yellowstone County, Montana	Site Location Map	FIGURE 1

2.0 RIVER STABILITY

It has long been known that stability of a river system is indicated by consistency of form. In general, rivers can be defined by a set of geomorphic parameters that are driven by the quantity of flow (discharge), sediment size, and, to a lesser extent, other factors. These parameters include sinuosity, channel gradient, width/depth ratio, and degree of braiding. When a river becomes unstable, these parameters invariably change; i.e., the river widens or narrows, becomes straighter and steeper (or vice-versa), and develops more or fewer secondary channels. The fact that the river migrates and erodes its banks is not a sign of instability. It is normal for stable rivers to migrate. However, when the size and shape of the channel undergo change, it is a clear sign that the river is in a period of instability. In many cases, rivers change form altogether, for example changing from a meandering planform to a braided one.

The Yellowstone is different from many "alluvial" rivers, which can migrate more-or-less freely and which have their geometry controlled primarily by the sediment available to them. The bed and banks of the Yellowstone are usually armored by gravels and cobbles deposited by very high velocity flows when the glaciers retreated in the distant past. The river is no longer competent to move the largest resistant clasts, so it tends to do two things. It wanders back and forth on top of its gravel armor, reworking the thin veneer of fine-grained soil on its flood plain (which is of great concern to farmers and others who work and dwell along the river). It also tends to follow the perimeter of its valley, because it is easier for the river to erode the soft rocks in the valley walls than the hard stones in its bed. The other factor peculiar to the Yellowstone and other northern rivers is the effects of ice. Ice jams alter the course of the river in unpredictable ways, particularly in the lower reaches below the Big Horn River confluence.

3.0 METHODS

The study employed three data sources: air photos, cross-sections surveyed in 1968 by the Corps of Engineers, and field measurements of cross-sections and armored reaches performed by Aquoneering with assistance from WAI in 1999.

3.1 AIR PHOTO INTERPRETATION

Stereo air photo pairs taken in 1957 and 1996 were obtained. The 1957 contact prints are at a scale of about 1:20,000, and the 1996 photos were enlarged to a similar scale. The 1996 photographs were shot in late August, and represent relatively low flow conditions (about 4,500 cfs at the Billings USGS stream gauge). The 1957 photos were shot at intervals between mid-June and late July, and represent flow conditions that varied from 13,000 to 37,000 cfs. The 1957 peak discharge was in excess of 56,000 cfs at Billings, and the 1996 peak discharge was about 62,000 cfs, so both sets of photographs were obtained during high flow years. Bankful flow at Billings is about 34,700 cfs. Active channels were marked and digitized into AutoCadd files. Section corners, roads, and other cultural features were also marked and digitized. Although there is some distortion, particularly along the edges of the photographs, the digitized features were normalized to landmarks such as section corners, which are reliable control points and can be readily identified on the photos. Air photos are a common source of information regarding historical positions and changes of rivers. Although there are certainly limits to the accuracy, the photo data are adequate for assessing the broad trends addressed by this study. Active channels interpreted from 1957 air photos are illustrated on the topographic maps of Exhibit 1-1 through 1-3, and active channels interpreted from 1996 air photos are illustrated on Exhibit 2-1 through 2-3.

The center of the thalweg identified on the photos and illustrated on Exhibits 1 and 2 was measured to calculate sinuosity (channel length divided by valley length). Total length of active channels was measured. Man-made features such as dikes, rip rap armoring, and barbs (hard points constructed perpendicular to the bank) could be identified in many cases on the air photos. However, trees and high water sometimes blocked such features, and some were certainly missed by the air photo interpretation. Channel training structures interpreted from 1957 air photos are illustrated on the topographic maps of Exhibit 1-1 through 1-3. Air photos were the only source of information available for the 1957 river interpretation. Although numerous human alterations were observed on the photos and have been identified on the maps, these are not to be considered a complete inventory. In particular, smaller armored areas, such as those protected by old car bodies and smaller stone, could not be seen.

Similarly, identification of secondary channels from air photos involved judgement. If a channel appeared to contain flowing water or evidence of scouring, it was placed on the map (Exhibits 1 and 2). If a dike or other constructed feature appeared to block a channel, the channel was considered inactive and not mapped. Where possible, the activity of secondary channels (back channels) was checked against the cross-sections. Flow occurs in some secondary channels only during unusual flood conditions, and appearance of channels may have been biased by differences in flow levels when the photos were taken, as well as by relative flows in the years preceding the air photos. However, peak flows were similar in 1957 and 1996 (56,200 and 61,900 cfs respectively).

3.2 SURVEYS

3.2.1 Corps of Engineers, 1968

The Corps of Engineers (Corps) surveyed 37 cross-sections in the study reach in 1968, which were later used in a FEMA flood plain study (FEMA, 1981). Data were available for 22 of the Corps cross-sections, mostly downstream of the Canyon Creek confluence. The other Corps cross-sections could not be located. Locations of Corps 1968 cross-sections are illustrated on Exhibit 1-1 through 1-3. The Corps cross-sections are in Appendix B.

3.2.2 Aquoneering, 1999

In 1999, Aquoneering completed a hydrographic survey of the entire study reach, and also surveyed a group of cross-sections, of which about 30 were considered to be representative of existing channel geometry. Locations of the 1999 cross-sections are illustrated on Exhibit 2-1 through 2-3. The work was done using a Trimble Survey Grade GPS unit and Odem Hydrotrac Survey Sounder. Base stations were established at five locations for control. The Aquoneering cross-sections are in Appendix B.

The survey data were used to develop longitudinal profiles and width/depth ratios at bankful flow. In some cases, access problems limited the length of the sections, and those that were judged to be too short were not used for calculation of width/depth ratios. Aquoneering calculated bankful depth at each cross-section assuming a discharge of 34,700 cfs for the Yellowstone downstream of the Clark Fork confluence and 27,500 cfs upstream of Clark Fork.

3.3 1999 CHANNEL TRAINING INVENTORY

An inventory of channel training structures was taken on the river in early November 1999. The inventory was limited by access, because many secondary channels were dry and could not be reached by boat, and some private properties were off limits. Therefore, it is believed that some armored areas and dikes were not observed. Channel training structures identified in 1999 are illustrated on Exhibit 2-1 through 2-3.

4.0 GEOMORPHOLOGY

The Yellowstone River is a braided gravel bed stream. Through most of the study reach, it hugs the south valley wall, switching to the north valley wall east of the I-90 bridge at Billings. The bedrock is shallow and the river is often in contact with bedrock along the south bank. In at least six places toward the upstream end of the study reach there is bedrock in the bed of the river (Exhibit 2-1) that apparently provides local grade control. For the most part the bedrock consists of Colorado shale. East of Billings the river encounters Upper Cretaceous sandstones that are often resistant.

The channel pattern may be characterized as braided with islands (Chorley, et al, 1984). Although there are multiple channels and the river tends to shift dramatically from channel to channel, many of the islands are recognizable over long periods of time. The river tends to be sinuous and less braided where it lies in contact with its valley wall. Sinuosity is low, generally about 1.15. The meander bend radius ranges from 3,000 to 4,000 feet, with an average of about 3,350 feet upstream of the Clarks Fork confluence and about 3,750 below.

As is typical for braided gravel bed rivers, the Yellowstone is wide and shallow through the study reach, as demonstrated by high width/depth (w/d) ratios. The survey data indicate w/d ratios of over 100 in highly braided reaches. Width/depth ratios are much lower at bridges, or where the river is confined by the valley walls or armoring, typically about 50.

The channel is typically about 800 to 900 feet wide and 8.5 to 10 feet deep at bankful flow upstream of the Clarks Fork confluence, and 800 to 1,400 feet wide and 9 to more than 20 feet deep downstream of Clarks Fork. Gradients of 0.0005 to 0.0015 were measured upstream of Laurel. The bed is deeply scoured at the Laurel bridges and flattens downstream due to aggradation. Downstream of Clarks Fork the gradients range from 0.0003 to 0.004.

The channel is heavily armored. Measurements taken near Laurel indicate that the mean grain size (d_{50}) of the armoring layer is about 200 mm (8 inches), and d_{50} of the underlying sand and gravel alluvium is about 50 mm (2 inches). The gravels and cobbles consist of durable stone from the Beartooth and Absaroka mountains to the south.

The study reach between Billings and Laurel is approximately 30 river miles long and has been divided into six reaches based on geomorphic character and apparent degree of human impact (Figure 1). Beginning at the west end upstream of Laurel the six reaches are:

A. Carbon County line to Clark Fork confluence.
B. Clark Fork confluence to approximately 1 mile west of the Duck Creek bridge, along the east boundary of section 5, T2S, R25E.
C. East boundary section 5 to Canyon Creek confluence in section 25, T1S, R25E.
D. Canyon Creek to about 1 mile south of the Billings water treatment plant, near the north boundary of section 14, T1S, R26E.
E. North boundary of section 14 to 1 mile north of the Billings East Bridge, near the center of section 26, T1N, R26E.
F. Center of section 26 to the east edge of the Billings East Quadrangle, about 1 mile east of Dovers Island.

The length and general geomorphic character of the six reaches are described in Table 1.

Table 1: Geomorphic Character by Reach

Reach	Valley Length	Sinuosity (1996)	Geomorphic Character
A	25,000 feet	1.23	Braided, total channel length about 3 times thalweg length. Confined by bridges, armoring, and canal intakes near Laurel. Highly braided just downstream of Laurel. Local bedrock control.
B	14,000 feet	1.10	Sinuous, slightly braided, total channel length about 2 times thalweg length. Channel not confined against valley wall. Little armoring
C	16,000 feet	1.20	Braided, total channel length about 3.4 times thalweg length. Follows south valley wall. Little armoring
D	35,000 feet	1.16	Very highly braided, total channel length about 5 times thalweg length. Channel generally north of valley wall. Reach heavily impacted by armoring and training.
E	24,000 feet	1.15	Sinuous, slightly braided, total channel length about 1.3 times thalweg length. Channel confined against east valley wall. West bank armored. Confined by bridges and Billings city facilities.
F	26,000 feet	1.15	Braided, total channel length about 3 times thalweg length. Channel follows north valley wall. Locally confined between bedrock and armoring near the Exxon refinery.

5.0 ANALYSIS

The Yellowstone River has not been channelized and trained to the extent that most other major rivers have, because it is not commercially navigable, it has not been dammed, and it drains a sparsely-populated region. The thalweg length through the study reach was essentially identical in 1957 and 1996 (about 30 miles), as interpreted from aerial photographs. Channel stabilization structures (dikes and armoring) occupied about 41% of the river bank in the summer of 1999, compared to about 21% in 1957. The degree of channel training in 1957 is probably underestimated because channel armoring in some cases could not be seen on the aerial photographs.

The greatest measurable change has occurred due to abandonment of secondary channels, primarily due to construction of dikes and secondarily due to channel armoring. This process is known as "river simplification" (Benner and Sedell, 1997). Braided streams with extensive back channels have traditionally been viewed as unstable and undesirable (Rosgen, 1989; Dorward, 1990); and for many years the Corps of Engineers and others attempted to close off as many "useless sloughs" as possible (Corps of Engineers, 1875). Dikes constructed to close off secondary channels can be observed under construction at several locations in the 1957 air photos, and dikes had been constructed along at least 3.5% of the river bank (about 11,000 feet) by 1957. An additional 5% of the river bank (about 16,000 feet) was altered by dikes between 1957 and 1996.

A relatively short dike at the upstream end of a braided reach can have a disproportionate effect, because it may effectively eliminate miles of channel. Figures 2 and 3 provide a graphic example of the effects of dikes. These aerial photographs of a portion of Reach D illustrate the effects of a dike installed sometime after 1957 that eliminated about 20,000 feet of channel. In this particular case it would probably be inappropriate to characterize the eliminated south channel as a secondary channel. The 1968 Corps cross-sections in this reach indicate that the south channel was about 500 to 1,200 feet wide, compared to a width of 240 to 540 feet for the north channel. By 1999 the active north channel had enlarged to about 900 feet wide in this area to accommodate the flow that formerly passed through the south channel.

Total channel length in the study reach, including high flow channels, decreased from about 490,000 feet (94 miles) in 1957 to about 468,000 feet (89 miles) in 1996, about a 5% overall reduction in 40 years. Although the overall change in total channel length does not appear to be significant, the change was uneven and some reaches experienced large local changes. In fact, increases in channel length triggered by river alteration in some reaches tended to counterbalance the losses that occurred due to dikes and armoring elsewhere.

In Reach A, which includes the bridge crossings and other hard structures at Laurel, the total channel length <u>increased</u> by about 12,000 feet (13%), apparently due to constriction of the channel at the bridge crossings and resultant widening upstream and downstream. Figures 4 and 5 are aerial photographs of the reach downstream of Laurel in 1957 and 1996 respectively, illustrating the abrupt widening triggered by the constriction at Laurel. Width/depth ratios are abnormally high in the widened reach. Aquoneering measured w/d ratios of about 300 in this reach (Exhibit 2-1), which is about twice the maximum values measured elsewhere.

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Yellowstone River Geomorphic Analysis Yellowstone County, Montana	Aerial Photograph Downstream of Laurel in 1957	FIGURE 2

WOMACK AND ASSOCIATES, INC.

Yellowstone River Geomorphic Analysis Yellowstone County, Montana	Aerial Photograph Downstream of Laurel in 1996	FIGURE 3

WOMACK AND ASSOCIATES, INC.

Yellowstone River
Geomorphic Analysis
Yellowstone County, Montana

Aerial Photograph
Upstream of the Blue Creek
Bridge in 1957

FIGURE
4

WOMACK AND ASSOCIATES, INC.

Yellowstone River
Geomorphic Analysis
Yellowstone County, Montana

Aerial Photograph
Upstream of the Blue Creek
Bridge in 1996

FIGURE

5

WOMACK AND ASSOCIATES, INC.

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Total channel length was apparently unchanged in Reach E, which encompasses the I-90 bridge east of Billings and hard structures around City facilities (Exhibit 1-3 and 2-3). The other reaches exhibited decreases in total channel length that appeared to roughly correlate with increases in length of channel training structures. The "braiding parameter" in Table 2 is simply total channel length divided by reach length, and is analogous to the "total sinuosity" defined by Richards (1982). As Table 2 illustrates, the degree of braiding decreased along most of the study reach between 1957 and 1996. The most heavily impacted reach (D) lost about 24,000 feet of backchannel, which is about 14% of its total channel length in 1957 (Exhibit 1-2 and 2-2). Simplification is now known to eliminate river frontage and wildlife habitat, as well as have detrimental hydraulic effects, and is generally not considered desirable (Galay, et al, 1998).

Geomorphic parameters have been summarized for reaches A through F in Table 2, as well as on Exhibits 1 and 2. Note that the dates between which various parameters have been compared vary. Parameters measured from air photos are compared between 1957 and 1996. Cross-sections were available for 1968 and 1999, and channel armoring was inventoried in the field in 1999 and compared visually where possible to the 1957 airphotos.

Table 2: Channel Training and Geomorphic Parameters by Reach

Reach	Thalweg Length (feet)		Total Channel Length (feet)		Braiding Parameter		Channel Armoring (%) *		Dikes (%) *		Average width/depth ratio**	
	1957	1996	1957	1996	1957	1996	1957	1999	1957	1996	1968	1999
A	33,000	30,000	94,000	106,000	2.9	3.5	19	32	3	4	NA	167
B	15,000	15,000	32,000	32,000	2.2	2.1	10	28	0	14	NA	49
C	18,000	19,000	56,000	52,000	3.1	2.8	21	28	0	2	NA	NA
D	38,000	40,000	170,000	146,000	4.5	3.6	15	39	4	15	126	48
E	27,000	27,000	44,000	44,000	1.6	1.6	27	41	2	0	55	53
F	29,000	30,000	99,000	88,000	3.4	2.9	14	26	9	11	57	NA
Total	160,000	161,000	495,000	468,000	3.1	2.9	18	33	3	8	NA	NA

**Note: In areas where dikes and armoring overlap, precedence was given to armoring, and dikes were counted as separate items only in places where they were not overlapped by armoring. Therefore, totaling the percentage of armoring and dikes in a reach gives an approximation of the extent of total channel alteration. For example, in Reach A, the 1957 channel was armored about 19% and diked about 3%, for a total of 22% alteration. In 1996, 32% of Reach A was armored and about 4% diked, for a total of 36% alteration.*

***Average w/d for entire study reach in 1968 and 1999 are weighted by thalweg length. The 1968 average w/d is for reaches D through F, and the average 1999 w/d is for reaches A, B, D and E. Reaches C and F have too few 1999 cross-sections to calculate averages.*

The width/depth (w/d) ratios were calculated by a simple division of bankful width by maximum depth. Bankful depth was calculated at each cross-section by Aquoneering using HEC-RAS. Width/depth ratios at bridges were not included in the averages, because the channels are artificially confined at those points and the w/d values were considered non-representative. Width/depth ratios at bridges are lower than normal and exhibit little change with time. The w/d averages must be used with caution. Although they have been utilized in this report to identify trends, in some places there are too few cross-sections to develop statistically valid averages for w/d.

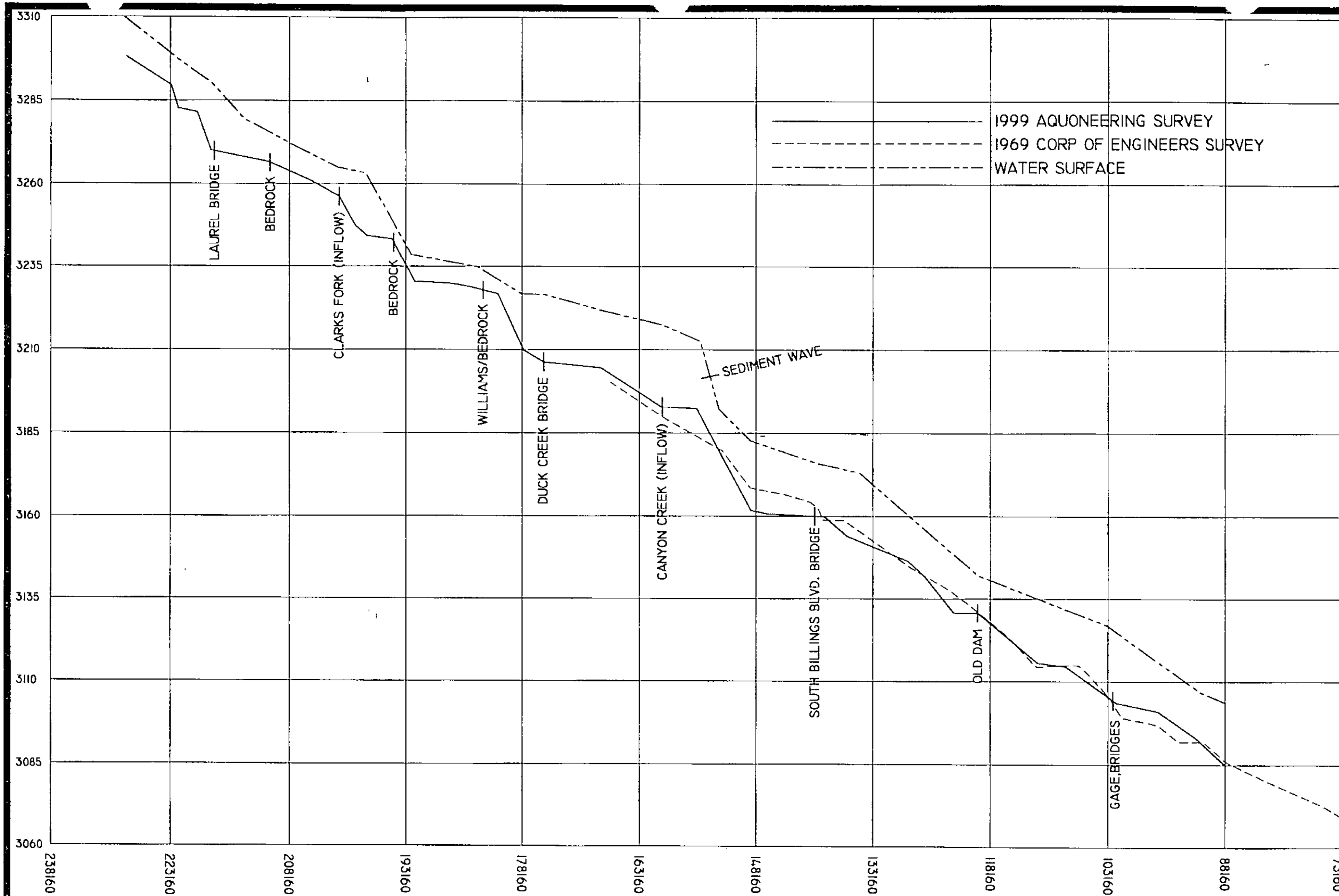
As shown by Table 2, w/d ratios could be compared between 1968 and 1999 only in reaches D and E, because the 1968 Corps cross-sections upstream of Reach D are no longer available. Obviously the largest documented changes in w/d ratio occurred in Reach D, where abandonment and closure of back channels resulted in relative deepening and narrowing of the remaining channels.

The very high average w/d ratios in Reach A appear to represent a response to the restriction at the Laurel bridges. Upstream of the bridges, the river is quite wide, with a meander belt 2,000 to 3,000 feet across (Exhibit 2-1). The cross-sections measured in 1999 were too short to determine w/d upstream of the bridges, although w/d ratios are obviously high. The w/d ratios show considerable narrowing downstream of the bridge, dropping to about 21 opposite the BBWA irrigation canal intake (Refer to cross-section 5 on Exhibit 2-1). About 2,000 feet downstream of the bridges and upstream of the Clark Fork confluence, the river widens considerably and has measured w/d ratios of about 300 (Cross-section 7 on Exhibit 2-1), which is about twice the maximum values measured elsewhere in the study reach. Sediment is apparently flushed through the narrow gut at the bridge and deposited downstream, resulting in local widening and aggradation (Galay, et al, 1998).

With the exception of the portion of Reach A described above, the changes in morphology appear to correspond to added channel armoring and dikes. The river apparently responded to the increase in the length of armored or diked banks by abandoning secondary channels, becoming simpler in planform, or more "canalized" (Hey, 1998), particularly in Reach D. It is obvious from a visual comparison of the 1957 and 1996 air photos that much of the channel loss can be attributed directly to construction of dikes across the inlets to secondary channels. It is also likely that armoring has reduced formation of new back channels.

As illustrated by Table 2, the average w/d ratios in heavily armored reaches also decreased as the total channel length and degree of braiding decreased. This trend reflects closure of back channels and shift toward a dominant single channel. Decreases in w/d ratio are often accompanied by decreases in discharge capacity and altered stage/discharge relationships. The documented changes imply that existing flood plain maps should be revised in some cases.

The longitudinal profiles (Figure 6) reveal some interesting patterns. The scouring at the Laurel bridges is obvious, as is the flattened reach downstream. Bedrock control creates steps in the channel in three places upstream of the Duck Creek bridge. The river bed profile measured by the Corps in 1968 and used for the FEMA flood study is similar to the Aquoneering profile, although Aquoneering's profile is more detailed and reveals riffles, pools, and sediment waves more clearly.



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OF ______

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(406) 628-2202

FIGURE 6
RIVER BED & WATER SURFACE PROFILE
YELLOWSTONE RIVER GEOMORPHIC ANALYSIS
YELLOWSTONE COUNTY, MONTANA

FIGURE8.DWG
99-550-01
DRAWN BY: RFS
CHECKED BY: RJP
APPROVED BY: RJP

DATE: 05/02/00
REVISED: 05/02/00

The largest change in longitudinal profile between 1968 and 1999 appears to be in the reach between the Canyon Creek confluence and the South Billings Boulevard (Blue Creek) bridge, where the profiles indicate about 8 feet of aggradation downstream of Canyon Creek, and about 7 feet of degradation upstream of the bridge. The degraded reach appears to extend about 13,000 feet upstream of the bridge, and corresponds to the portion of Reach D affected by the long dike illustrated on Figure 3 and Exhibit 2-2. In this reach where the river has been confined to a single channel, it has deepened the remaining channel. The w/d ratios have shown a corresponding decrease, as shown on Table 2. The FEMA flood plain profiles and maps may not be current in this reach.

6.0 POTENTIAL AND ACTUAL IMPACTS OF CHANNEL TRAINING

Channel training (dikes and armoring) typically has local as well as upstream and downstream effects that have been documented along many rivers. The intent of this study was to examine the Yellowstone and identify trends that indicate whether phenomena associated with river training in other places are occurring here.

6.1 INCREASED EROSION OF UNPROTECTED BANKS

As the extent of channel armoring increases, the river may attack those areas that are unprotected, in order to acquire the sediment load needed to satisfy its hydraulic energy requirements. Increased erosion rates have not been documented by this study. However, the acceleration in channel armoring in recent years may be an indication that landowners are responding to increased erosion rates.

6.2 CHANGES IN GEOMETRY

A stable river exhibits a consistency of geometry and channel pattern. Stability does not imply that the river is not meandering and eroding its banks. In fact, a stable river must erode its banks and move sediment downstream in order to satisfy the energy requirements of the moving water. Consistency of form--i.e., relatively constant channel gradient, sinuosity, and width/depth ratio--implies stability. Channel pattern should also be consistent. A common sign of instability is a major change in pattern; e.g., if a meandering river becomes braided or vice versa.

Local changes in geometry as expressed by w/d ratios and degree of braiding have been documented by this study. These changes have apparently altered stage-discharge relationships, with the result that flood levels may be higher in some areas. At this point in time the changes in flood stage are localized. However, it is reasonable to assume that these changes will become more widespread if the trend of increasing the degree of channel training continues.

6.3 LOSS OF BACK CHANNELS AND HABITAT

Channel armoring and training often leads to a loss in total channel length, because the smaller side channels are artificially blocked off or abandoned by the river due to a change in form. Back channels may be important fisheries habitat, providing spawning sites and migration routes. These sites are also used intensively by land animals and waterfowl and may be critical for dampening flood effects. Dramatic loss in back channel capacity has been documented in modern times on the Willamette River (Sedell and Froggett, 1984) and the Missouri River (Morris, et al, 1968; and Keller, 1976).

This study has demonstrated that channel lengths have decreased in some reaches due to channel training. Overall, the total channel length through the study reach has decreased only about 5% since 1957. However, this statement may be somewhat misleading, because large reductions in channel length along much of the study reach were offset by a sizeable local increase in channel length in the reach downstream of Laurel triggered by constriction of the channel at the bridges.

7.0 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions have emerged from this study:

- The extent of channel training (dikes and armoring) has increased from approximately 21% in 1957 to 41% in 1999.
- Dikes and armoring have simplified the channel, leading to significant reduction in total channel length in some reaches.
- The river is much more braided where it is not confined against its valley wall.
- The more heavily braided reaches are the least stable in terms of channel migration, and have experienced the most intensive channel training efforts.
- Width/depth ratios are typically on the order of 50 at bridges and in reaches confined by valley walls or training, and upwards of 100 in more braided reaches. Channel armoring has caused a tendency for braided reaches to become narrower and have lower w/d ratios. Changes in geometry have caused local changes in flood-discharge relationships.
- The bridges are short compared to the width of the meander belt, and confine the river, causing widening of adjacent reaches.

The following recommendations are offered as potential starting points for discussion and ways to improve our knowledge of the river and reduce negative impacts:

- Public policy regarding river training, as expressed by the permitting process, should address overall effects to river morphology. It may be helpful to require geomorphic analyses for permits.
- There is a need to develop a public policy regarding development in the meander corridor.
- Fisheries experts should review the potential effects on fisheries caused by channel loss.
- New bridges should be longer. Galay, et al (1998) suggest that the length of new bridges should be a minimum of 1.5 times the "regime" width (i.e., bankful width).
- Blocking secondary channels should be unacceptable.
- Rapid airborne reconnaissance would be a useful tool for inventory of channel training structures and channel conditions, as well as detection of violations of river management regulations.

- Channel armoring and training should be consistent with river morphology, maintaining channel geometry, meander radius, etc. Eroding banks should not simply be armored in their existing condition. Instead, the normal meander radius in the reach should be evaluated and the work should be matched to that value.
- Long riprap lengths are not recommended. Weirs and spurs are preferable to riprap.
- It may be appropriate to update floodplain maps in areas where significant change has occurred.

8.0 REFERENCES

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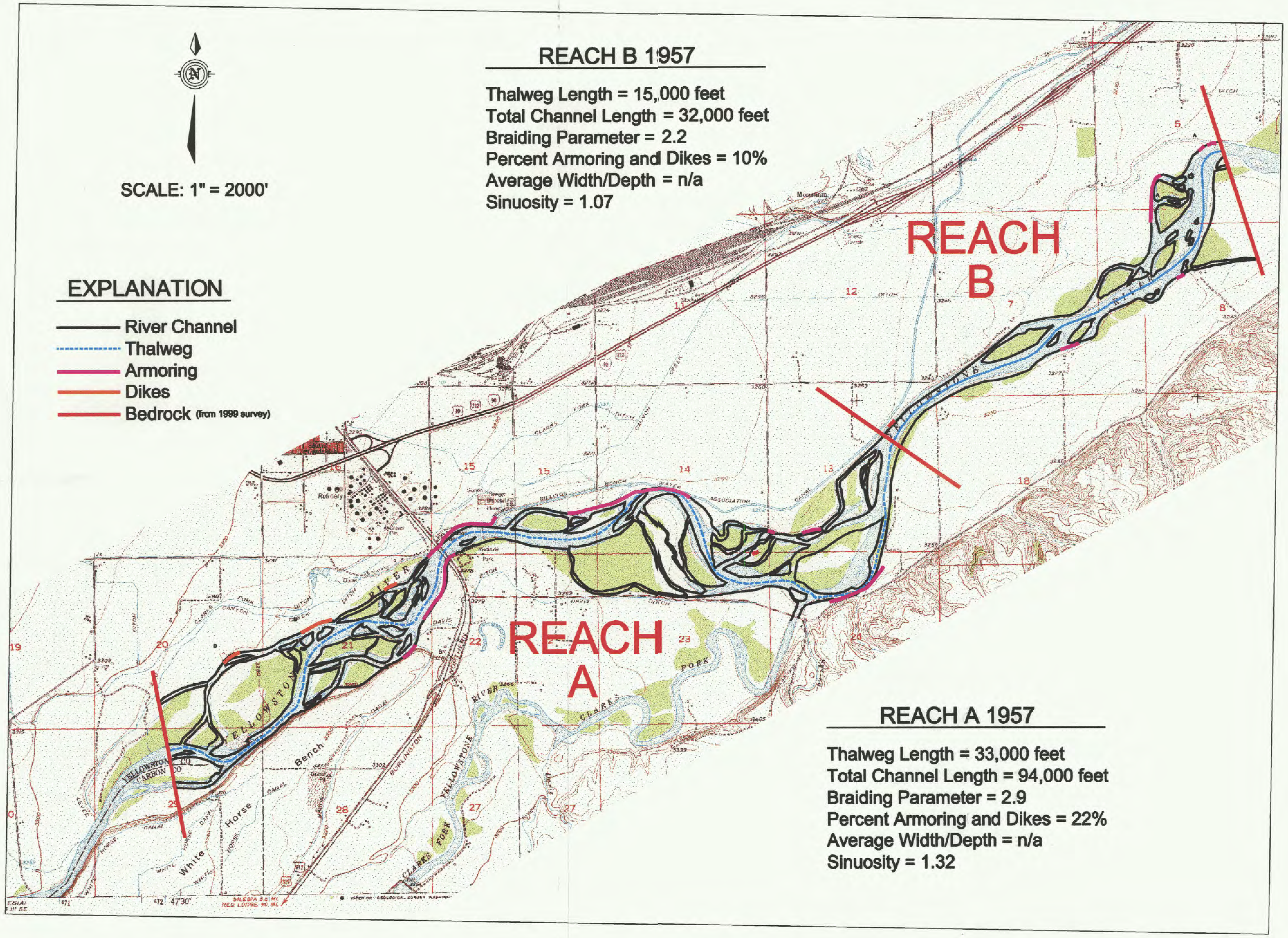


NOTE: THE 1968 ARMY CORPS OF ENGINEERS CROSS SECTION DATA ARE NOT AVAILABLE FOR REACHES A AND B.

YELLOWSTONE RIVER
GEOMORPHIC ANALYSIS
YELLOWSTONE COUNTY, MONTANA

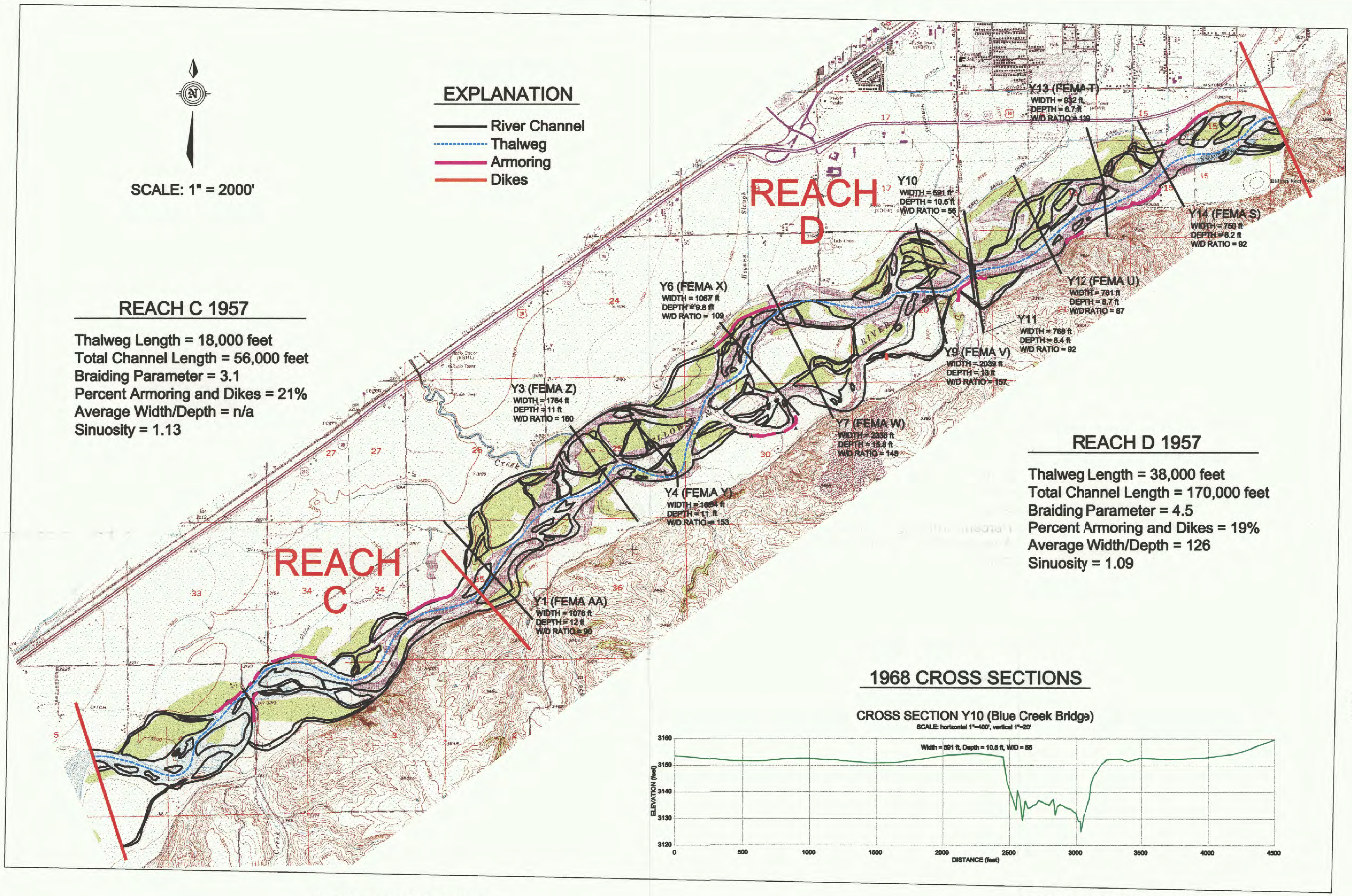
REACH A AND B
1957 RIVER CHANNEL

Drawn: gsv
Checked:
Approved:
Date: 042800
Rev. #:
Proj. #:

EXHIBIT
1-1

WOMACK AND ASSOCIATES, INC.
BILLINGS, MONTANA
5825 LAZY LANE (406) 656-5398

AUTOCAD LT2000
YRC57AB.dwg



REACH C 1957

Thalweg Length = 18,000 feet
Total Channel Length = 56,000 feet
Braiding Parameter = 3.1
Percent Armoring and Dikes = 21%
Average Width/Depth = n/a
Sinuosity = 1.13

REACH D 1957

Thalweg Length = 38,000 feet
Total Channel Length = 170,000 feet
Braiding Parameter = 4.5
Percent Armoring and Dikes = 19%
Average Width/Depth = 126
Sinuosity = 1.09

1968 CROSS SECTIONS

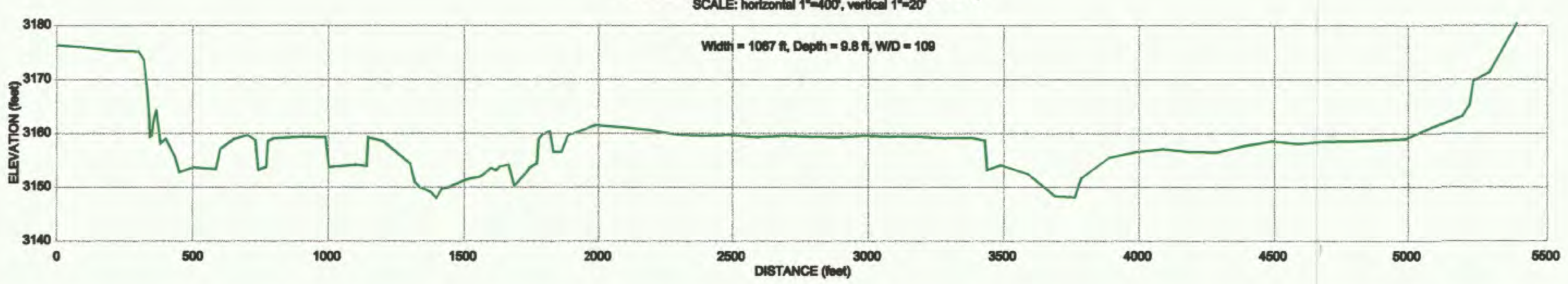
CROSS SECTION Y10 (Blue Creek Bridge)

SCALE: horizontal 1"=400', vertical 1"=20'

NOTE: THE ARMY CORPS OF ENGINEERS CROSS SECTION DATA ARE NOT AVAILABLE FOR REACH C.

CROSS SECTION Y6 (FEMA X)

SCALE: horizontal 1"=400', vertical 1"=20'



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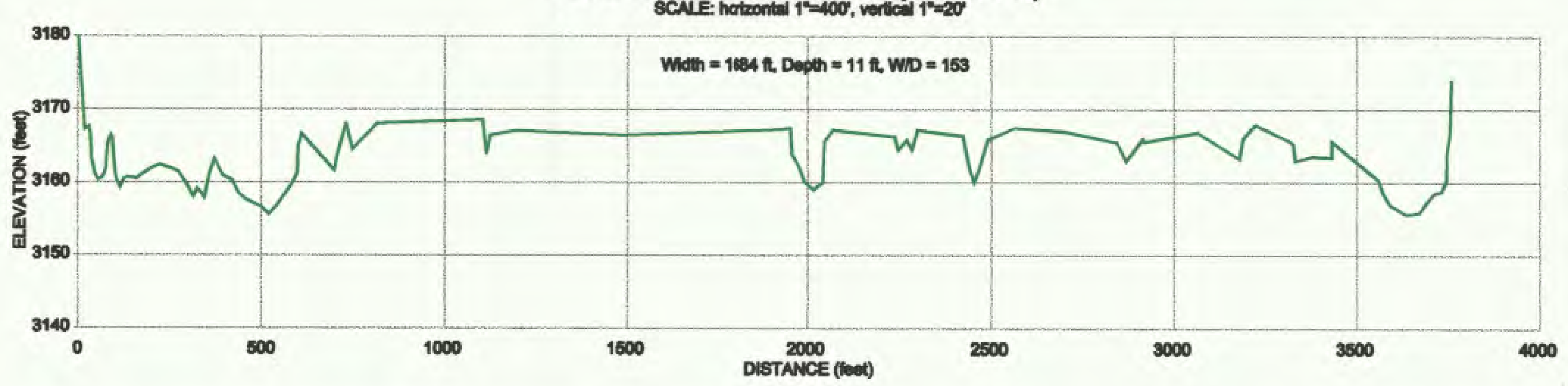

YELLOWSTONE RIVER
GEOMORPHIC ANALYSIS
YELLOWSTONE COUNTY, MONTANA

REACH C AND D 1957 RIVER CHANNEL WITH 1968 CROSS SECTIONS

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Date: 050300
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Proj. #:

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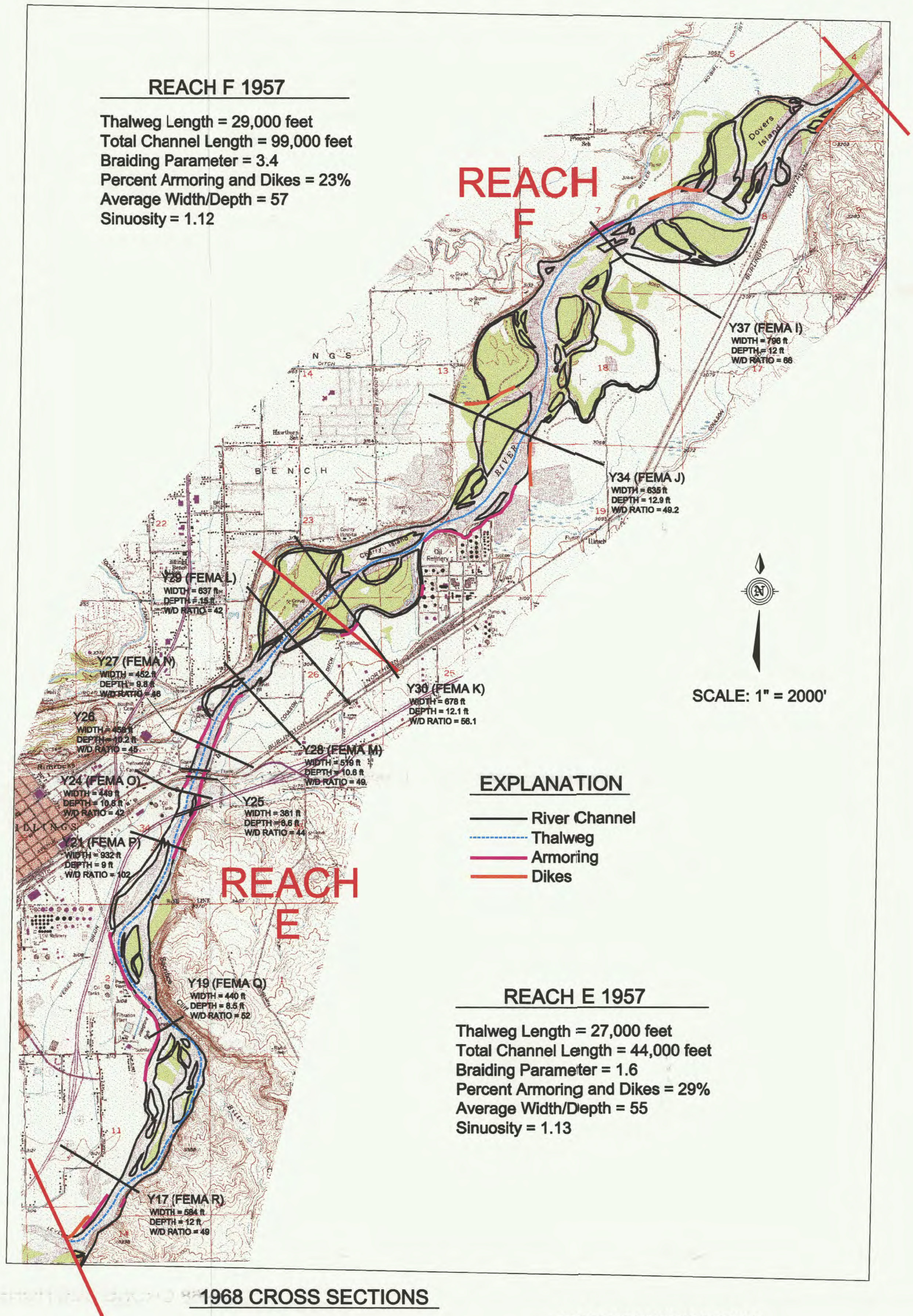
WOMACK AND ASSOCIATES, INC.
5825 LAZY LANE BILLINGS, MONTANA (406) 656-5398



REACH F 1957

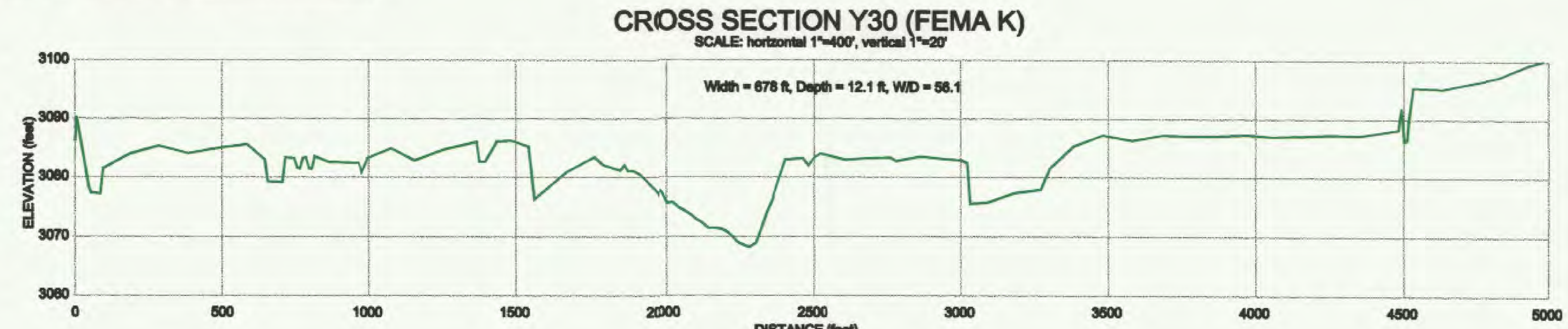
Thalweg Length = 29,000 feet
Total Channel Length = 99,000 feet
Braiding Parameter = 3.4
Percent Armoring and Dikes = 23%
Average Width/Depth = 57
Sinuosity = 1.12

REACH E 1957

Thalweg Length = 27,000 feet
Total Channel Length = 44,000 feet
Braiding Parameter = 1.6
Percent Armoring and Dikes = 29%
Average Width/Depth = 55
Sinuosity = 1.13

1968 CROSS SECTIONS

CROSS SECTION Y30 (FEMA K)
SCALE: horizontal 1"=400', vertical 1"=20'



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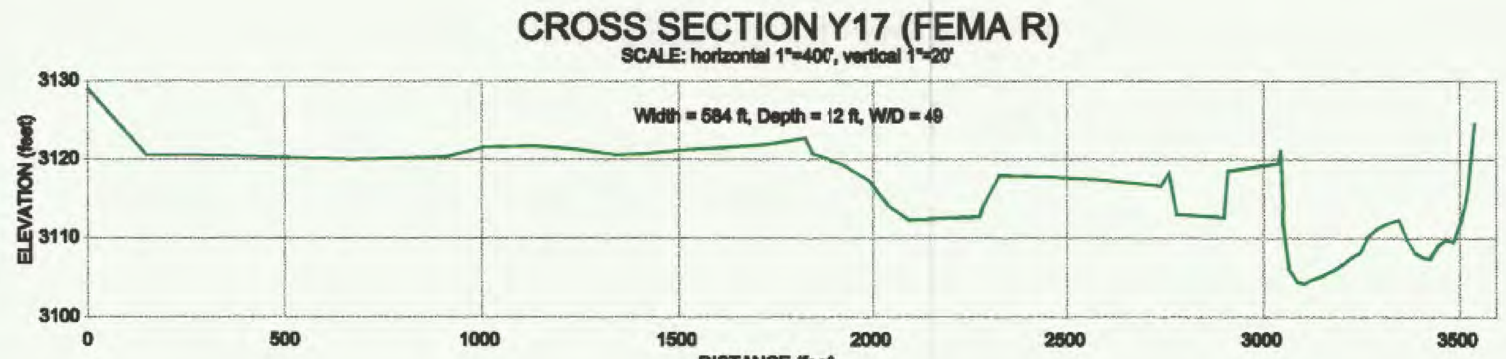

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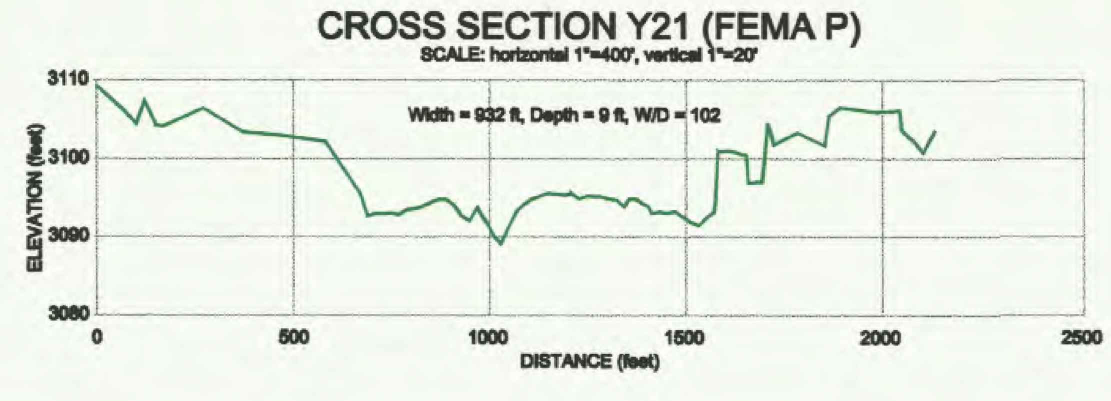

YELLOWSTONE RIVER
GEOMORPHIC ANALYSIS
YELLOWSTONE COUNTY, MONTANA

REACH E AND F 1957 RIVER CHANNEL WITH 1968 CROSS SECTIONS

Drawn: gsv
Checked: wrw
Approved: wrw
Date: 050300
Rev. #: 050500
Proj. #:

EXHIBIT 1-3

AUTOCAD LT2000
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BILLINGS, MONTANA
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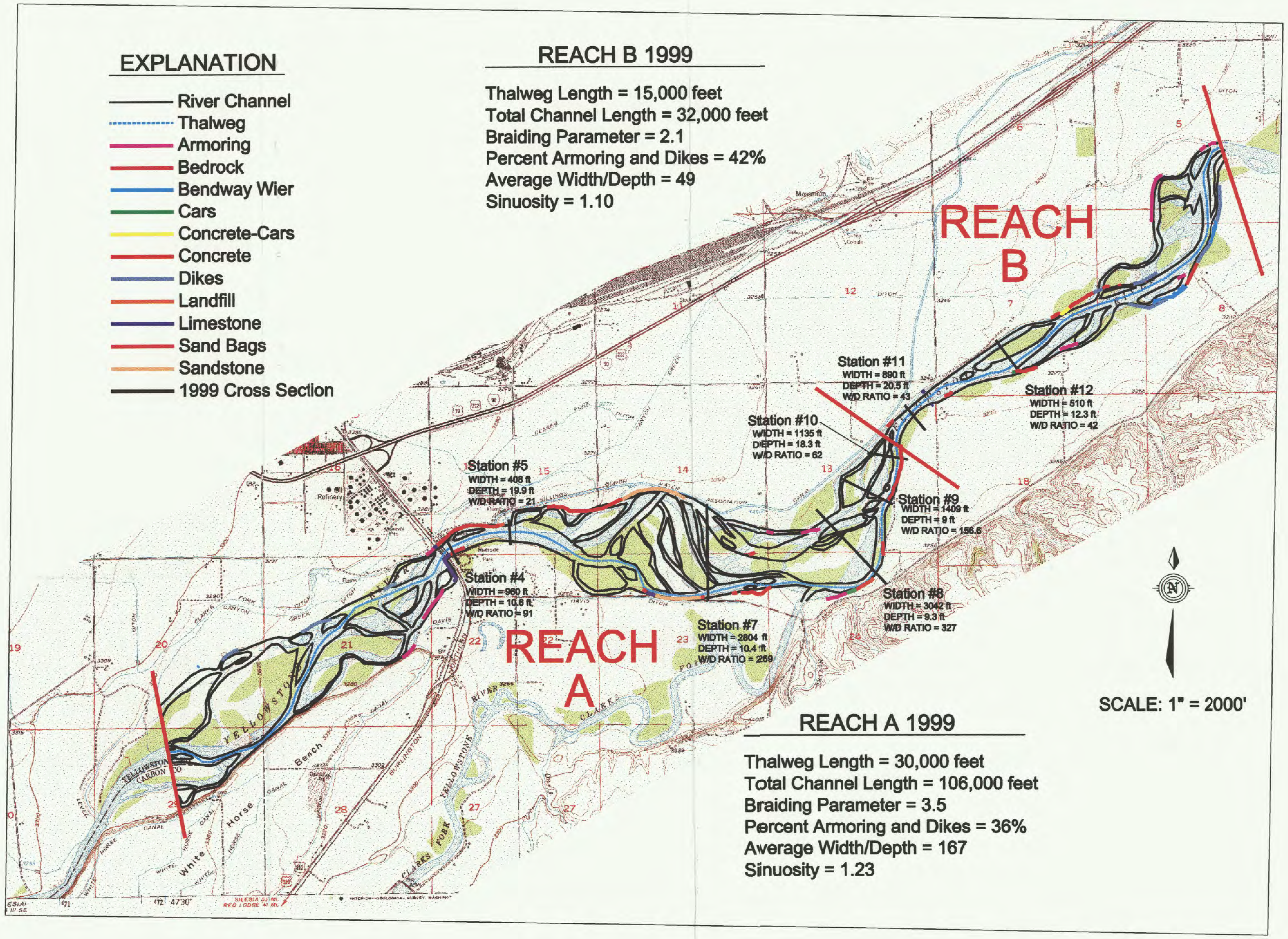

1999 CROSS SECTIONS

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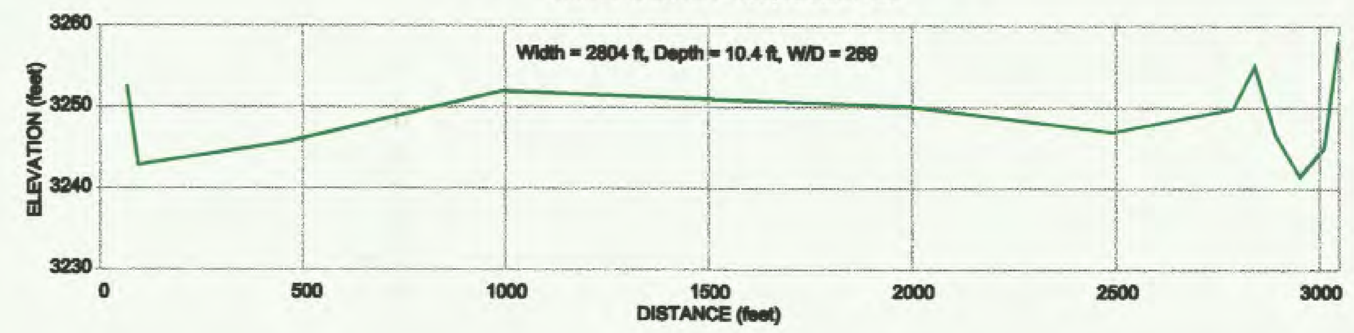

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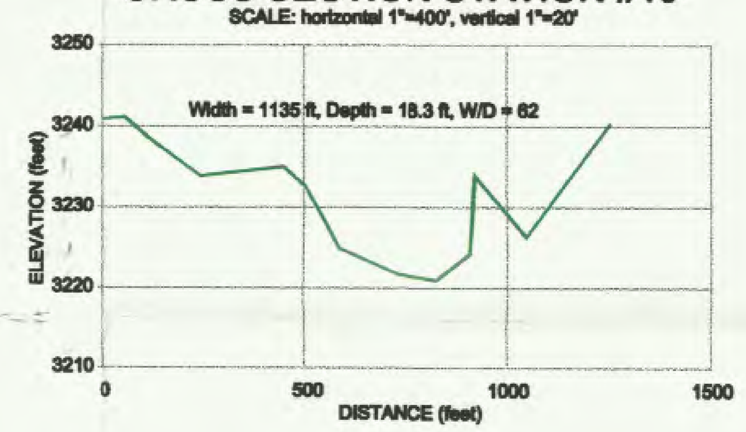

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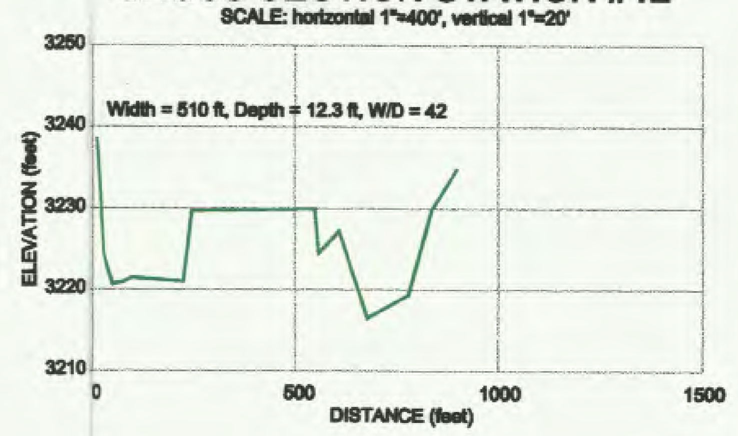

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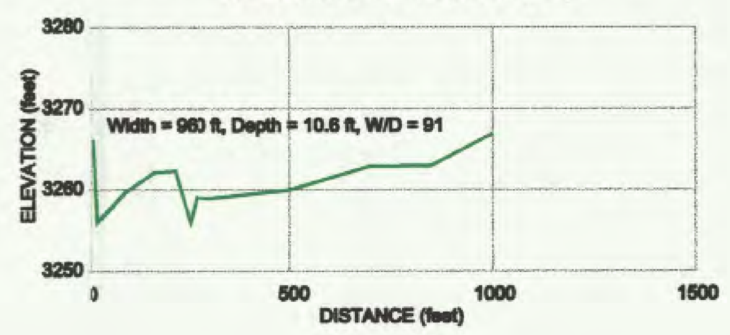

CROSS SECTION STATION #5
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YELLOWSTONE RIVER
GEOMORPHIC ANALYSIS
YELLOWSTONE COUNTY, MONTANA

REACH A AND B 1996 RIVER
CHANNEL WITH 1999 CROSS SECTIONS

Drawn: gsv
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Date: 050300
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EXHIBIT 2-1

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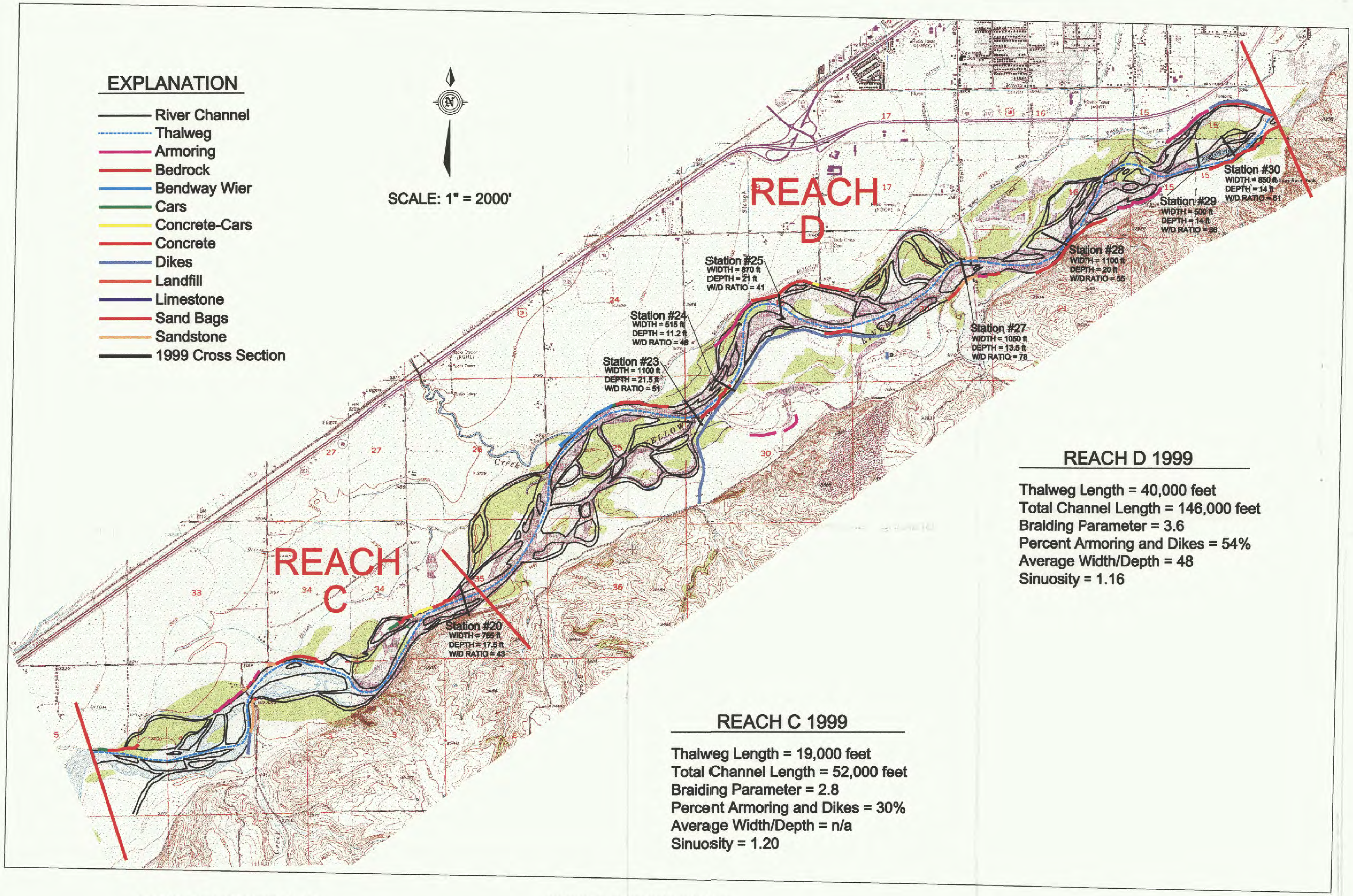

1999 CROSS SECTIONS

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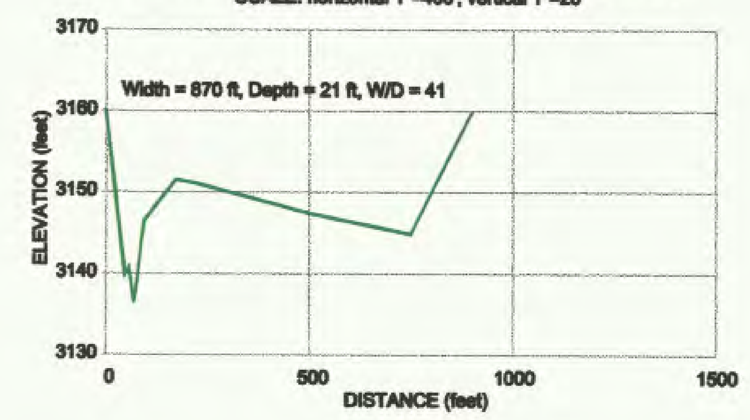

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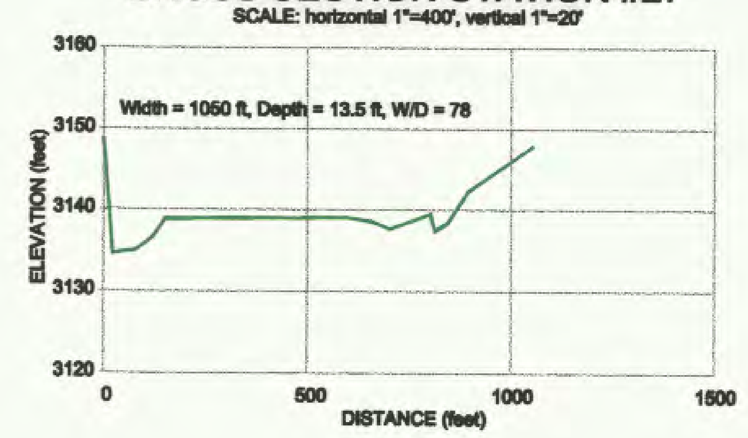

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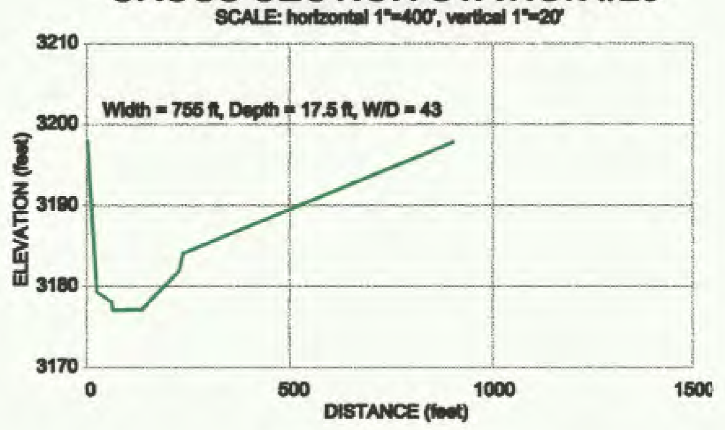

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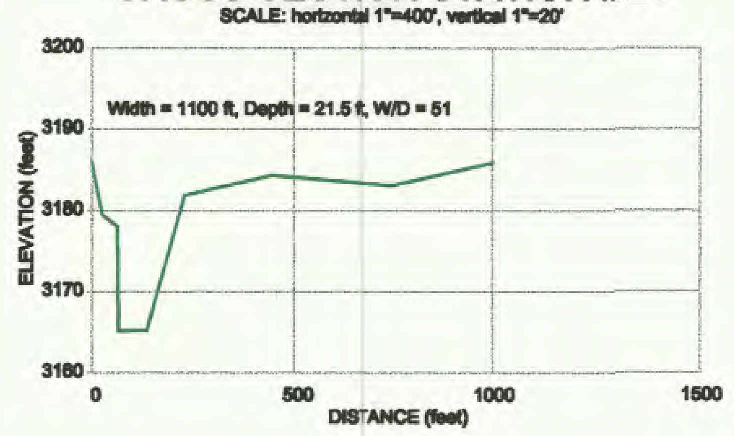

YELLOWSTONE RIVER
GEOMORPHIC ANALYSIS
YELLOWSTONE COUNTY, MONTANA

REACH C AND D 1996 RIVER CHANNEL WITH 1999 CROSS SECTIONS

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Checked: wrw
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Date: 050700
Rev. #:
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BILLINGS, MONTANA
5825 LAZY LANE (406) 656-5398

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2-2

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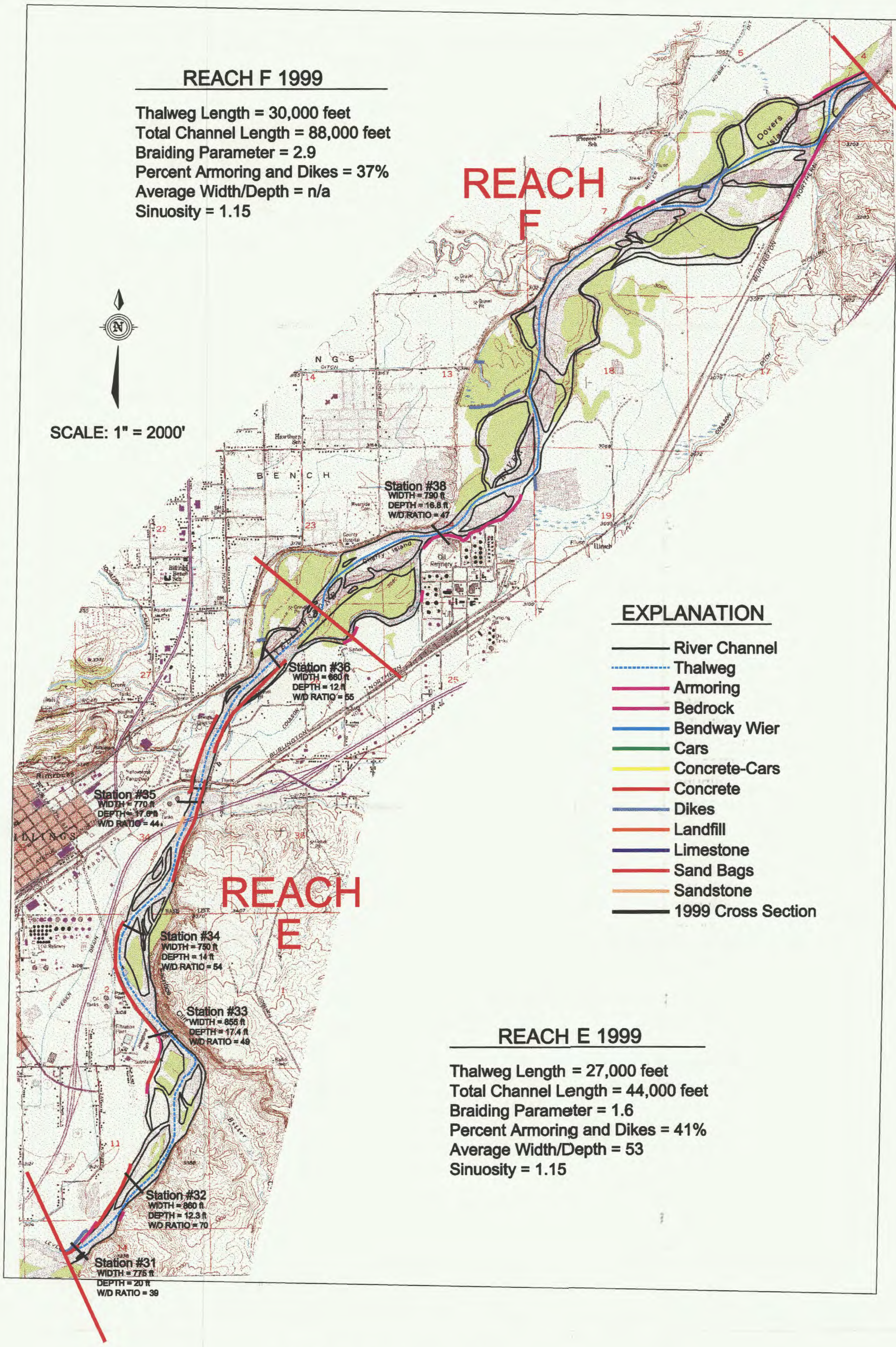

1999 CROSS SECTIONS

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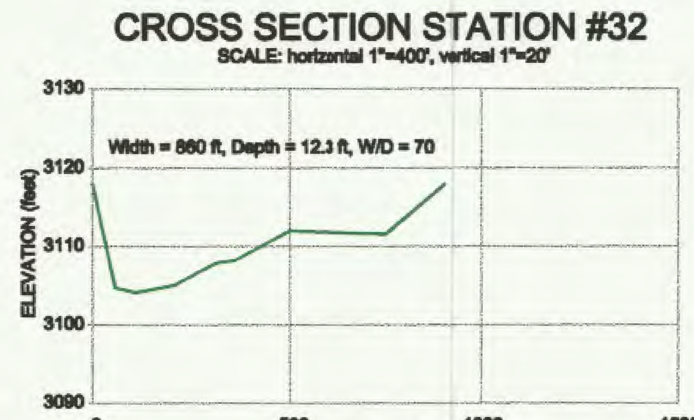

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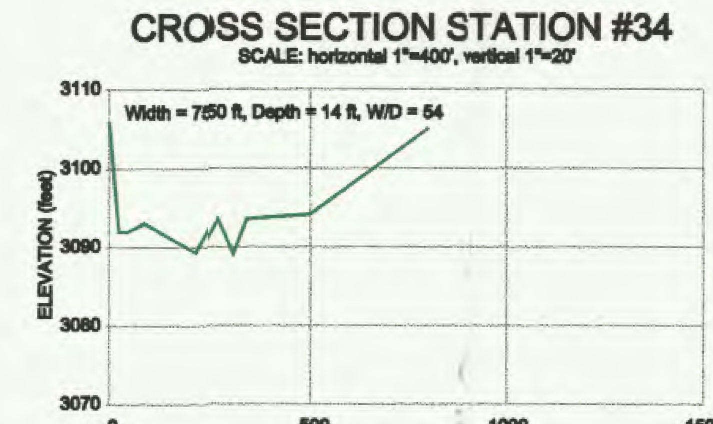


YELLOWSTONE RIVER GEOMORPHIC ANALYSIS YELLOWSTONE COUNTY, MONTANA	
REACH E AND F 1996 RIVER CHANNEL WITH 1999 CROSS SECTIONS	Drawn: gsv Checked: wrw Approved: wrw Date: 050700 Rev. #: Proj. #:
WOMACK AND ASSOCIATES, INC. BILLINGS, MONTANA 5825 LAZY LANE (406) 656-5398	EXHIBIT 2-3 AUTOCAD LT2000 YRC99EF.dwg

APPENDIX A:

PHOTOGRAPHS

Photo 1: Example of armoring - Concrete spur.

Photo 2: Example of armoring – Dumped concrete rubble spur.

Photo 3: Example of armoring – Limestone and sandstone.

Photo 4: Example of armoring – Cabled trees.

Photo 5: Example of armoring – Miscellaneous junk.

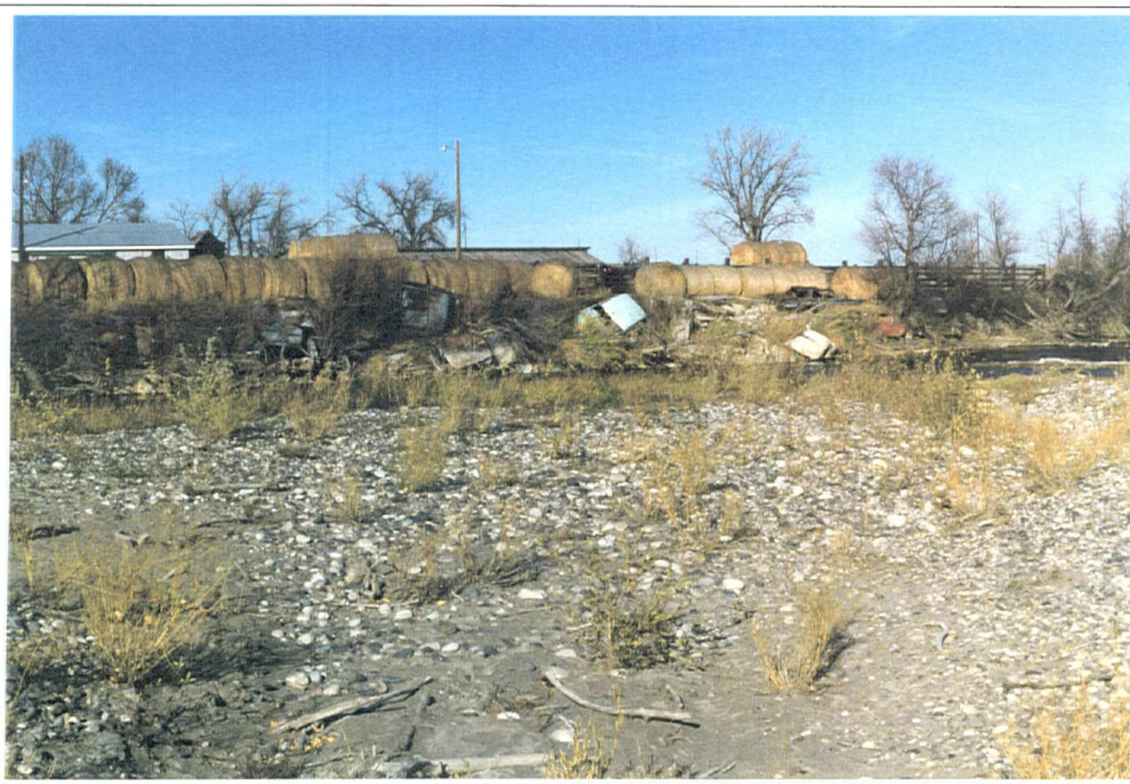


Photo 6: Example of armoring – Car bodies.

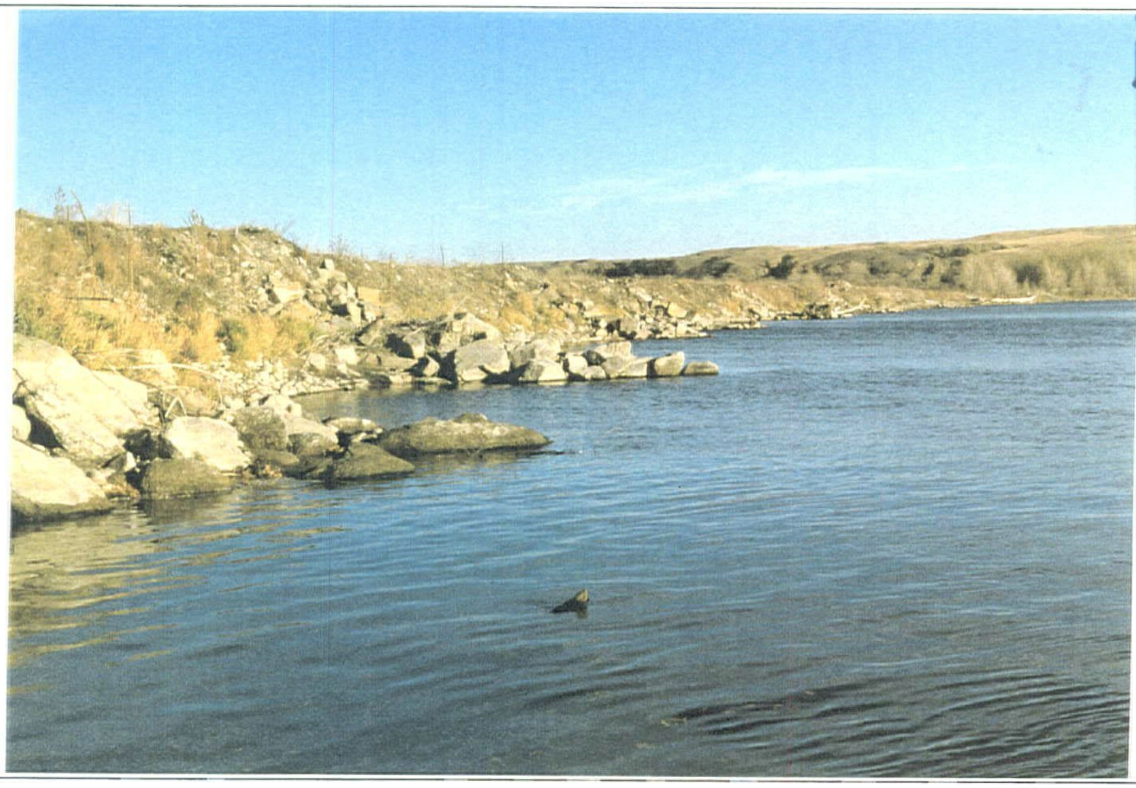


Photo 7: Example of armoring – Wiers.

Photo 8: Example of armoring – Hand placed sandstone.

Photo 9: Boat with sounding and logging equipment.

Photo 10: Example of development close to river.

Photo 11: Bedrock outcrop in river near Laurel.

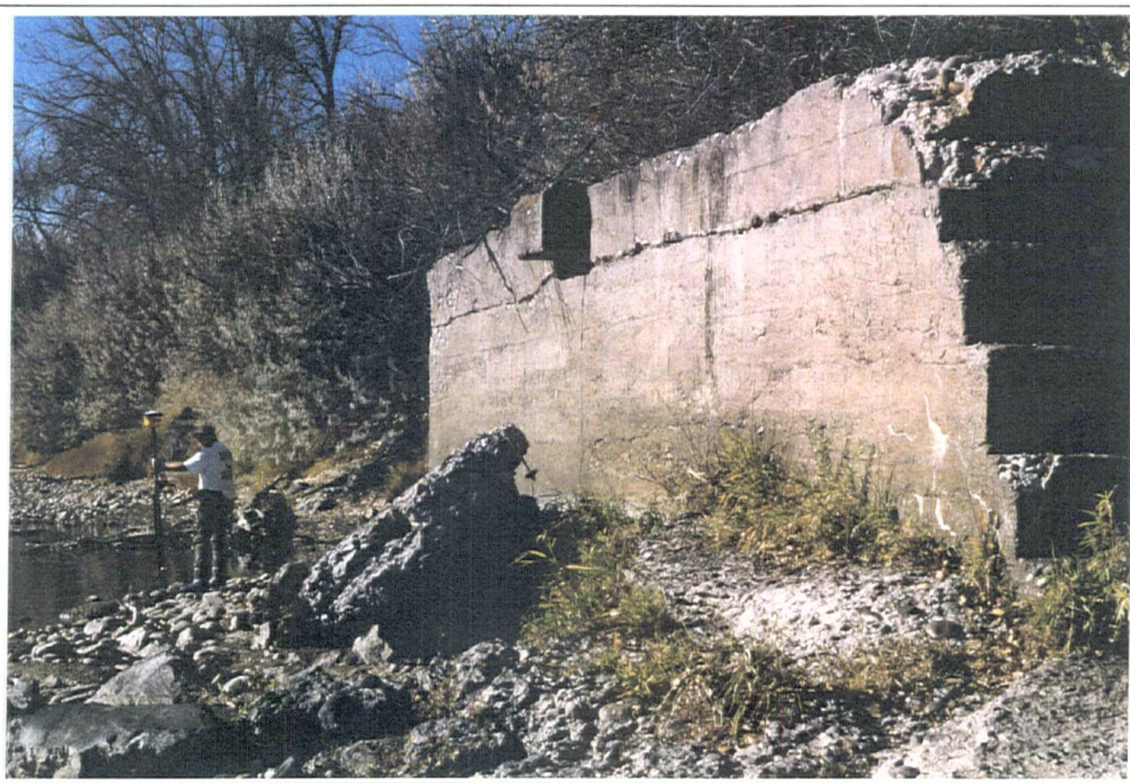
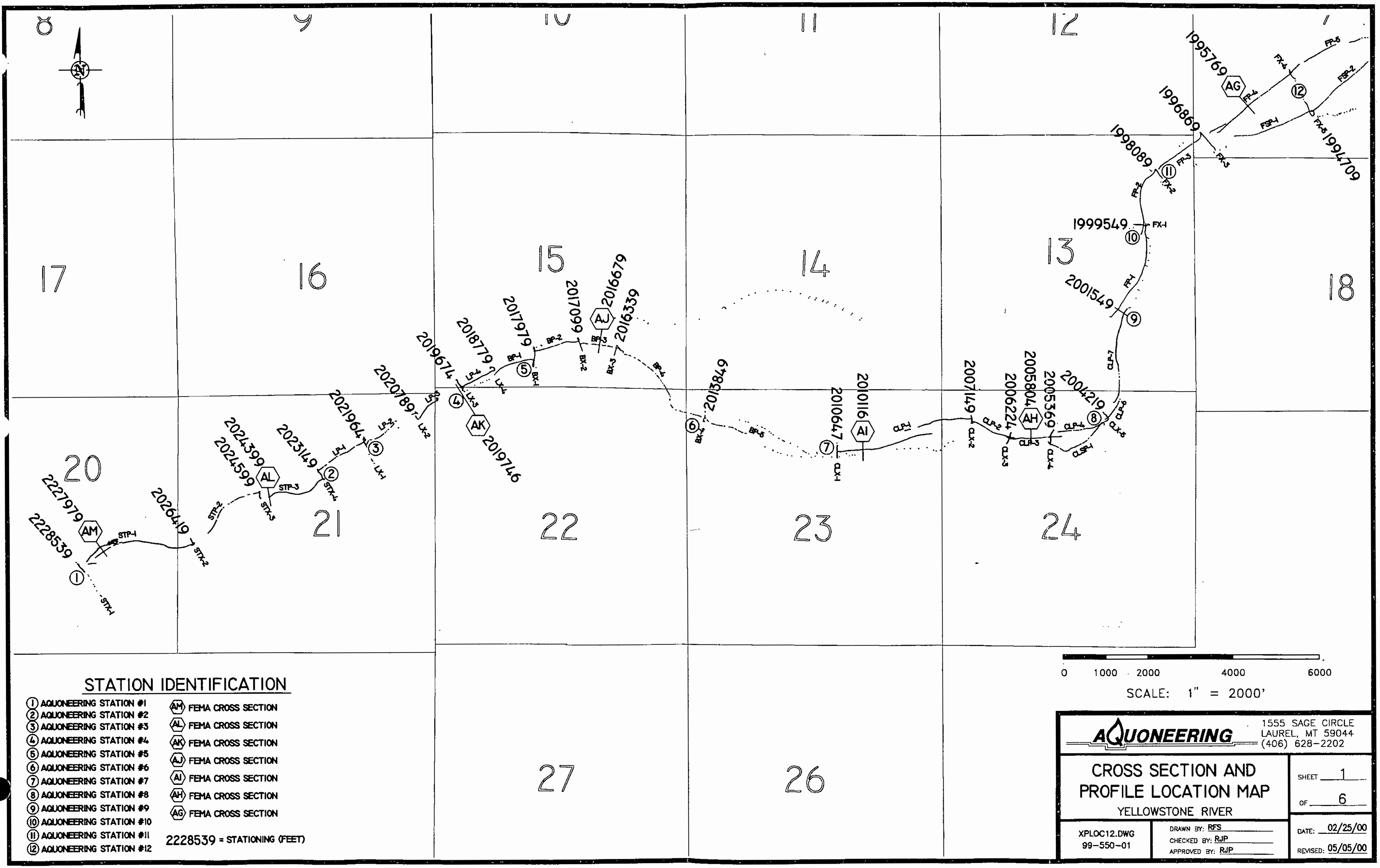


Photo 12: Old power dam abutment.

APPENDIX B:

CROSS SECTIONS



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LAUREL, MT 59044
(406) 628-2202
CROSS SECTION AND
PROFILE LOCATION MAP
YELLOWSTONE RIVER
SHEET 1
OF 6
XPLOC12.DWG
99-550-01
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CHECKED BY: RJP
APPROVED BY: RJP
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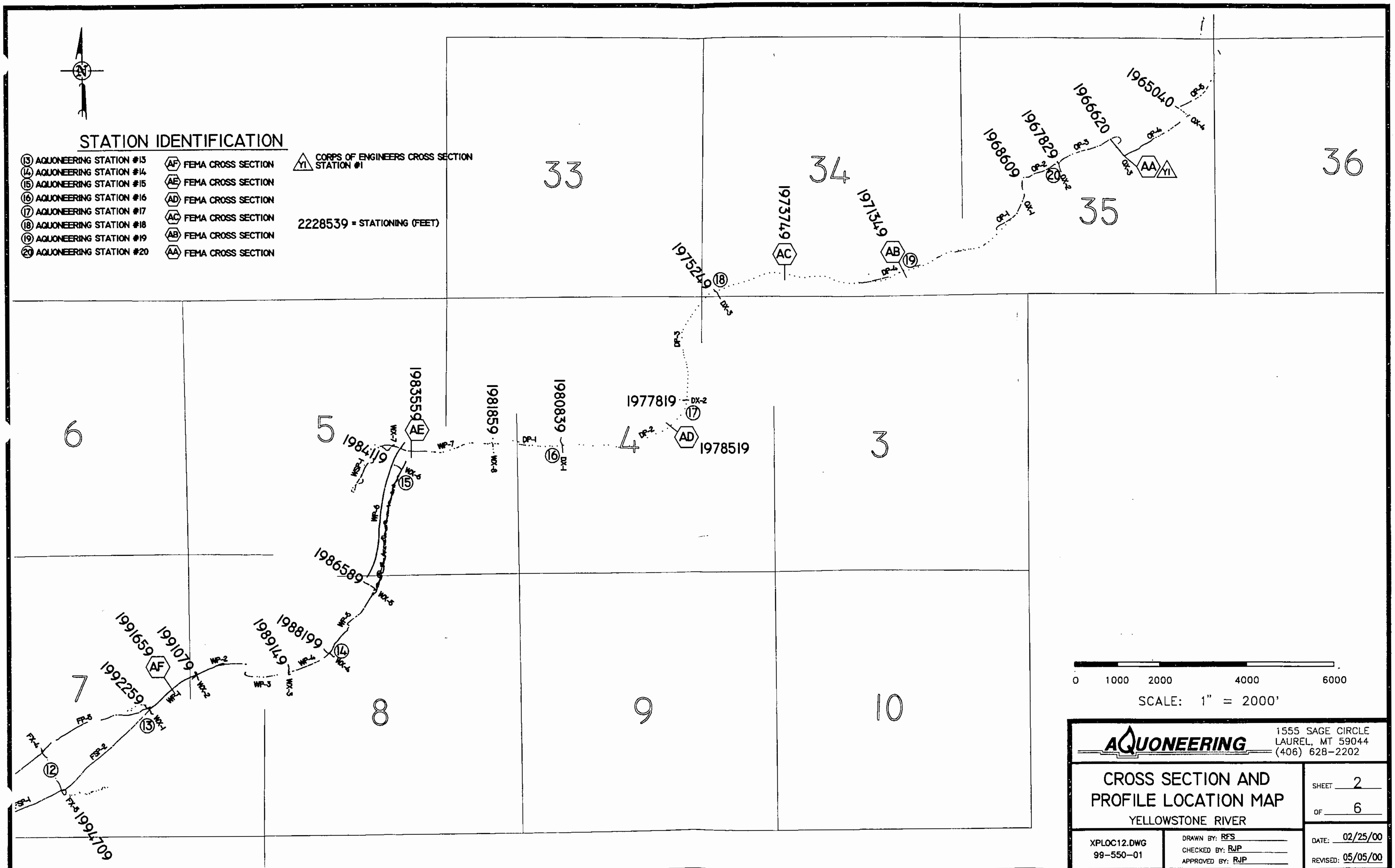
REVISED: 05/05/00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(406) 628-2202
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SHEET 2
OF 6
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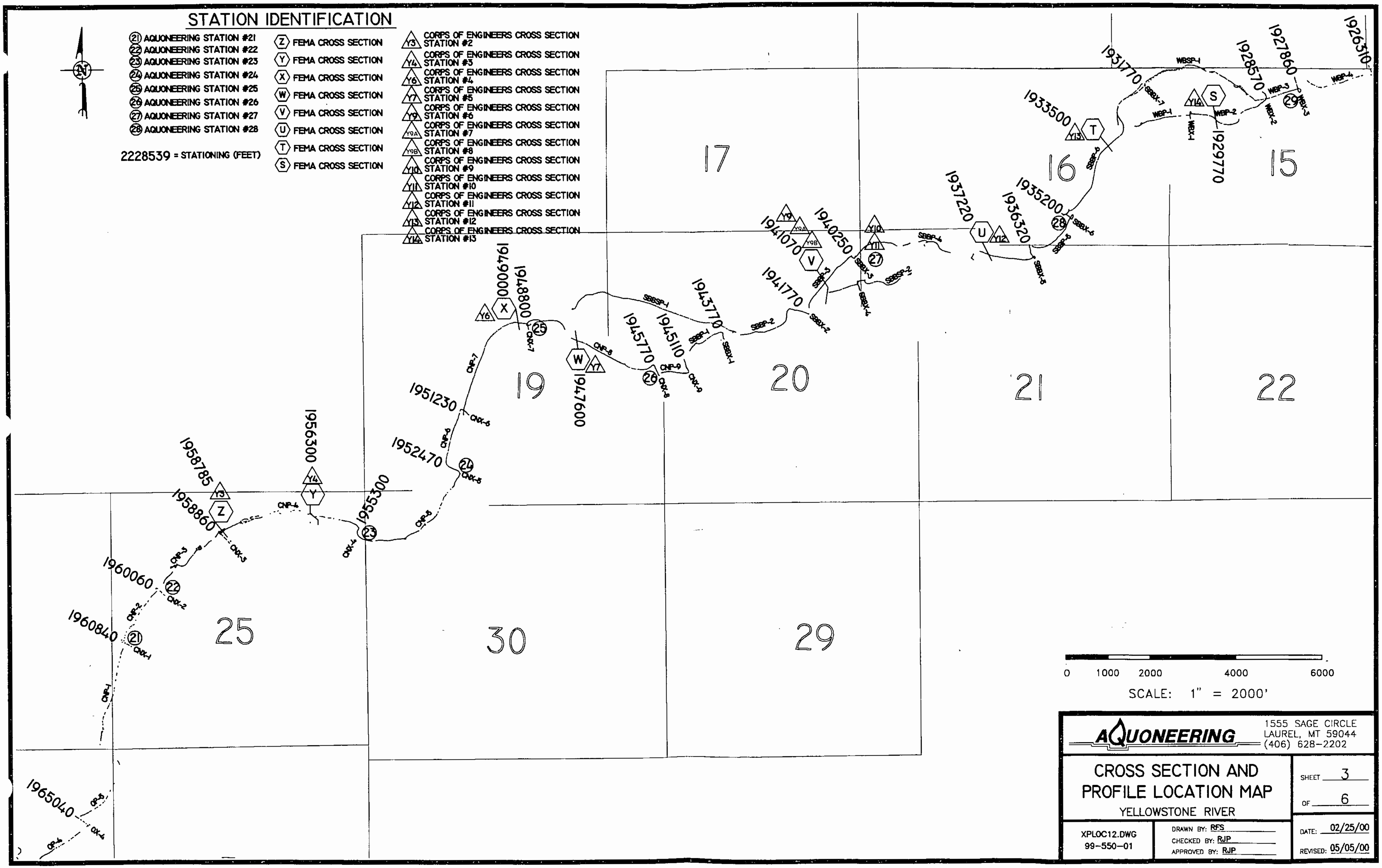

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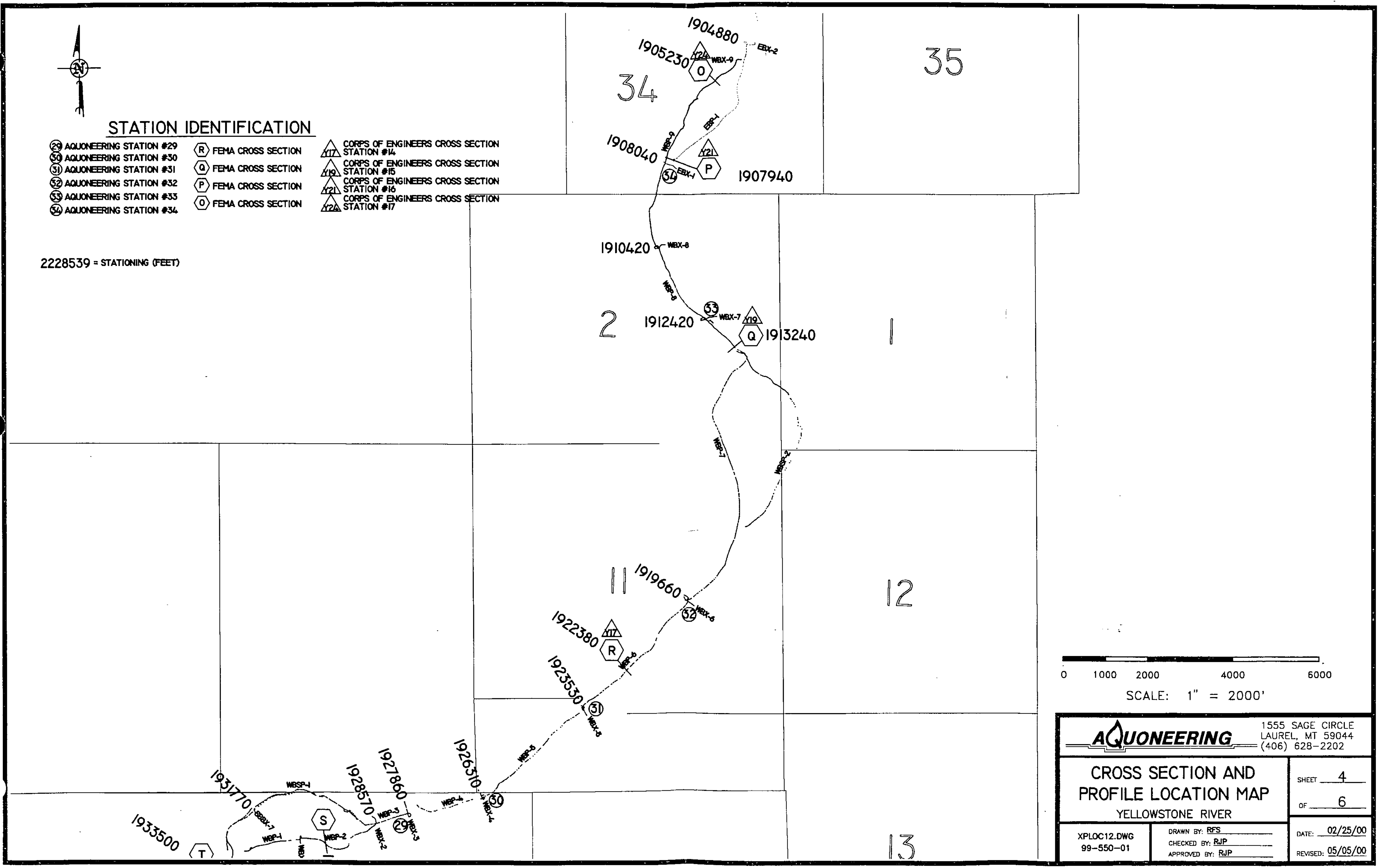
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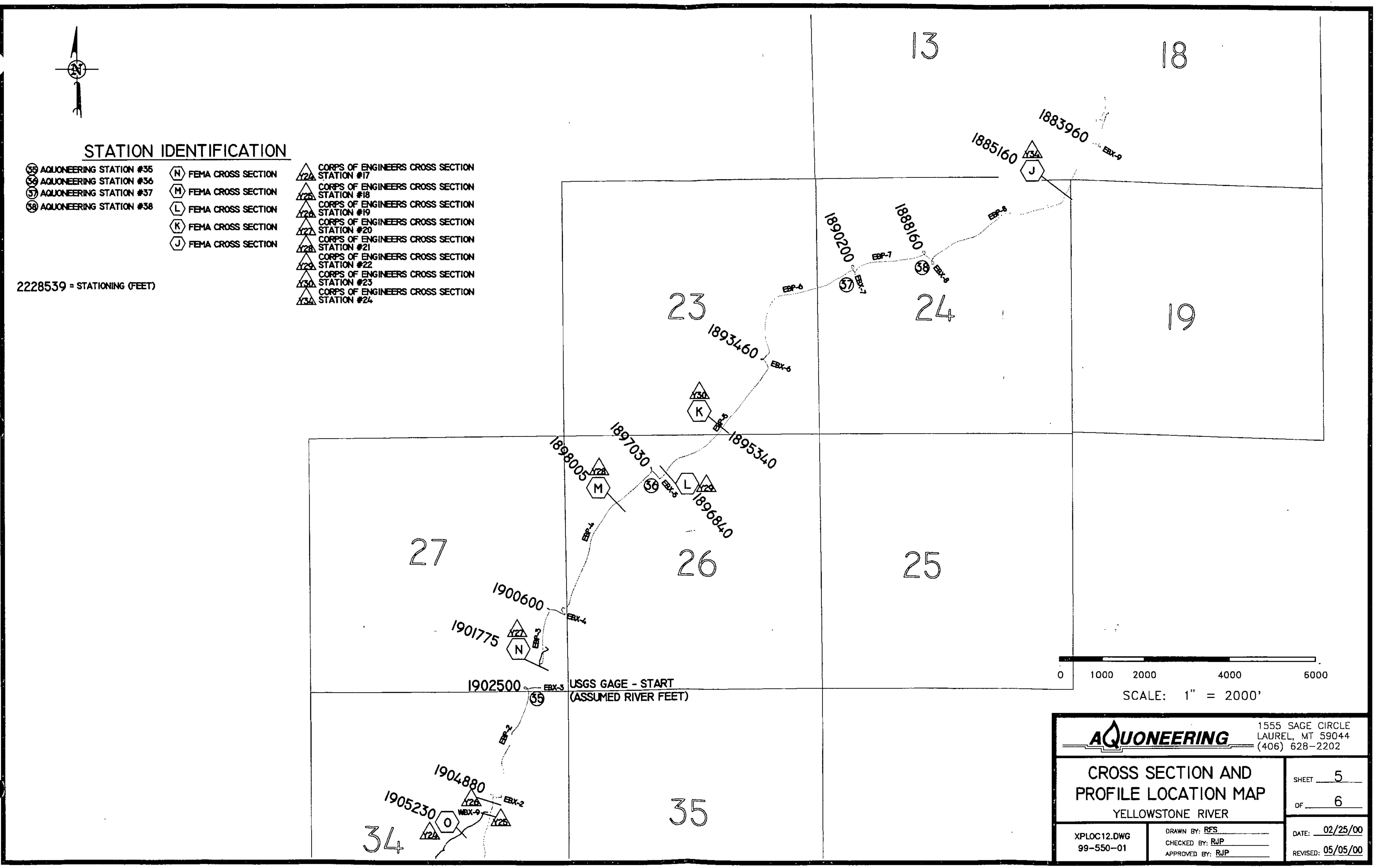
34 AQUONEERING STATION #34
R FEMA CROSS SECTION
Q FEMA CROSS SECTION
P FEMA CROSS SECTION
O FEMA CROSS SECTION
Y17 CORPS OF ENGINEERS CROSS SECTION STATION #14
Y19 CORPS OF ENGINEERS CROSS SECTION STATION #15
Y21 CORPS OF ENGINEERS CROSS SECTION STATION #16
Y24 CORPS OF ENGINEERS CROSS SECTION STATION #17
2228539 = STATIONING (FEET)
34
35
2
1
11
12
13
1904880
1905230
1907940
1908040
1910420
1912420
1913240
1919660
1922380
1923530
1926310
1927860
1928570
1931770
1933500
EBX-2
WBX-9
EBP-1
WBP-9
EBX-1
WBX-8
WBP-8
WBX-7
WBP-7
WBSP-2
WBX-6
WBX-5
WBP-5
WBP-4
WBX-4
WBX-3
WBP-3
WBX-2
WBP-2
WBP-1
WBSP-1
EBBX-1
0 1000 2000 4000 6000
SCALE: 1" = 2000'
AQUONEERING
1555 SAGE CIRCLE
LAUREL, MT 59044
(406) 628-2202
CROSS SECTION AND PROFILE LOCATION MAP
YELLOWSTONE RIVER
SHEET 4 OF 6
XPLOC12.DWG
99-550-01
DRAWN BY: RFS
CHECKED BY: RJP
APPROVED BY: RJP
DATE: 02/25/00
REVISED: 05/05/00



AQUONEERING
1555 SAGE CIRCLE
LAUREL, MT 59044
(406) 628-2202

CROSS SECTION AND PROFILE LOCATION MAP

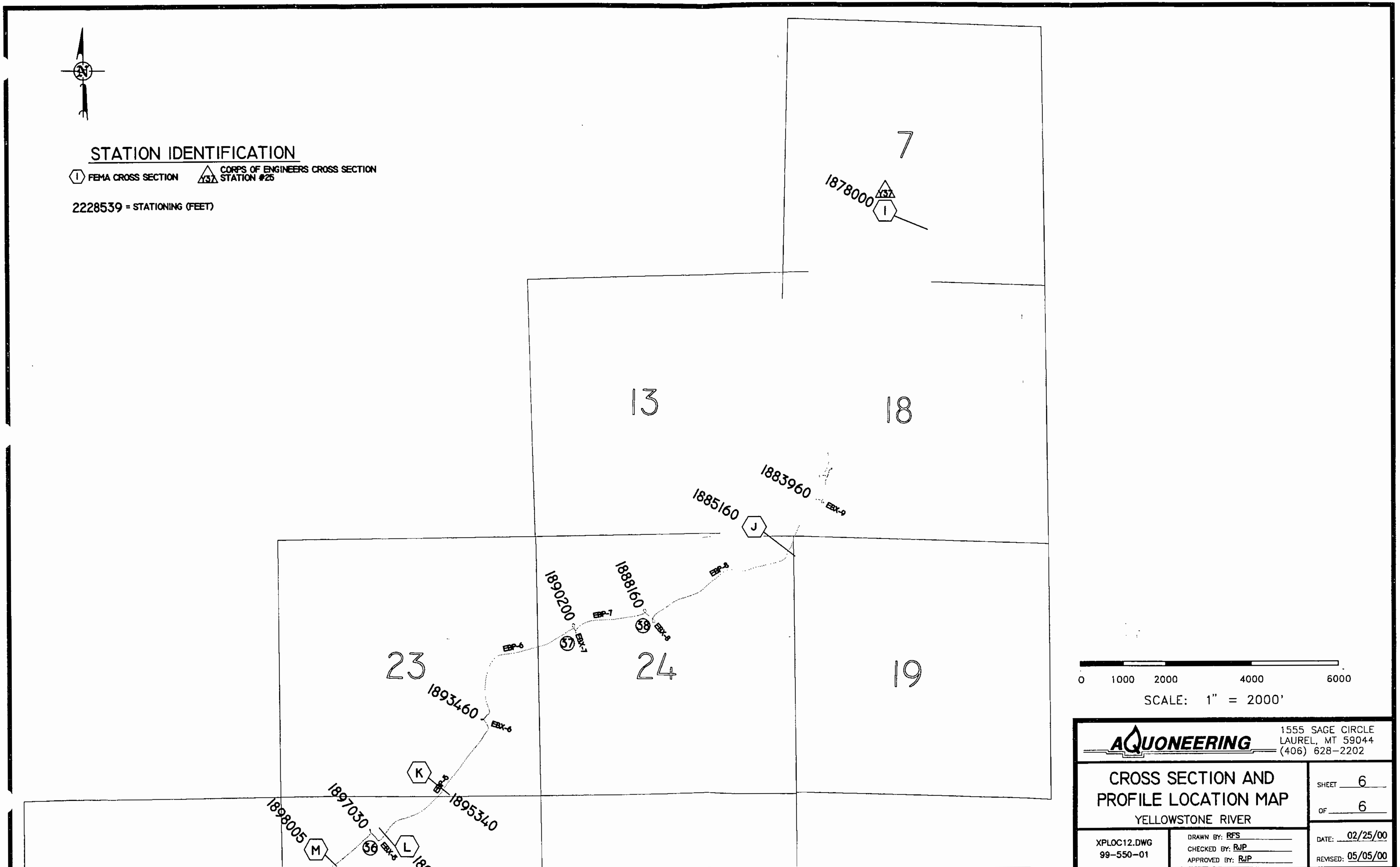
YELLOWSTONE RIVER

SHEET 5 OF 6

XPLOC12.DWG
99-550-01

DRAWN BY: RFS
CHECKED BY: RJP
APPROVED BY: RJP

DATE: 02/25/00
REVISED: 05/05/00



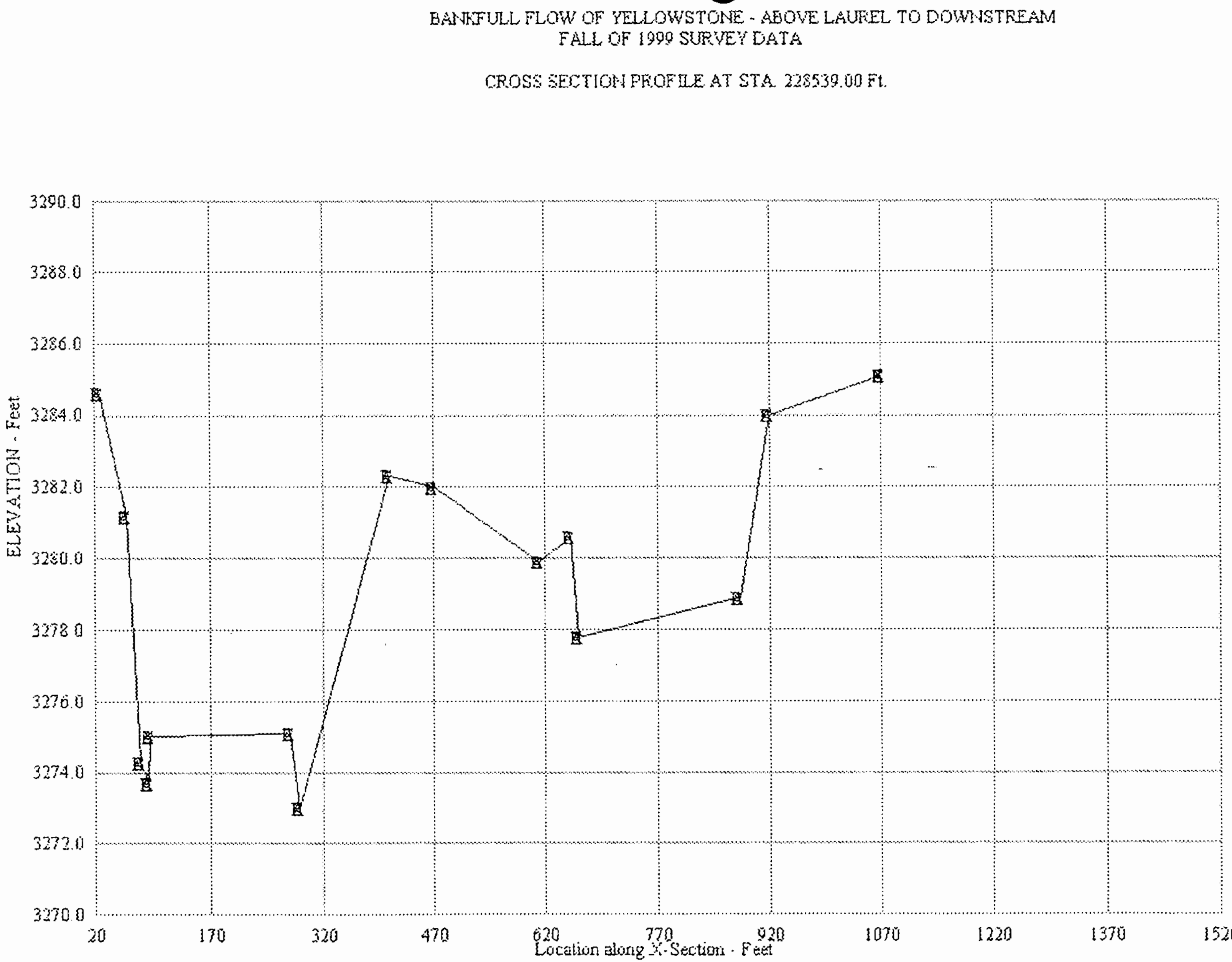
AQUONEERING
1555 SAGE CIRCLE
LAUREL, MT 59044
(406) 628-2202

CROSS SECTION AND PROFILE LOCATION MAP

YELLOWSTONE RIVER

SHEET 6	OF 6	
XPLOC12.DWG 99-550-01	DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 02/25/00 REVISED: 05/05/00

AQUONEERING
1999
CROSS SECTIONS



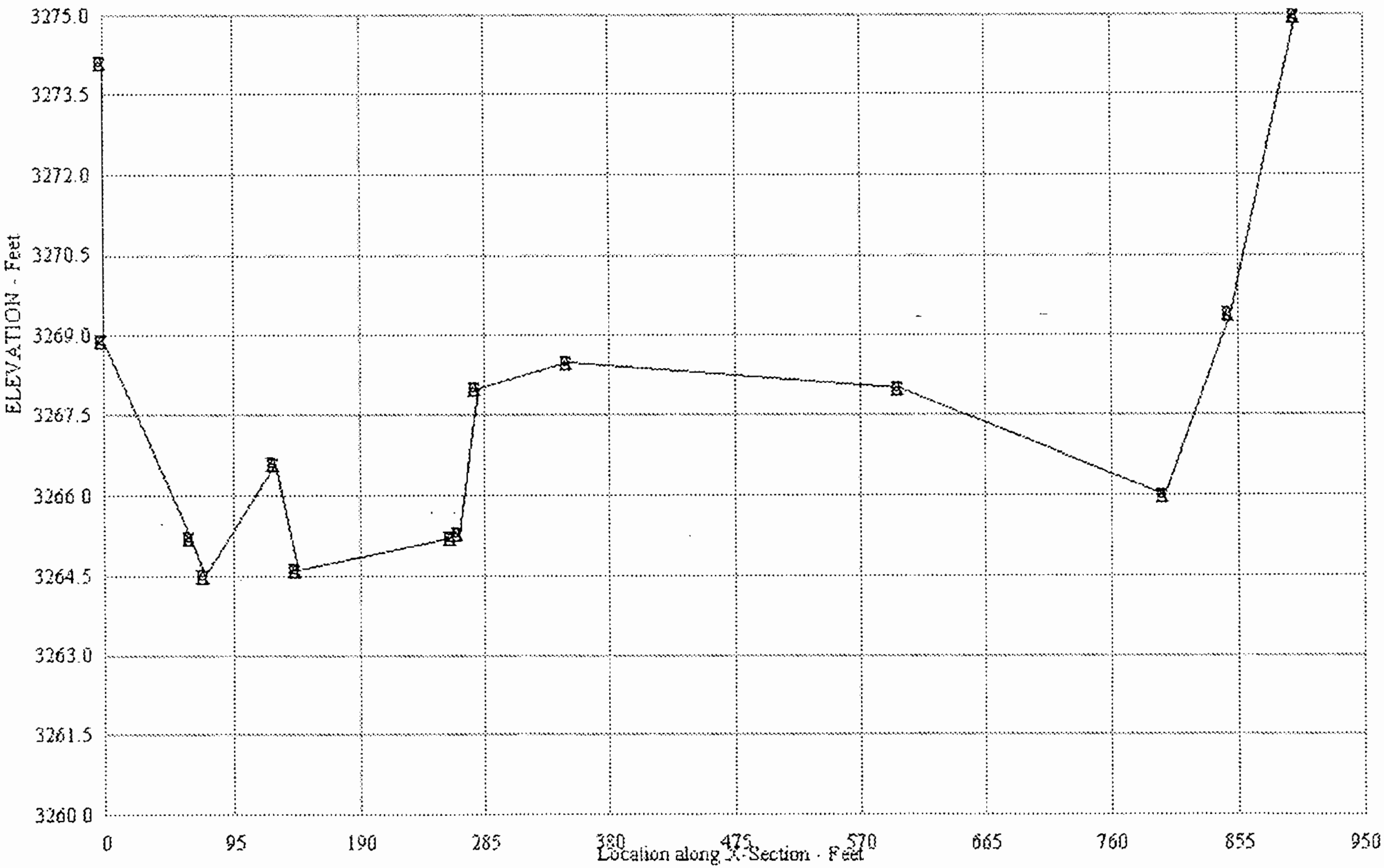
STATION #1

SLOPE = 0.001577
ELEV. = 3283.6
WIDTH = 900'
DEPTH = 8.6'
W/D = 104.7

SHEET 1 OF 38	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS AQUONEERING YELLOWSTONE RIVER	8X11AQUO.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/04/00 REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
FALL OF 1999 SURVEY DATA

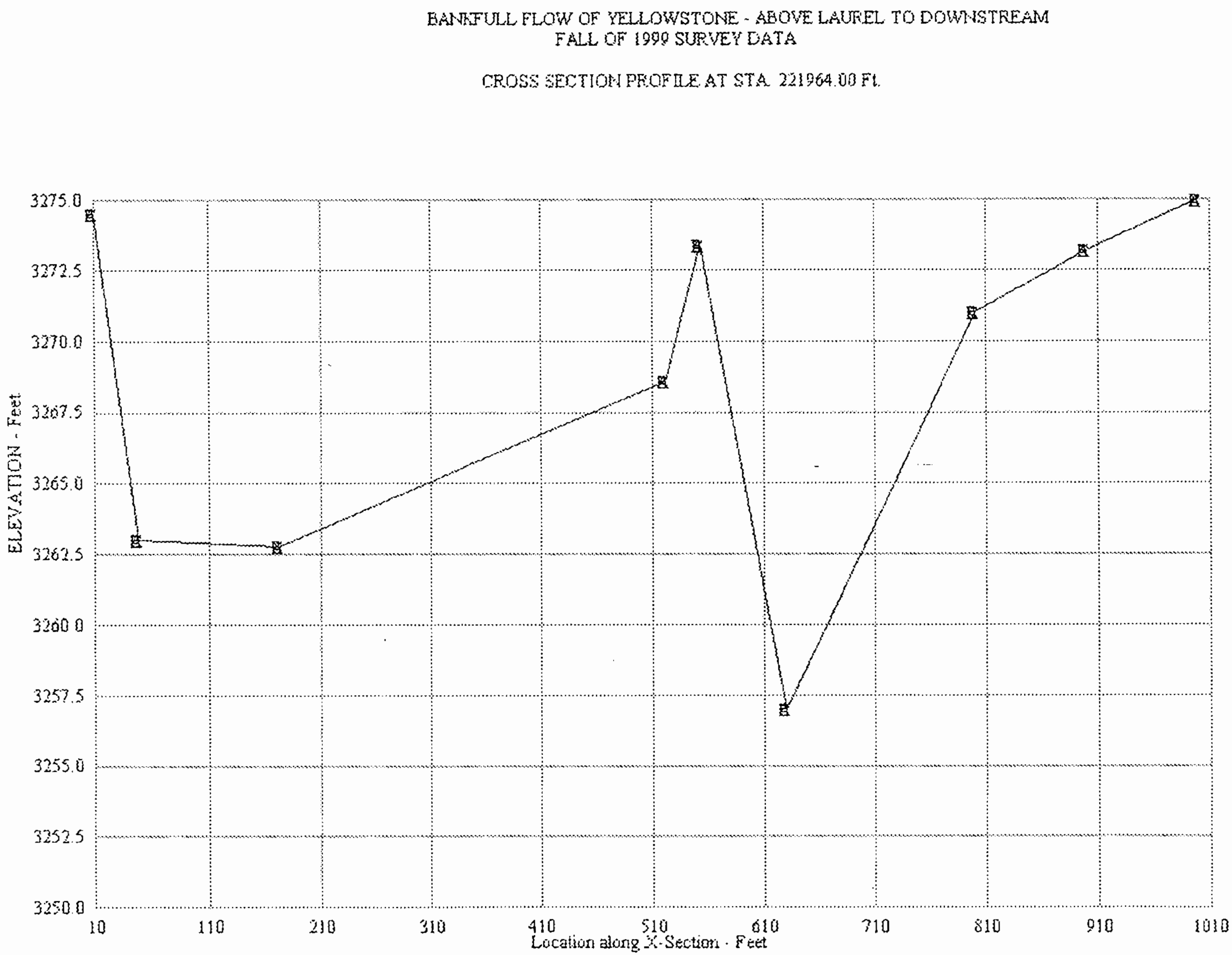
CROSS SECTION PROFILE AT STA. 223149.00 Ft.



STATION #2

SLOPE-= 0.001577
ELEV. = 3273.9
WIDTH = 885'
DEPTH = 9.4'
W/D = 94.1

SHEET 2 OF 38	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS AQUONEERING YELLOWSTONE RIVER	8X11AQUO.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/04/00 REVISED:



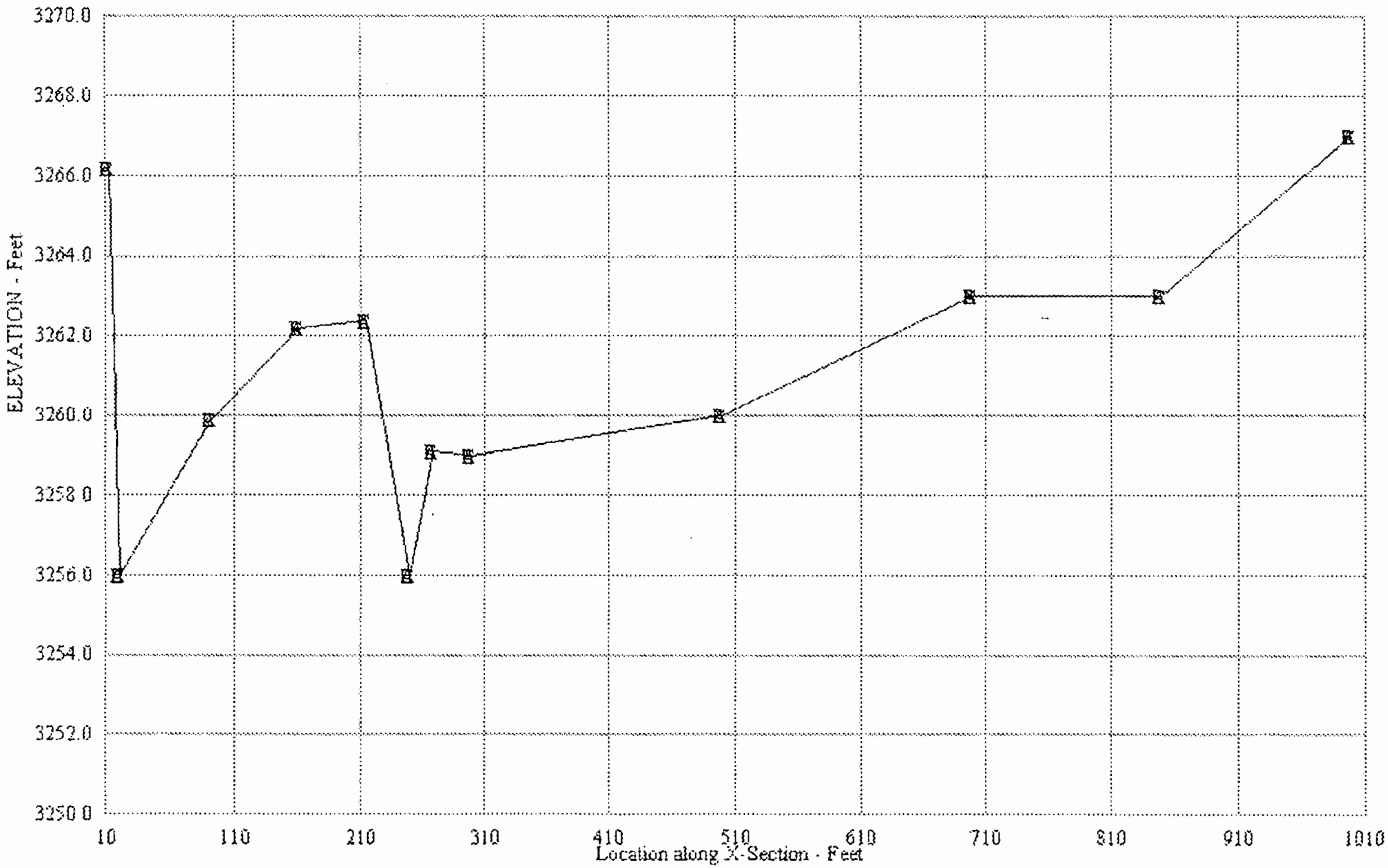
STATION #3

SLOPE-= 0.006329
ELEV. = 3271.9
WIDTH = 816'
DEPTH = 10'
W/D = 81.6

SHEET 3 OF 38	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS AQUONEERING YELLOWSTONE RIVER	8X11AQUO.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/04/00 REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
FALL OF 1999 SURVEY DATA

CROSS SECTION PROFILE AT STA. 219764.00 Ft.



STATION #4

SLOPE-= 0.000455
ELEV. = 3266.3
WIDTH = 960'
DEPTH = 10.6'
W/D = 90.6

SHEET 4 OF 38

AQUONEERING

1555 SAGE CIRCLE
LAUREL, MT 59044
(406) 628-2202

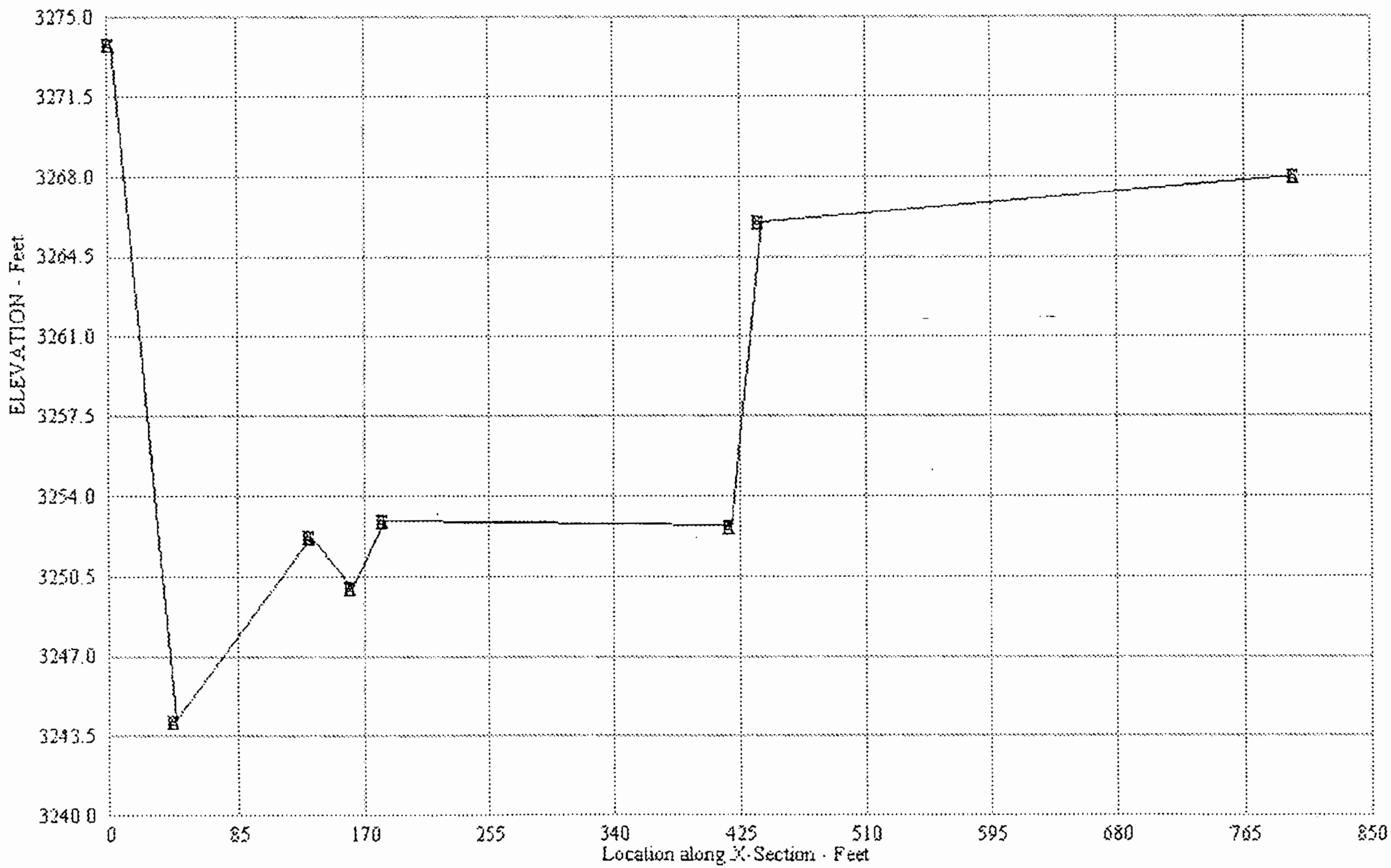
CROSS SECTIONS
AQUONEERING
YELLOWSTONE RIVER

8X11AQUO.DWG
99-550-01
DRAWN BY: RFS
CHECKED BY: RJP
APPROVED BY: RJP

DATE: 05/04/00
REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
FALL OF 1999 SURVEY DATA

CROSS SECTION PROFILE AT STA. 217979.00 Ft.

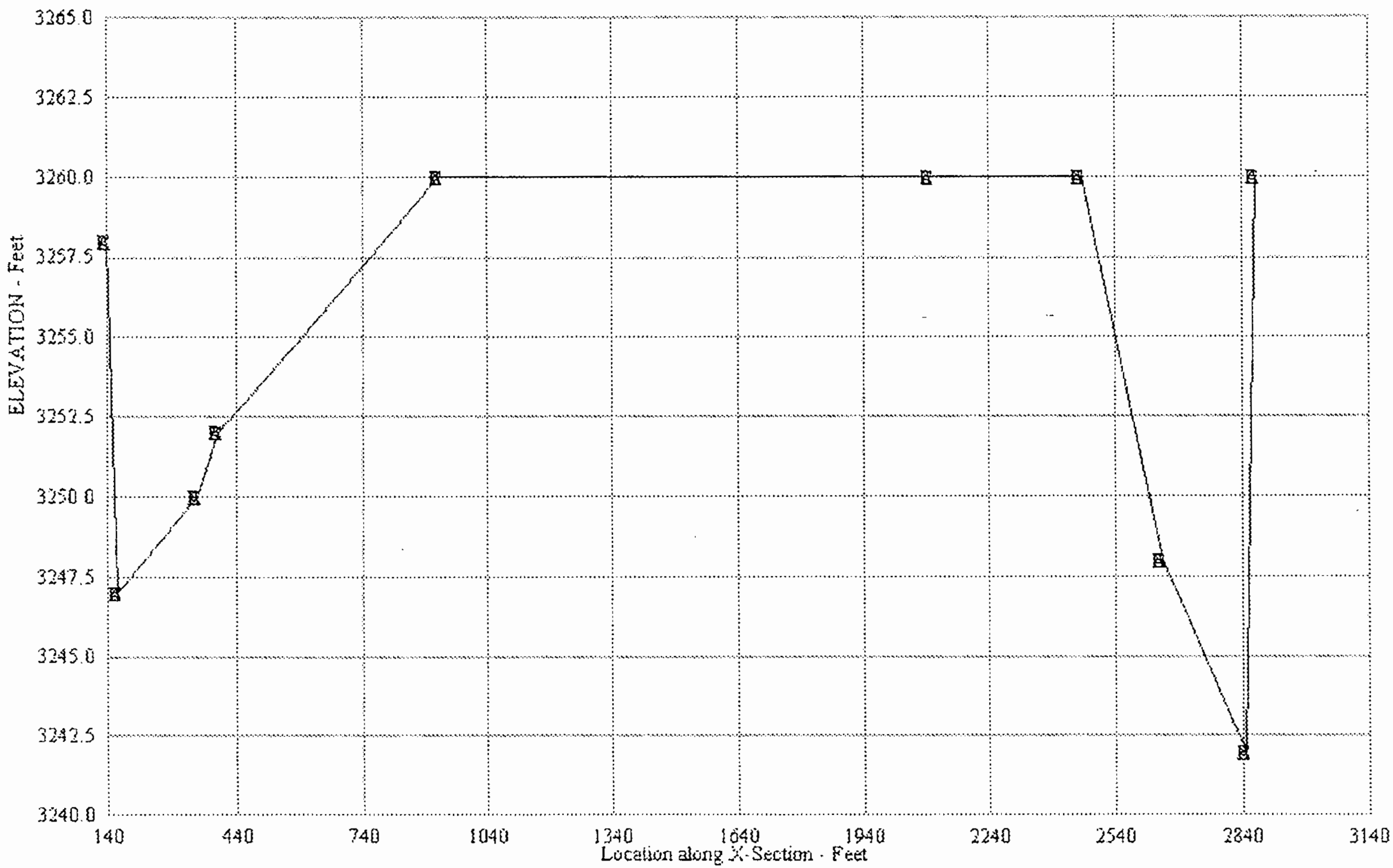


STATION #5
BBWA INTAKE
SLOPE-= 0.006611
ELEV. = 3262.0
WIDTH = 408'
DEPTH = 19.9'
W/D = 20.5

SHEET 5 OF 38	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS AQUONEERING YELLOWSTONE RIVER	8X11AQUO.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/04/00 REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
FALL OF 1999 SURVEY DATA

CROSS SECTION PROFILE AT STA. 213849.00 Ft.



STATION #6

SLOPE = 0.000533
ELEV. = 3255.4
WIDTH = 700'
DEPTH = 8'
W/D = 87.5

SHEET 6 OF 38

AQUONEERING

1555 SAGE CIRCLE
LAUREL, MT 59044
(406) 628-2202

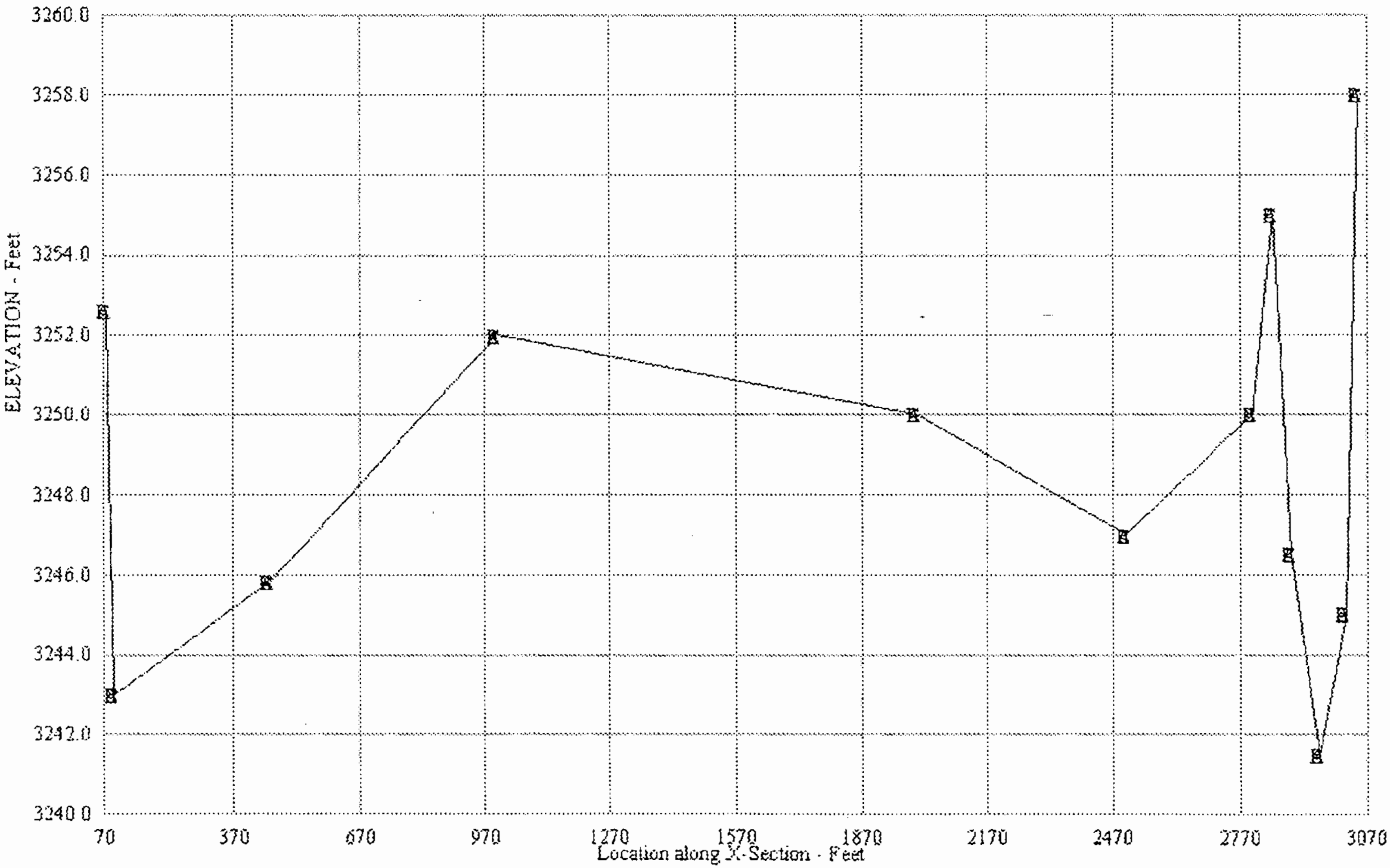
CROSS SECTIONS
AQUONEERING
YELLOWSTONE RIVER

8X11AQUO.DWG
99-550-01
DRAWN BY: RFS
CHECKED BY: RJP
APPROVED BY: RJP

DATE: 05/04/00
REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
FALL OF 1999 SURVEY DATA

CROSS SECTION PROFILE AT STA. 210649.00 Ft.



STATION #7

SLOPE-= 0.0001562
ELEV. = 3251.8
WIDTH = 2804'
DEPTH = 10.4'
W/D = 269

SHEET 7 OF 38

AQUONEERING

1555 SAGE CIRCLE
LAUREL, MT 59044
(406) 628-2202

CROSS SECTIONS
AQUONEERING
YELLOWSTONE RIVER

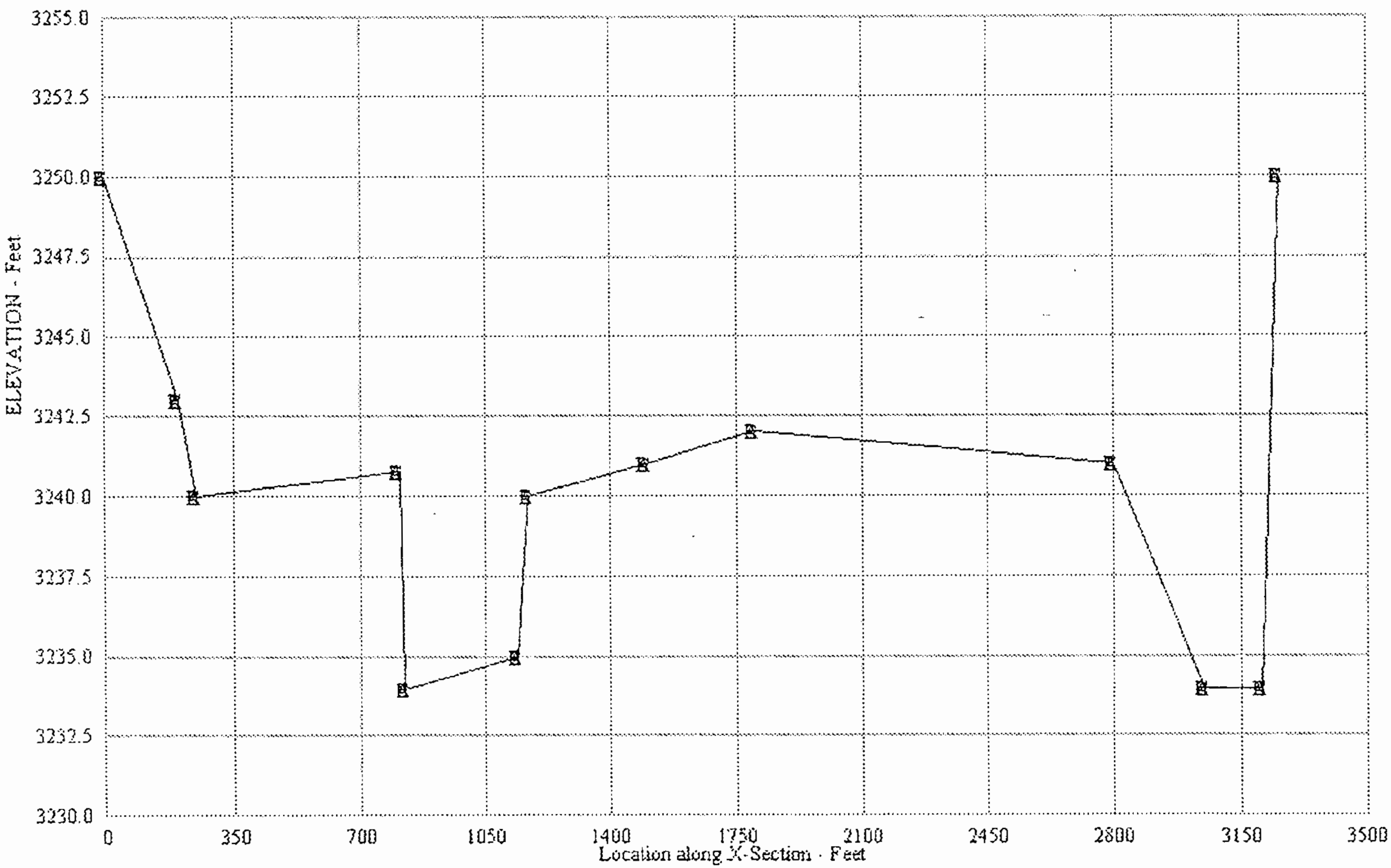
8X11AQUO.DWG
99-550-01
DRAWN BY: RFS
CHECKED BY: RJP
APPROVED BY: RJP

DATE: 05/04/00
REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
FALL OF 1999 SURVEY DATA

CROSS SECTION PROFILE AT STA. 204219.00 Ft.

SPLIT CHANNELS FORM CLARKS FORK AND YELLOWSTONE RIVERS



STATION #8

SLOPE = 0.001166
ELEV. = 3241.8
WIDTH = 3042'
DEPTH = 9.3'
W/D = 327

SHEET 8 OF 38

AQUONEERING
1555 SAGE CIRCLE
LAUREL, MT 59044
(406) 628-2202

CROSS SECTIONS
AQUONEERING
YELLOWSTONE RIVER

8X11AQUO.DWG
99-550-01
DRAWN BY: RFS
CHECKED BY: RJP
APPROVED BY: RJP

DATE: 05/04/00
REVISED:

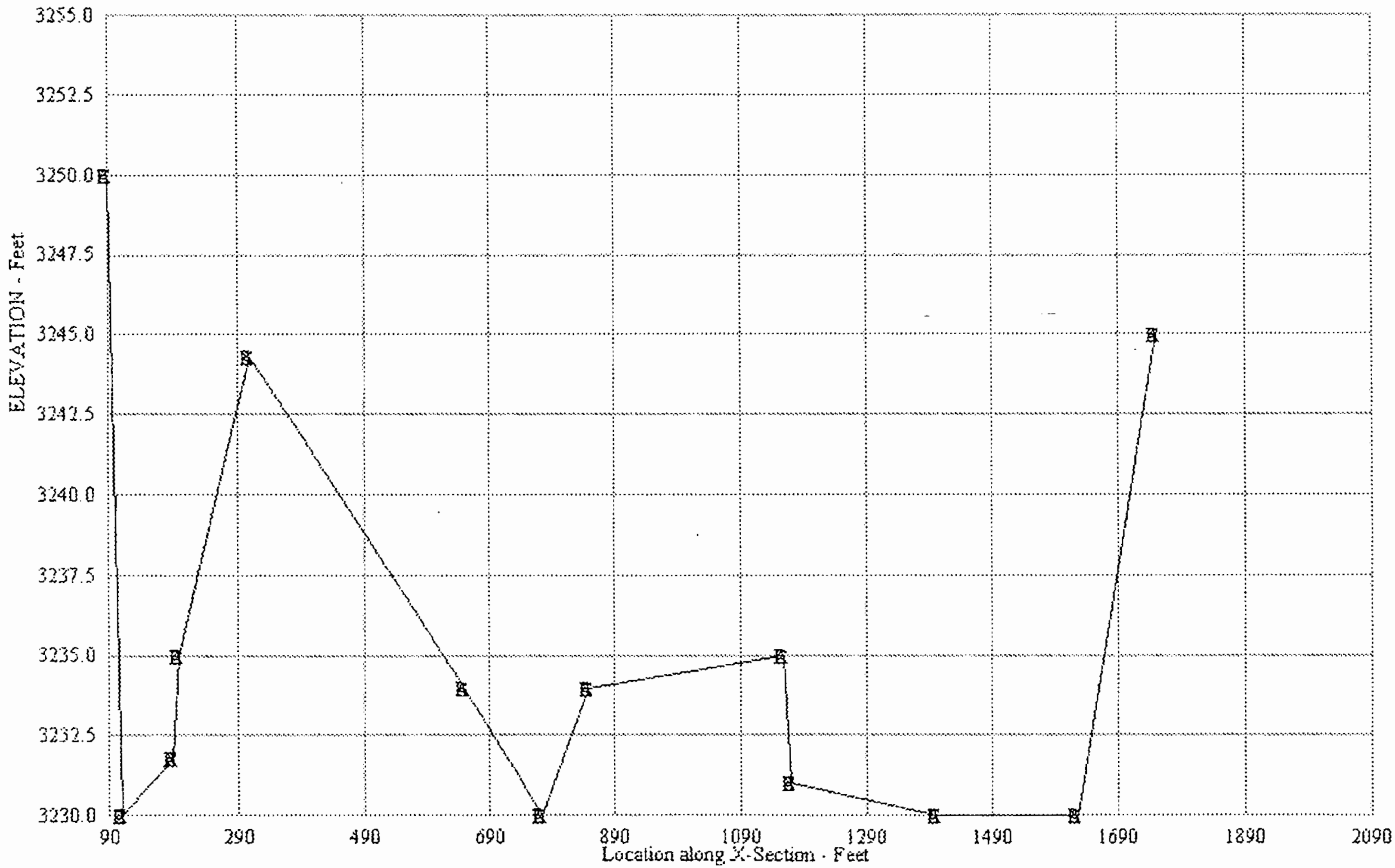
BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
FALL OF 1999 SURVEY DATA

CROSS SECTION PROFILE AT STA. 201549.00 Ft.

NORTH CHANNEL OF YELLOWSTONE RIVER COMES IN HERE

STATION #9

SLOPE = 0.0014981
ELEV. = 3240.1
WIDTH = 1409'
DEPTH = 9'
W/D = 156.6



SHEET 9 OF 38	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS AQUONEERING YELLOWSTONE RIVER	8X11AQUO.DWG 99-550-01 DRAWN BY: RES CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/04/00 REVISED:

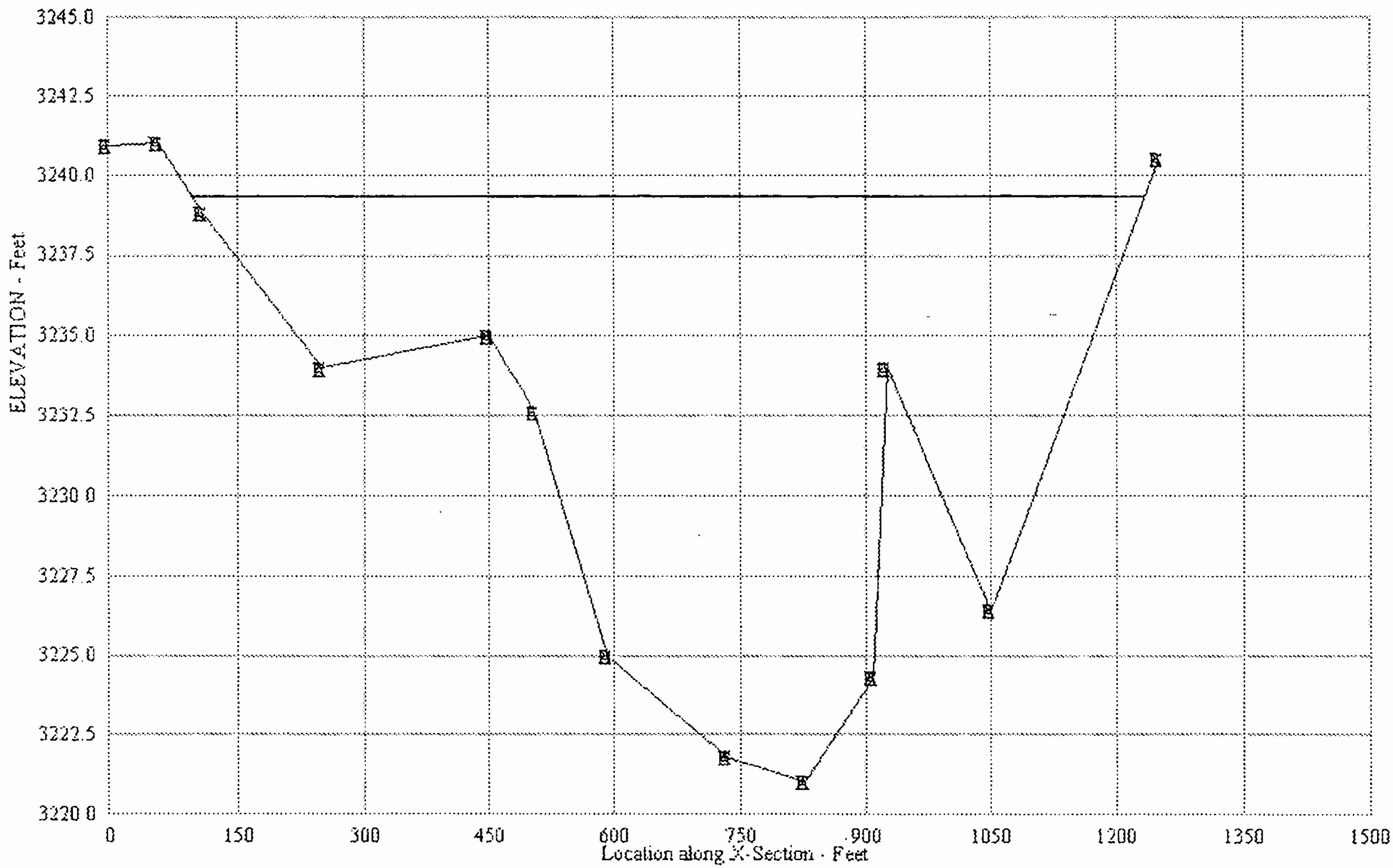
BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
FALL OF 1999 SURVEY DATA

CROSS SECTION PROFILE AT STA. 199549.00 Ft.

ABOVE CLIFF BY FRAZER-HARTMAN-BBWA BEDROCK CLOSE

STATION #10

SLOPE = 0.0045
ELEV. = 3239.3
WIDTH = 1132'
DEPTH = 18.3'
W/D = 62



SHEET 10 OF 38	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS AQUONEERING YELLOWSTONE RIVER	8X11AQUO.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/04/00 REVISED:

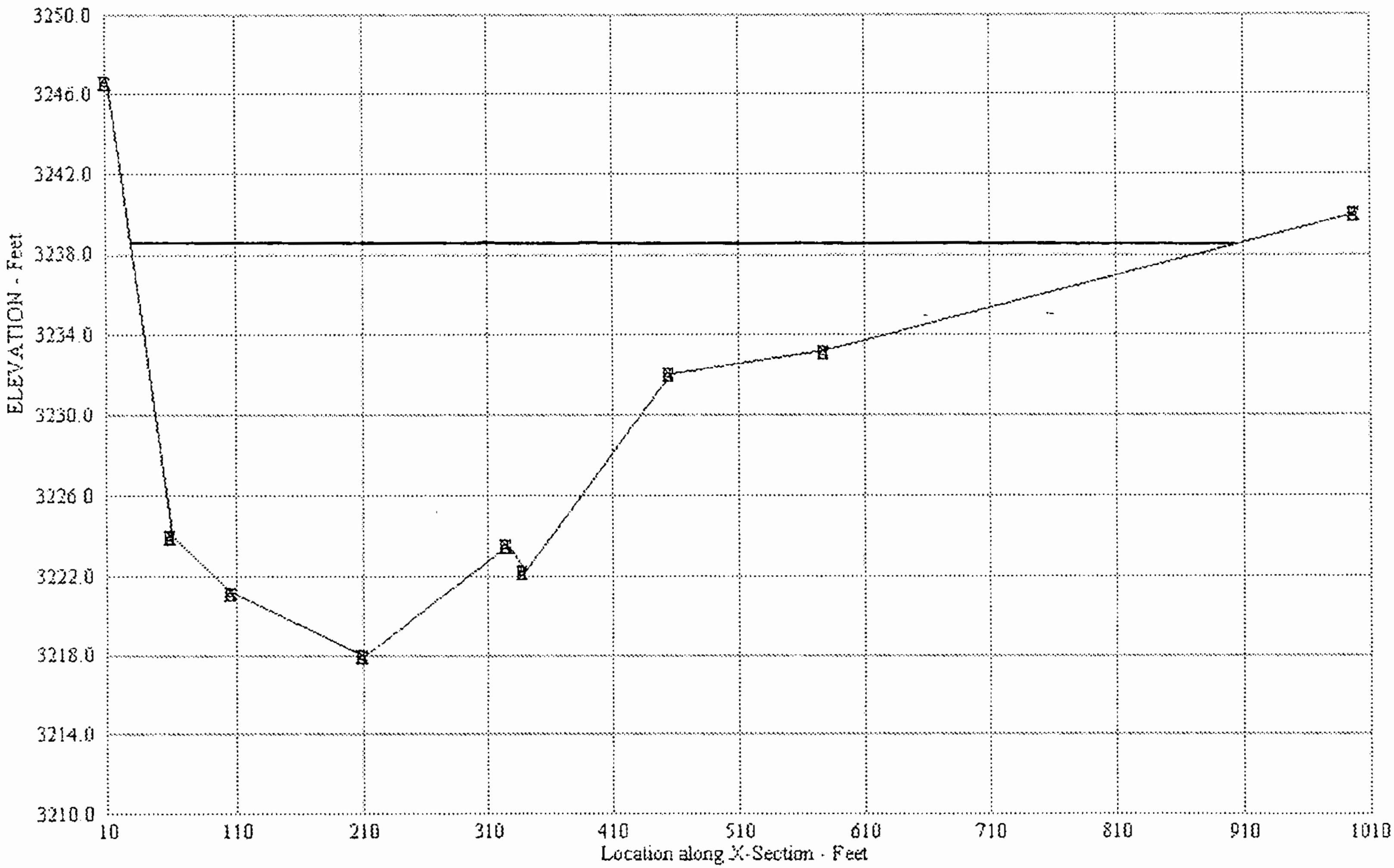
BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
FALL OF 1999 SURVEY DATA

CROSS SECTION PROFILE AT STA. 198089.00 Ft.

RIVER UP AGAINST SHALE BEDROCK

STATION #11

SLOPE = 0.0019809
ELEV. = 3238.5
WIDTH = 890'
DEPTH = 20.5'
W/D = 43.4



SHEET 11 OF 38

AQUONEERING
1555 SAGE CIRCLE
LAUREL, MT 59044
(406) 628-2202

CROSS SECTIONS
AQUONEERING
YELLOWSTONE RIVER

8X11AQUO.DWG
99-550-01
DRAWN BY: RFS
CHECKED BY: RJP
APPROVED BY: RJP

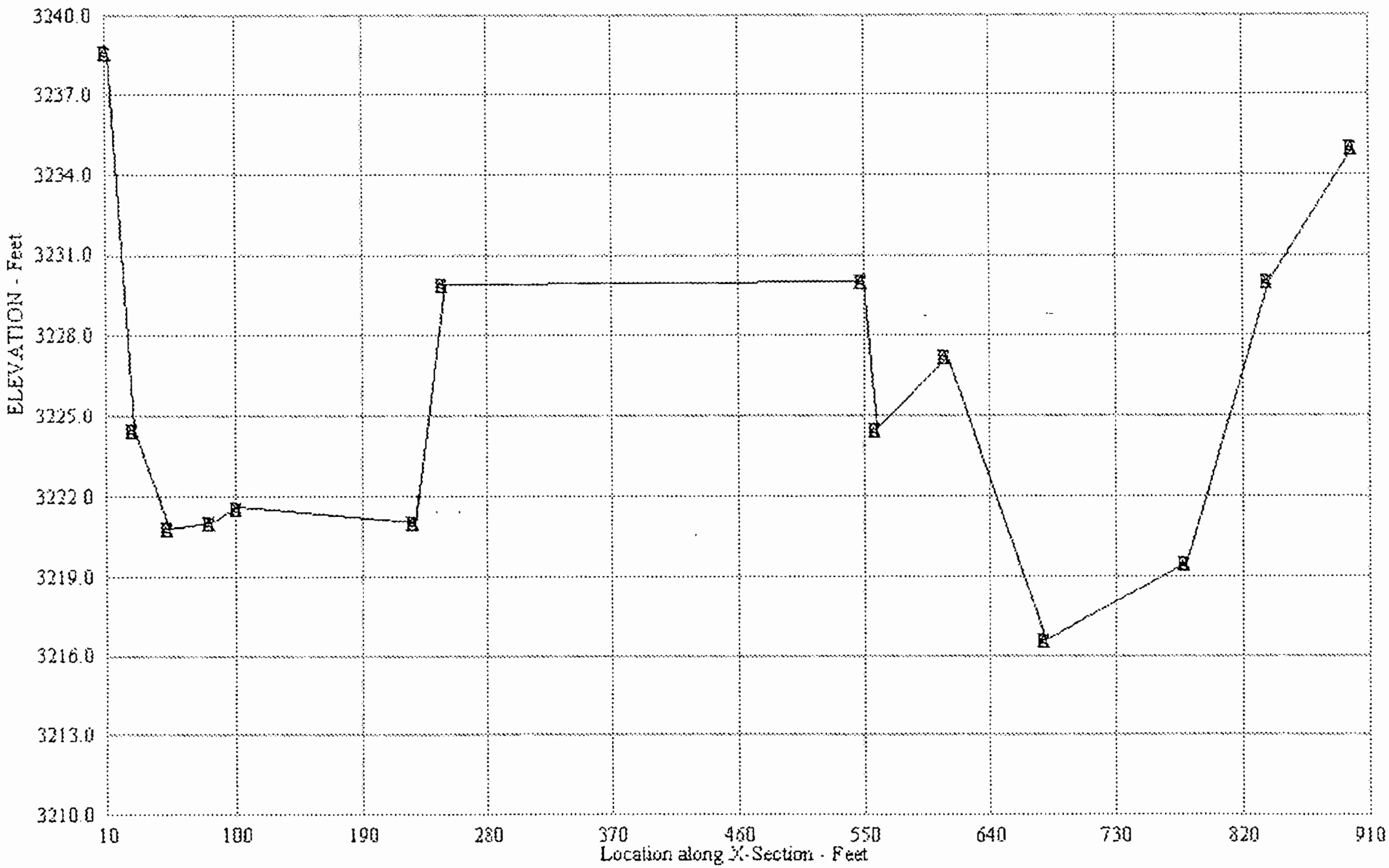
DATE: 05/04/00
REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
FALL OF 1999 SURVEY DATA

CROSS SECTION PROFILE AT STA. 194709.00 Ft.

STATION #12

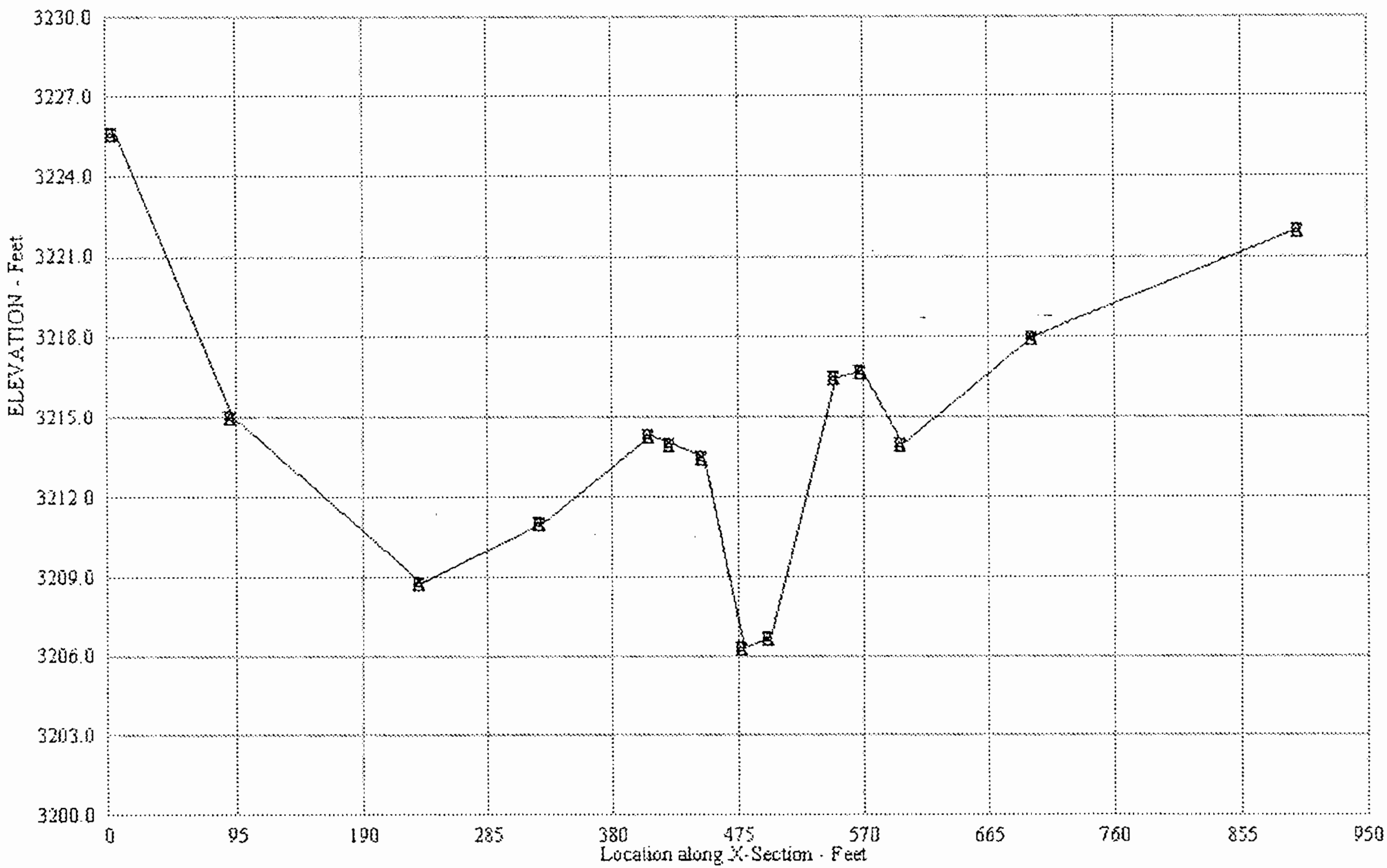
SLOPE = 0.0004142
ELEV. = 3229.0
WIDTH = 510'
DEPTH = 12.3'
W/D = 41.5



SHEET 12 OF 38	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS AQUONEERING YELLOWSTONE RIVER	8X11AQUO.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/04/00 REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
FALL OF 1999 SURVEY DATA

CROSS SECTION PROFILE AT STA 192259.00 Ft.



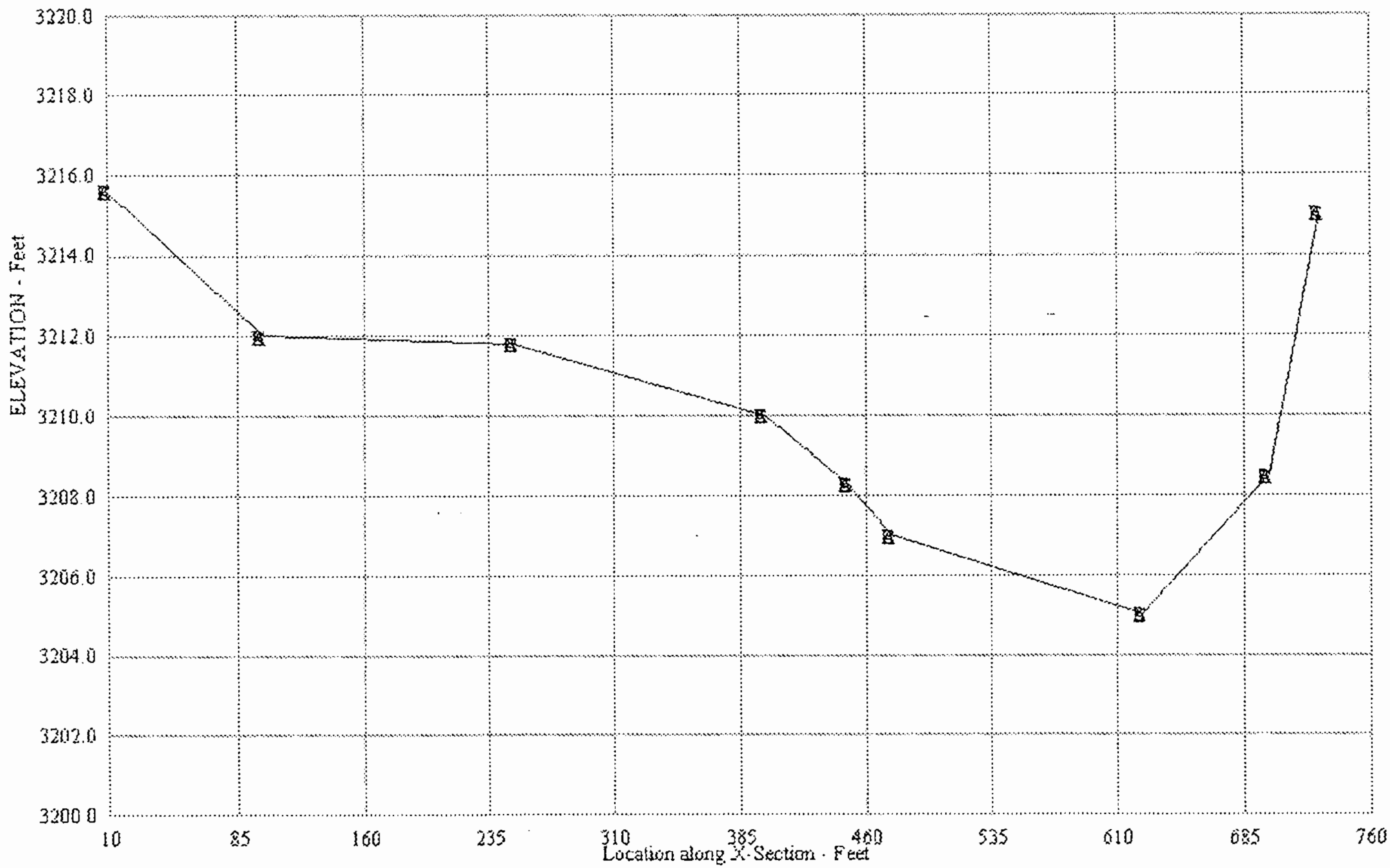
STATION #13

SLOPE = 0.0042041
ELEV. = 3224.5
WIDTH ≅ 987'
DEPTH = 17.9'
W/D ≅ 55

SHEET 13 OF 38	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS AQUONEERING YELLOWSTONE RIVER	8X11AQUO.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/04/00 REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
FALL OF 1999 SURVEY DATA

CROSS SECTION PROFILE AT STA. 188199.00 Ft.



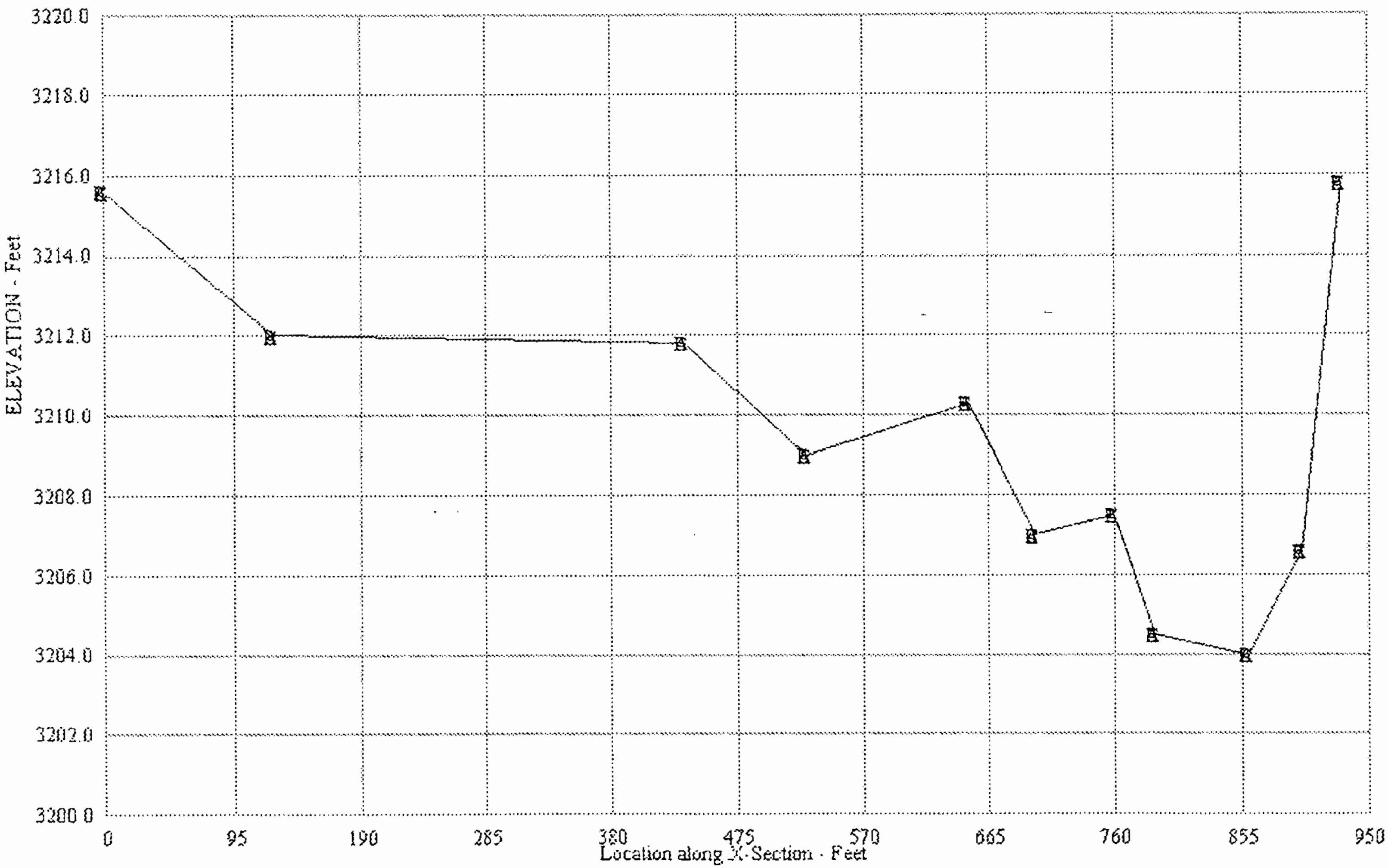
STATION #14

SLOPE = 0.0003202
ELEV. = 3222.8
WIDTH ≅ 850'
DEPTH = 17.8'
W/D ≅ 48

SHEET 14 OF 38	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS AQUONEERING YELLOWSTONE RIVER	8X11AQUO.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/04/00 REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
FALL OF 1999 SURVEY DATA

CROSS SECTION PROFILE AT STA. 186589.00 Ft.



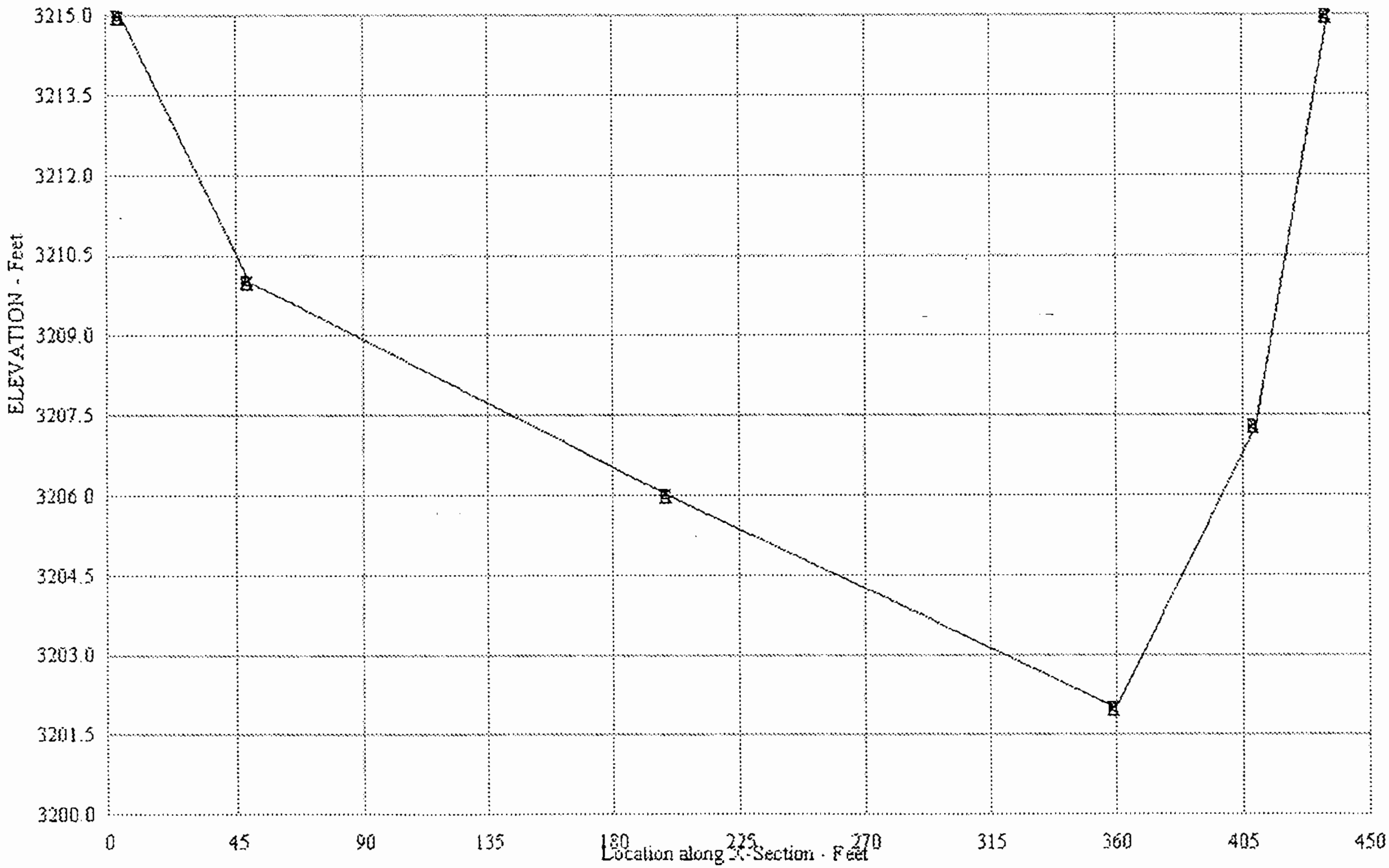
STATION #15

SLOPE= 0.00062112
ELEV. = 3222.3
WIDTH = 1127'
DEPTH = 18.3'
W/D = 62

SHEET 15 OF 38	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS AQUONEERING YELLOWSTONE RIVER	8X11AQUO.DWG 99-550-01 DRAWN BY: RES CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/04/00 REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
FALL OF 1999 SURVEY DATA

CROSS SECTION PROFILE AT STA. 184119.00 Ft.



STATION #16

SLOPE=0.00080972
ELEV. = 3220.3
WIDTH ≅ 493'
DEPTH = 18.3'
W/D ≅ 27

SHEET 16
OF 38

AQUONEERING
1555 SAGE CIRCLE
LAUREL, MT 59044
(406) 628-2202

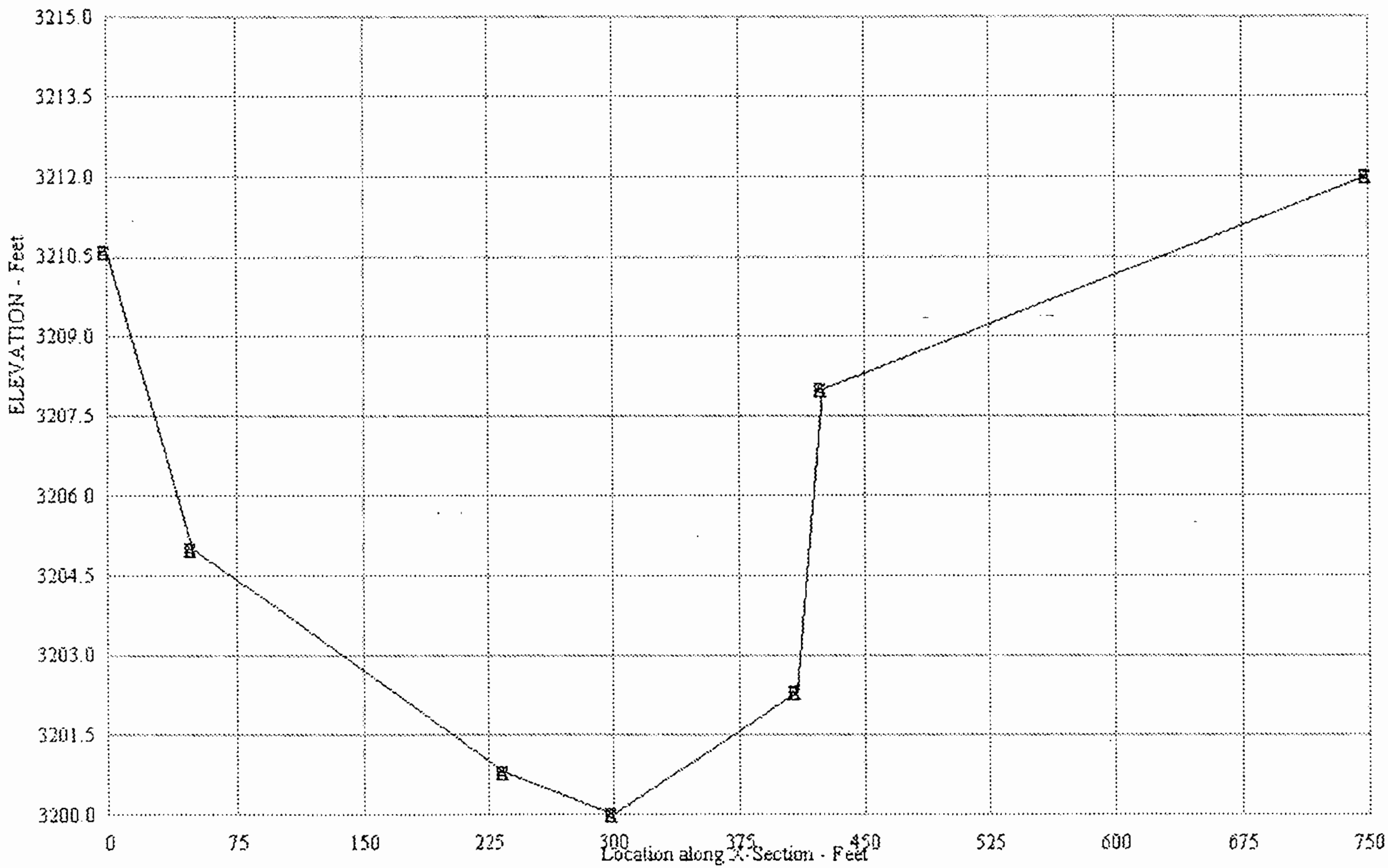
CROSS SECTIONS
AQUONEERING
YELLOWSTONE RIVER

8X11AQUO.DWG
99-550-01
DRAWN BY: RFS
CHECKED BY: RJP
APPROVED BY: RJP

DATE: 05/04/00
REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
FALL OF 1999 SURVEY DATA

CROSS SECTION PROFILE AT STA. 180839.00 Ft.



STATION #17

SLOPE= 0.0006097
ELEV. = 3211.3
WIDTH ≅ 695'
DEPTH = 11.3'
W/D ≅ 61

SHEET 17 OF 38

AQUONEERING
1555 SAGE CIRCLE
LAUREL, MT 59044
(406) 628-2202

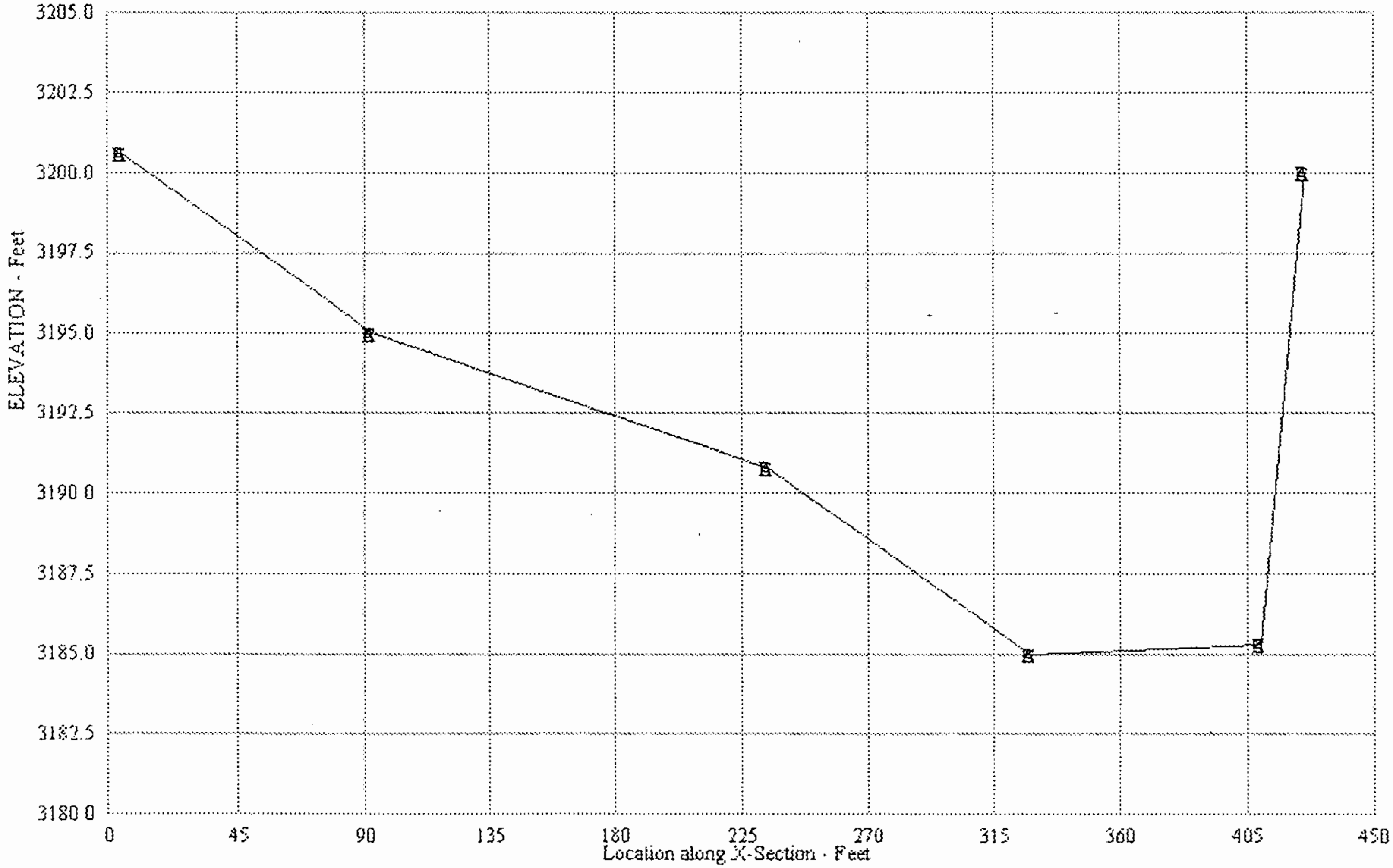
CROSS SECTIONS
AQUONEERING
YELLOWSTONE RIVER

8X11AQUO.DWG
99-550-01
DRAWN BY: RFS
CHECKED BY: RJP
APPROVED BY: RJP

DATE: 05/04/00
REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
FALL OF 1999 SURVEY DATA

CROSS SECTION PROFILE AT STA. 177819.00 Ft.



STATION #18

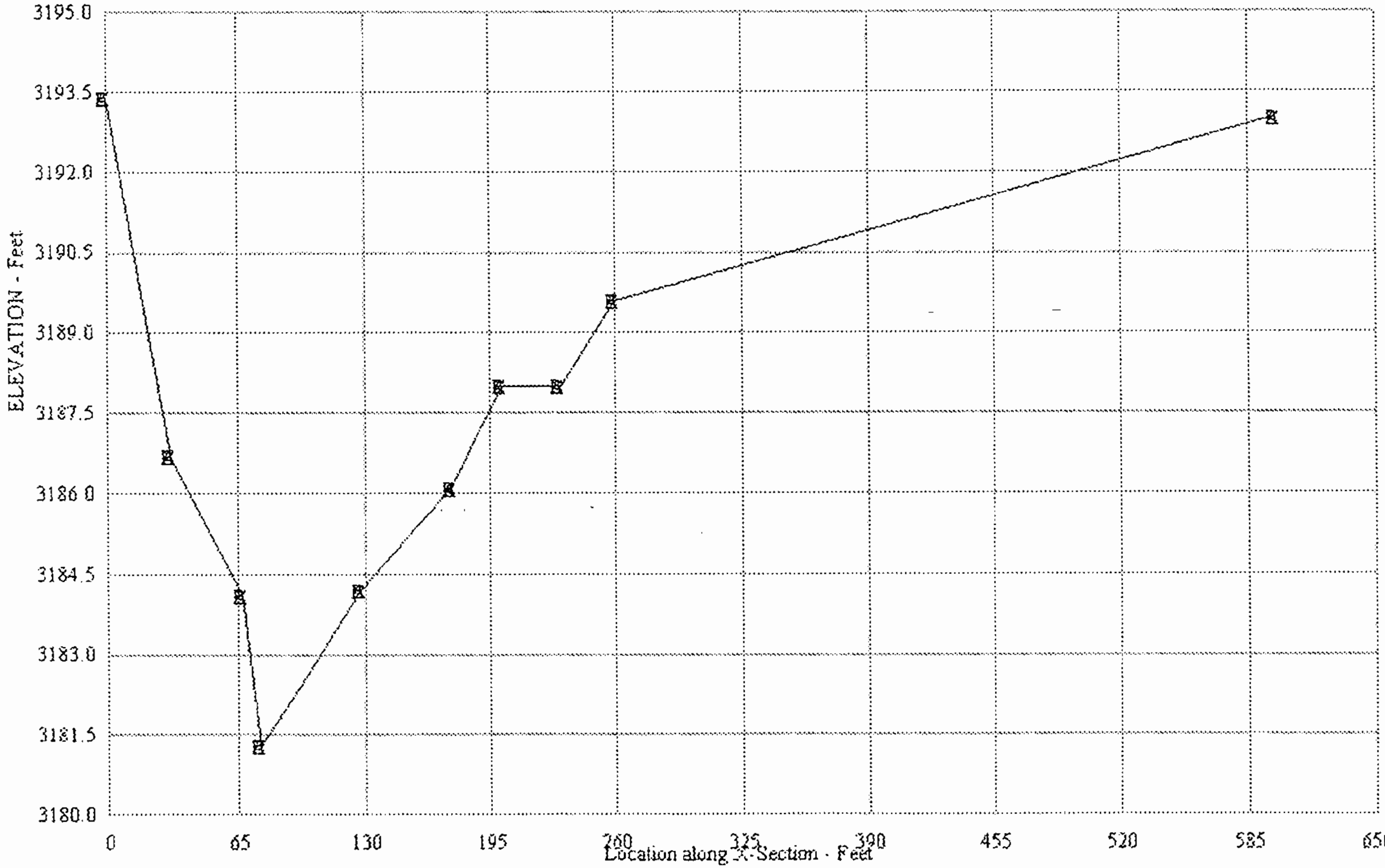
SLOPE= 0.0049609
ELEV. = 3211.3
WIDTH ≅
DEPTH = 26.3'?
W/D ≅

TO FAR TO EXTRAPOLATE

SHEET 18 OF 38	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS AQUONEERING YELLOWSTONE RIVER	8X11AQUO.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/04/00 REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
FALL OF 1999 SURVEY DATA

CROSS SECTION PROFILE AT STA 175249.00 Ft.



STATION #19

SLOPE = 0.0014397
ELEV. = 3201.6
WIDTH =
DEPTH = 20.3'
W/D =

TO FAR TO EXTRAPOLATE

SHEET 19 OF 38	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS AQUONEERING YELLOWSTONE RIVER	8X11AQUO.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/04/00 REVISED:

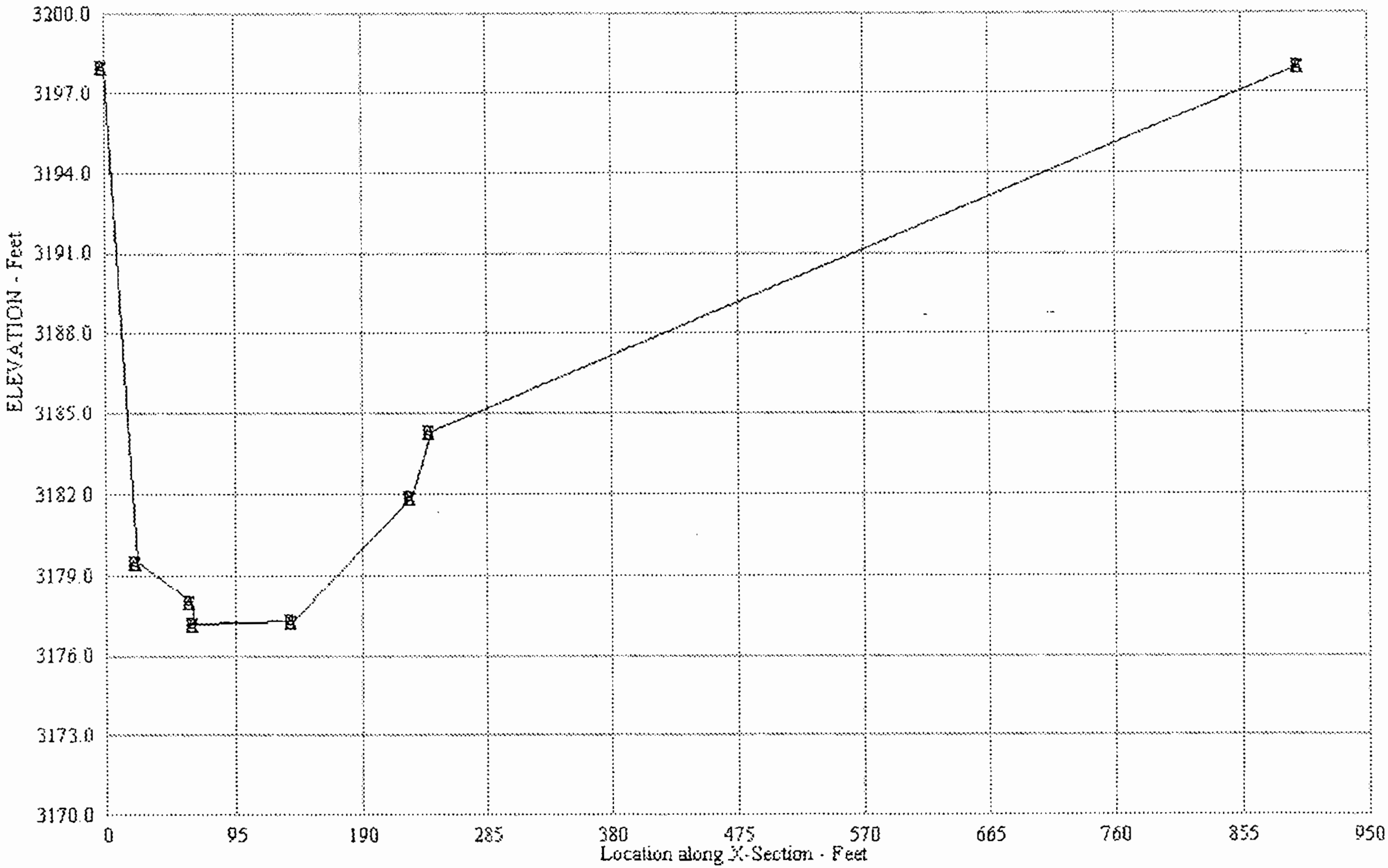
BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
FALL OF 1999 SURVEY DATA

CROSS SECTION PROFILE AT STA. 167829.00 Ft.

OSCARS DREAMLAND RIPRAP

STATION #20

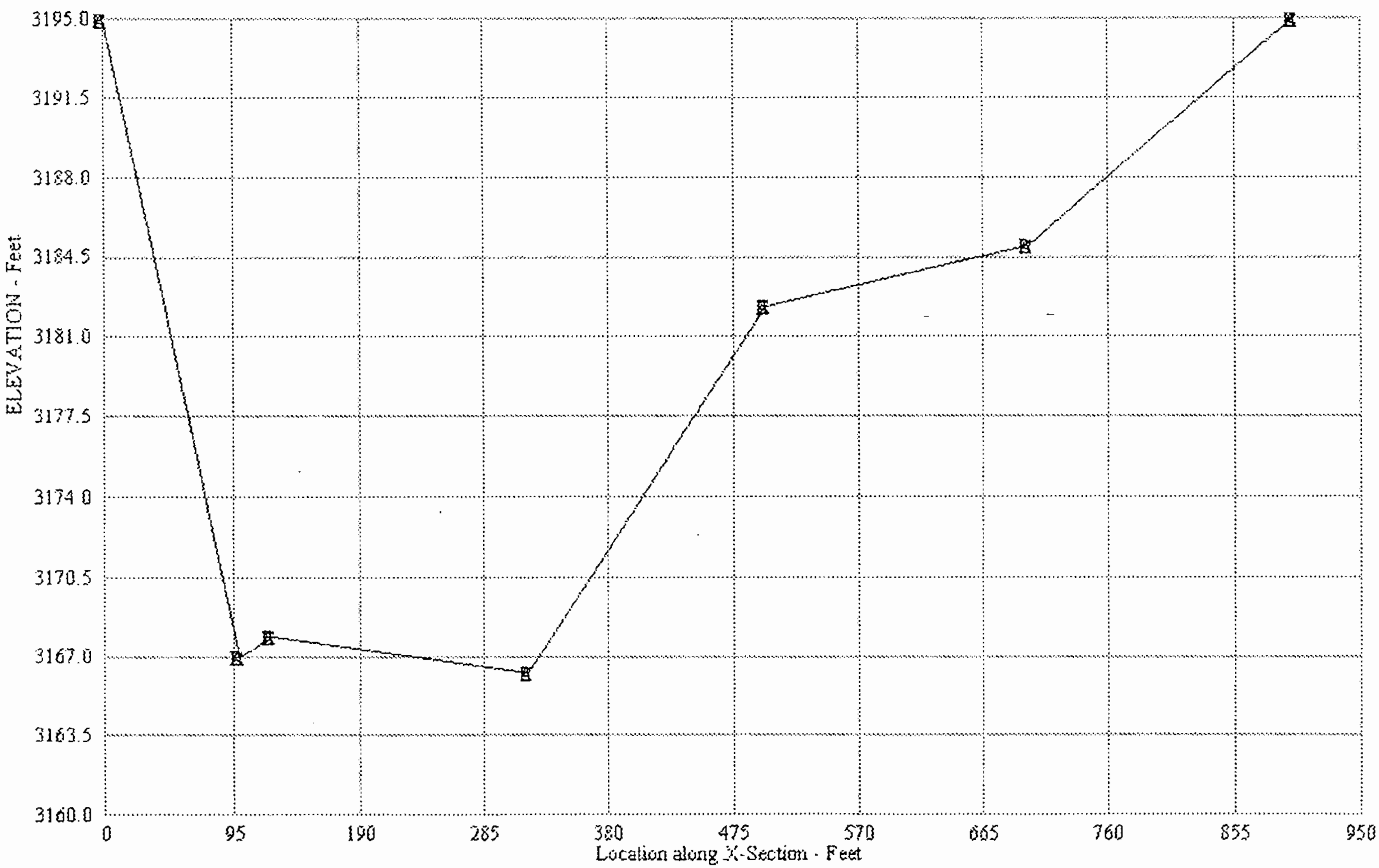
SLOPE= 0.0005256
ELEV. = 3195.5
WIDTH = 755'
DEPTH = 17.5'
W/D = 43.2



SHEET 20 OF 38	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS AQUONEERING YELLOWSTONE RIVER	8X11AQUO.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/04/00 REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
FALL OF 1999 SURVEY DATA

CROSS SECTION PROFILE AT STA. 160840.00 Ft.



STATION #21

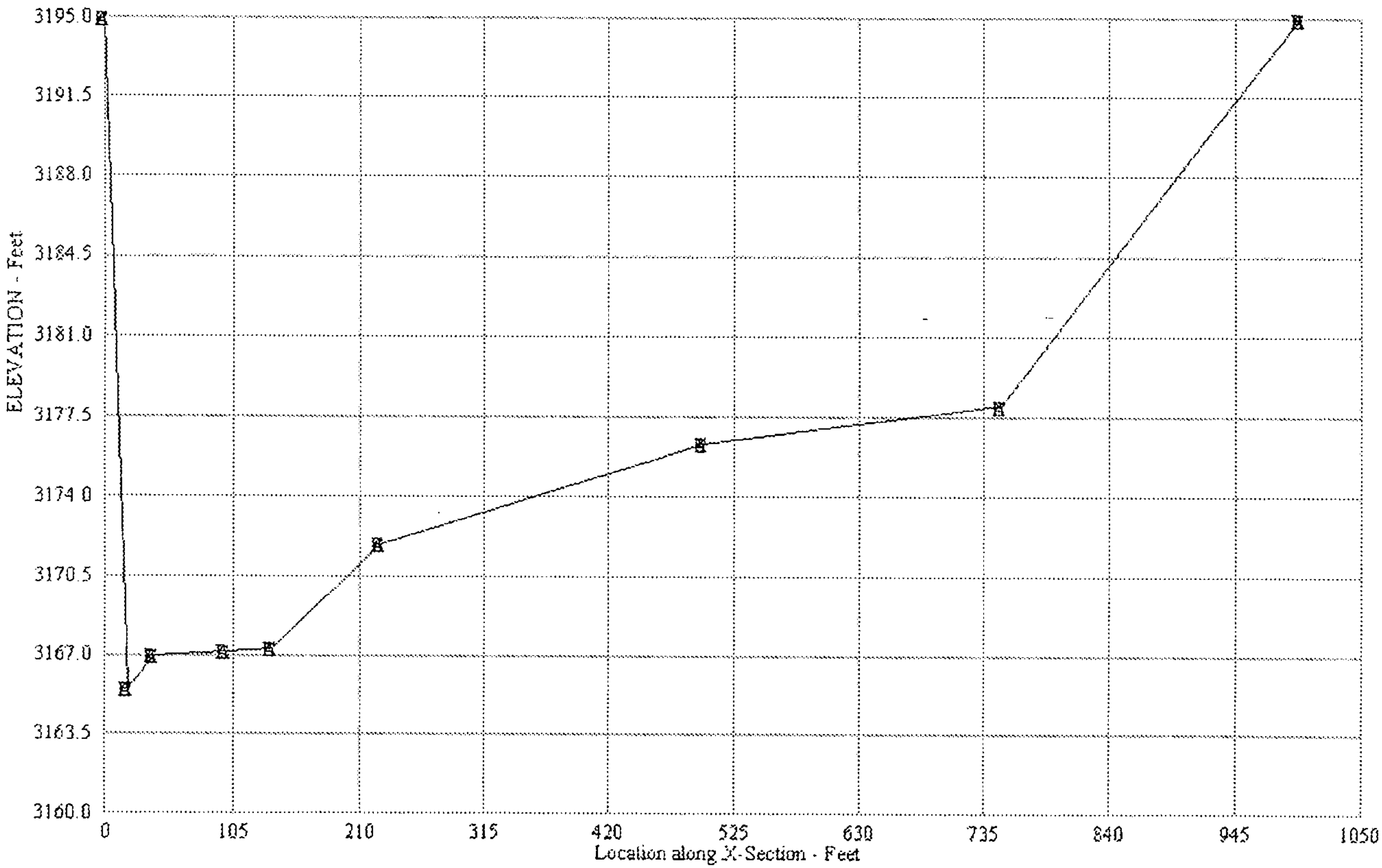
SLOPE=-0.0015546
ELEV. = 3191.9
WIDTH = 831'
DEPTH = 25'
W/D = 33.2

REFERENCE
REACH

SHEET 21 OF 38	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS AQUONEERING YELLOWSTONE RIVER	8X11AQUO.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/04/00 REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
FALL OF 1999 SURVEY DATA

CROSS SECTION PROFILE AT STA. 160060.00 Ft.



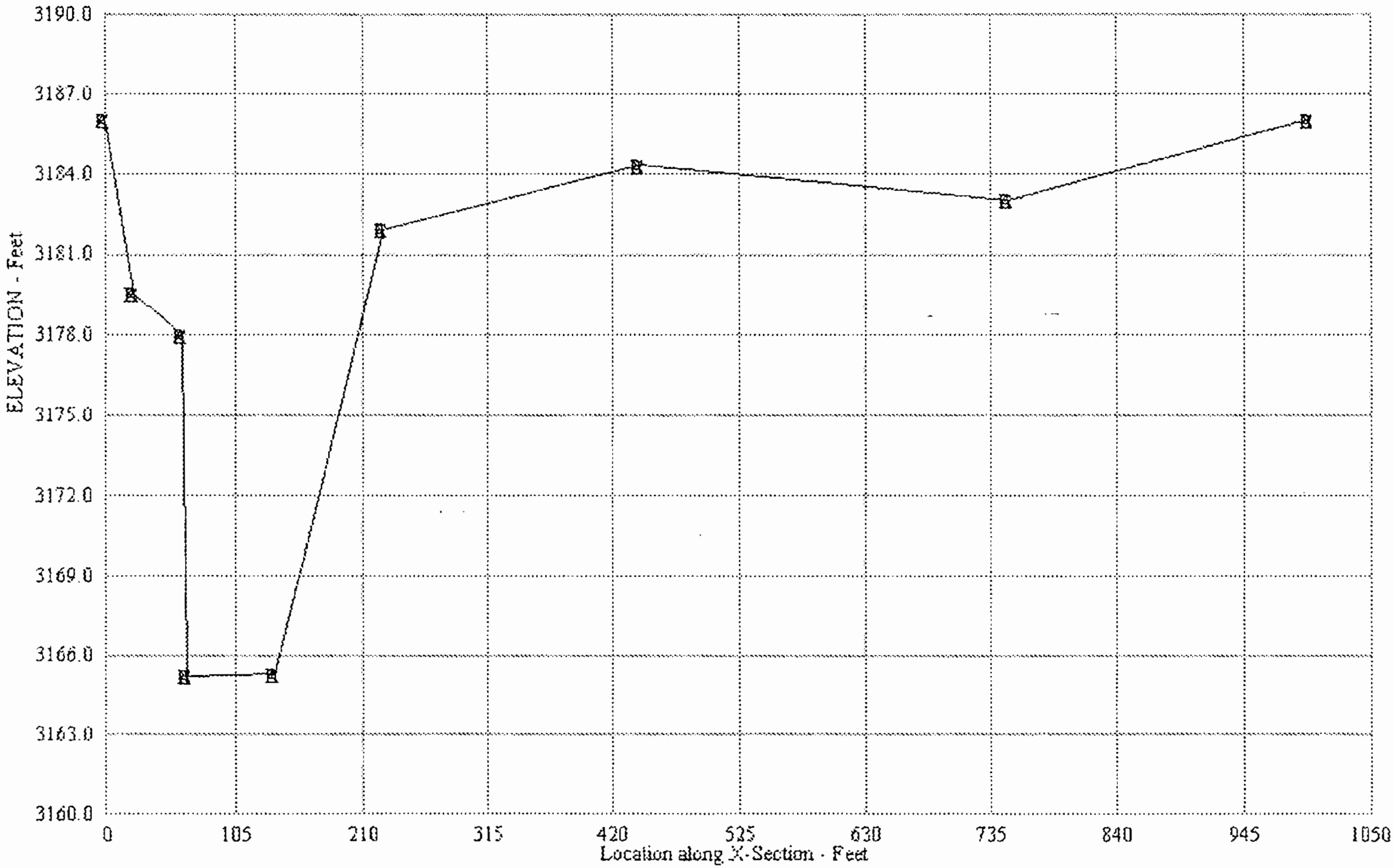
STATION #22
CANYON CREEK
SLOPE = 0.001256
ELEV. = 3191.9
WIDTH = 945'
DEPTH = 24.7'
W/D = 37.8

REFERENCE
REACH

SHEET 22 OF 38	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS AQUONEERING YELLOWSTONE RIVER	8X11AQUO.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/04/00 REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
FALL OF 1999 SURVEY DATA

CROSS SECTION PROFILE AT STA. 155300.00 Ft.



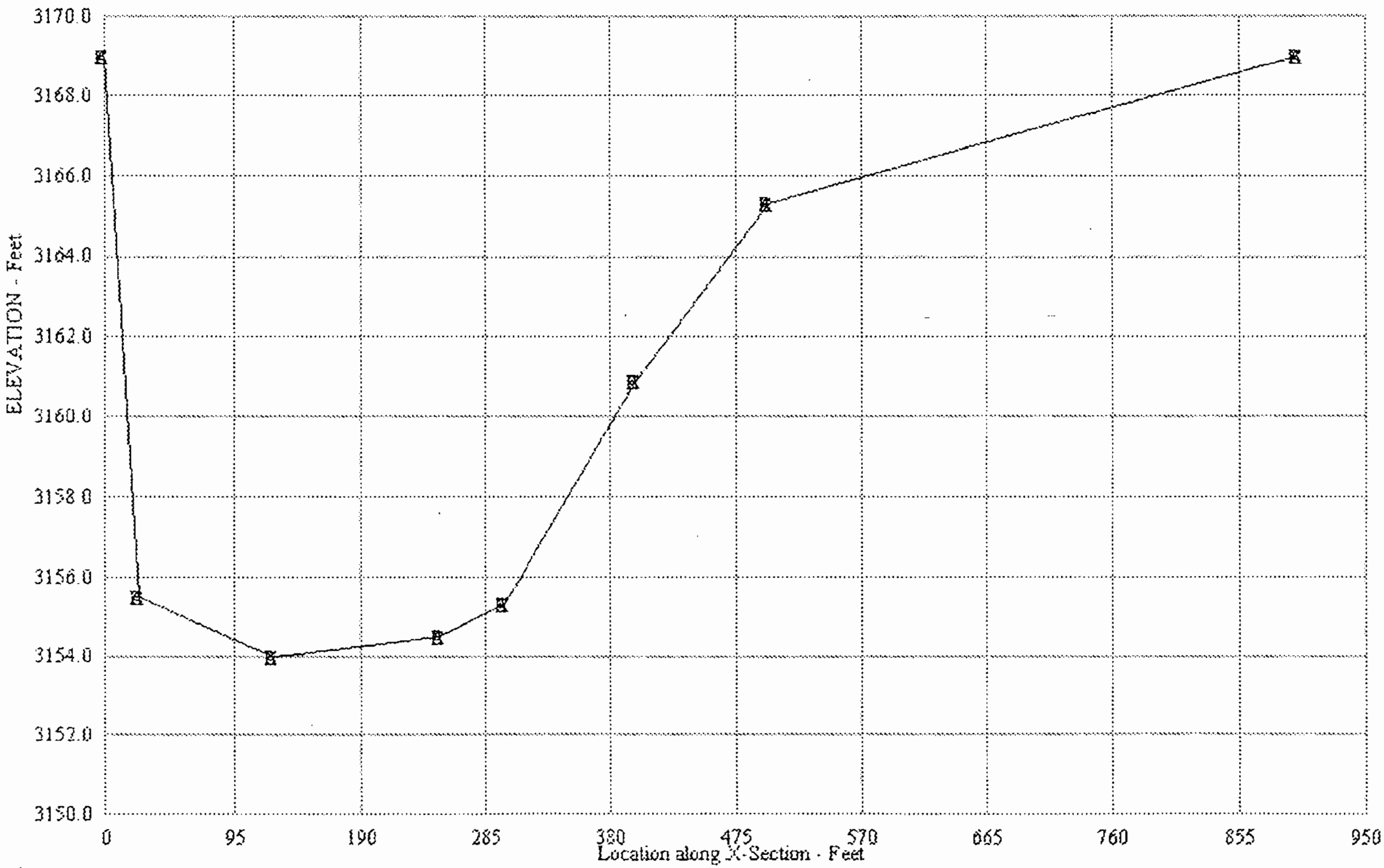
STATION #23

SLOPE=0.00006302
ELEV. = 3187.3
WIDTH ≅ 1105'
DEPTH = 21.5'
W/D ≅ 51

SHEET 23 OF 38	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS AQUONEERING YELLOWSTONE RIVER	8X11AQUO.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/04/00 REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
FALL OF 1999 SURVEY DATA

CROSS SECTION PROFILE AT STA. 152470.00 Ft.



STATION #24

SLOPE= 0.0039576
ELEV. = 3165.2
WIDTH = 515'
DEPTH = 11.2'
W/D = 46

SHEET 24 OF 38

AQUONEERING
1555 SAGE CIRCLE
LAUREL, MT 59044
(406) 628-2202

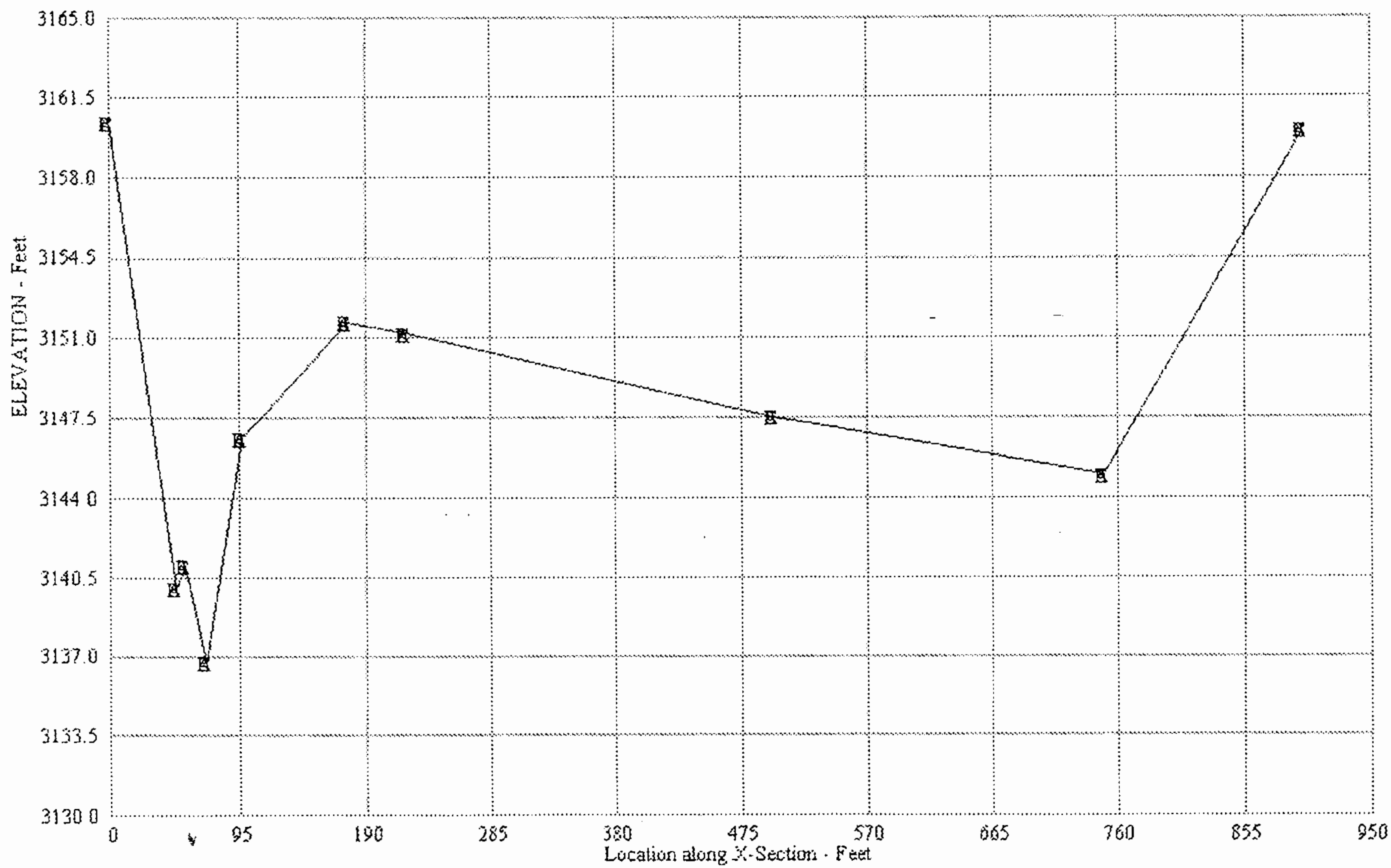
CROSS SECTIONS
AQUONEERING
YELLOWSTONE RIVER

8X11AQUO.DWG
99-550-01
DRAWN BY: RFS
CHECKED BY: RJP
APPROVED BY: RJP

DATE: 05/04/00
REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
FALL OF 1999 SURVEY DATA

CROSS SECTION PROFILE AT STA. 148800.00 Ft.



STATION #25

SLOPE = 0.0047139
ELEV. = 3158.0
WIDTH = 870'
DEPTH = 21'
W/D = 41.4

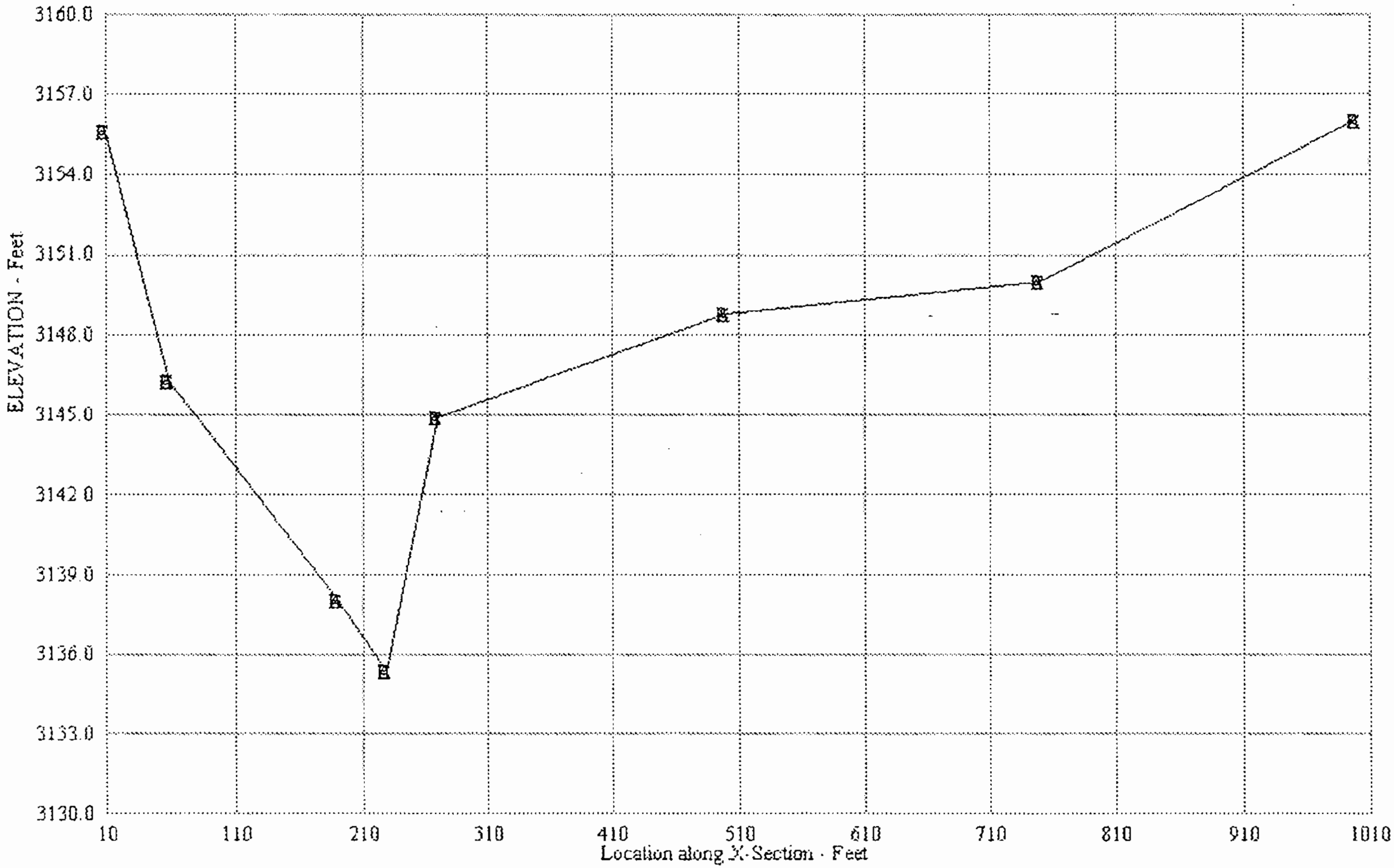
SHEET 25 OF 38	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS AQUONEERING YELLOWSTONE RIVER	8X11AQUO.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/04/00 REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
FALL OF 1999 SURVEY DATA

CROSS SECTION PROFILE AT STA. 145770.00 Ft.

STATION #26

SLOPE =
ELEV. = 3154.1
WIDTH = 920'
DEPTH = 19'
W/D = 48

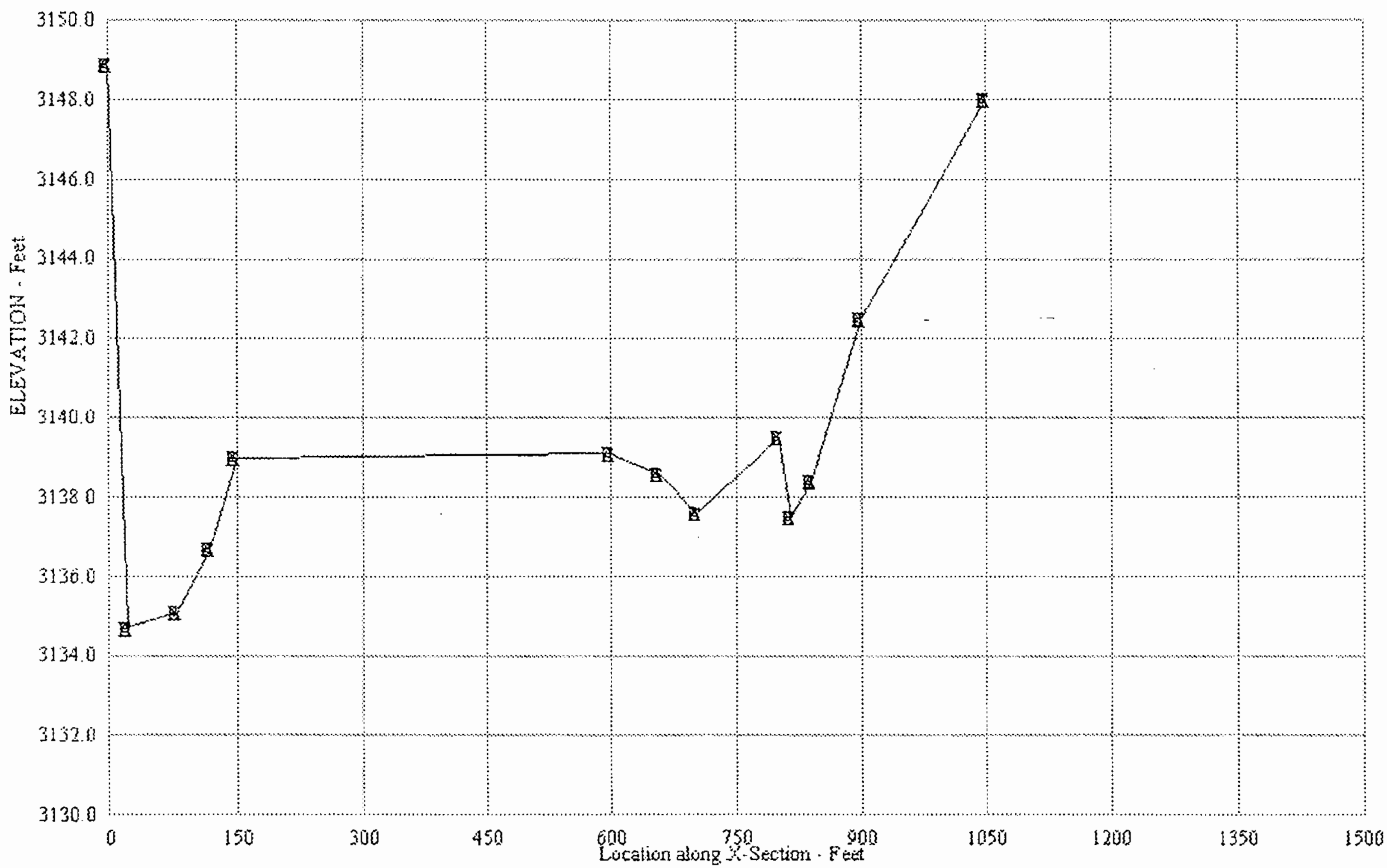


SHEET 26 OF 38	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS AQUONEERING YELLOWSTONE RIVER	8X11AQUO.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/04/00 REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
FALL OF 1999 SURVEY DATA

CROSS SECTION PROFILE AT STA. 140250.00 Ft.

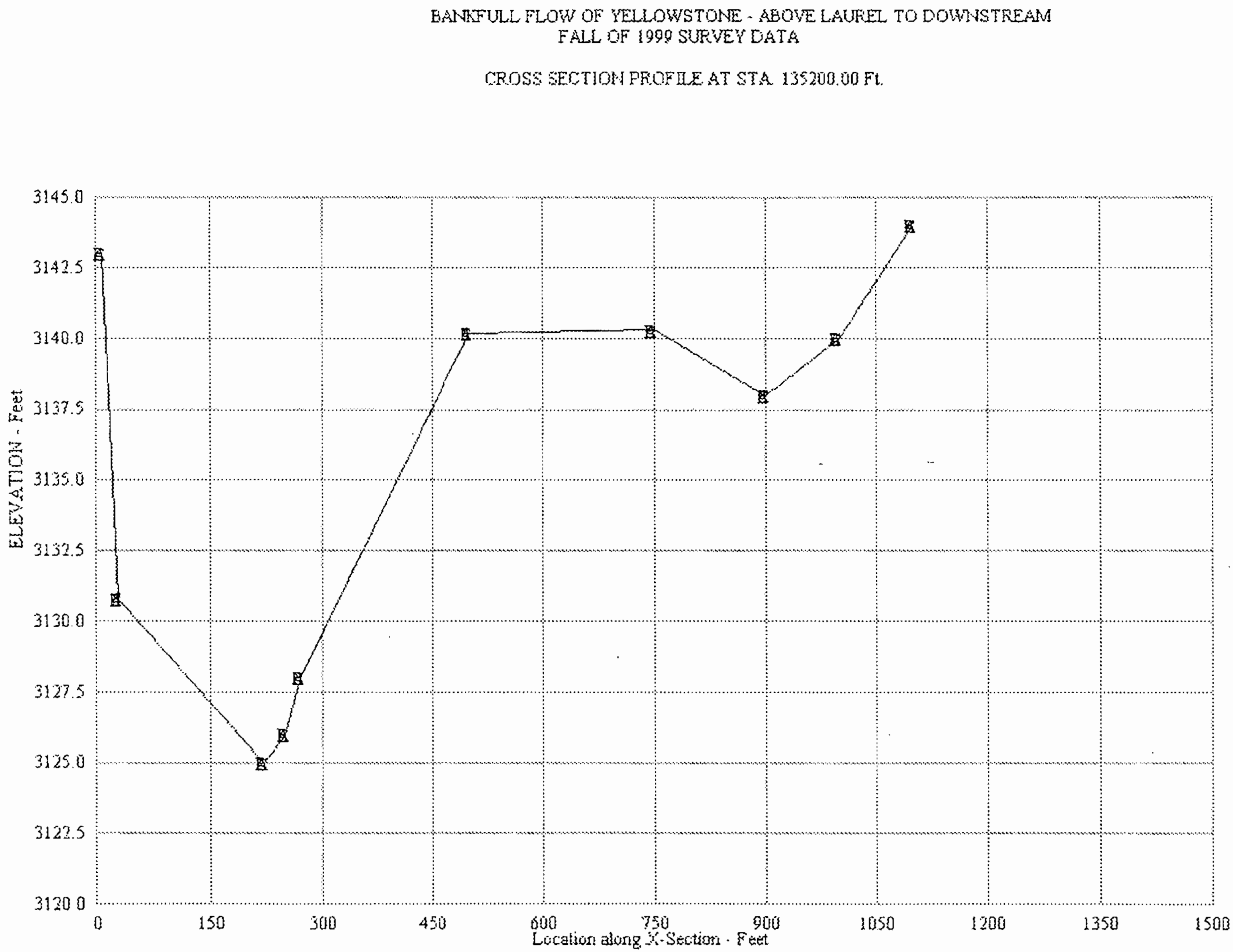
SOUTH BILLINGS BLVD. BRIDGE



STATION #27

SLOPE= 0.00012691
ELEV. = 3148.2
WIDTH = 1050'
DEPTH = 13.5'
W/D = 77.8

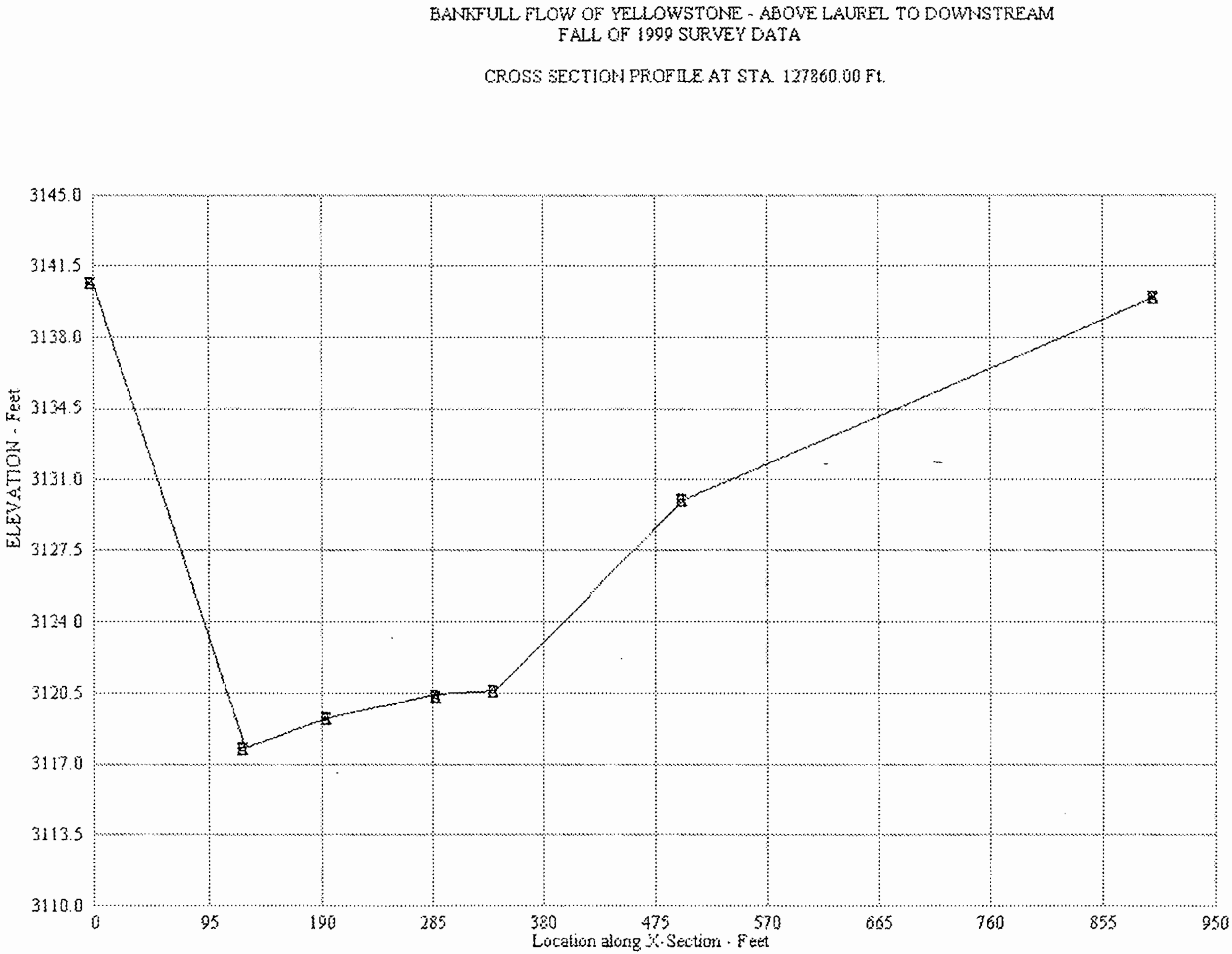
SHEET 27 OF 38	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS AQUONEERING YELLOWSTONE RIVER	8X11AQUO.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/04/00 REVISED:



STATION #28

SLOPE = 0.0019208
ELEV. = 3145.8
WIDTH = 1100'
DEPTH = 20'
W/D = 55

SHEET 28 OF 38	AQUONEERING	1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS AQUONEERING YELLOWSTONE RIVER	8X11AQUO.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/04/00 REVISED:



STATION #29

SLOPE=0.00098093
ELEV. = 3131.4
WIDTH = 500'
DEPTH = 14'
W/D = 36

SHEET 29 OF 38

AQUONEERING
1555 SAGE CIRCLE
LAUREL, MT 59044
(406) 628-2202

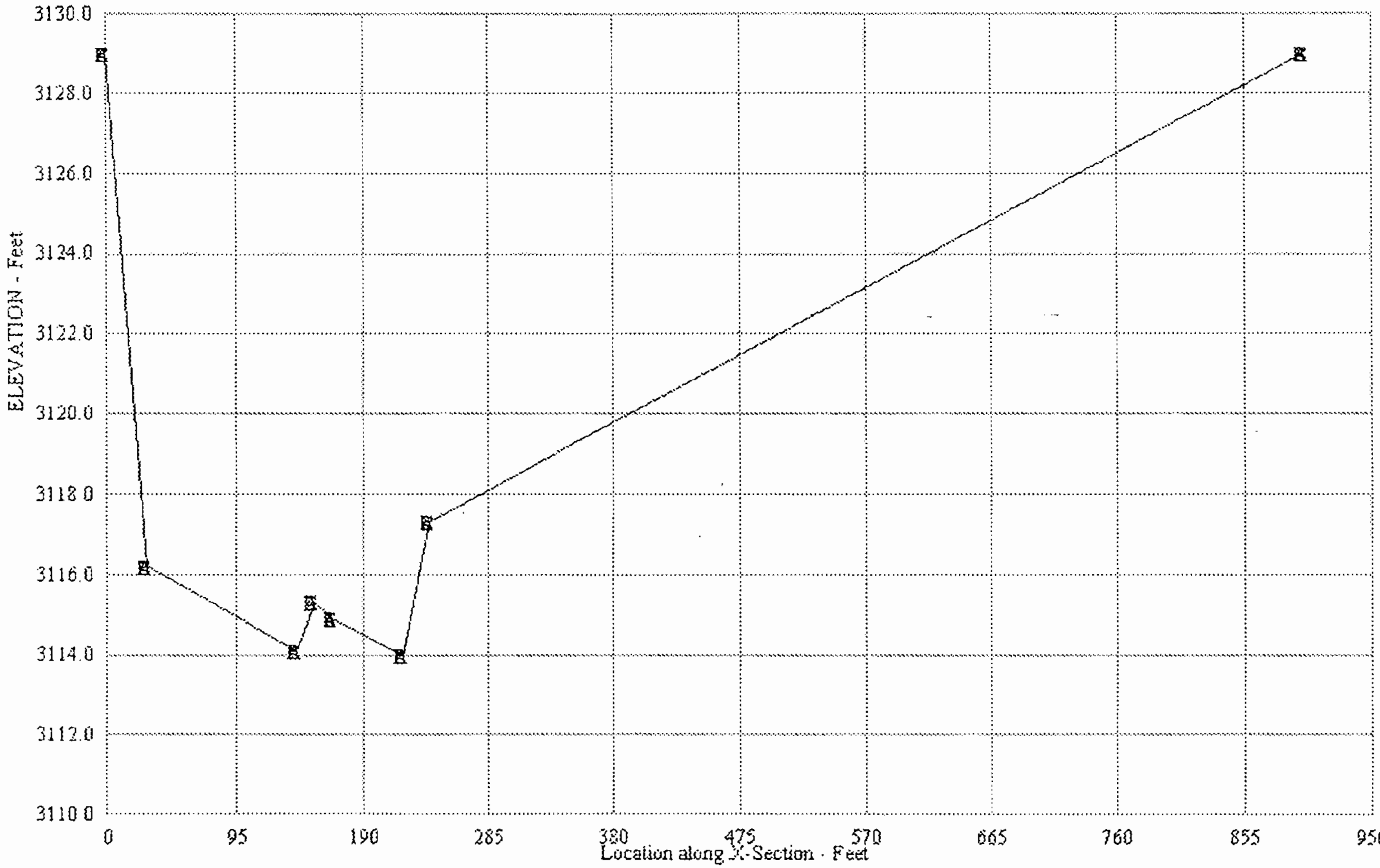
CROSS SECTIONS
AQUONEERING
YELLOWSTONE RIVER

8X11AQUO.DWG
99-550-01
DRAWN BY: RFS
CHECKED BY: RJP
APPROVED BY: RJP

DATE: 05/04/00
REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
FALL OF 1999 SURVEY DATA

CROSS SECTION PROFILE AT STA. 126310.00 Ft.



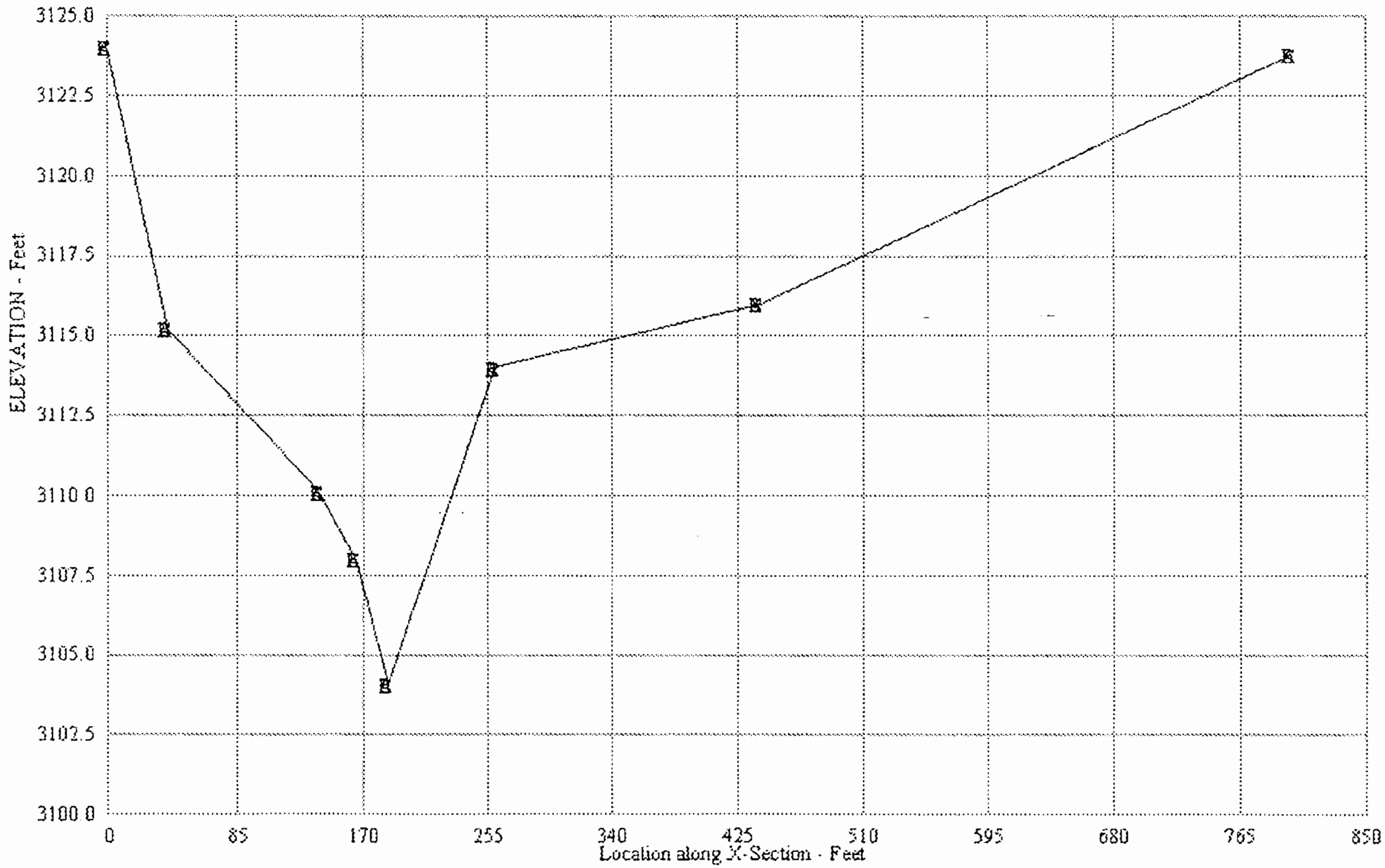
STATION #30

SLOPE = 0.0024516
ELEV. = 3128.1
WIDTH = 850'
DEPTH = 14'
W/D = 60.6

SHEET 30 OF 38	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS AQUONEERING YELLOWSTONE RIVER	8X11AQUO.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/04/00 REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
FALL OF 1999 SURVEY DATA

CROSS SECTION PROFILE AT STA. 123530.00 Ft.



STATION #31

SLOPE = 0.0035612
ELEV. = 3123.4
WIDTH = 775'
DEPTH = 20'
W/D = 38.7

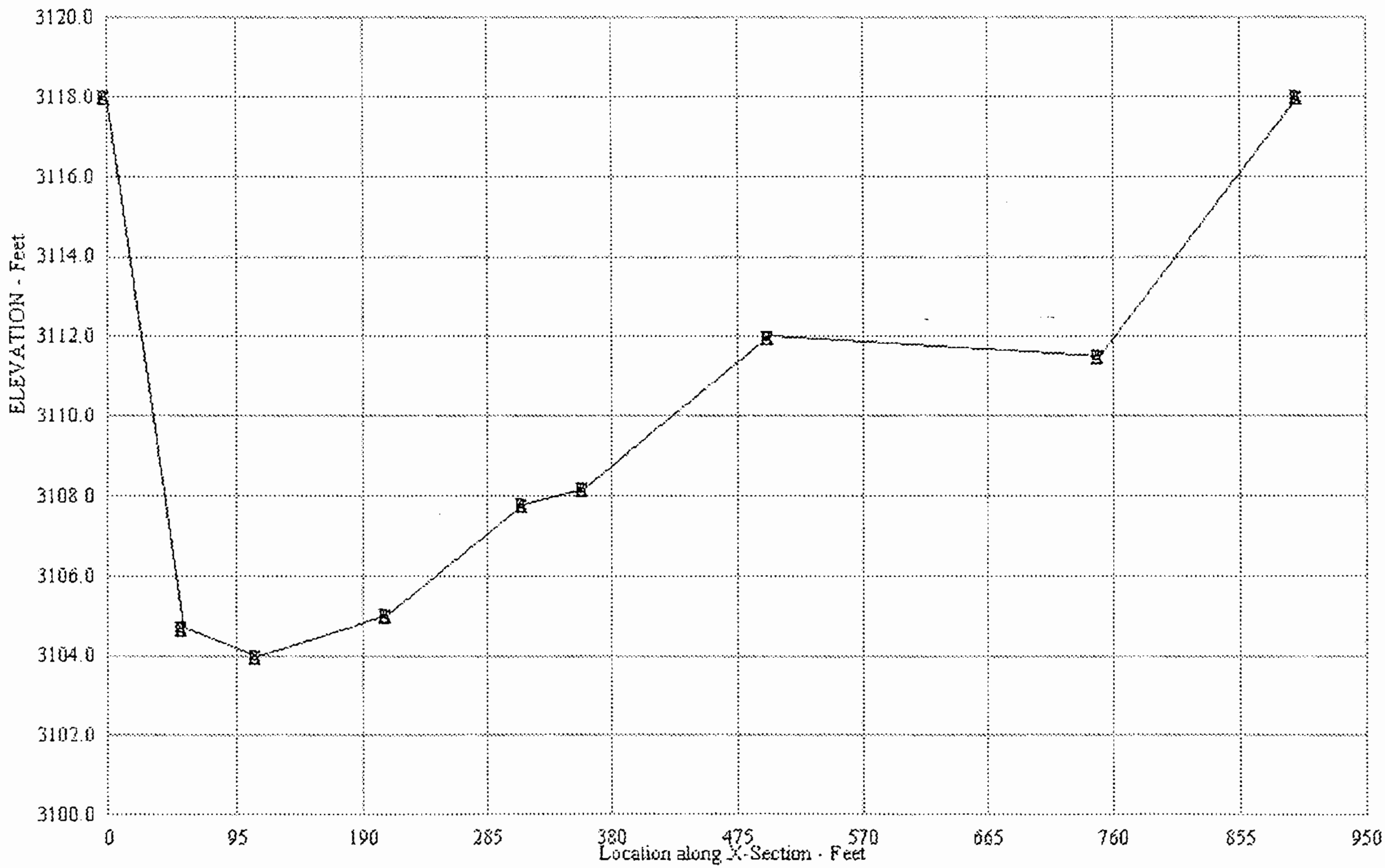
SHEET 31 OF 38	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS AQUONEERING YELLOWSTONE RIVER	8X11AQUO.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/04/00 REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
FALL OF 1999 SURVEY DATA

CROSS SECTION PROFILE AT STA. 119660.00 Ft.

STATION #32

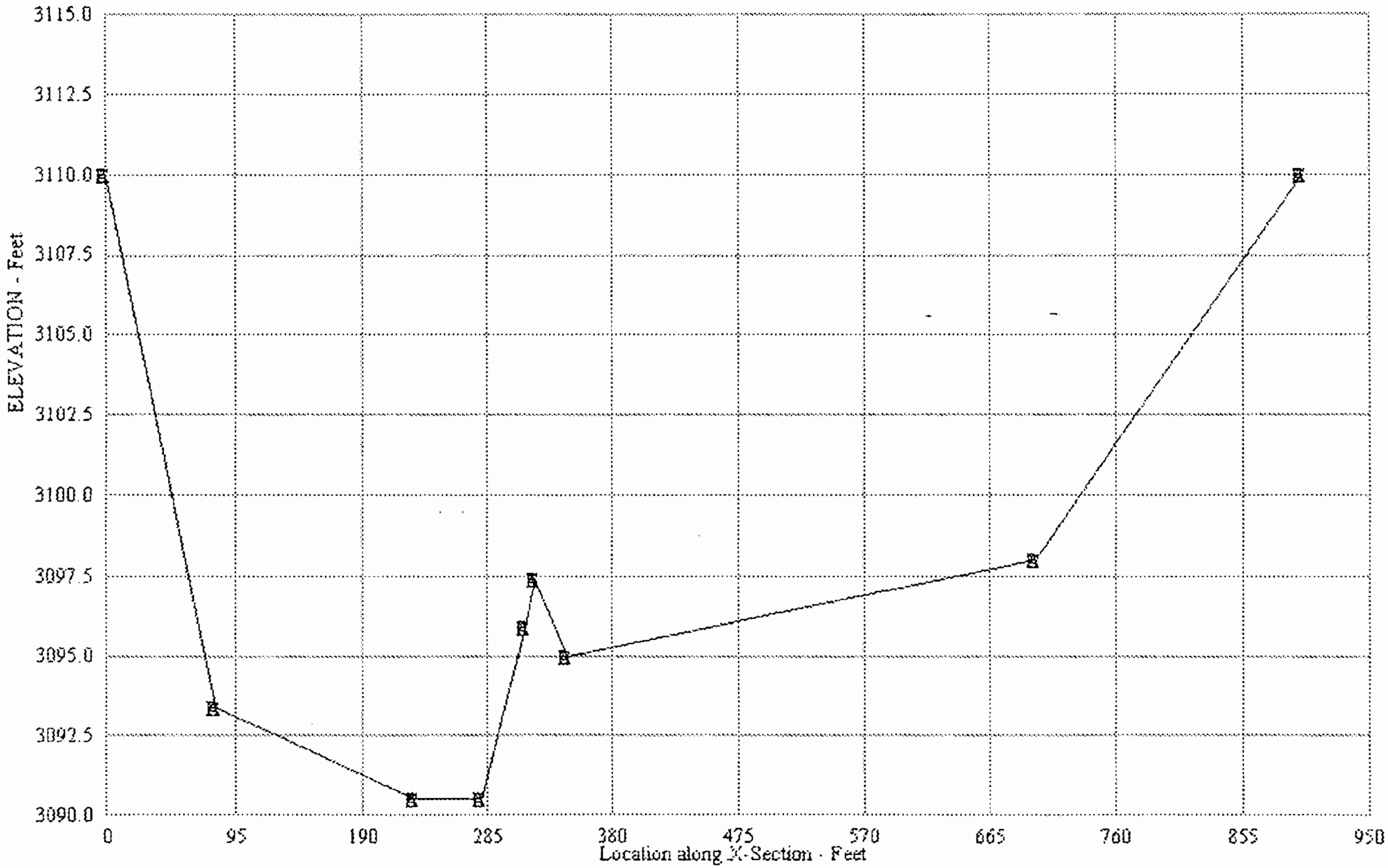
SLOPE= 0.0000584
ELEV. = 3116.3
WIDTH = 860'
DEPTH = 12.3'
W/D = 70



SHEET 32 OF 38	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS AQUONEERING YELLOWSTONE RIVER	8X11AQUO.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/04/00 REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
FALL OF 1999 SURVEY DATA

CROSS SECTION PROFILE AT STA. 112420.00 Ft.



STATION #33

SLOPE = 0.001864
ELEV. = 3107.4
WIDTH = 855'
DEPTH = 17.4'
W/D = 49.2

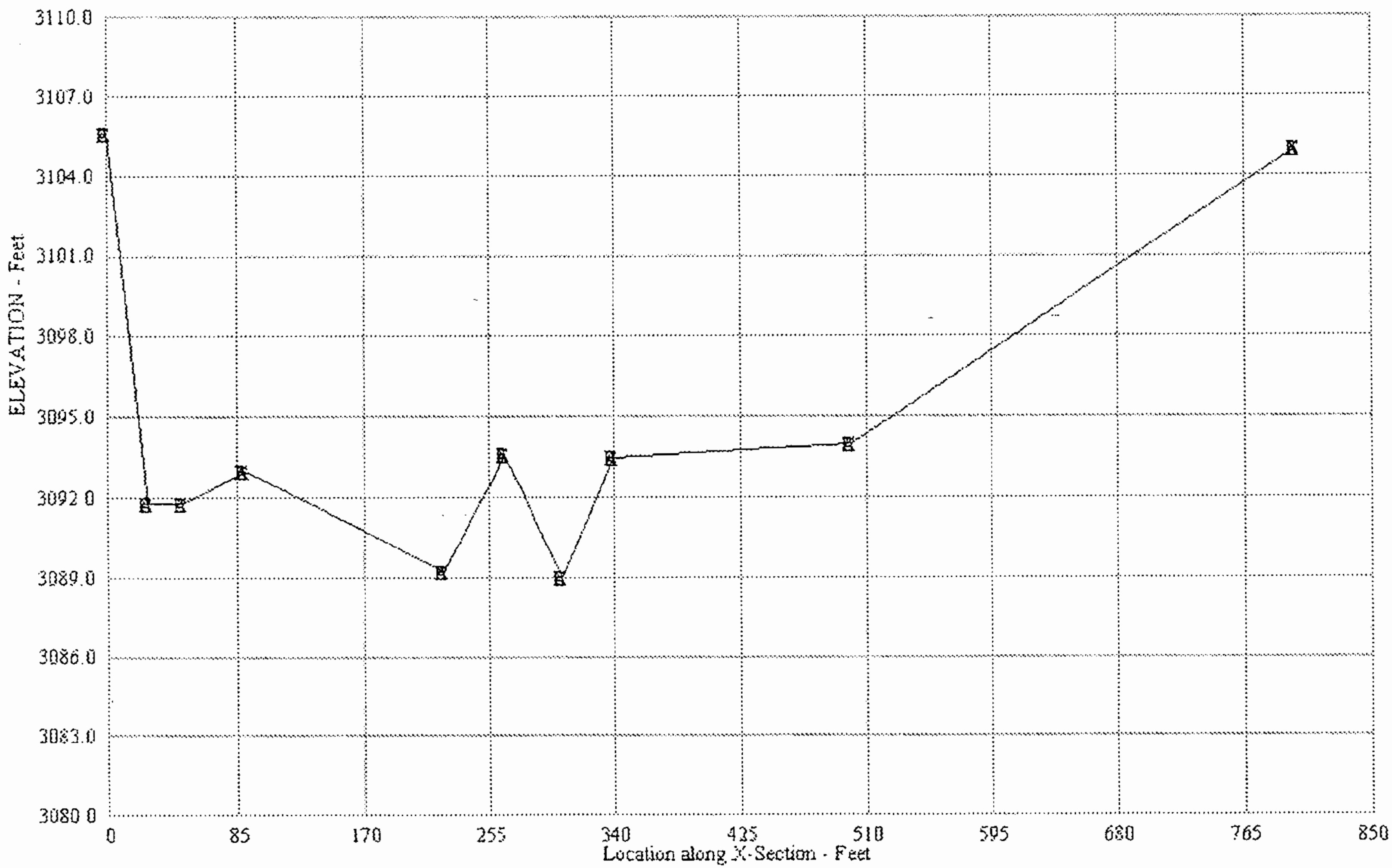
SHEET 33 OF 38	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS AQUONEERING YELLOWSTONE RIVER	8X11AQUO.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/04/00 REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
FALL OF 1999 SURVEY DATA

CROSS SECTION PROFILE AT STA. 108040.00 Ft.

STATION #34

SLOPE= 0.0003427
ELEV. = 3103.1
WIDTH = 750'
DEPTH = 14'
W/D = 53.8



SHEET 34
OF 38

AQUONEERING
1555 SAGE CIRCLE
LAUREL, MT 59044
(406) 628-2202

CROSS SECTIONS
AQUONEERING
YELLOWSTONE RIVER

8X11AQUO.DWG
99-550-01
DRAWN BY: RFS
CHECKED BY: RJP
APPROVED BY: RJP

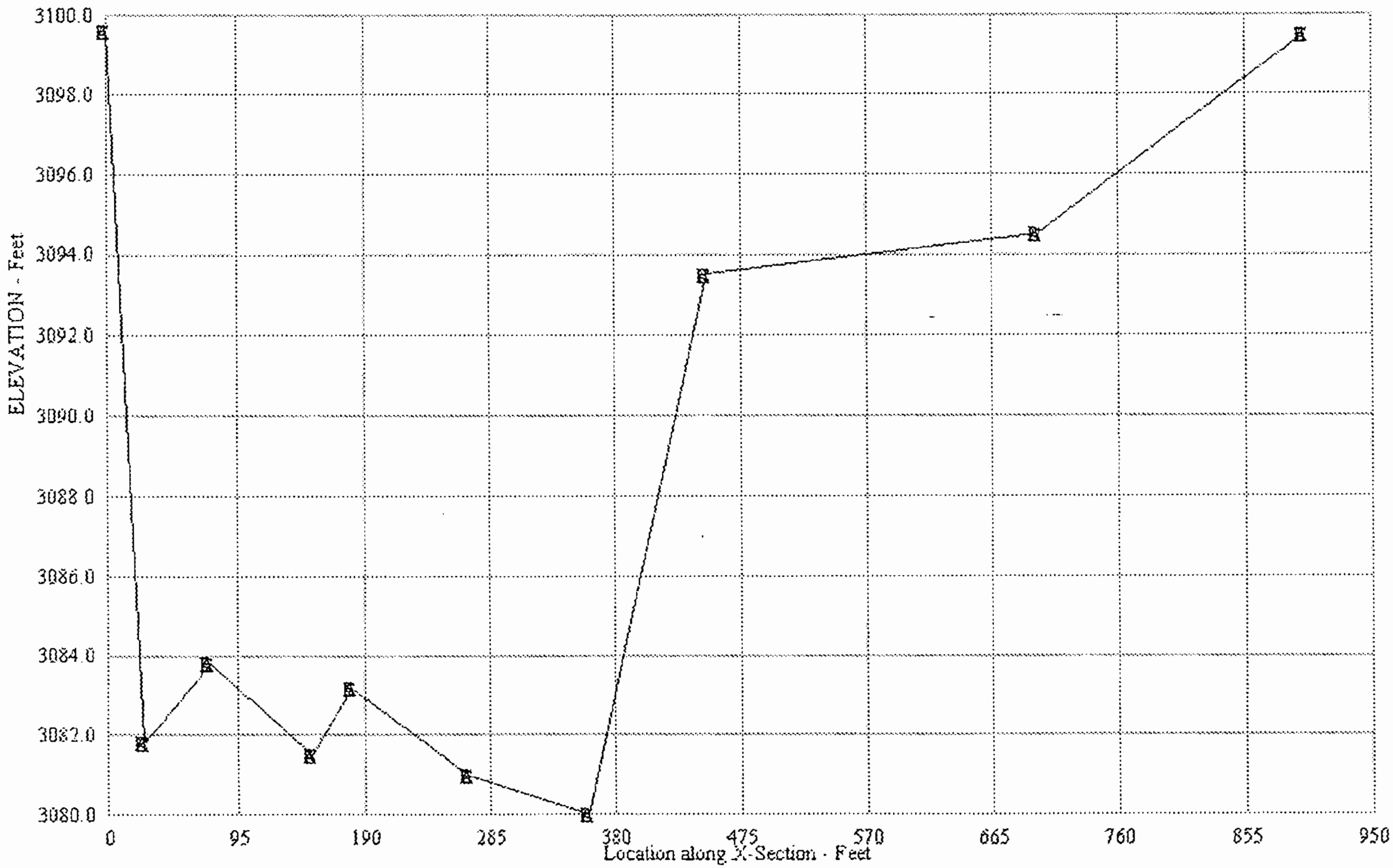
DATE: 05/04/00
REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
FALL OF 1999 SURVEY DATA

CROSS SECTION PROFILE AT STA. 102500.00 Ft.

STATION #35

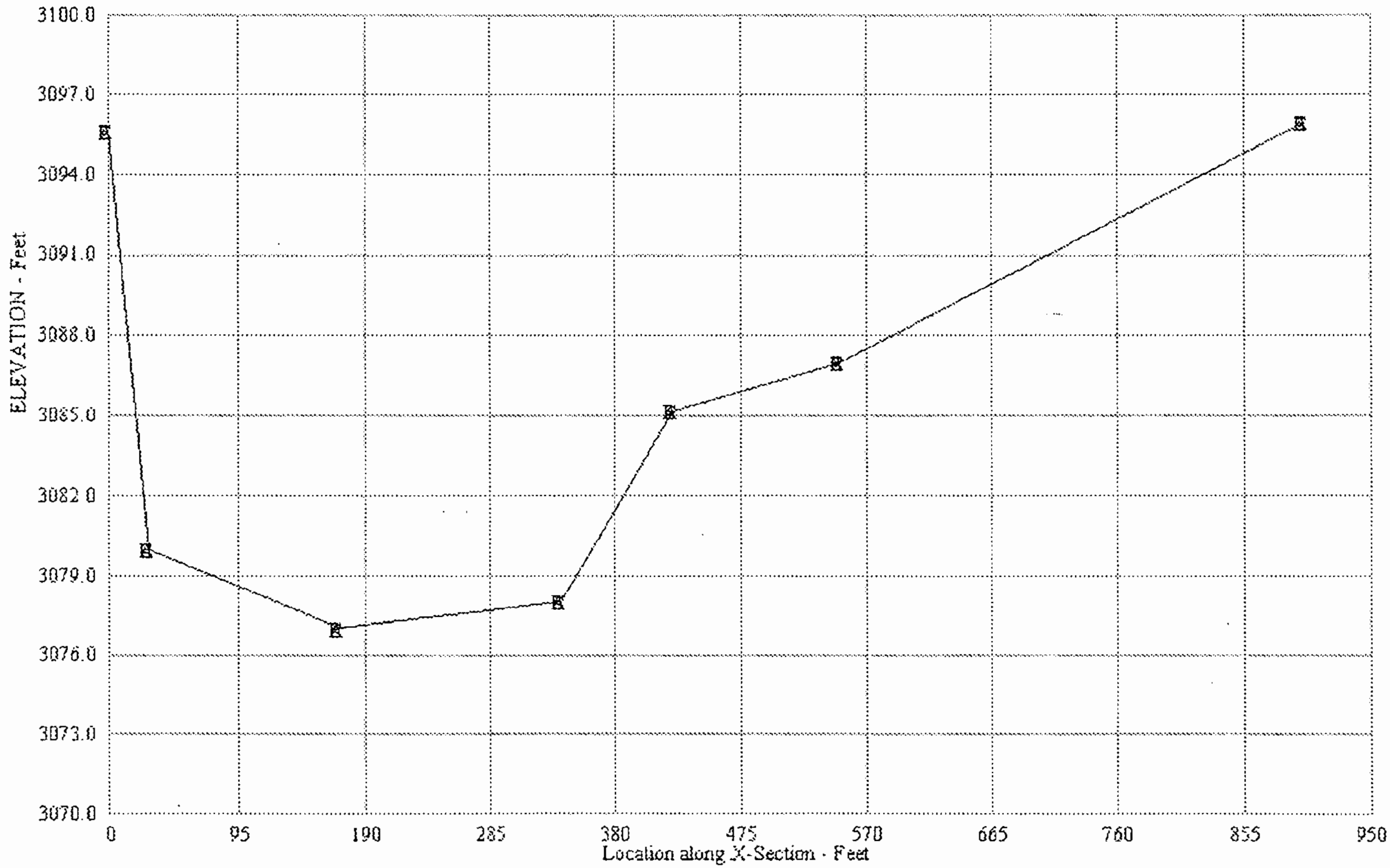
SLOPE = 0.0016245
ELEV. = 3097.6
WIDTH = 770'
DEPTH = 17.6'
W/D = 43.7



SHEET 35 OF 38	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS AQUONEERING YELLOWSTONE RIVER	8X11AQUO.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/04/00 REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
FALL OF 1999 SURVEY DATA

CROSS SECTION PROFILE AT STA. 97030.00 Ft.



STATION #36

SLOPE= 0.0005484
ELEV. = 3089.8
WIDTH = 660'
DEPTH = 12'
W/D = 55

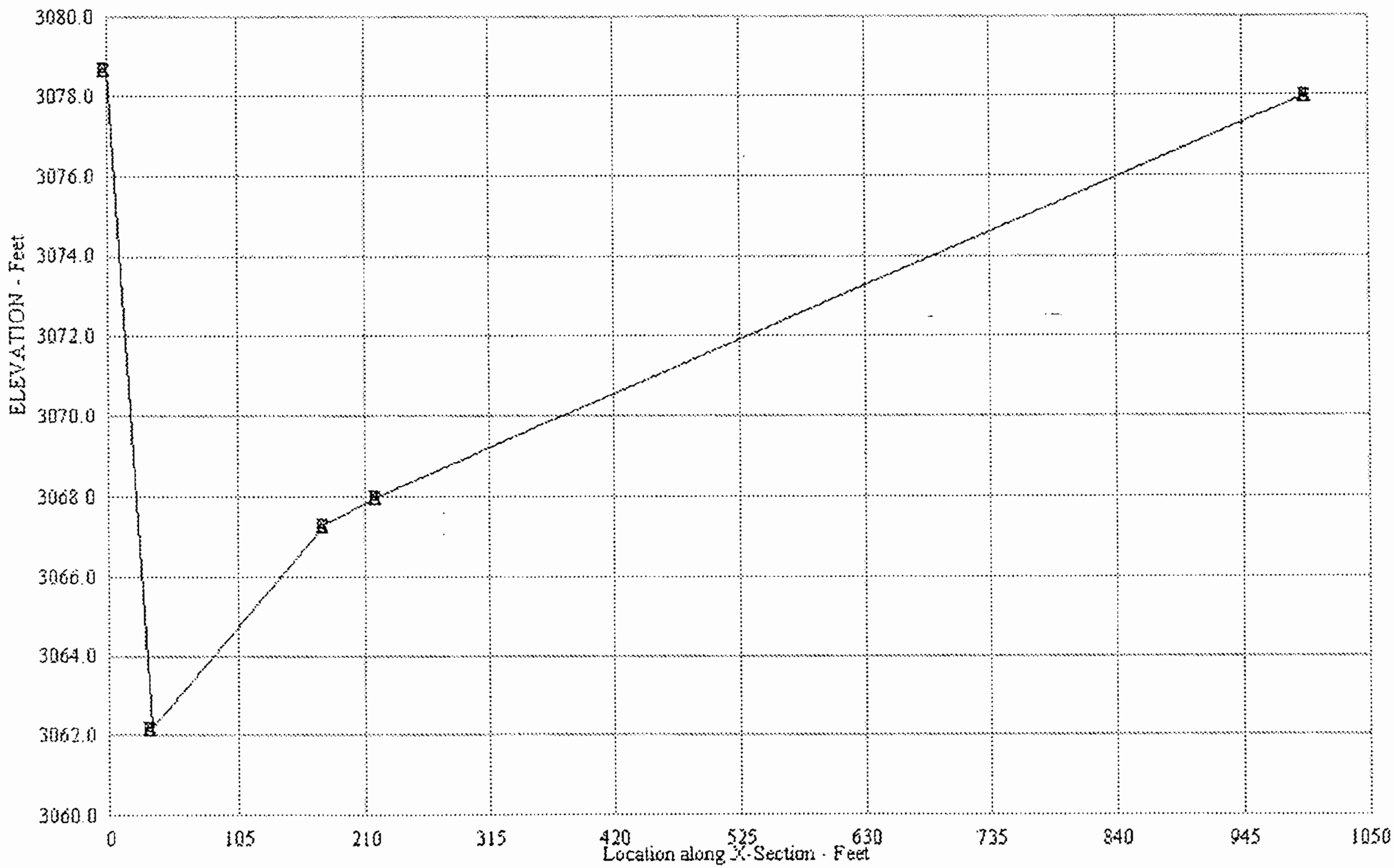
SHEET 36 OF 38	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS AQUONEERING YELLOWSTONE RIVER	8X11AQUO.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/04/00 REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
FALL OF 1999 SURVEY DATA

CROSS SECTION PROFILE AT STA. 90200.00 Ft.

STATION #37

SLOPE = 0.0021669
ELEV. = 3078.6
WIDTH = 975'
DEPTH = 16.8'
W/D = 58



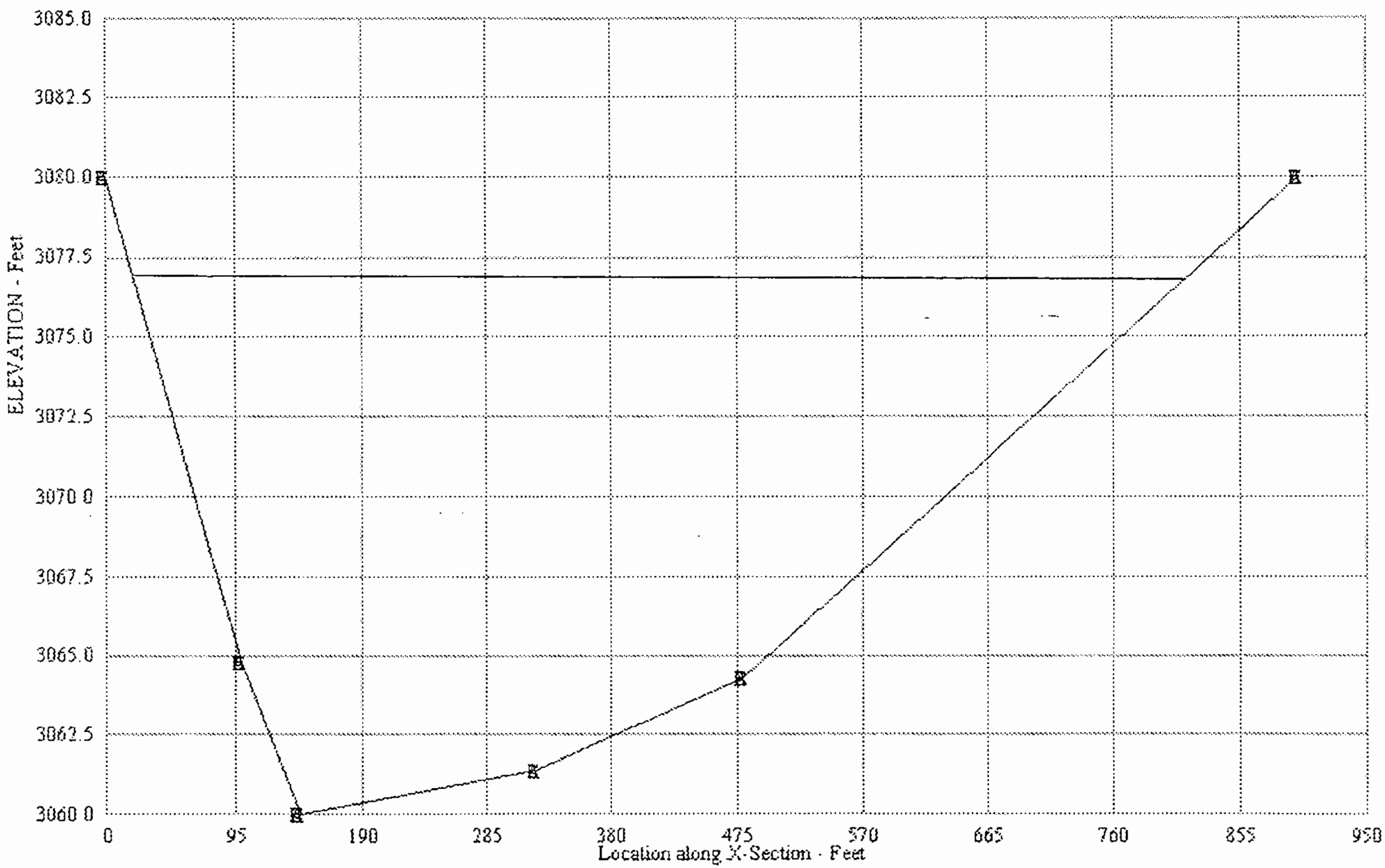
SHEET 37 OF 38	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS AQUONEERING YELLOWSTONE RIVER	8X11AQUO.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/04/00 REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
FALL OF 1999 SURVEY DATA

CROSS SECTION PROFILE AT STA. 88160.00 Ft.

STATION #38

SLOPE = 0.001784
ELEV. = 3076.8
WIDTH = 790'
DEPTH = 16.8'
W/D = 47



SHEET 38 OF 38	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS AQUONEERING YELLOWSTONE RIVER	8X11AQUO.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/04/00 REVISED:

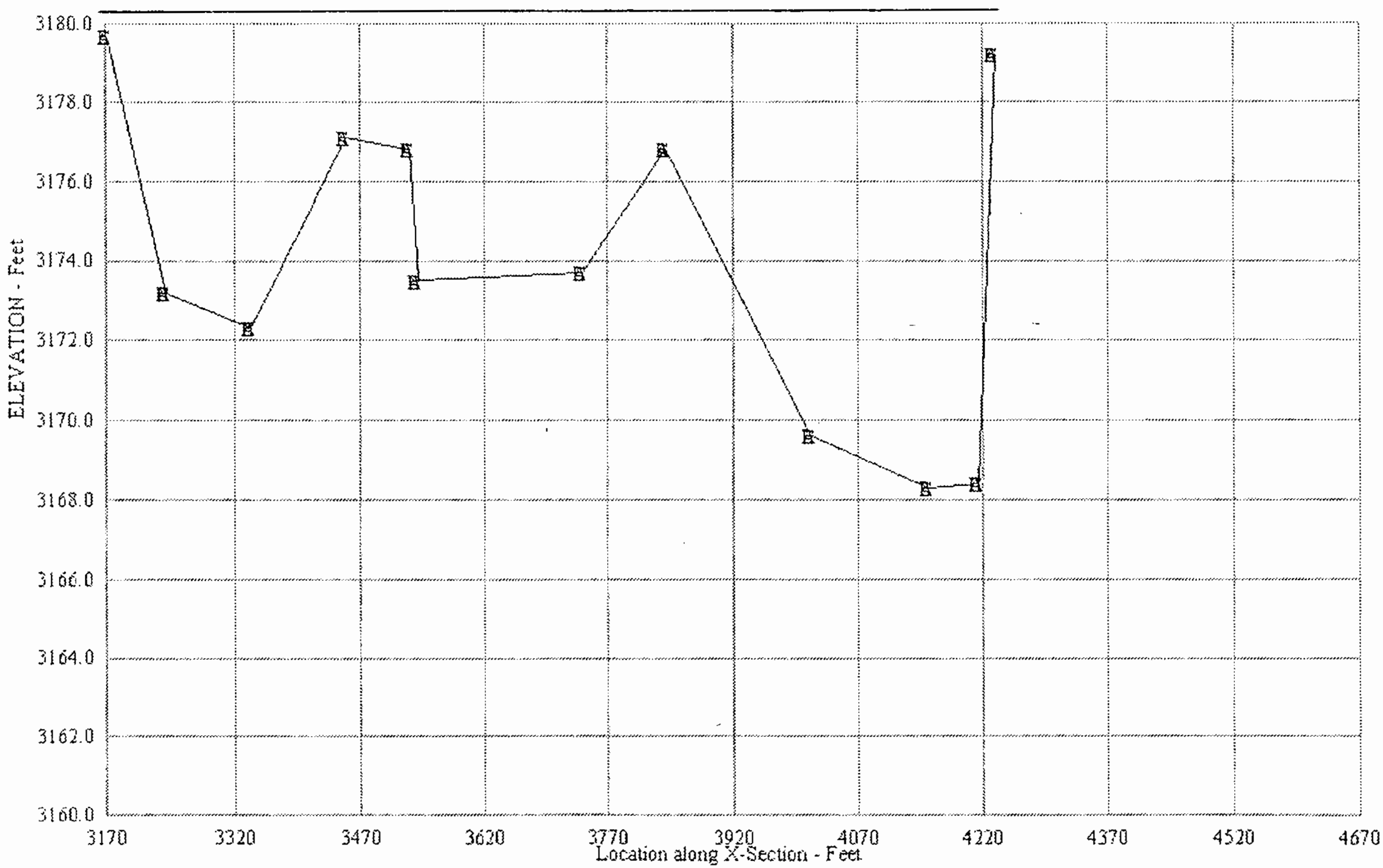
CORPS OF ENGINEERS
1970
CROSS SECTIONS

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
1970'S CORPS OF ENGINEERS DATA

CROSS SECTION PROFILE AT STA. 90950.00 Ft.

STATION #1

SLOPE = 0.001645
ELEV. = 3180.2
WIDTH = 1076'
DEPTH = 12'
W/D = 89.6



SHEET 1 OF 25

AQUONEERING

1555 SAGE CIRCLE
LAUREL, MT 59044
(406) 628-2202

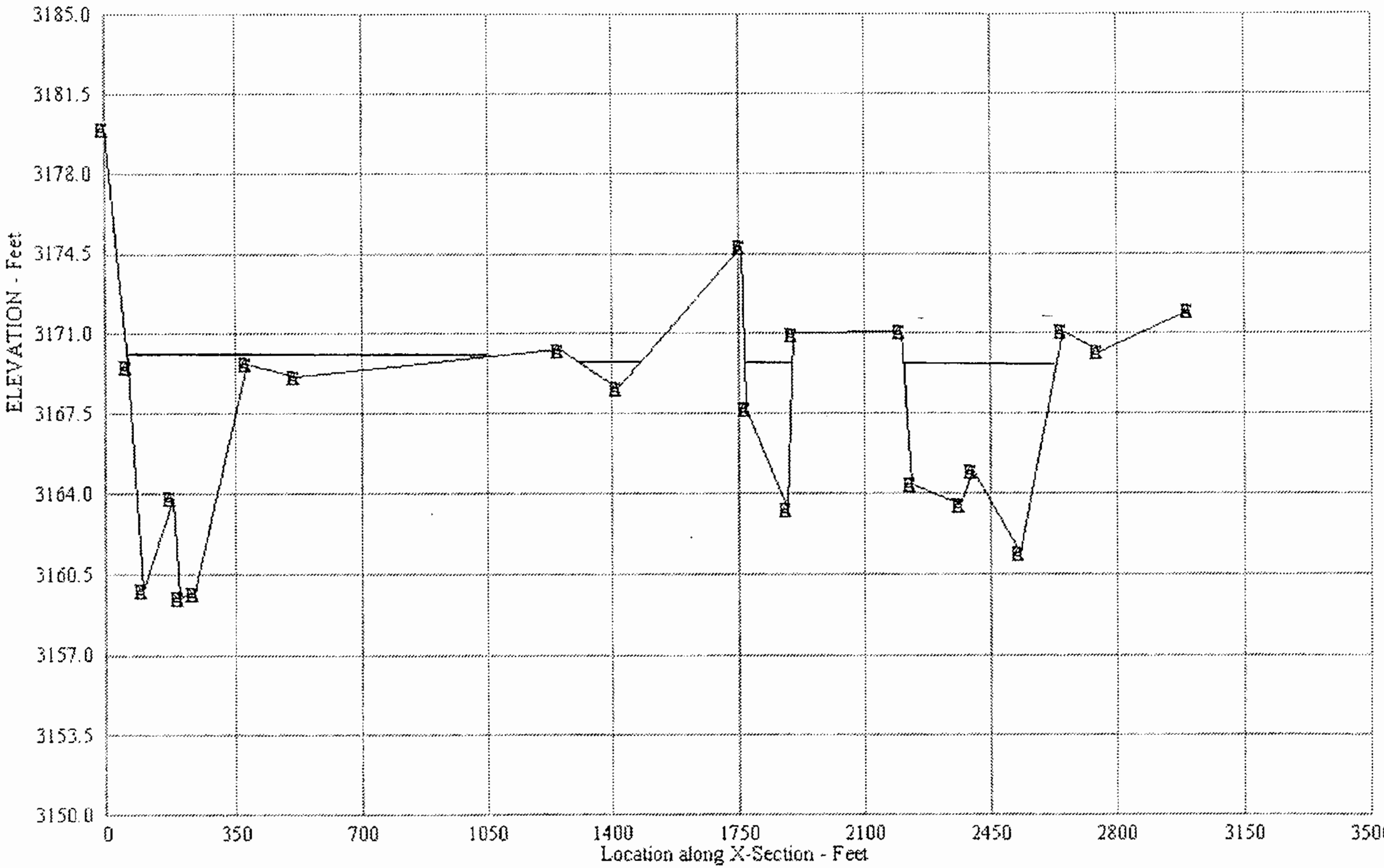
CROSS SECTIONS
CORP OF ENGINEERS
YELLOWSTONE RIVER

8X11CORP.DWG
99-550-01
DRAWN BY: RFS
CHECKED BY: RJP
APPROVED BY: RJP

DATE: 05/03/00
REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
1970'S CORPS OF ENGINEERS DATA

CROSS SECTION PROFILE AT STA. 85600.00 Ft.



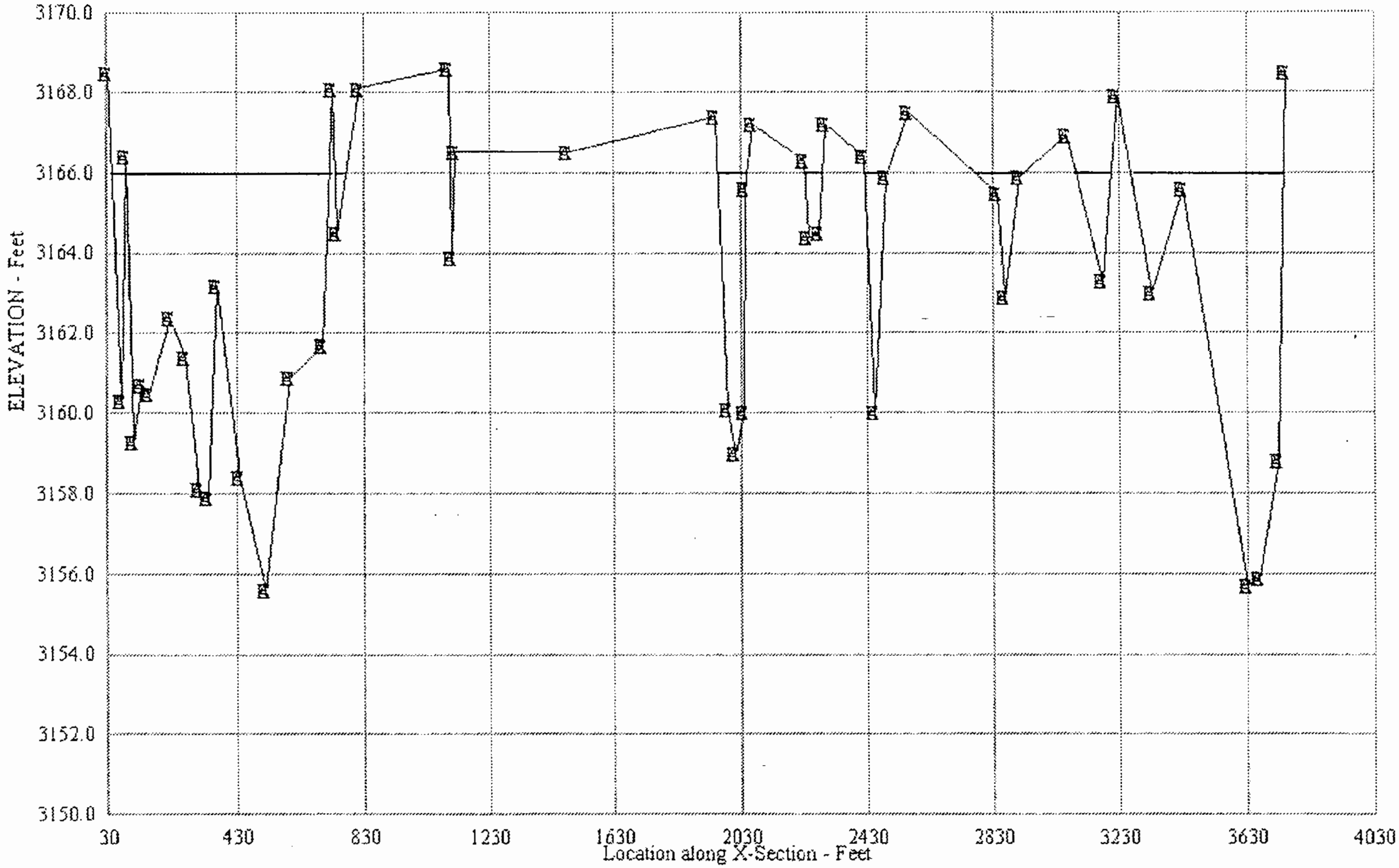
STATION #2

SLOPE = 0.0016449
ELEV. = 3170.0
WIDTH = 1764'
DEPTH = 11'
W/D = 160

SHEET 2 OF 25	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS CORP OF ENGINEERS YELLOWSTONE RIVER	8X11CORP.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/03/00 REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
1970'S CORPS OF ENGINEERS DATA

CROSS SECTION PROFILE AT STA. 83450.00 Ft.



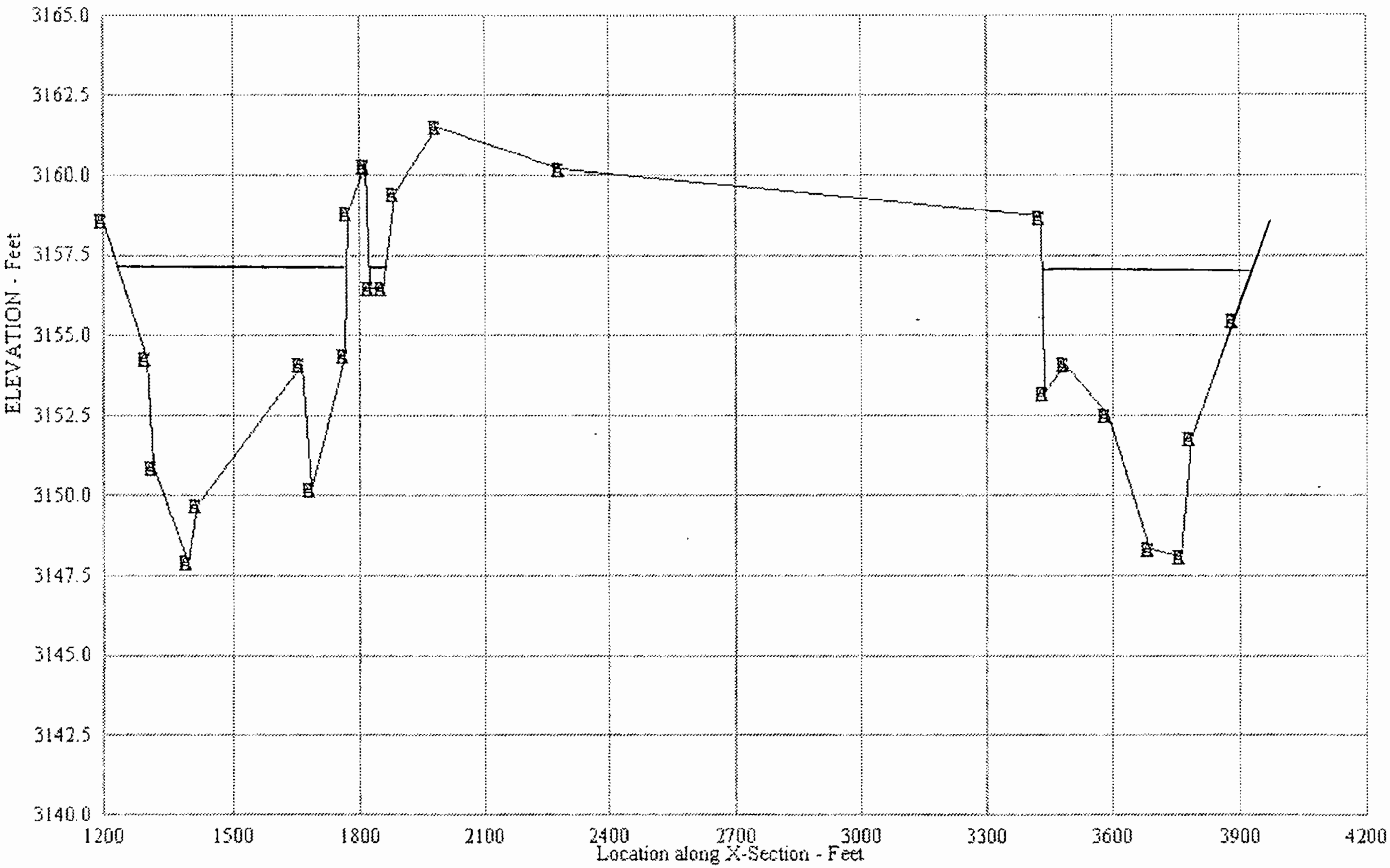
STATION #3

SLOPE = 0.001814
ELEV. = 3166.1
WIDTH = 1684'
DEPTH = 11'
W/D = 153

SHEET 3 OF 25	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS CORP OF ENGINEERS YELLOWSTONE RIVER	8X11CORP.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/03/00 REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
1970'S CORPS OF ENGINEERS DATA

CROSS SECTION PROFILE AT STA. 78500.00 Ft.



STATION #4

SLOPE = 0.001556
ELEV. = 3157.4
WIDTH = 1067'
DEPTH = 9.8'
W/D = 109

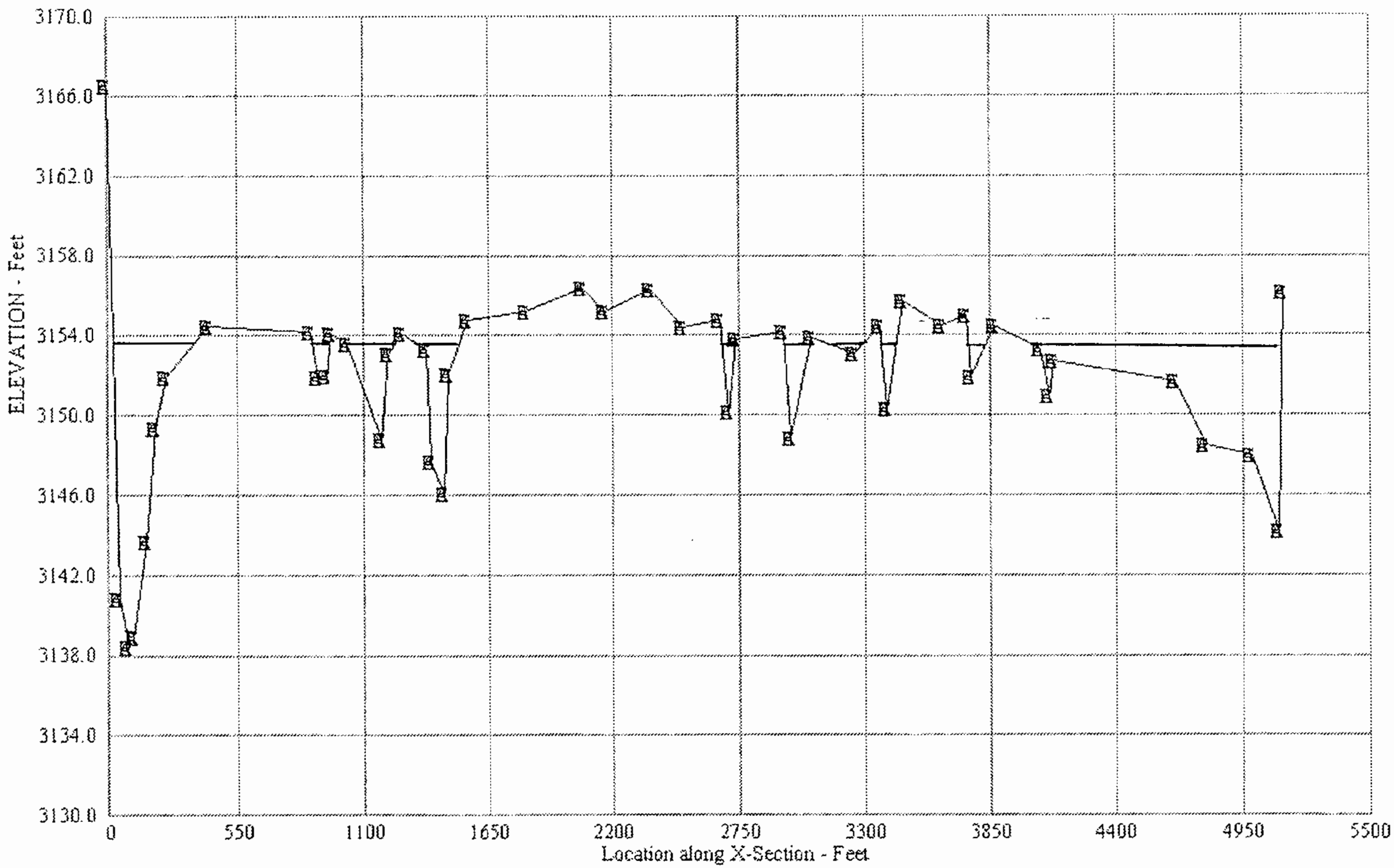
SHEET 4 OF 25	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS CORP OF ENGINEERS YELLOWSTONE RIVER	8X11CORP.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/03/00 REVISED:

STATION #5

SLOPE. = 0.0044186
ELEV. = 3153.8
WIDTH = 2336'
DEPTH = 15.8'
W/D = 148

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
1970'S CORPS OF ENGINEERS DATA

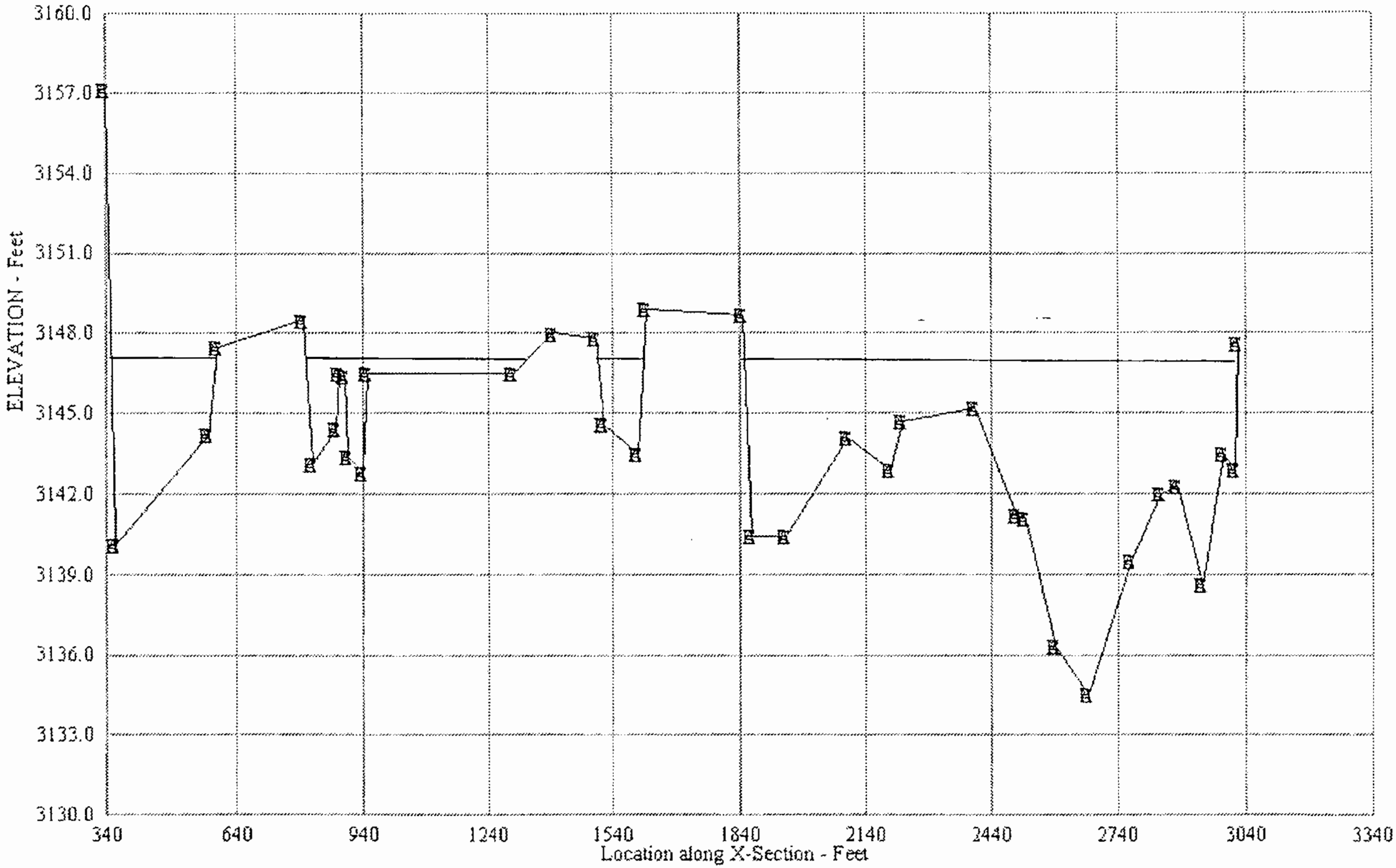
CROSS SECTION PROFILE AT STA. 76350.00 Ft.



SHEET 5 OF 25	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS CORP OF ENGINEERS YELLOWSTONE RIVER	8X11CORP.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/03/00 REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
1970'S CORPS OF ENGINEERS DATA

CROSS SECTION PROFILE AT STA. 70300.00 Ft.



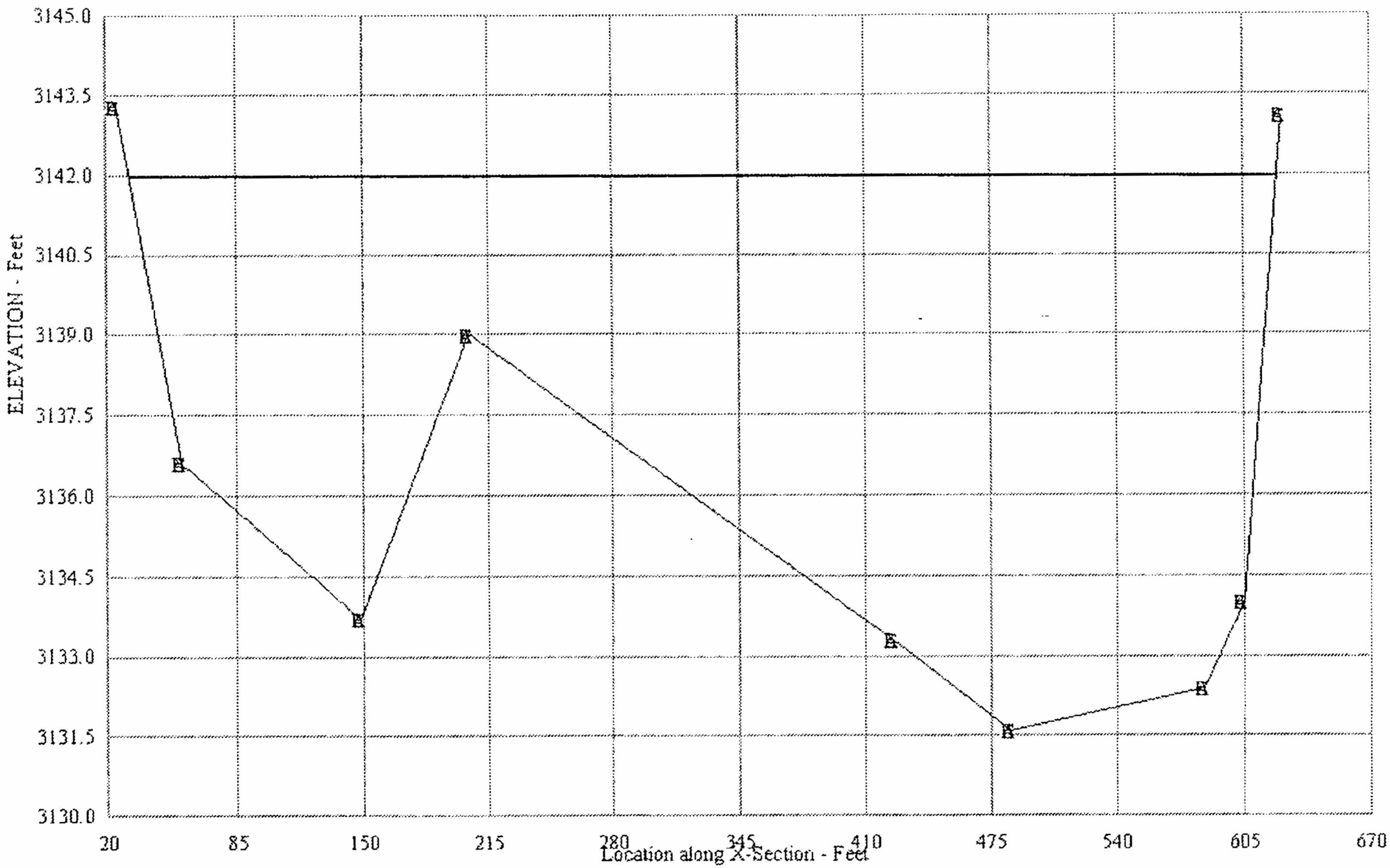
STATION #6

SLOPE=0.00064463
ELEV. = 3147.1
WIDTH = 2039'
DEPTH = 13'
W/D = 157

SHEET 6 OF 25	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS CORP OF ENGINEERS YELLOWSTONE RIVER	8X11CORP.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/03/00 REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
1970'S CORPS OF ENGINEERS DATA

CROSS SECTION PROFILE AT STA. 68750.00 Ft.



STATION #7

SLOPE = 0.001871
ELEV. = 3142.0
WIDTH = 591'
DEPTH = 10.5'
W/D = 56.3

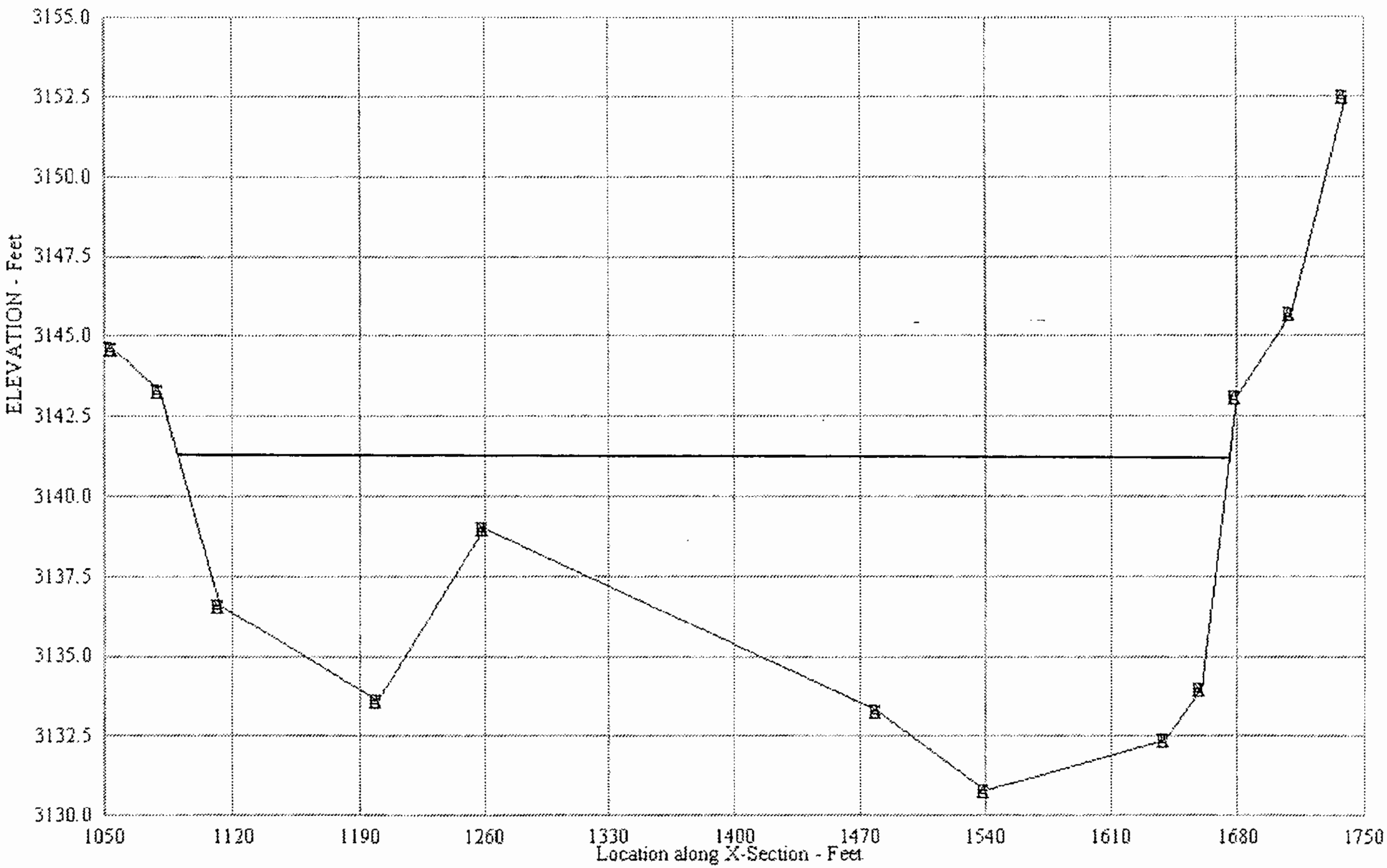
SHEET 7 OF 25	AQUONEERING — 1555 SAGE CIRCLE, LAUREL, MT 59044, (406) 628-2202	CROSS SECTIONS CORP OF ENGINEERS YELLOWSTONE RIVER	8X11CORP.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/03/00 REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
1970'S CORPS OF ENGINEERS DATA

CROSS SECTION PROFILE AT STA. 68720.00 Ft.

STATION #8

SLOPE = 0.02667
ELEV. = 3141.8
WIDTH = 585'
DEPTH = 11.3'
W/D = 51.8



SHEET 8 OF 25

AQUONEERING

1555 SAGE CIRCLE
LAUREL, MT 59044
(406) 628-2202

CROSS SECTIONS
CORP OF ENGINEERS
YELLOWSTONE RIVER

8X11CORP.DWG
99-550-01
DRAWN BY: RFS
CHECKED BY: RJP
APPROVED BY: RJP

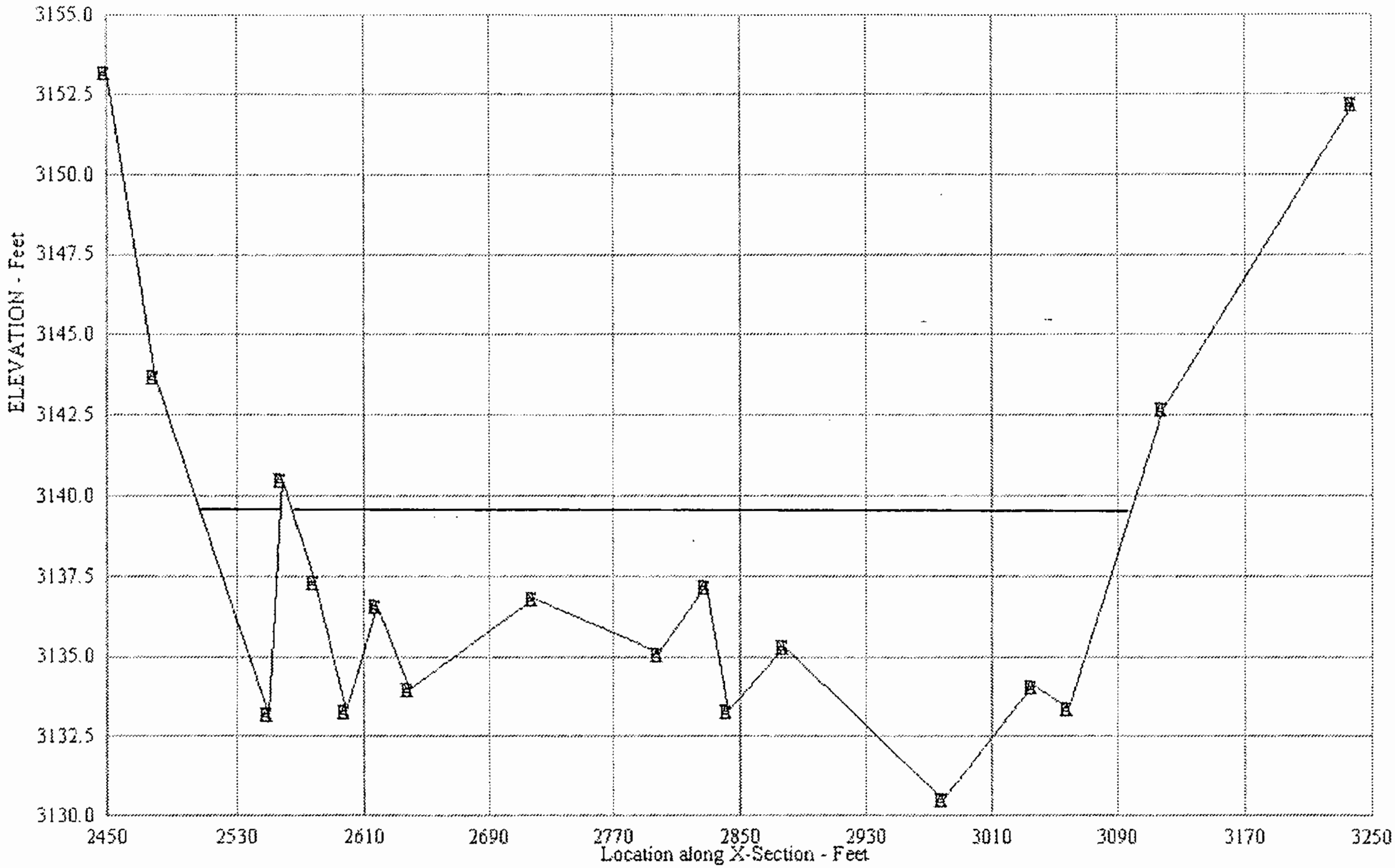
DATE: 05/03/00
REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
1970'S CORPS OF ENGINEERS DATA

CROSS SECTION PROFILE AT STA. 68650.00 Ft.

STATION #9

SLOPE = 0.0042857
ELEV. = 3139.8
WIDTH = 768'
DEPTH = 8.4'
W/D = 91.5



SHEET 9 OF 25

AQUONEERING
1555 SAGE CIRCLE
LAUREL, MT 59044
(406) 628-2202

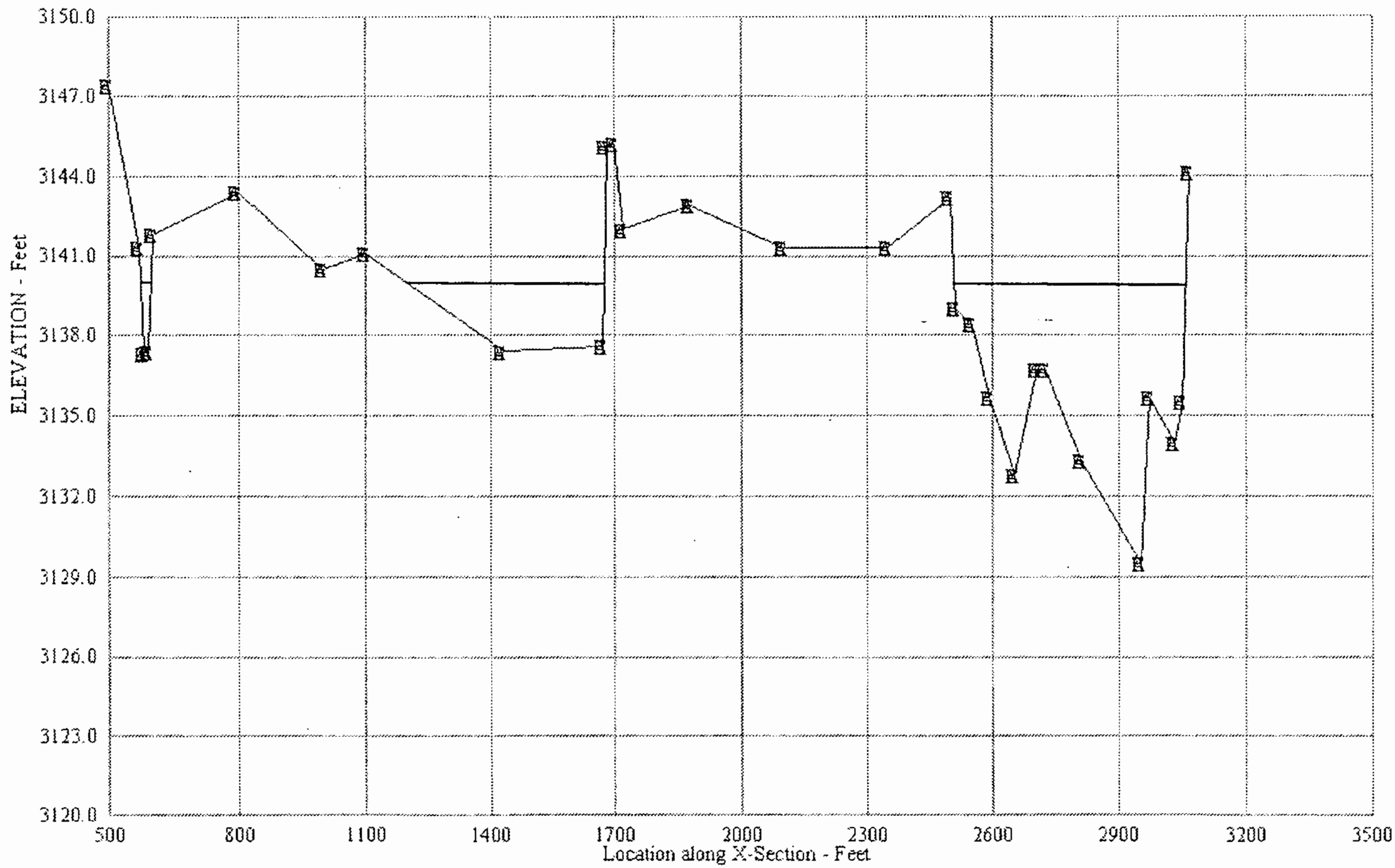
CROSS SECTIONS
CORP OF ENGINEERS
YELLOWSTONE RIVER

8X11CORP.DWG
99-550-01
DRAWN BY: RFS
CHECKED BY: RJP
APPROVED BY: RJP

DATE: 05/03/00
REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
1970'S CORPS OF ENGINEERS DATA

CROSS SECTION PROFILE AT STA. 68500.00 Ft.



STATION #10

SLOPE = 0.006667
ELEV. = 3139.5
WIDTH = 1016'
DEPTH = 10.2'
W/D = 99.6

SHEET 10 OF 25

AQUONEERING
1555 SAGE CIRCLE
LAUREL, MT 59044
(406) 628-2202

CROSS SECTIONS
CORP OF ENGINEERS
YELLOWSTONE RIVER

8X11CORP.DWG
99-550-01
DRAWN BY: RFS
CHECKED BY: RJP
APPROVED BY: RJP

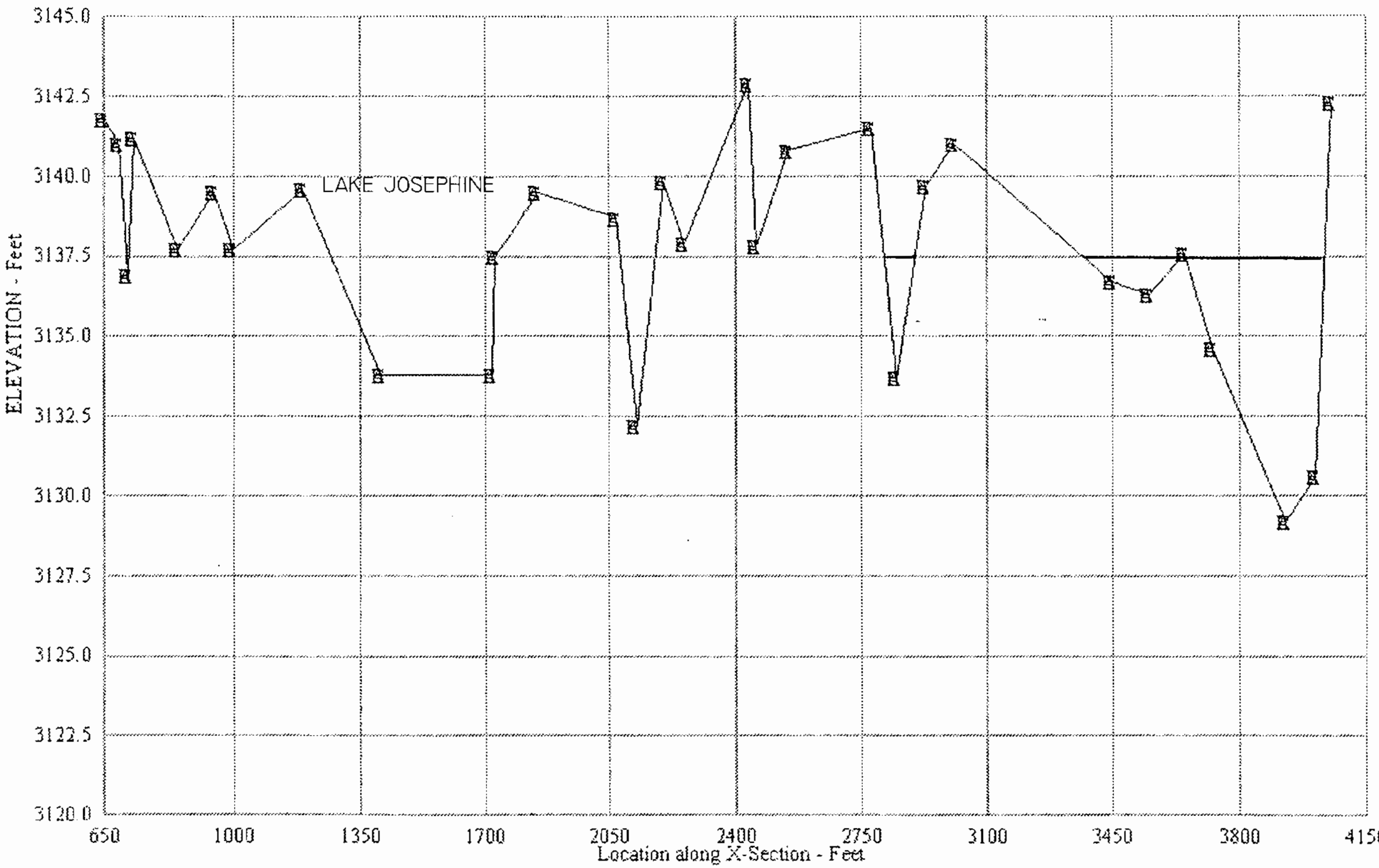
DATE: 05/03/00
REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
1970'S CORPS OF ENGINEERS DATA

CROSS SECTION PROFILE AT STA. 66000.00 Ft.

STATION #11

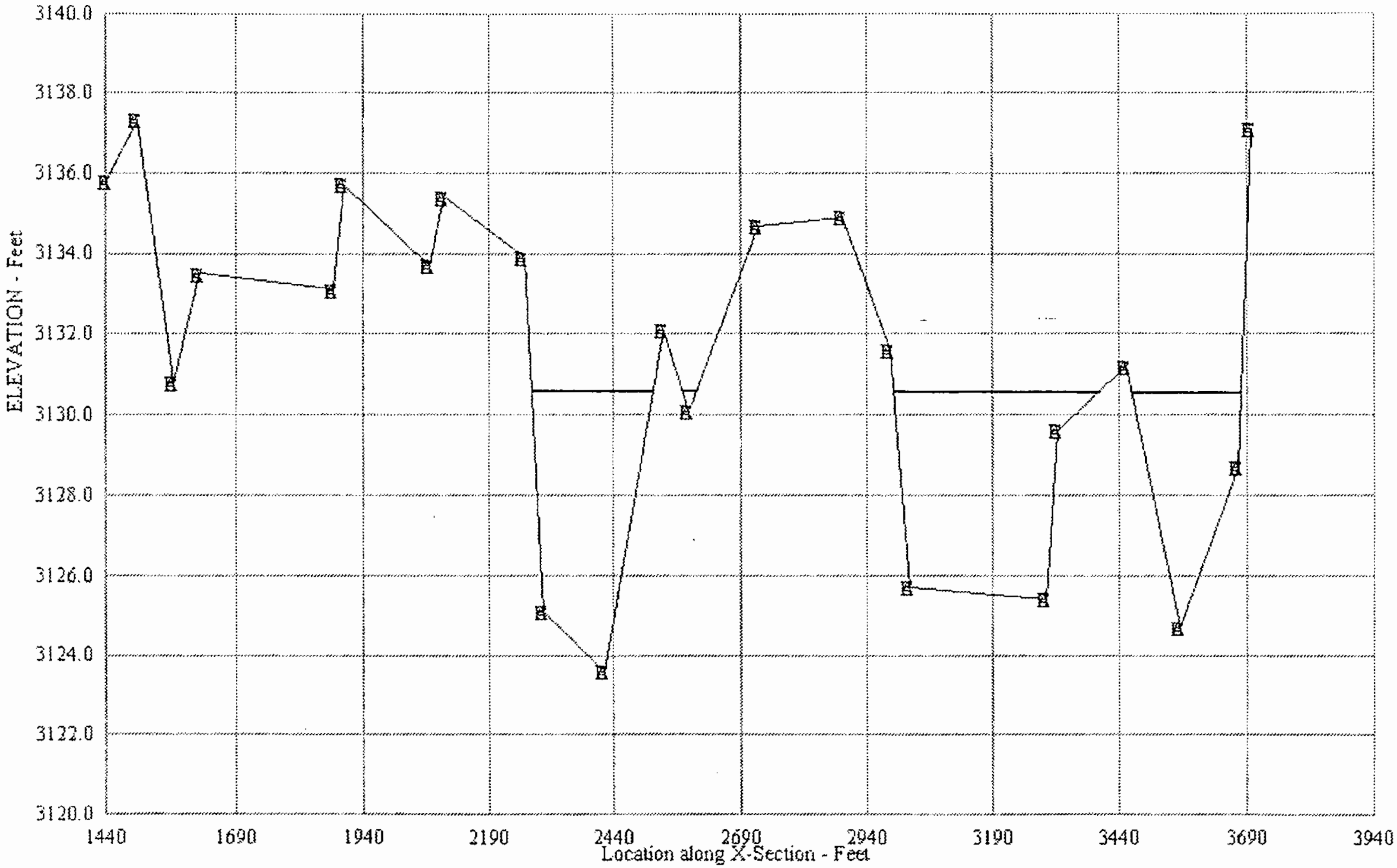
SLOPE = 0.00012
ELEV. = 3137.7
WIDTH = 761'
DEPTH = 8.7'
W/D = 87



SHEET 11 OF 25	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS CORP OF ENGINEERS YELLOWSTONE RIVER	8X11CORP.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/03/00 REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
1970'S CORPS OF ENGINEERS DATA

CROSS SECTION PROFILE AT STA. 63300.00 Ft.



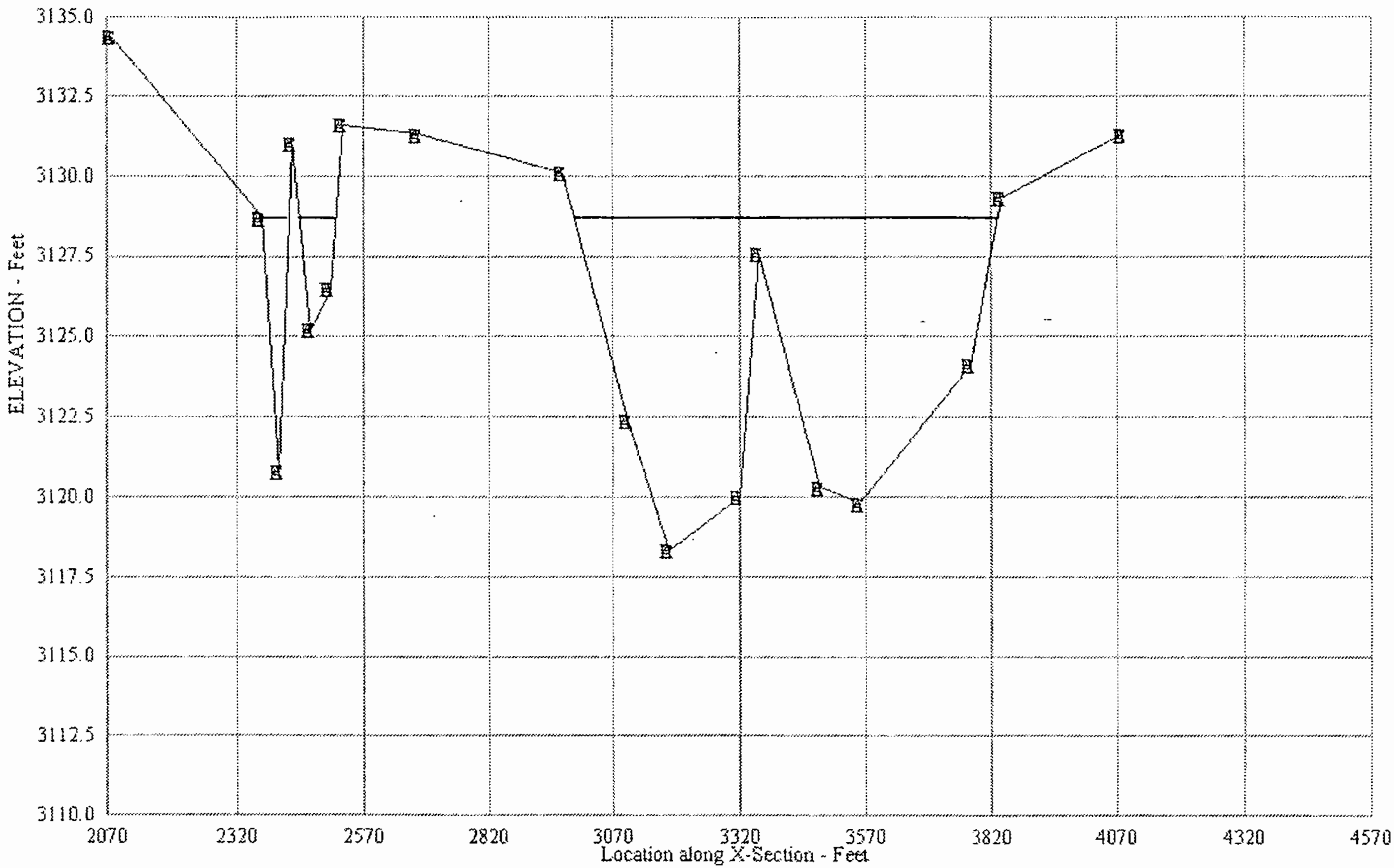
STATION #12

SLOPE = 0.002741
ELEV. = 3130.5
WIDTH = 932'
DEPTH = 6.7'
W/D = 139.1

SHEET 12 OF 25	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS CORP OF ENGINEERS YELLOWSTONE RIVER	8X11CORP.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/03/00 REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
1970'S CORPS OF ENGINEERS DATA

CROSS SECTION PROFILE AT STA. 60630.00 Ft.



STATION #13

SLOPE = 0.002741
ELEV. = 3125.8
WIDTH = 750'
DEPTH = 8.2'
W/D = 91.5

SHEET 13 OF 25

AQUONEERING
1555 SAGE CIRCLE
LAUREL, MT 59044
(406) 628-2202

CROSS SECTIONS
CORP OF ENGINEERS
YELLOWSTONE RIVER

8X11CORP.DWG
99-550-01
DRAWN BY: RFS
CHECKED BY: RJP
APPROVED BY: RJP

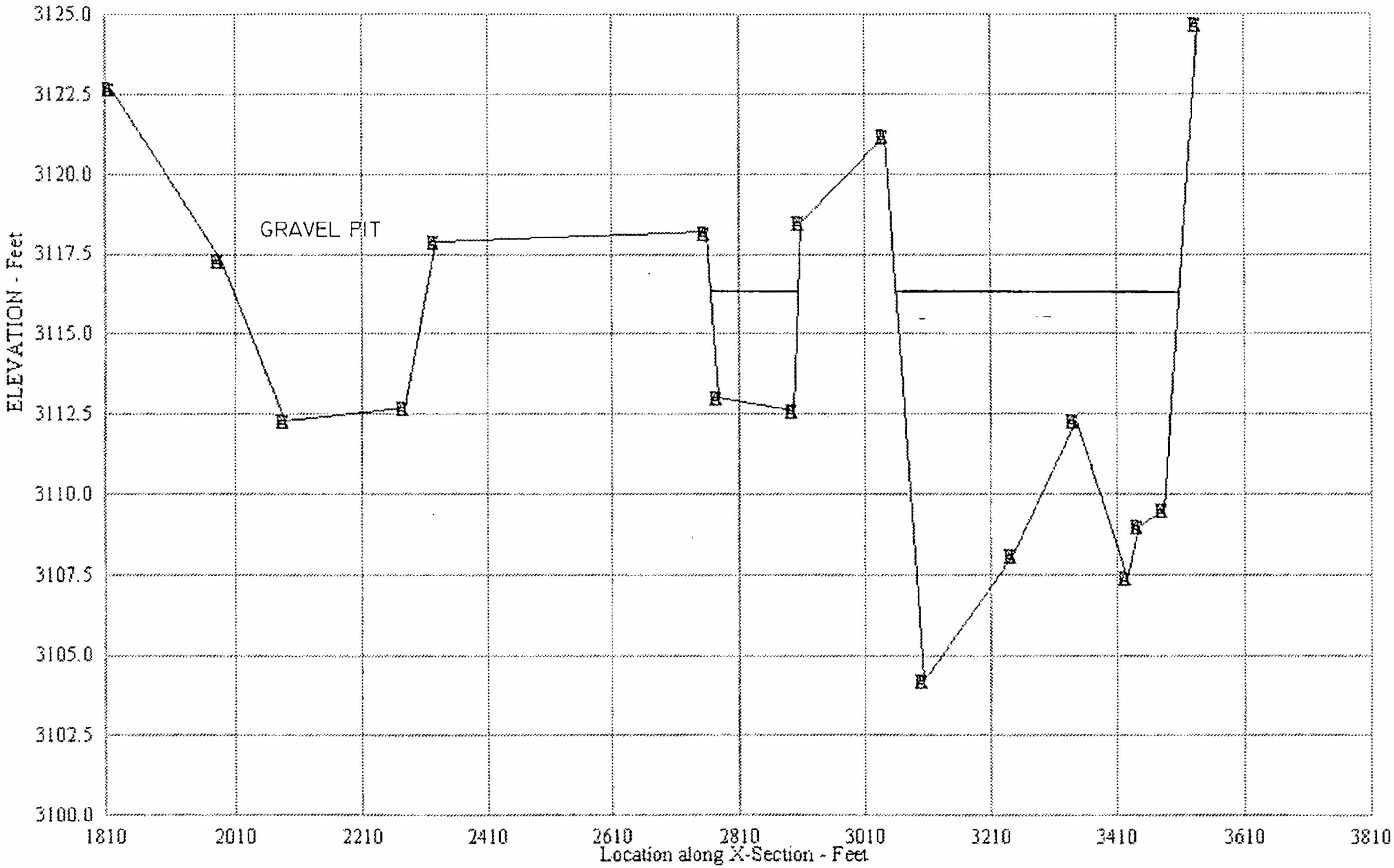
DATE: 05/03/00
REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
1970'S CORPS OF ENGINEERS DATA

CROSS SECTION PROFILE AT STA. 52300.00 Ft.

STATION #14

SLOPE = 0.0016927
ELEV. = 3116.9
WIDTH = 584'
DEPTH = 12'
W/D = 49



SHEET 14 OF 25

AQUONEERING
1555 SAGE CIRCLE
LAUREL, MT 59044
(406) 628-2202

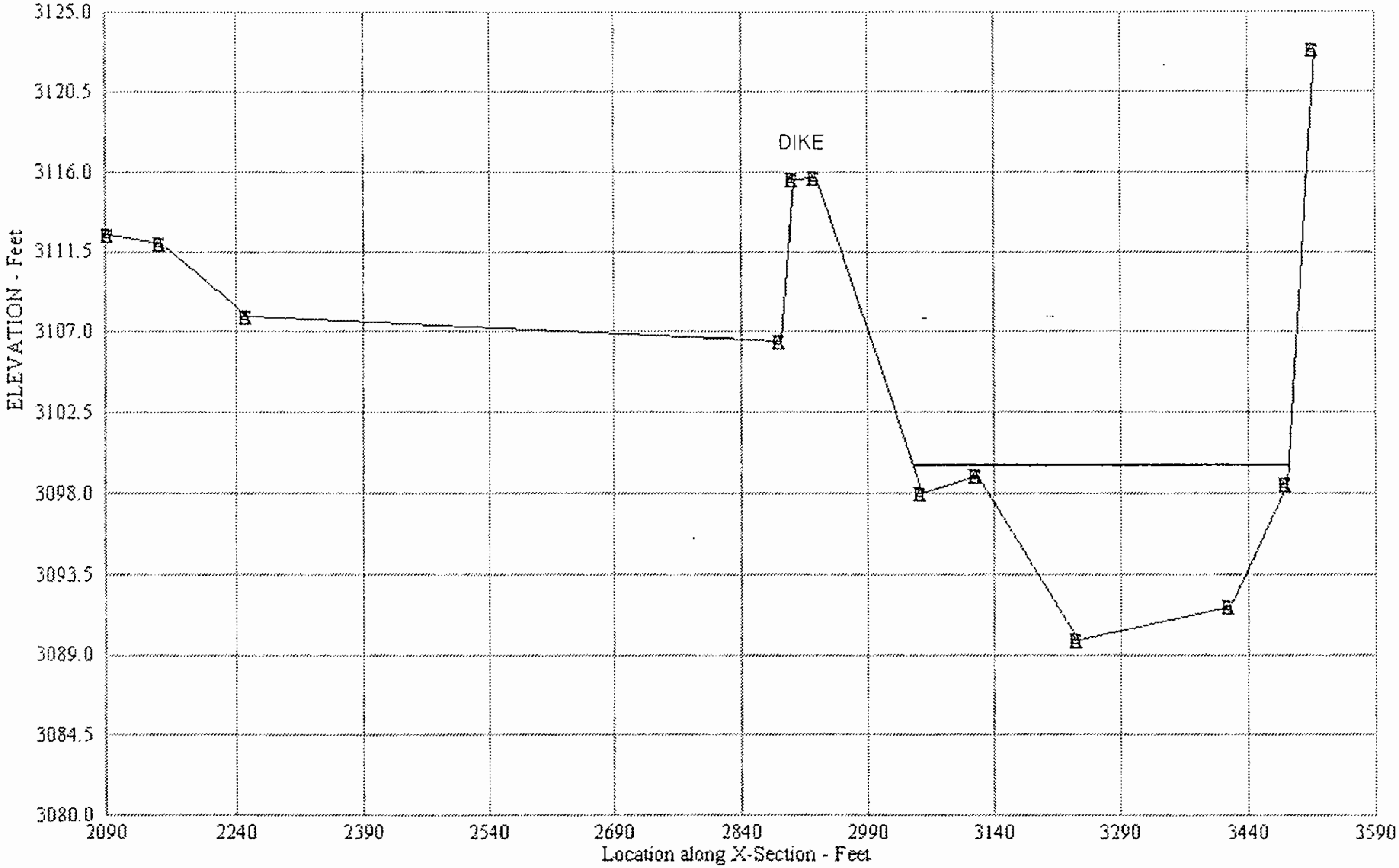
CROSS SECTIONS
CORP OF ENGINEERS
YELLOWSTONE RIVER

8X11CORP.DWG
99-550-01
DRAWN BY: RFS
CHECKED BY: RJP
APPROVED BY: RJP

DATE: 05/03/00
REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
1970'S CORPS OF ENGINEERS DATA

CROSS SECTION PROFILE AT STA. 45800.00 Ft.



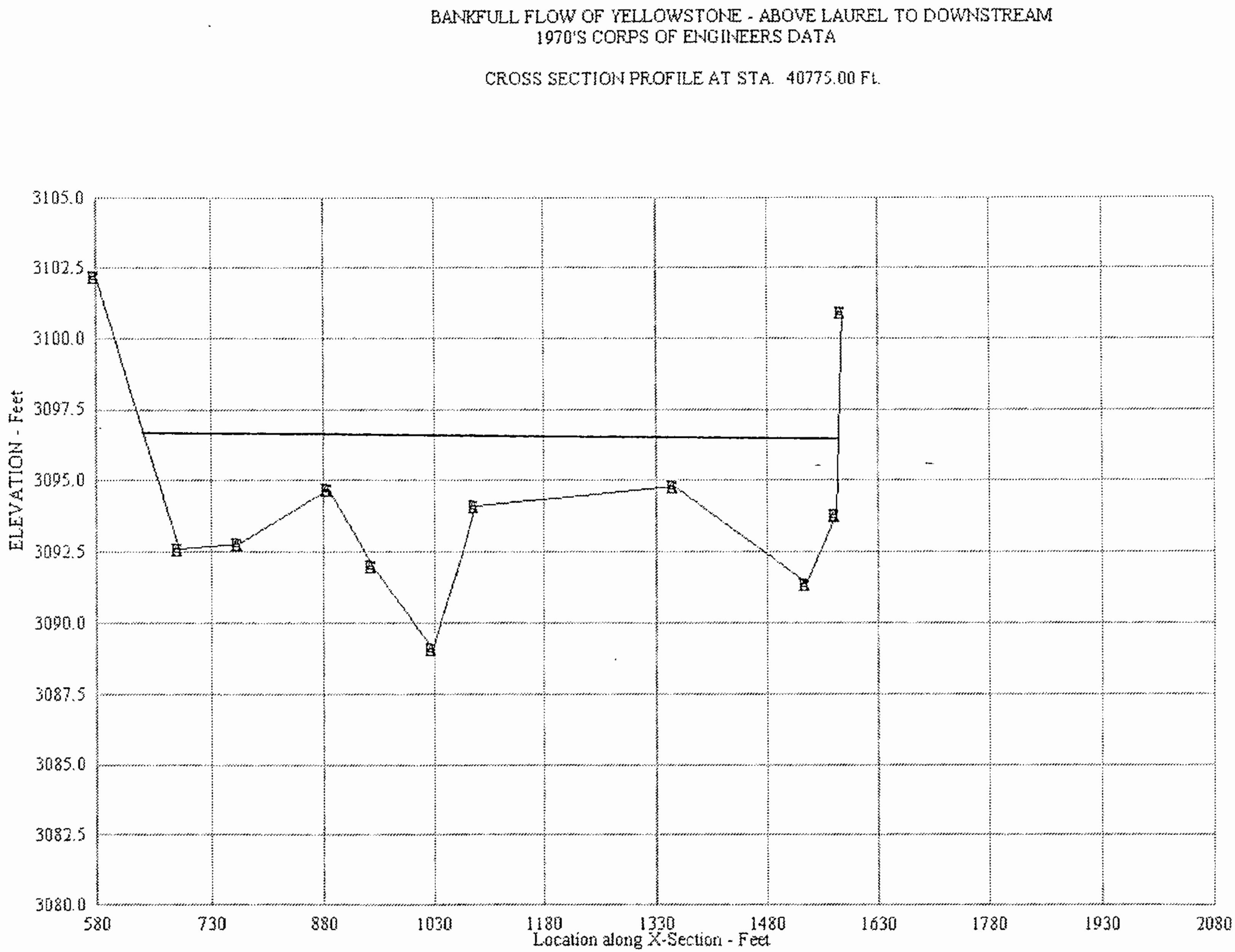
STATION #15

SLOPE = 0.0022154
ELEV. = 3099.7
WIDTH = 440'
DEPTH = 8.5'
W/D = 51.7

SHEET 15 OF 25	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS CORP OF ENGINEERS YELLOWSTONE RIVER	8X11CORP.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/03/00 REVISED:

STATION #16

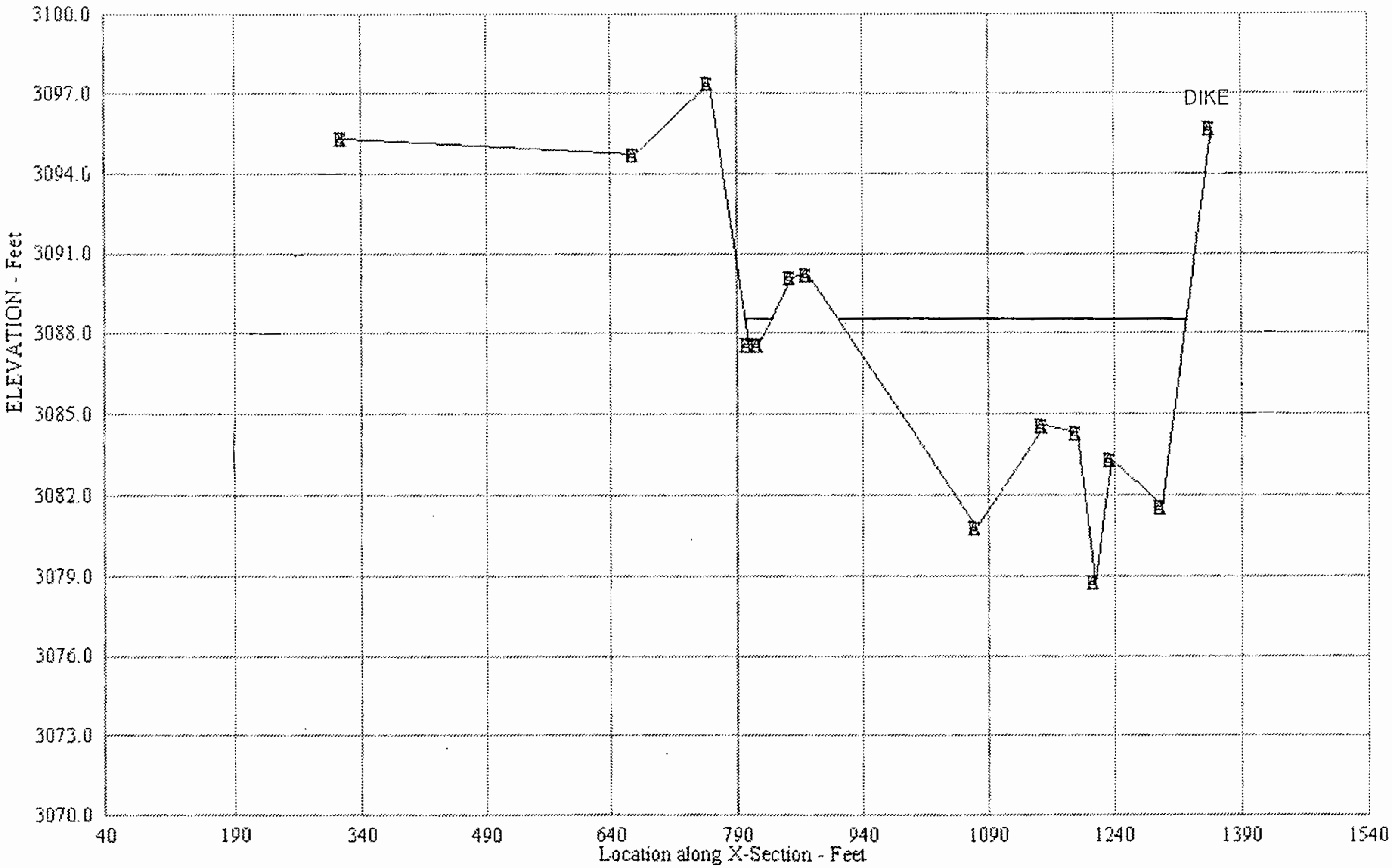
SLOPE = 0.000139
ELEV. = 3097.1
WIDTH = 932'
DEPTH = 9.1'
W/D = 102.4



SHEET 16 OF 25	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS CORP OF ENGINEERS YELLOWSTONE RIVER	8X11CORP.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/03/00 REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
1970'S CORPS OF ENGINEERS DATA

CROSS SECTION PROFILE AT STA. 37200.00 Ft.



STATION #17

SLOPE = 0.002881
ELEV. = 3089.8
WIDTH = 449'
DEPTH = 10.8'
W/D = 42

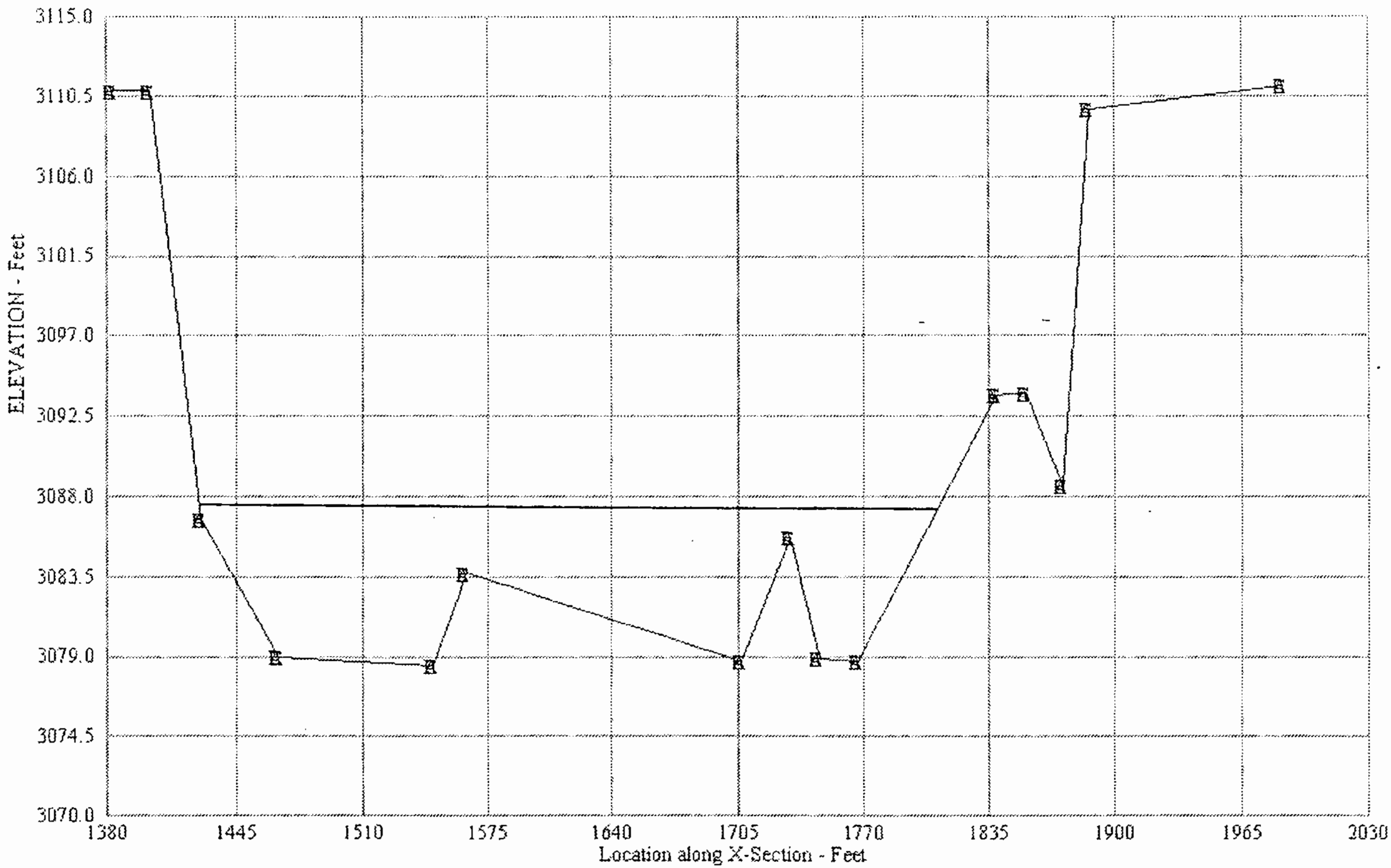
SHEET 17 OF 25	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS CORP OF ENGINEERS YELLOWSTONE RIVER	8X11CORP.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/03/00 REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
1970'S CORPS OF ENGINEERS DATA

CROSS SECTION PROFILE AT STA. 36600.00 Ft.

STATION #18

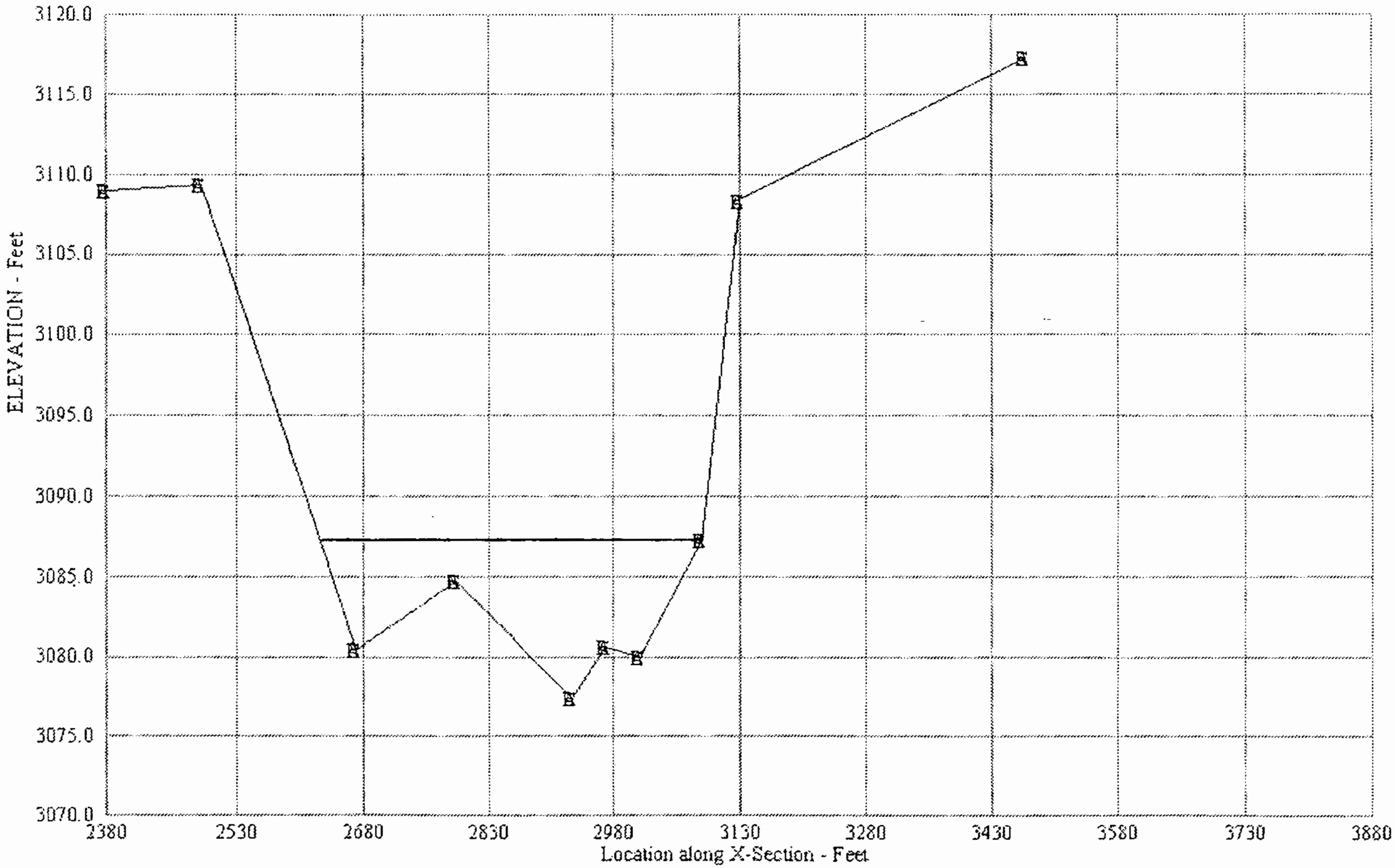
SLOPE = 0.0005
ELEV. = 3087.6
WIDTH = 381'
DEPTH = 8.6'
W/D = 44.3



SHEET 18 OF 25	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS CORP OF ENGINEERS YELLOWSTONE RIVER	8X11CORP.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/03/00 REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
1970'S CORPS OF ENGINEERS DATA

CROSS SECTION PROFILE AT STA. 36384.00 Ft.



STATION #19

SLOPE =0.0050926
ELEV. = 3087.7
WIDTH = 457.6'
DEPTH = 10.2'
W/D = 44.9

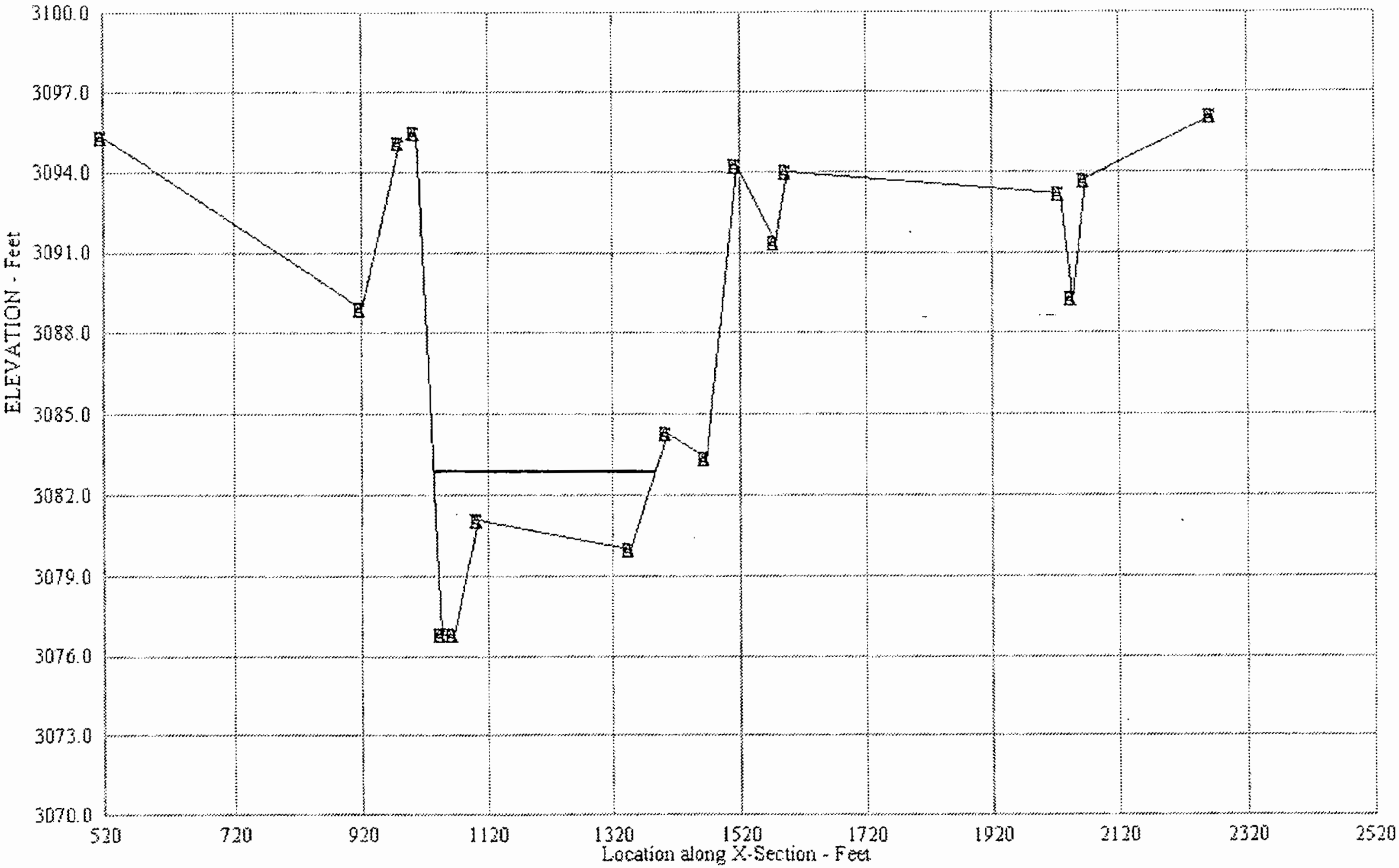
SHEET 19 OF 25	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS CORP OF ENGINEERS YELLOWSTONE RIVER	8X11CORP.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/03/00 REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
1970'S CORPS OF ENGINEERS DATA

STATION #20

SLOPE=0.00067873
ELEV. = 3086.9
WIDTH = 452'
DEPTH = 9.8'
W/D = 46.1

CROSS SECTION PROFILE AT STA. 35500.00 Ft.



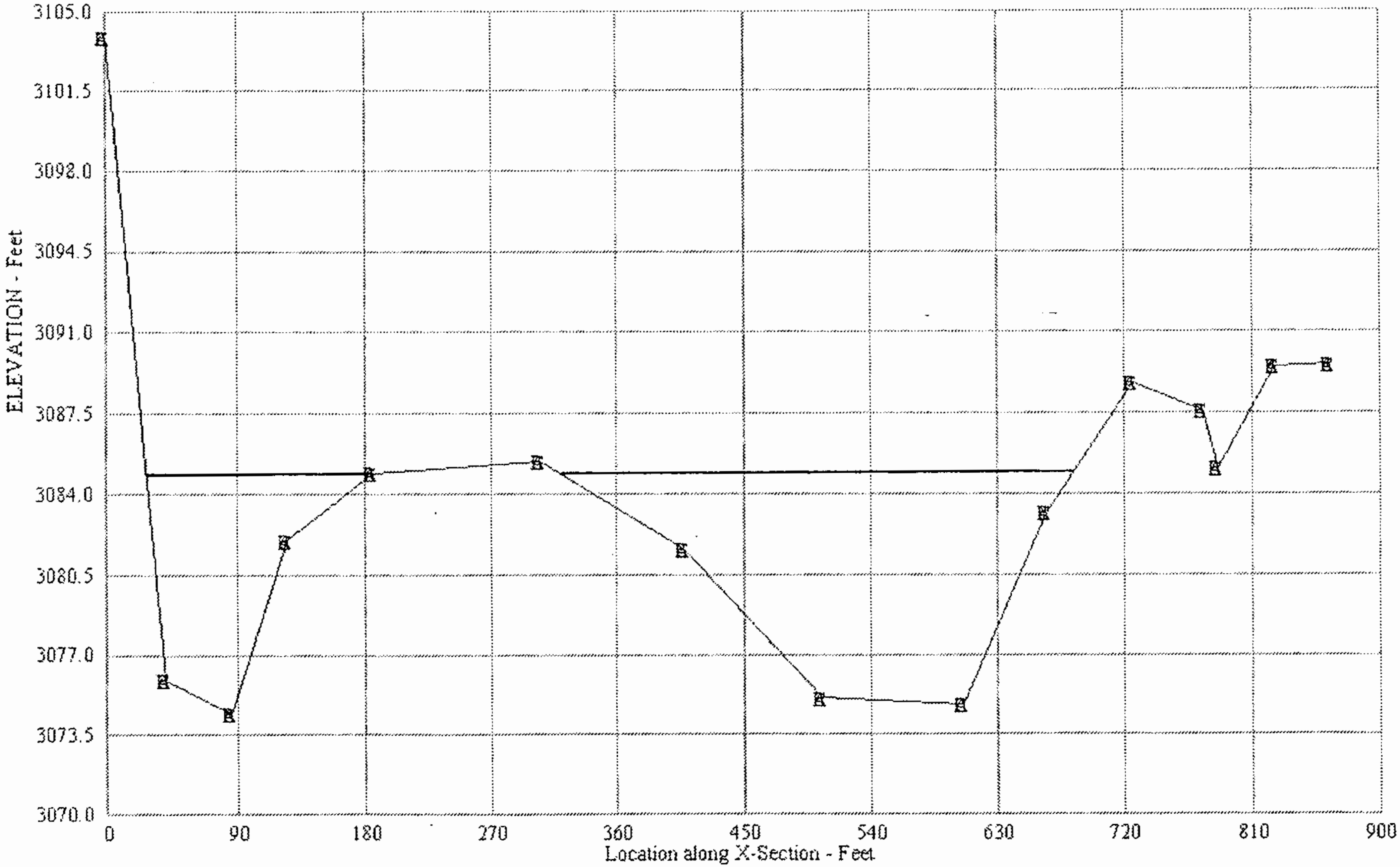
SHEET 20 OF 25	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS CORP OF ENGINEERS YELLOWSTONE RIVER	8X11CORP.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/03/00 REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
1970'S CORPS OF ENGINEERS DATA

CROSS SECTION PROFILE AT STA. 32800.00 Ft.

STATION #21

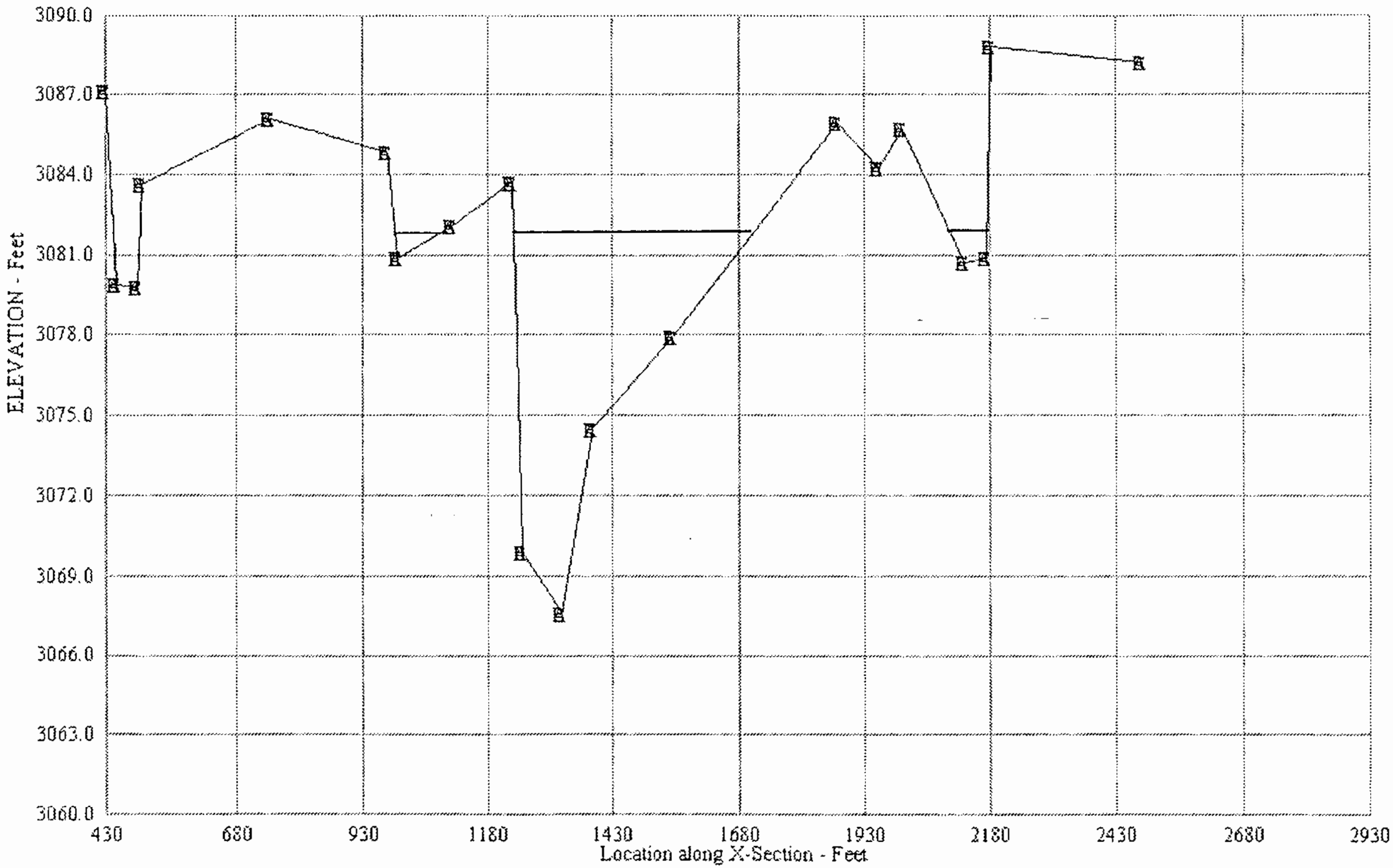
SLOPE = 0.0008889
ELEV. = 3084.8
WIDTH = 518.6'
DEPTH = 10.6'
W/D = 48.9



SHEET 21 OF 25	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS CORP OF ENGINEERS YELLOWSTONE RIVER	8X11CORP.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/03/00 REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
1970'S CORPS OF ENGINEERS DATA

CROSS SECTION PROFILE AT STA. 30500.00 Ft.



STATION #22

SLOPE = 0.002956
ELEV. = 3082.1
WIDTH = 637'
DEPTH = 15.1'
W/D = 42

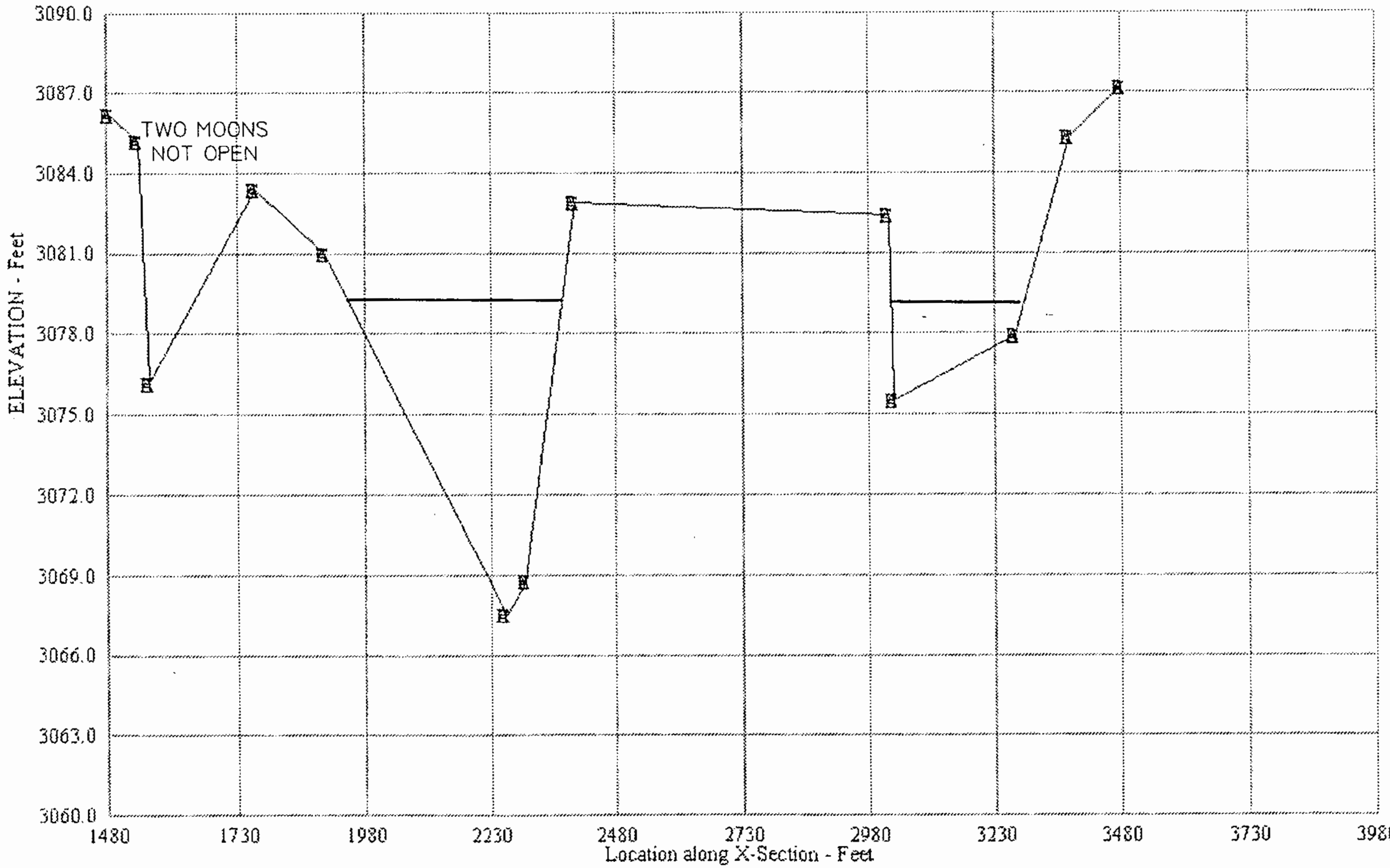
SHEET 22 OF 25	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS CORP OF ENGINEERS YELLOWSTONE RIVER	8X11CORP.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/03/00 REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
1970'S CORPS OF ENGINEERS DATA

CROSS SECTION PROFILE AT STA. 28300.00 Ft.

STATION #23

SLOPE=0.00004545
ELEV. = 3079.1
N WIDTH = 425'
W/D = 56
S WIDTH = 260'
DEPTH = 12'



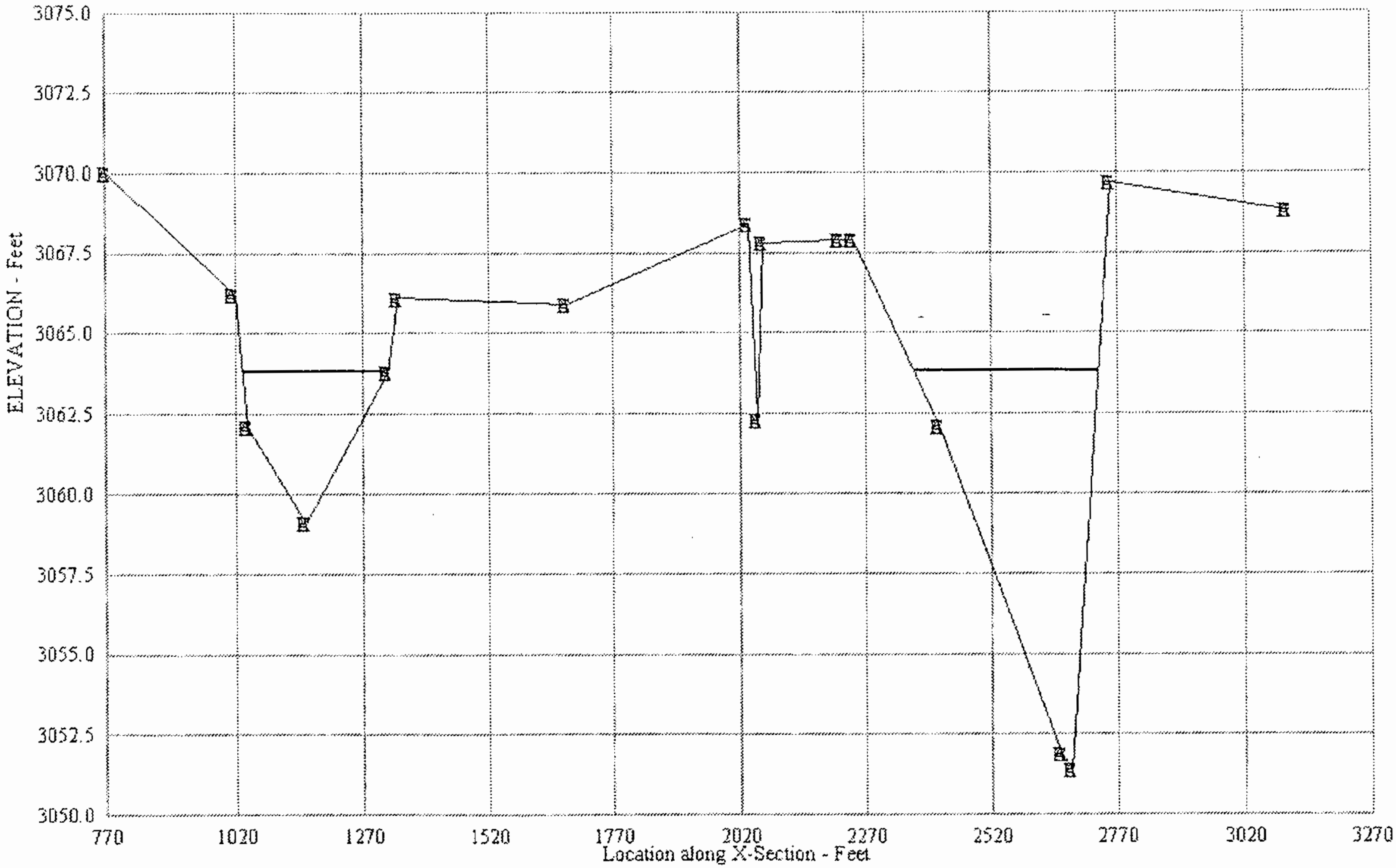
SHEET 23 OF 25	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS CORP OF ENGINEERS YELLOWSTONE RIVER	8X11CORP.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/03/00 REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
1970'S CORPS OF ENGINEERS DATA

CROSS SECTION PROFILE AT STA. 19600.00 Ft.

STATION #24

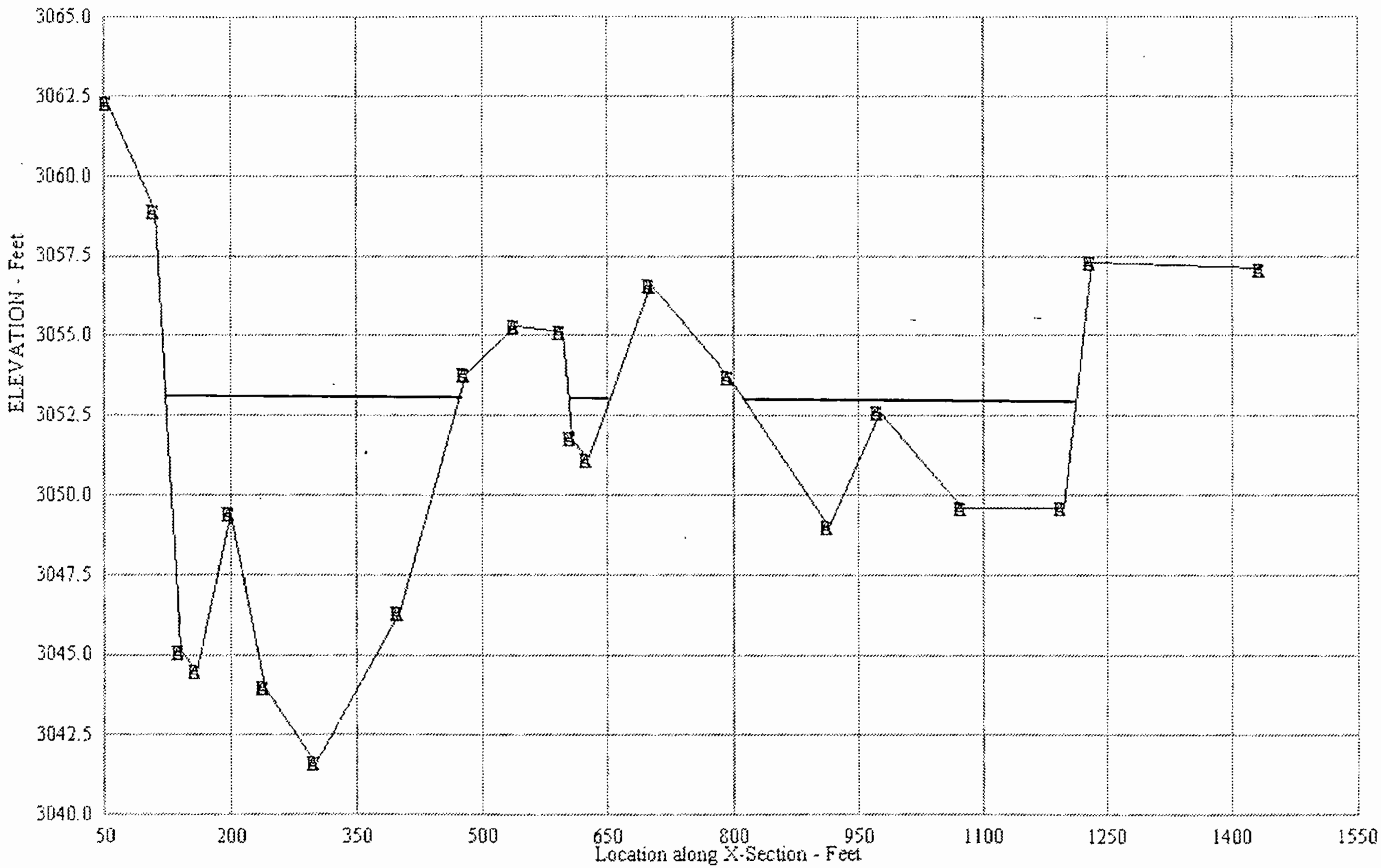
SLOPE = 0.0018506
ELEV. = 3063.9
N WIDTH = 277'
W/D = 49.2
S WIDTH = 365'
DEPTH = 12.9'



SHEET 24 OF 25	AQUONEERING 1555 SAGE CIRCLE LAUREL, MT 59044 (406) 628-2202	CROSS SECTIONS CORP OF ENGINEERS YELLOWSTONE RIVER	8X11CORP.DWG 99-550-01 DRAWN BY: RFS CHECKED BY: RJP APPROVED BY: RJP	DATE: 05/03/00 REVISED:

BANKFULL FLOW OF YELLOWSTONE - ABOVE LAUREL TO DOWNSTREAM
1970'S CORPS OF ENGINEERS DATA

CROSS SECTION PROFILE AT STA. 11550.00 Ft.



STATION #25

SLOPE = 0.0012174
ELEV. = 3053.1
N WIDTH = 348'
C WIDTH = 49'
S WIDTH = 399'
DEPTH = 12'
W/D = 65

SHEET 25 OF 25

AQUONEERING
1555 SAGE CIRCLE
LAUREL, MT 59044
(406) 628-2202

CROSS SECTIONS
CORP OF ENGINEERS
YELLOWSTONE RIVER

8X11CORP.DWG
99-550-01
DRAWN BY: RFS
CHECKED BY: RJP
APPROVED BY: RJP

DATE: 05/03/00
REVISED: