DECIDUOUS RIPARIAN VEGETATION AND DISCHARGE REGULATION ON THE LOWER FLATHEAD RIVER FLOODPLAIN

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Department of Geography
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Igor Suchomel
B.S. University of Brno

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

PROBLEM

Driving along or floating the lower Flathead River, one can see that black cottonwoods (*Populus trichocarpa*) and sandbar willows (*Salix exigua*) in seedling or sapling stages are almost absent from the floodplain. Climax riparian community types, mostly stands of Ponderosa pine (*Pinus ponderosa*), dominate the floodplain and are replacing old cottonwood stands. Recruitment of pioneer riparian black cottonwoods and sandbar willows has been extremely slow.

HYPOTHESIS

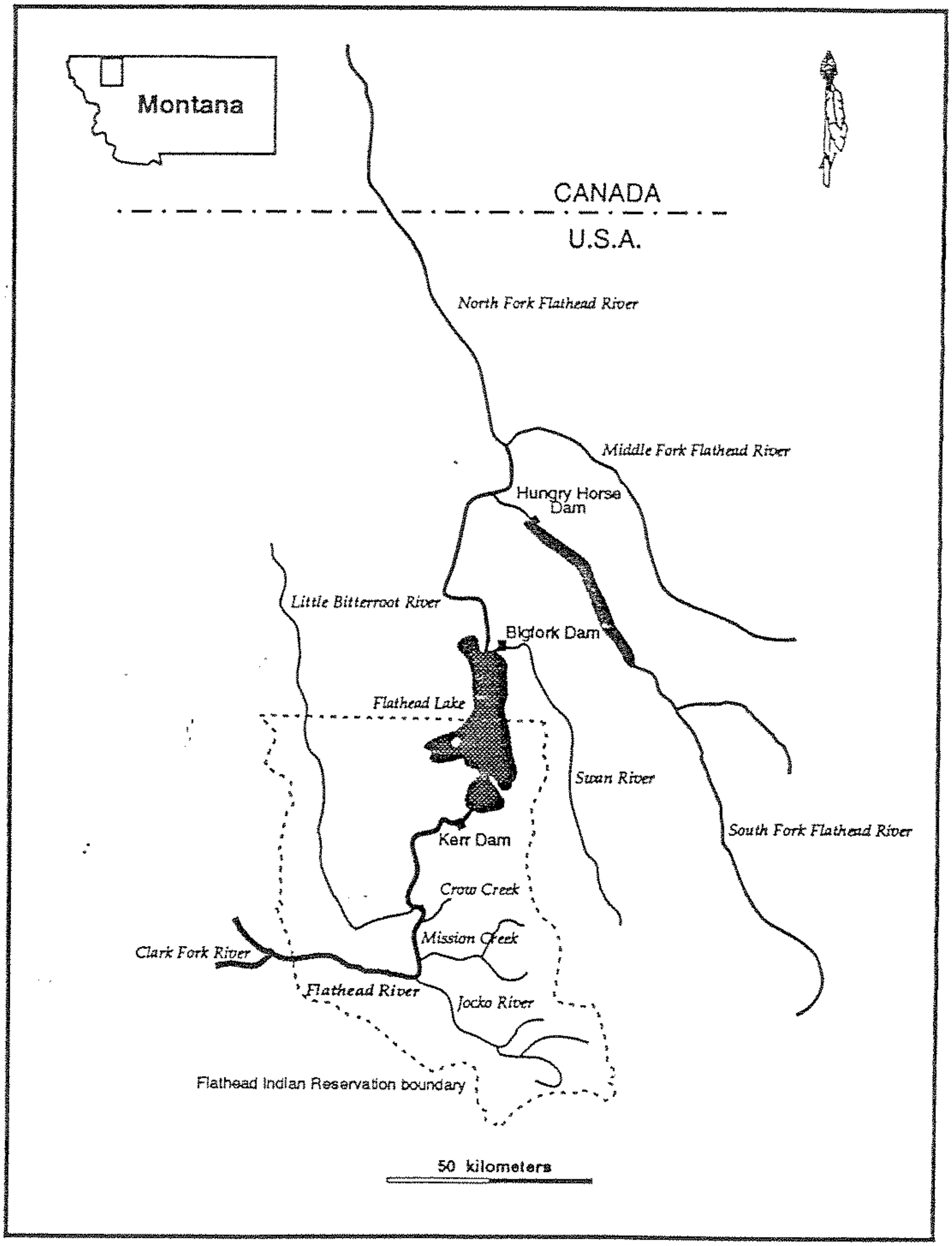
The hypothesis is that interference by man in the hydrologic-geomorphic system of the Flathead River has been the principal cause of change. Particularly, lower Flathead River flow regulation by two reservoirs has recently impacted the river in several ways known to be deleterious for the regeneration and growth of cottonwoods and willows in the riparian zone.

The following potentially harmful effects of upstream reservoirs on downstream cottonwoods and willows are considered in this thesis:

1) increased winter flows causing ice scour of existing bars;
2) frequent daily flow fluctuations of strong amplitudes causing unstable water regime of existing bars; and
3) diminished bedload mobility reducing the availability of new fluvial surfaces for black cottonwood and sandbar willow establishment.

Evidence to show that these effects occur, or are highly likely to occur, along the lower Flathead River will be introduced. Considered separately or in sum, this evidence indicates that the failure to restock black cottonwoods and sandbar willows originates in the regulation of stream discharge by reservoirs upstream.

Figure 1. Flathead River catchment



PURPOSE AND FORMAT OF THE STUDY

Objective

This study will introduce strong evidence that regulation of the lower Flathead River by Kerr Dam and Hungry Horse Reservoir will seriously reduce recruitment of pioneering riparian species *Populus trichocarpa* and *Salix exigua*.

Order of Evidence Presentation

First, from a literature review, I will document the seedbed requirements of *Populus trichocarpa* and *Salix exigua*. *Populus trichocarpa* and *Salix exigua* are pioneering species that require fresh alluvial bars deposited just before or during their seed dispersal to ensure successful seed germination. Deposition of fluvial surfaces depends on the magnitude and frequency of floods. Both *Populus trichocarpa* and *Salix exigua* do not reproduce in their own shade.

Second, through interpretation of pre-dam 1934, 1938, 1944 and post-dam 1988 aerial photography, I will document a decrease in the areal extent of deciduous forest (*Populus trichocarpa*) and an increase of coniferous forest (*Pinus ponderosa*). In the absence of *Populus trichocarpa* regeneration, *Pinus ponderosa* becomes the dominant riparian species along the lower Flathead River. Also, a lack of noticeable channel erosion or deposition during the period and relative stability of the riparian zone between the pre-dam and post-dam aerial photo flights is shown.

Third, I will describe riparian communities and habitat types encountered along eight riparian transects. Substrate textures of the upper one meter of different fluvial surfaces will be described also. This information illuminates geomorphic and riparian successional processes along the River.

Fourth, using U.S. Geological Survey (USGS) streamflow data, I will analyze the hydrology of the Lower Flathead River during the pre-regulation period from 1908 to 1937; then I will compare pre-dam flows to those regulated by Kerr Dam only and then to flows regulated by both Kerr Dam and Hungry Horse Reservoir. Factors analyzed include annual flood frequency distributions, mean daily flows and hourly regulated discharge fluctuations.

Fifth, I will discuss the geology and fluvial geomorphology of the lower Flathead River placing emphasis on sediment sources, sediment availability, and floodplain-channel dynamics. I will provide percentile substrate size distributions of mid-channel gravel bars and calculate shear stresses needed to move such gravels through four channel transects. Lack of appreciable changes in channel geometry at USGS measuring transect at Perma will be shown. Five island-channel transects illustrating riparian covers, substrate textures of upper two meters, and discharge-stage rating curves are presented. Relationships between discharge magnitudes, new fluvial surfaces creation, and riparian community types will be noted.

Finally, it will be shown that the lower part of the lower Flathead River is a stable, anastomosing system dominated by secondary plant succession. Here new fluvial surfaces available for *Populus trichocarpa* and *Salix exigua* colonization are created only by flows of high magnitudes and low frequencies. Such floods, although "catastrophic," would be now controlled by Hungry Horse Reservoir and Kerr Dam.

CHAPTER I

LOWER FLATHEAD RIVER RIPARIAN ZONE

Mosaic of riparian plant species and plant community types found on the floodplain of the lower Flathead River reflects different physical conditions and age of the sites. The river can erode existing sites and create new ones. The new sites are then colonized by pioneer riparian species, which change the site's original physical conditions and are in turn succeeded by other species more adapted to the new conditions. Along the lower Flathead River, *Populus trichocarpa* and *Salix exigua* are the primary colonizers of new fluvial surfaces, while *Pinus ponderosa* dominates the climax community types.

PIONEERING SPECIES SEEDBED REQUIREMENTS

Reduction of peak flows by dams may reduce creation of new fluvial surfaces essential for cottonwood and sandbar willow establishment. Cottonwoods (*Populus trichocarpa, deltoides* and *angustifolia)* regenerate by one of two means (Hansen and Suchomel, 1990): 1) clonal propagation by suckering (new shoot production from existing roots) and 2) seed dispersal. In general, the suckering capabilities of cottonwoods decrease dramatically as they mature. Therefore, the principal method of cottonwood regeneration results from seed establishment after dispersal. Seedbed requirements of pioneer cottonwoods and sandbar willow (*Salix exigua)* have been well documented (Read, 1958; Everitt, 1968; Wilson, 1970; Johnson and others, 1976; Noble, 1979, Hansen, 1980, Bradley, and Smith, 1986). Suitable sites are moist, barren, newly deposited alluvium exposed to full sunlight. Generally, these sites are common along streams, particularly on point, side, mid-channel and delta bar surfaces. Pioneering riparian species -- black cottonwood and sandbar willow -- absolutely require fresh, moist alluvium for seed germination.

SEED DISPERSAL AND ADAPTATIONS

Black cottonwoods and sandbar willows developed their regeneration methods to correspond to a general annual hydrologic cycle. These pioneer species share several adaptations that ensure their establishment. Large variations in seed dispersal dates often characterize adjacent individuals, thereby providing seeds over a protracted period of time (Schreiner, 1974). The seed dispersal time period for these pioneer species along the lower Flathead River is about four to six weeks, extending from the end of May to mid-July.

Although the dispersal period may be fairly long, cottonwood seeds are viable only for about two weeks. However, a plethora are produced, each having plumes attached to provide for ready dispersal by wind and stream. Bessey (1904) estimated the number of seeds produced by one mature cottonwood approaches 28 million. Seed plume hairs easily attach to moist alluvium or stream surfaces. In addition, Ridley (1930) observed that the capsules of willow catkins open on contact with water, thereby releasing their plumed seeds. All these adaptations increase the possibility that at least a small part of the annual seed crop will reach favorable germination sites before experiencing losses in viability. Moss (1938) showed that the substrate must be moist for at least one week to ensure successful germination and establishment. Germination occurs within eight hours to one day on most moist surfaces. However, establishment will be foiled should the substrate dry during the first several days after germination.

STAND COMPOSITION

Ratios of cottonwoods to willows depend on many factors not yet fully understood. Research throughout the United States suggests that the size of recently deposited sediments may, to some degree, control the species composition of pioneer stands. Generally, dense stands of willows occupy fine-textured materials, such as oxbows, old side channels, or backwater areas. Cottonwoods tend to flourish on gravel and sand bars (Hefley, 1937; Ware and Penfound, 1949; Shelford, 1954; Wistendahl, 1958; Everitt, 1968; Linsday and others, 1961; Wilson, 1970; Johnson and others, 1976). However, these observations are only general; seed availability during the recession stage of floods and sediment deposition after plant establishment also influence the pioneer species composition. Often, a bar is colonized by both species, but cottonwood saplings eventually overtop and shade out the willows (Wilson, 1970).

SEEDLING SURVIVAL

Large, rapid water-table fluctuations and regular ice-scouring reduce cottonwood and sandbar willow seedling survival. During the summer, survival of seedlings depends on their proximity to surface water and water table. Proximity depends on the topography of newly deposited bars and on the manner of stream's flood water recession. Commonly, bands of seedlings of identical age take root on bars. Widths of these uniform bands largely depend on the slopes of the bars; steeper may have several narrow bands of different age, whereas flat may be covered by large uniform stands of seedlings. After establishment, survival of the pioneer species depends mainly on future sediment movement, ice-scouring, and flooding. Older classes display higher survival rates. Recent studies indicate favorable survival rates for Great Plains cottonwood and sandbar willow despite eight weeks of total inundation. Generally, there seems to exist a critical relationship between newly deposited fluvial surface levels and stream and ground water levels. The bare seedbeds need to be high enough to avoid drowning by later floods but low enough to allow newly established seedlings to tap the alluvial ground water. Otherwise, if a bar is exposed before or after the span of cottonwood and sandbar willow seed viability, the seeds do not take root, and the bar may become colonized by herbaceous species. Once established, cottonwoods and sandbar willows fail to regenerate in their own shade. Eventually, stands are gradually replaced by other species (specific to different physiographic regions) in the course of secondary succession. Thus *Populus trichocarpa* and *Salix exigua* depend on periodic flood disturbances and deposition -- agents of primary succession -- for not just their establishment but their survival.

AERIAL PHOTOGRAPHY INTERPRETATION

Aerial photo interpretation is a very useful comparative method when photos of the same area are available for different dates. Particularly, visible changes in vegetation and topography can help determine rates of landscape change over a period of time.

Objective

The main objective of the aerial photography interpretation was:

1) to determine plant cover changes in the riparian zone of the lower Flathead River since the construction of the Kerr Dam;
2) to document any decrease in the extent of black cottonwood community types within the riparian zone, and
3) to quantify extension of new erosion and deposition within the active channel.

The results of the aerial photography interpretation are discussed by Hansen and Suchomel (1990).

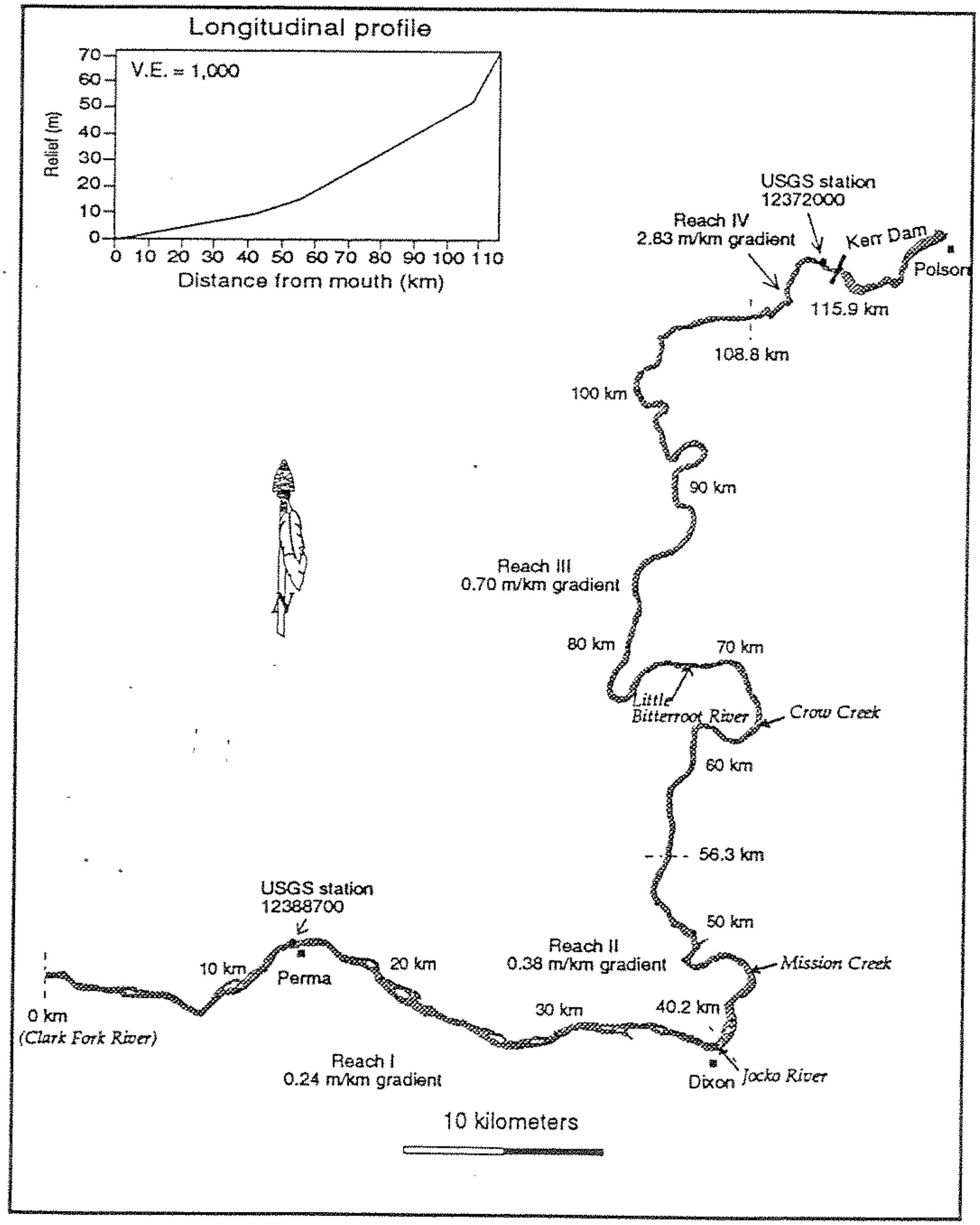
Aerial Photography Sets

I interpreted two sets of aerial photography to identify changes in vegetation and channel shape. The "pre-dam" set consisted of 1934 and 1935 photos at 1:16,200 scale (river kilometer 11.3 to river kilometer 17.7), 1944 photos at 1:20,000 scale (river kilometer 17.7 to river kilometer 40.2), and 1937 photos at 1:20,000 scale (river kilometer 40.2 to river kilometer 51.5; Figure 2). There is no complete pre-dam aerial photo coverage of the lower Flathead River. All "pre-dam" photos were black-and-white. The post-dam set consisted of 1981 natural color photos at 1:24,000 scale.

Riparian Cover Types

I could identify 15 cover types on the both sets of aerial photography (Table 1). Each occurrence of a cover type was delineated as a polygon on an acetate overlay. Using a computer

Figure 2. Lower Flathead River gradient reaches



planimeter, I measured the area of each polygon.

Direct measurements from aerial photographs may be subject to distortion and displacement (Paine,1981). However, since the same procedure was applied to both sets of the photos and since the interpreted terrain is mostly flat, it is reasonable to expect that errors are relatively small and would tend to cancel each other.

To eliminate potential effects of a railroad built before Kerr Dam was, the track served as the outer boundary of the riparian zone. This excluded less than 10 percent of the riparian zone.

Table 1. Aerial photography interpretation criteria for the pre-dam black-and-white (BW) and post-dam natural color (C) photo sets.

Riparian Cover Type	Interpretation Criteria
Coniferous forest - closed canopy (>60% canopy cover)	BW - coarse texture; dark gray; conical shadows. C - Coarse texture; dark green; conical shadows.
Coniferous forest - open canopy (25-60% canopy cover)	Same as for the closed coniferous forest except for the lower canopy cover.
shrub understory	BW - medium coarse texture, small shadows. C - fine texture; light green; no shadows.
herbaceous understory	BW - ultra-fine texture; medium gray; no shadows. C - ultra-fine texture; dark green to light brown.
Deciduous forest - closed canopy (>60% canopy cover)	BW - coarse texture; medium gray; rounded shadows. C - coarse texture; medium green; rounded shadows.
Deciduous forest - open canopy (25-60% canopy cover)	Same as for the closed deciduous forest except for the lower canopy cover.
shrub understory	BW - medium coarse texture, small shadows. C - fine texture; light green; no shadows.
herbaceous understory	BW - ultra-fine texture; medium gray; no shadows. C - ultra-fine texture; dark green to light brown.
Mixed forest - closed canopy (>60% canopy cover)	Combination of criteria used for coniferous and deciduous types. Each type at least 10% coverage.
Mixed forest - open canopy (25-60% canopy cover)	Same as for the closed mixed forest except for the lower canopy cover.
shrub understory	BW - medium coarse texture, small shadows. C - fine texture; light green; no shadows.
herbaceous understory	BW - ultra-fine texture; medium gray; no shadows. C - ultra-fine texture; dark green to light brown.

Cont. Table 1. Aerial photography interpretation criteria for the pre-dam black-and-white (BW) and post-dam natural color (C) photo sets.

Riparian Cover Type	Interpretation Criteria
Dense shrub (>60% canopy cover)	BW - Medium texture; medium gray; small shadows. C - Fine texture; light green; no shadows.
Sparse shrub (25-60% canopy cover)	BW and C - sparse dark spots on lighter, fine-textured background.
Herbaceous	BW - ultra-fine texture; medium gray; no shadows. C - ultra-fine texture; dark green to light brown.
Agricultural land	BW - ultra-fine texture; variable gray; regular lines. C - ultra-fine texture; variable color; regular lines.
Barren land (<25% canopy cover)	BW - ultra-fine texture; very light gray, no shadows. C - ultra-fine texture; yellowish-white; no shadows.

Aerial Photo Classification Conventions

A riparian cover type classification was used that includes general surface features that could be reliably identified on both the pre-dam black-and-white and on the post-dam color aerial photography. I did not consider understory vegetation because it could not be identified consistently on the photography. The various riparian cover types were classified according to the tallest visible layer within a homogenous area (mapping unit). This means, for example, that, although the understory of a herbaceous polygon may be dominated by seedlings of either shrubs or trees, the polygon would be identified as a herbaceous cover type. In addition, because of the low resolution of the photographs, some shrub categories may contain cottonwood or aspen in the sapling stage of development.

When a polygon from the post-dam set was interpreted to have a different riparian cover type from the pre-dam set, the change was noted as a complete conversion. When only part of a polygon was interpreted to have changed, the change was noted as such. Therefore, the interpreted changes in the acreage of individual riparian cover types can be attributed to either a complete conversion from one riparian cover type to another or to a change in polygon size (partial conversion).

Two interpretive categories, barren land and low banks, were lumped together after the initial photo interpretation, since water level elevations were not available and the distinction was arbitrary.

Results of Photo Interpretation

Besides other changes, the photo interpretation verified increased coniferous and decreased deciduous forest (*Populus trichocarpa*) coverage -- a result of the prevalence of secondary over primary successional processes. This indicates lack of new fluvial deposition since the pre-dam photo set was taken.

Areal Extent of Individual Riparian Cover Types

The total number of riparian acres identified in the aerial photography was 4,547 acres in the pre-dam set and 4,478 in the post-dam set. The extent of individual riparian cover types and the percentages of total area for the pre-dam and the post-dam photo sets are shown in Table 2. In the pre-dam photo set, the three largest categories were the herbaceous type with 31.4 percent of the total riparian acres, the agricultural cover type with 17.4 percent, and the barren type with 13.7 percent.

In the post-dam photography, the three largest categories included the same three types.

Table 2. Riparian cover type changes from the the pre-dam and post-dam aerial photography.

Riparian Cover Type	Pre-dam Conditions Acres	Pre-dam Conditions % of Total	Post-dam Conditions Acres	Post-dam Conditions % of Total
Coniferous forest - closed canopy	95.5	2.1	178.6	4.0
Coniferous forest - open canopy				
shrub understory	65.9	1.5	97.3	2.2
herbaceous understory	73.4	1.6	93.1	2.1

Cont. Table 2. Riparian cover type changes from the the pre-dam and post-dam aerial photography.

Riparian Cover Type	Pre-dam Conditions Acres	Pre-dam Conditions % of Total	Post-dam Conditions Acres	Post-dam Conditions % of Total
Deciduous forest - closed canopy	262.4	5.8	152.7	3.4
Deciduous forest - open canopy				
shrub understory	248.2	5.5	156.4	3.5
herbaceous understory	45.7	1.0	29.6	0.7
Mixed forest - closed canopy	215.5	4.7	155.1	3.5
Mixed forest open canopy				
shrub understory	231.4	5.1	171.0	3.8
herbaceous understory	44.1	1.0	29.3	0.7
Dense shrub	185.6	4.1	304.8	6.8
Sparse shrub	238.6	5.3	165.3	3.7
Herbaceous	1 427.7	31.4	937.0	20.9
Agricultural land	791.9	17.4	1 542.8	34.4
Barren land	621.0	13.7	465.7	10.4
Total	4 546.9	100.2	4 478.7	100.1

Source: aerial photographs, 1934, 1935, 1937, 1944, and 1988.

However, the areal extents of these vegetal classes changed notably. Of the total riparian acres, the herbaceous cover type decreased from 31.4 percent to 20.9 percent, while the agricultural category increased from 17.4 percent to 34.4 percent. The barren land category remained nearly the same at 10.4 percent of the total.

The magnitude of relative change (gain or loss) of each riparian cover type is shown in Table 3. Again, the greatest change occurred in the agricultural land category with an increase of 94.8 percent since the construction of the Kerr Dam. The next greatest change was in closed canopy coniferous forest with an increase of 87.0 percent. The dense shrub category showed a large increase of 64.2 percent. Finally, large increases also occurred in both sub-categories of the open canopy coniferous forest cover type.

Areal Changes in Riparian Cover Types

In the terms of losses, the greatest occurred in the closed canopy deciduous forest -- 41.8 percent (Table 3). This decrease was closely followed by decreases in both sub-categories of open canopy deciduous forest. Also, the acreage of mixed forest cover types decreased.

Table 3. Acreage changes in acres and percent for riparian cover types from the pre-dam to the post-dam aerial photography.

Riparian Cover Type	Change in acres	Percent change
Coniferous forest - closed canopy	+83.1	+87.0
Coniferous forest - open canopy		
shrub understory	+31.4	+47.6
herbaceous understory	+19.7	+26.8
Deciduous forest - closed canopy	-109.7	-41.8
Deciduous forest - open canopy		
shrub understory	-91.8	-37.0
herbaceous understory	-16.1	-35.2
Mixed forest - closed canopy	-60.4	-28.0
Mixed forest - open canopy		
shrub understory	-60.4	-26.1
herbaceous understory	-14.8	-33.6
Dense shrub	+119.2	+64.2
Sparse shrub	-73.3	-30.7
Herbaceous	-409.7	-28.7
Agricultural land	+750.9	+94.8
Barren land	-155.3	-25.0

Source: aerial photographs, 1934, 1935, 1937, 1944, and 1988.

Table 4 is a summary in which related categories were lumped together to show the "big picture." Three categories show increases: agricultural land, coniferous forest and shrub covers. In contrast, four categories show decreases: deciduous forest, mixed forest, herbaceous, and barren land . Figure 3 illustrates these details.

Table 4. Acreage changes: major dominant riparian cover types.

Riparian Cover Type	Change (acres)	Change (%)
Agricultural land	+750.9	+94.8
Coniferous forest	+134.2	+57.2
Shrub	+45.9	+10.8
Deciduous forest	-217.6	-39.1
Herbaceous	-409.7	-28.7
Mixed forest	-135.6	-27.6
Barren land	-155.3	-25.0

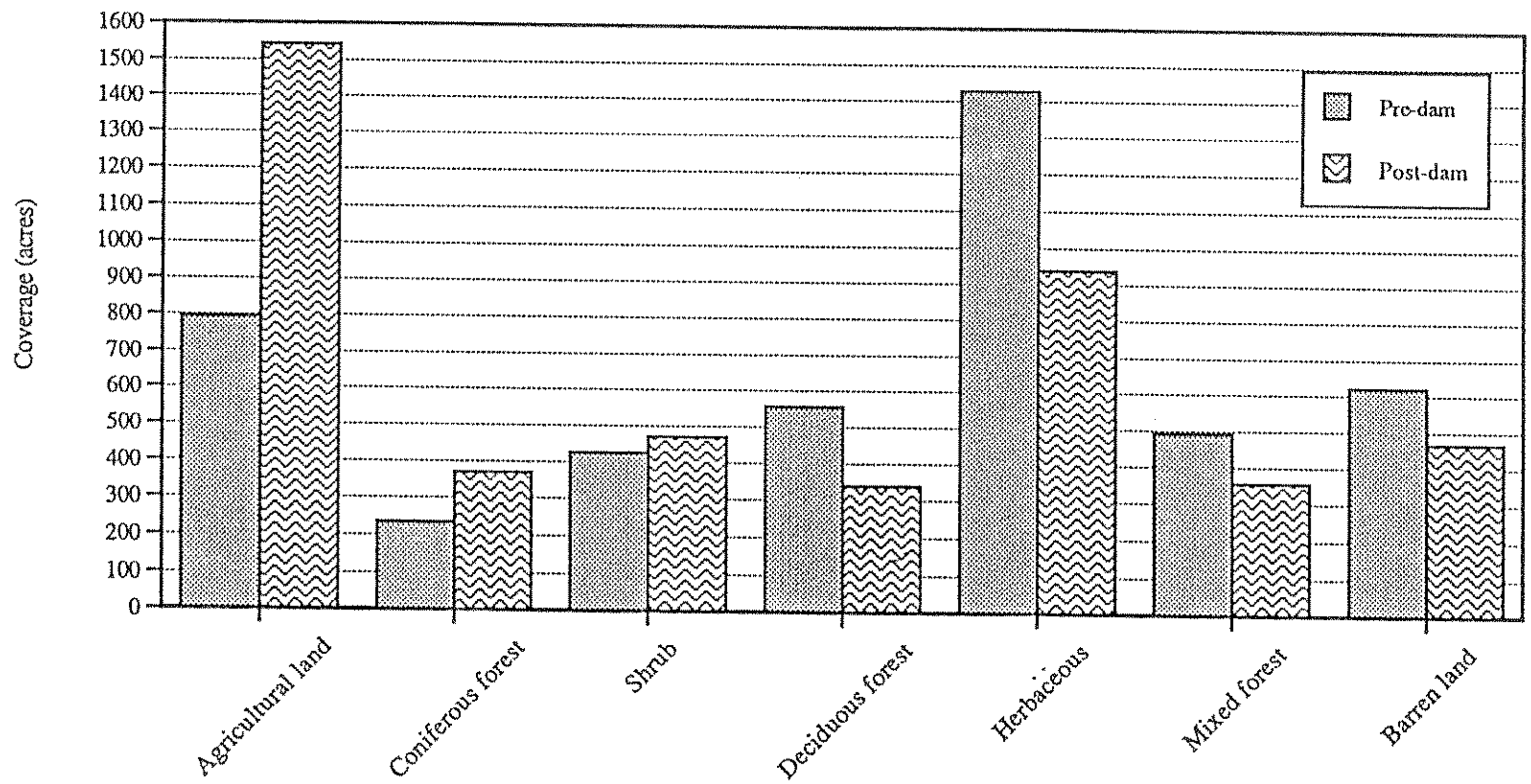
Source: aerial photographs, 1934, 1935, 1937, 1944, and 1988.

As shown later, the coniferous forest riparian cover type represents a successional climax stage (habitat type) along the lower Flathead River. It commonly replaces riparian community types, like black cottonwoods, unable to reproduce in the shade. Replacement occurs gradually, progressing from deciduous forest through mixed forest to coniferous forest. Also, dewatering of floodplain alluvium, because of flood peak flow reduction reduces plant vigor and accelerates cottonwood mortality. (Rood, Heinze-Milne, 1989). Abertson and Weaver (1945) reported that following the prolonged drought of the 1930's, with its reduced stream flows and streambank recharge, cottonwood mortality was extensive in the central and northern Great Plains.

Successional Trends Identified in Aerial Photography

Successional trends involve losses of deciduous forest types to

Figure 3. Acreage changes for major riparian cover types.



mixed forest types and shrub types, and losses of mixed forest types to coniferous and shrub types (Table 5). Later field survey showed that logging on mid-channel islands also caused conversion of tree cover categories (particularly mixed forest category) to dry shrub cover types (hawthorn and chokecherry).

The overall loss in the deciduous forest category (largely cottonwoods) shows clearly that no new major establishment has taken place since the pre-dam photos were taken. The change in area of sandbar willows was impossible to determine, since the willows have the same signature as red-osier dogwood, which replaces sandbar willow stands, as field survey proved.

Table 5. Acreage: major tree riparian cover types.

Categories of Change	Coniferous Forest	Mixed Forest	Deciduous Forest
Loss to coniferous forest	X	94.5	---
Loss to mixed forest	- - -	X	37.4
Loss to deciduous forest	- - -	- - -	X
Loss to shrub	2.4	75.5	27.6
Loss to herbaceous	1.3	4.9	10.7
Loss to agricultural land	2.6	10.4	76.4
Loss to barren land	- - -	---	0.3
Loss due to decrease in size	- - -	17.7	100.4

Loss to decrease in size represents a reduction in the overall size of a polygon. All other categories of loss represent a complete conversion of a polygon from one riparian cover type to another.
Source: aerial photographs, 1934, 1935, 1937, 1944, and 1988.

Barren lands need special mention. They represent all low-level, gravel, mid-channel, delta, and side bars (there are virtually no classic point bars in the lower Flathead River). Field survey revealed that high bar levels were colonized by Rocky Mountain junipers, now at the sapling stage (which show as shrubs on the air photos) and by herbaceous cover since the pre-dam photo set was taken. Also, the lower resolution of the pre-dam aerial photography probably caused sparse herbaceous or shrub cover to be interpreted as barren land.

Lack of Channel Changes and of Bar Creation

No bars were lost or created in the period between the pre-dam and post-dam flights. Indeed, when tracked individually, all the bars from the pre-dam photo set appeared on the post-dam photo set and retained their shape and position. The same stability can be attributed to the river banks. In addition, slight increases in the size of some tributary alluvial deltas imply lack of erosional power of the main river. This is an important observation; on its own it indicates a relative erosional and depositional stability of the river. It provides a perspective on the question of new fluvial surface creation along the lower Flathead River floodplain.

FIELD ASSESSMENT OF THE AERIAL PHOTO INTERPRETATION AND THE LOWER RIVER FLOODPLAIN SUCCESSION

Aerial photography interpretation is not an exact science. Field verification of the interpreted cover types can reveal potential errors and other information not discernible on the photos. The ground truthing confirmed good agreement between the cover categories from the 1981 photo set and the ground. Dead, fallen cottonwoods found in most coniferous covers show that these sites were once colonized by *Populus trichocarpa.*

Ground Truthing

To ground-truth the interpretation of the 1981 aerial photography set and to gather more information on successional trends of the lower Flathead River riparian zone, I selected eight transects (Table 6 and Figures 4 to 11) perpendicular to the river (across the riparian zone). Purposely, the selection was not random; I selected the

Figure 4. Profile: Riparian transect # 1

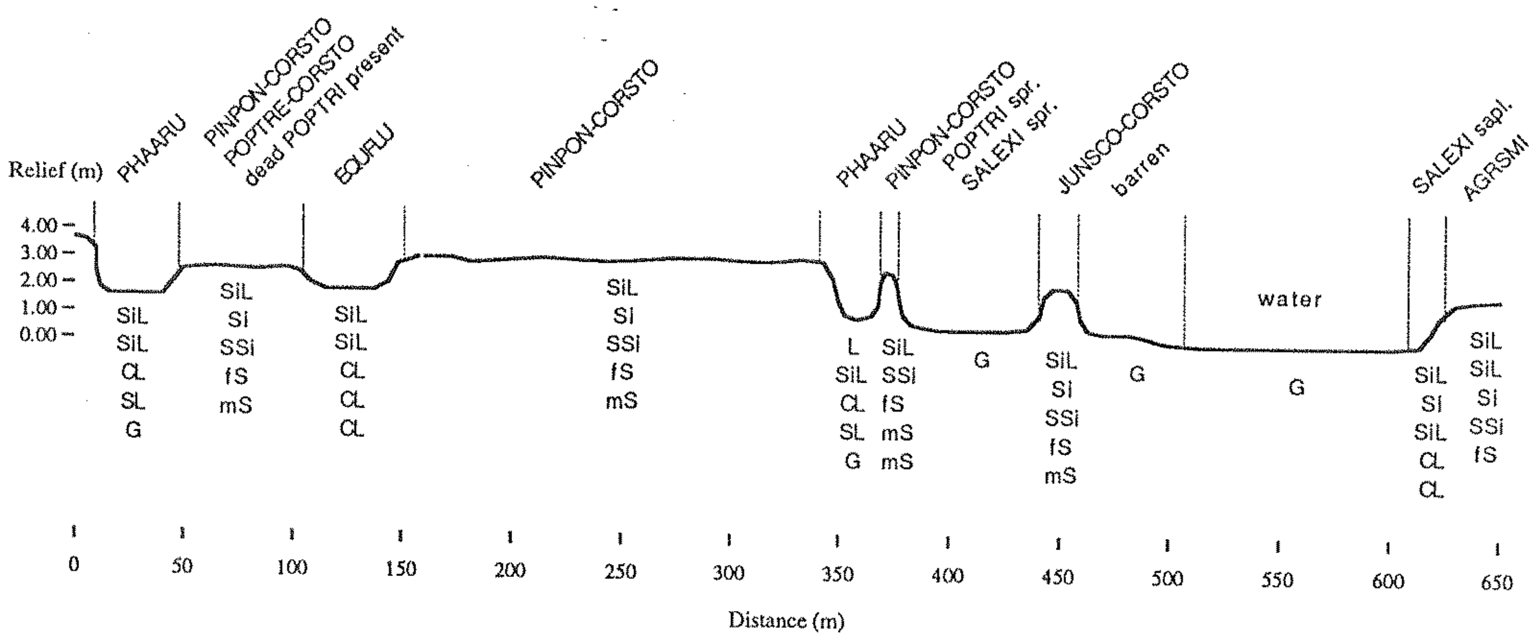


Figure 5. Profile: Riparian transect # 2

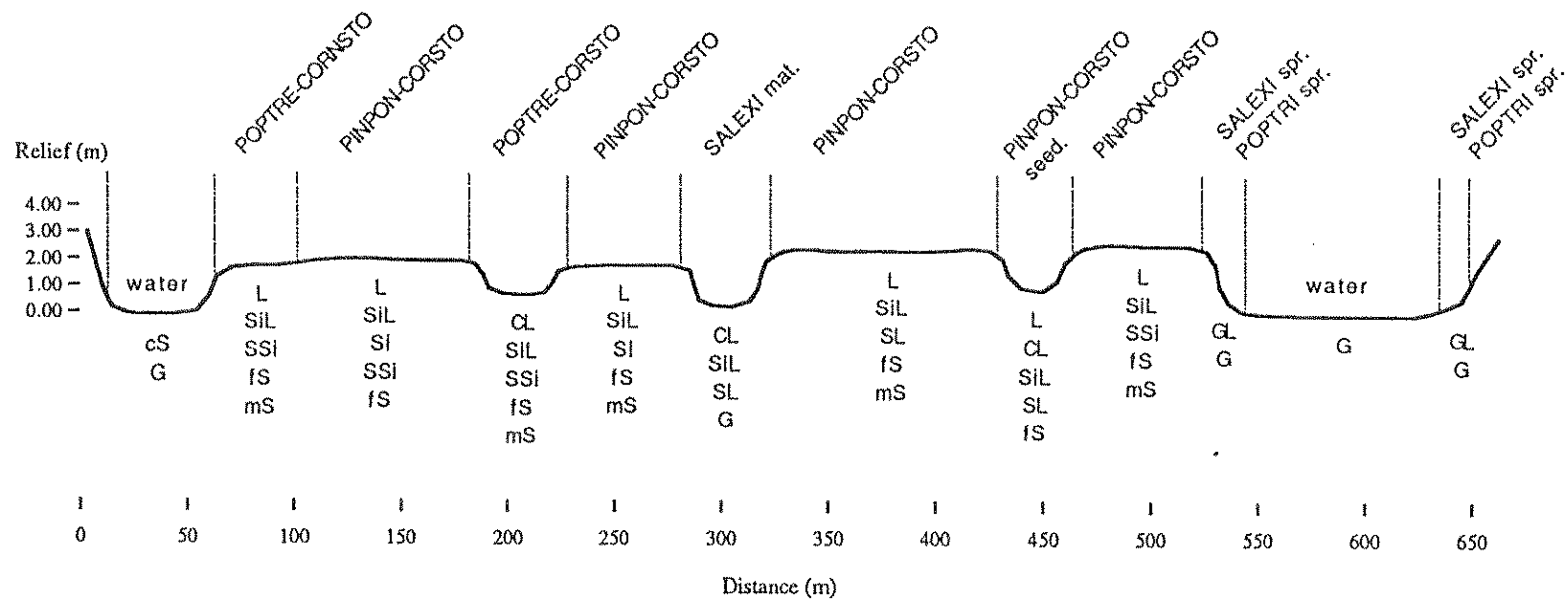


Figure 6. Profile: Riparian transect # 3

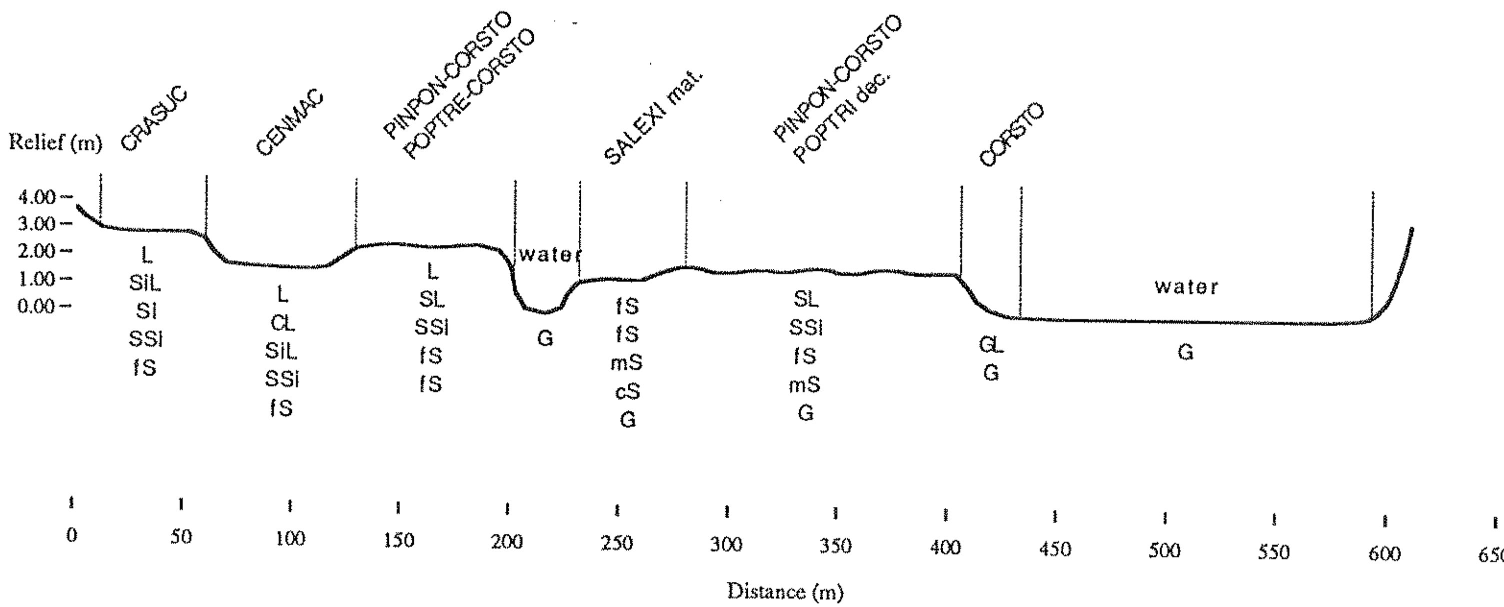


Figure 7. Profile: Riparian transect # 4

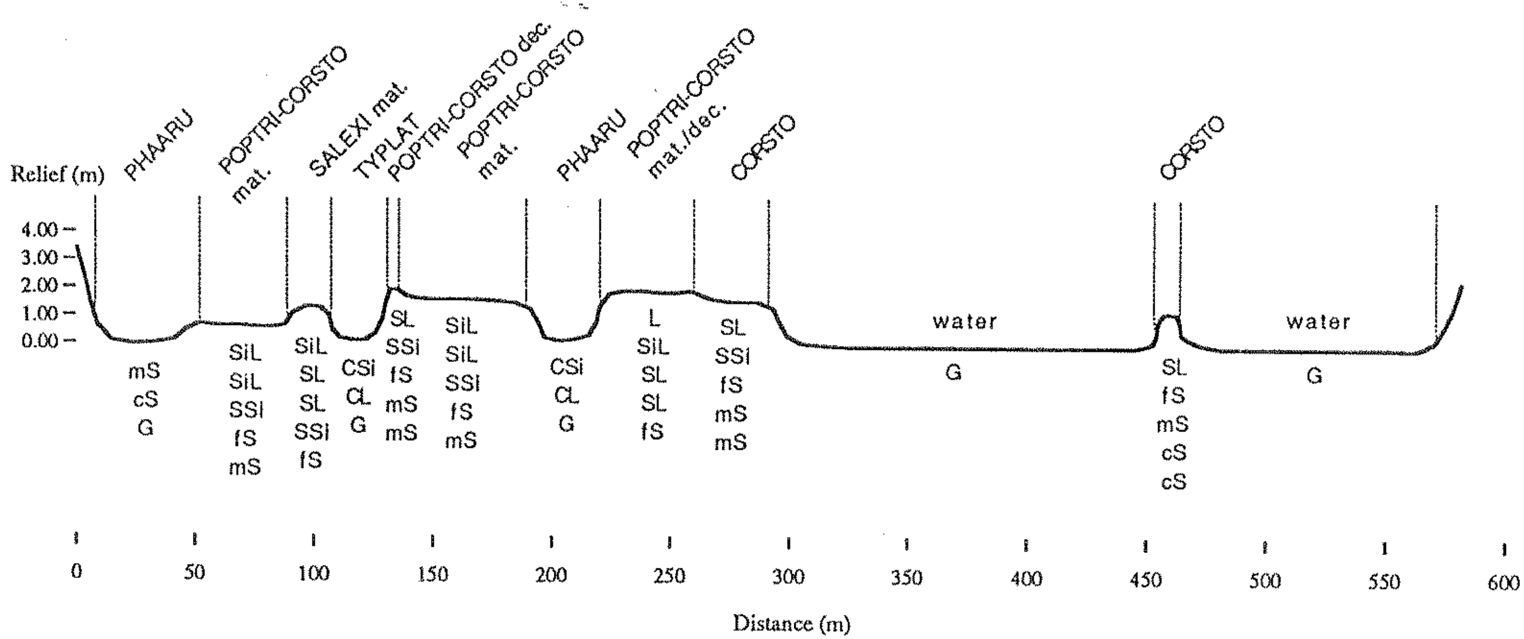


Figure 8. Profile: Riparian transect # 5

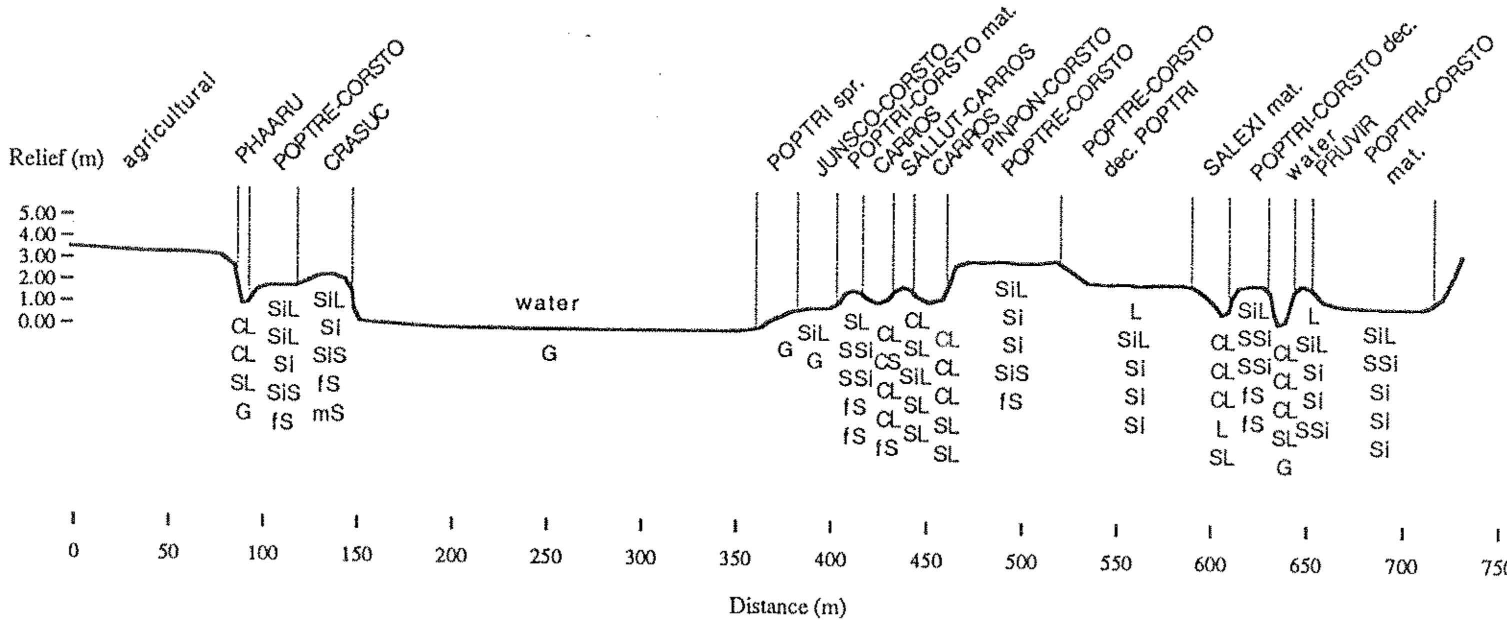


Figure 9. Profile: Riparian transect # 6

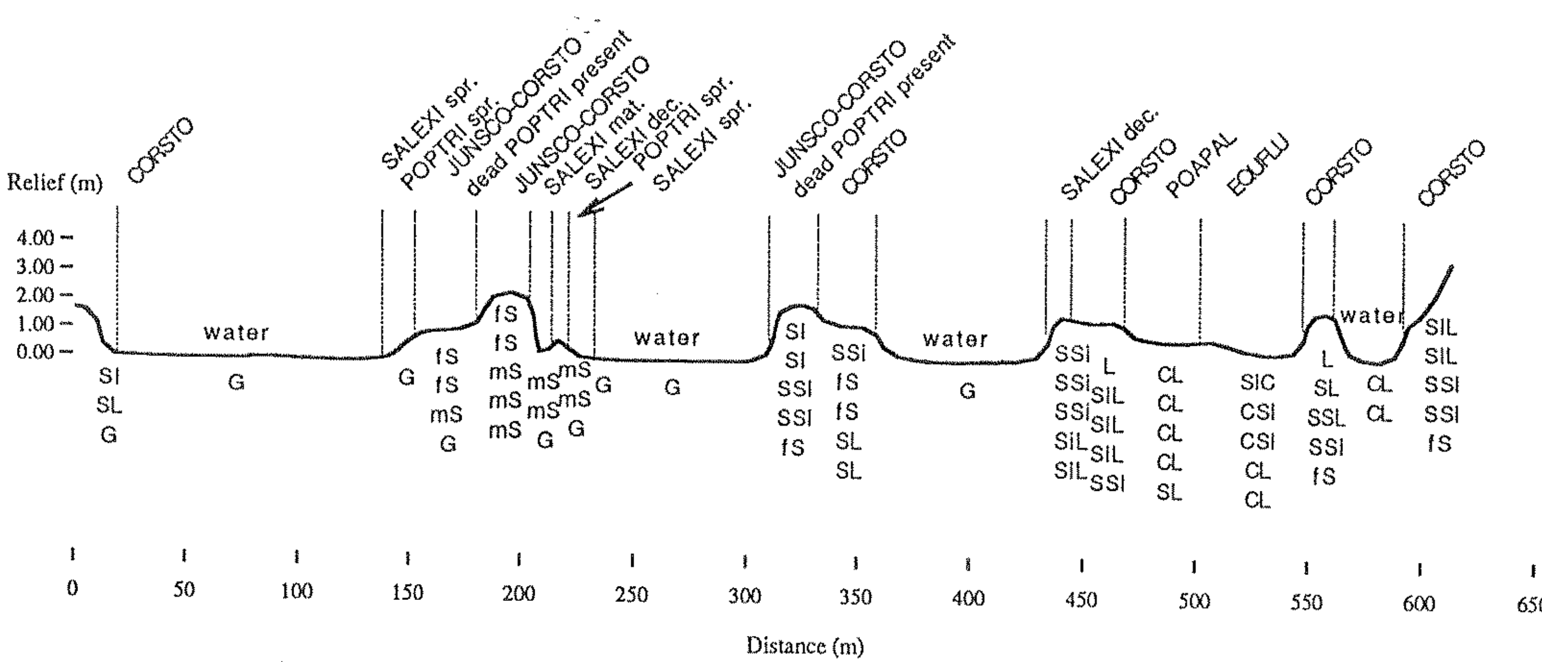


Figure 10. Profile: Riparian transect # 7 .

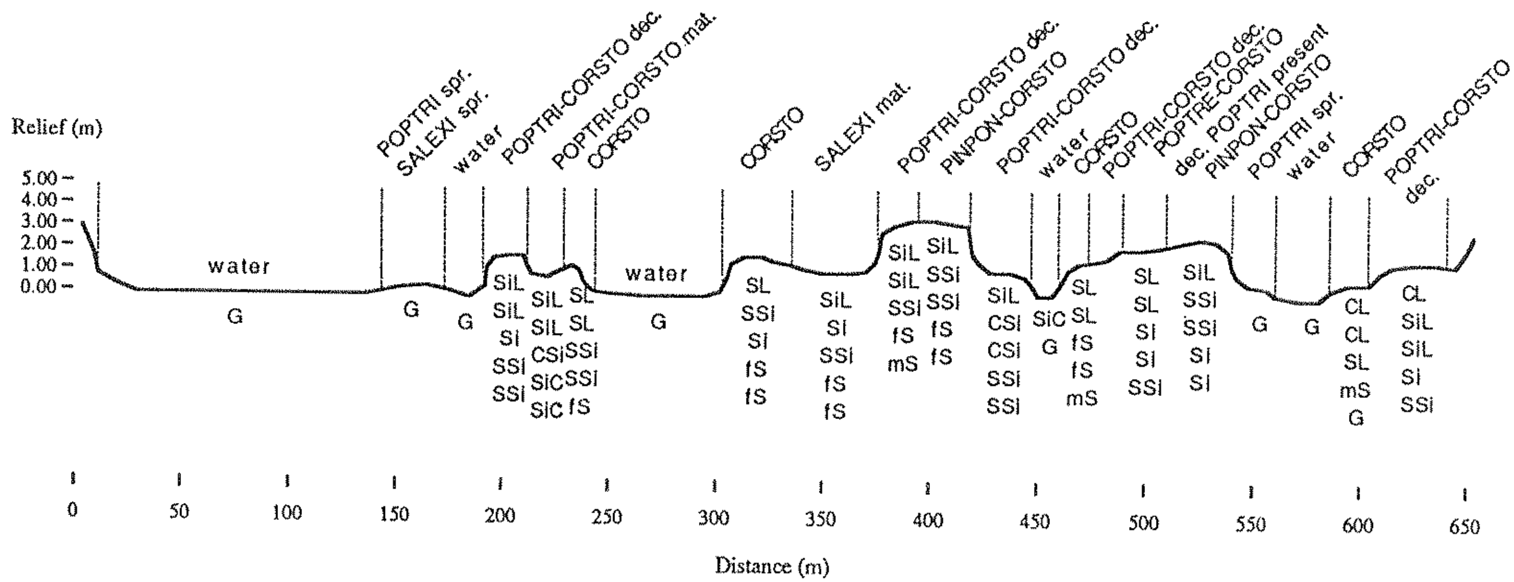
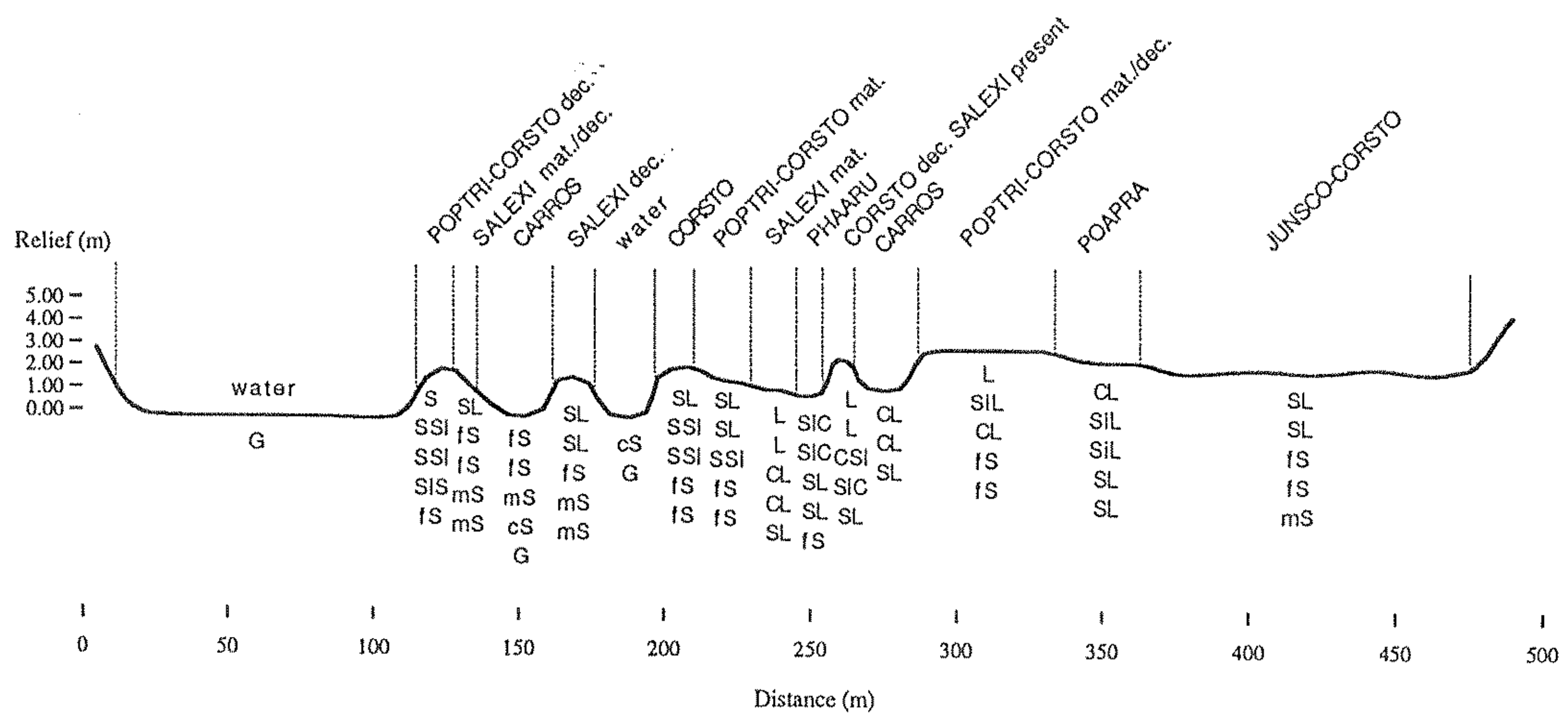


Figure 11. Profile: Riparian transect # 8



placements to include the widest range of the interpreted riparian cover types and level fluvial surfaces (Figure 12). This allowed me to: 1) cover all of the interpreted cover type categories, and 2) to describe the variety of riparian community types as they relate to different level fluvial surfaces. There is very little randomness in the way different riparian communities relate to fluvial surfaces.

Table 6. Transect locations measured from Flathead-Clark Fork junction

Transect Number	River Kilometer
1	46.7
2	45.8
3	36.2
4	34.6
5	31.2
6	31.8
7	23.0
8	23.6

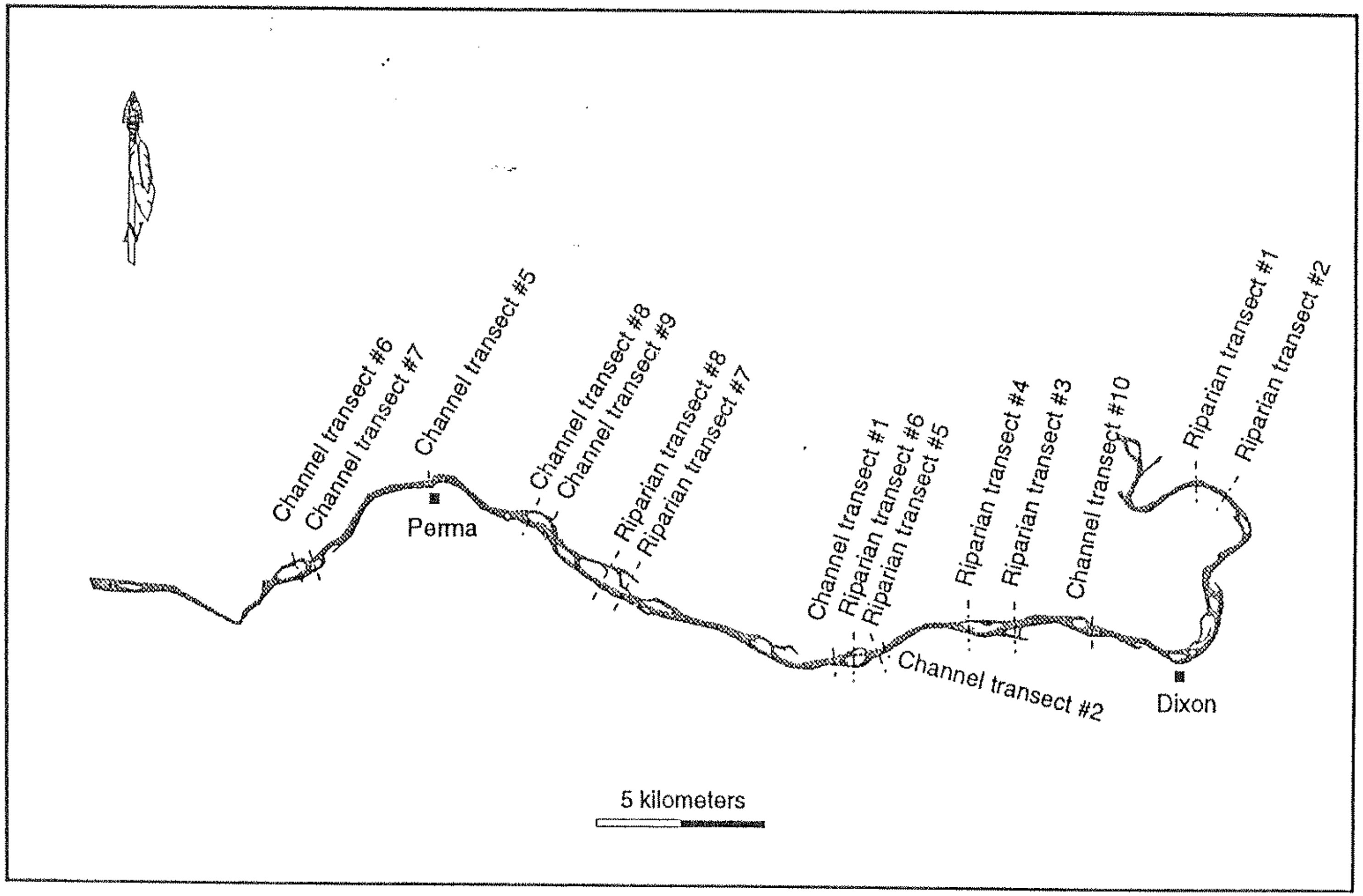
Data Recorded Along Transects

Each homogenous dominant riparian community type along a transect became an unit. Its relative elevation above the current water level (the flows during the survey did not exceed 800 m^3/s), its distance from its nearest boundary to the river, its soil texture to one meter depth taken at 20 centimeter intervals (Table 7), its type of fluvial landform, and finally its riparian community or habitat type (Appendix A) were recorded (see figures 4 to 11).

Table 7. Soil texture abbreviations used in the transect descriptions.

C	clay
Si	silt or silty
S	sand or sandy
L	loam or loamy
f,m,c	fine, medium, coarse

Figure n, Locations of transects



The determination of the riparian types did not strictly follow the Montana Riparian Association (MRA) (Hansen et al., 1993) classification: where *Pinus ponderosa* canopy coverage within *Populus trichocarpa* type was less than 25 percent, the stand was classified as *Populus trichocarpa* community type. Since all *Populus trichocarpa* stands contained some *Pinus ponderosa*, they would key out as *Pinus ponderosa* habitat (climax) types. However, this would obscure the existence of mature to decadent black cottonwood community types in the riparian zone of the lower Flathead River.

Field Verification of Photo Interpretation

All riparian cover types interpreted on 1981 aerial photography on the transects matched those in the field except for the following: some Rocky Mountain juniper sapling cover types were interpreted on the photos as shrubs, and some barren lands (the gravel bars) supported sparse covers of tortured, ice-plucked and sheared, beaver-damaged, sprouting black cottonwoods and sandbar willows. A few dead or decadent black cottonwoods were in almost all conifer stands.

FLOODPLAIN SUCCESSION

Knowledge of riparian plant successional trends is essential to interpret the past and predict the future behavior of a floodplain and specifically to portend the response of riparian plant communities to changes in flows.

Primary and Secondary Succession

Observations made along the transects helped in identifying primary and secondary succession. The riparian zone is a dynamic environment. Floods and low flows, erosion and deposition contribute to the creation and destruction of different sites used by different plant communities. Primary succession consists of plant species compositional changes caused by river processes. Secondary succession, occurring at higher relative elevations such as terraces, consists of plant species compositional changes caused by inter-specific plant competition and site modifications that lead to a climax community; the potential climax community of a site (absent any significant changes caused by river processes) determines the habitat type of a site. For example, a Ponderosa pine riparian habitat type site may have a black cottonwood stand as a current cover type.

Within a floodplain characterized by a meandering river and much erosion and deposition, only a few sites reach advanced successional stages or climax; the river frequently recycles cottonwood and sandbar willows stands. With diminishing fluvial disturbance, succession attains higher stages. Reduced levels of erosion and deposition increase the proportion of late and climax communities to pioneer. Cottonwoods, a relatively short-lived species, are generally replaced by later successional communities after 75 to 200 years.

Lower Flathead River Successional Community Types

Fluvial sites at different relative elevations are usually constructed by either different flood events or by different stages of an event. Distinct physical conditions of the sites then result in different riparian community types. Usually, the lowest (youngest) bars support pioneer community types, and the highest (oldest) stable terraces sustain climax types. Ponderosa pine, Rocky Mountain juniper (*Juniperus scopulorum*) and quaking aspen (*Populus tremuloides*) are the climax tree species along the lower Flathead River floodplain. In an absence of new fluvial surface creation, they gradually replace black cottonwood pioneer community types. Red-Osier dogwood (*Cornus stolonifera*) shrub community types usually replace sandbar willow community types.

Gravel Bars

The existing bars along the lower Flathead River are not favorable to *Populus trichocarpa* or *Salix exigua* growth. I did not find any *Populus trichocarpa* or *Salix exigua* seedlings on any mid-channel, side, or point bars. All bars had gravelly surfaces (26.5 millimeters average b-axis median size), and their plant covers consisted of *Populus trichocarpa* and *Salix exigua* sprouts of uncertain age. Canopy coverages ranged from 1 to 6 percent. The plants were less then 1.5 meters high and exhibited marks of heavy ice damage caused by plucking, bending, breaking, and shearing. Long horizontal roots on substrate surfaces extended upstream, while tortured potato-like plant stems (except the new sprouts) did not exceed 15 centimeters in height. Some sites also bore signs of beaver use.

The higher ground of gravel bars supported *Juniperus scopulorum* and occasional *Pinus ponderosa* plants ranging from seedlings to poles, and a few *Populus trichocarpa* and *Salix exigua* saplings and poles. The plants bore ice scars, but the damage was much less than on lower ground. Grasses with canopy coverages of about 20 percent were also present.

Clearly, the recruitment of black cottonwoods and sandbar willows on the bars is close to nill. Plants existing on the low portions of bars struggle to survive the annual ice damage, while Rocky Mountain juniper and Ponderosa pine -- later successional species -- are colonizing the higher bar ground.

Overflow Channels

Concave (blocked at the ends), back-water side-channels, often with pockets of standing water and clay-silt top soil rich in organic matter, support herbaceous riparian communities such as beaked sedge (*Carex rostrata*) habitat type, water sedge (*Carex aquatilis*) habitat type, reed canarygrass (*Phalaris arundincea*) habitat type, foxtail barley (*Hordeum jubatum*) comunity type, Baltic rush (*Juncus balticus*) community type, common spikesedge (*Eleocharis palustris*) habitat type, redtop (*Agrostis stolonifera*) community type, hardstem bulrush (*Scirpus acutus*) habitat type, fowl bluegrass (*Poa palustris*) community type, and water horsetail (*Equisetum fluviatile*) habitat type.

Flow-through overflow channels usually have gravel or coarse sand bottoms and support the same riparian cover as the bars. Again, many *Populus trichocarpa* and *Salix exigua* in these channels exhibit ice damage.

Under the present regulated flow regime, high spring flows usually reach both the concave and the convex side-channels and the lower parts of the bars.

Low Terraces

The *Cornus stolonifera* community type occupied about a third of the surveyed lower terraces; its canopy coverage was around 80 percent. Mature and decadent *Salix exigua* plants (with canopy coverage of about 10 percent) were usually present within the *Cornus stolonifera* community type. Some low terraces supported pure mature and decadent *Salix exigua* community type stands. *Rosa woodsii* was almost always present. I found a few mature to decadent stands of *Salix lasiandra* community type and *Salix lutea/Calmagrostis canadensis* habitat type.

Mature to decadent stands of *Populus trichocarpa/Cornus stolonifera* community type dominated about a third of the surveyed lower terraces. *Rosa woodsii, Symphoricarpos occidentalis, Prunus virginiana and Crataegus succulenta* dominated the understory of open, grazed sites. *Pinus ponderosa, Juniperus scopulorum* and *Populus tremuloides* in stages from seedling to mature were always present with canopy coverages from 5 to 15 percent.

I attempted to core the *Populus trichocarpa* trees but failed; the tree cores were rotten. I then cored the largest *Pinus ponderosa* trees within the stands. Their ages varied from 110 to 160 years. *Pinus ponderosa* can invade *Populus trichocarpa* stands once a site is no longer subject to frequent flooding; I observed occasional *Pinus ponderosa* seedlings on the higher parts of bars. Thus, it is possible to assume that the rotted black cottonwoods plants are not much older than the Ponderosa pines.

High Terraces

Grazed and logged higher terraces were dominated by open stands of *Prunus virginiana, Crataegus succulenta, Symphoricarpos occidentalis* and *Rosa woodsii* community types. *Populus tremuloides/Poa pratensis* community types dominated swales of the disturbed sites. Many of these community types had occasional *Pinus ponderosa* plants present.

Relatively undisturbed sites on the higher terraces largely supported *Pinus ponderosa/Cornus stolonifera* habitat type with *Populus tremuloides/Cornus stolonifera* habitat type occupying wetter microsites (swales) and *Juniperus scopulorum/Cornus stolonifera* (*Rosa woodsii* and *Symphoricarpos occidentalis* were the dominant understory) populating sandier and drier microsites. Mature to decadent or dead or fallen *Populus trichocarpa* were usually present within the coniferous habitat types. The age of the largest *Pinus ponderosa* trees on the high terraces varied from 160 to over 240 years. All age classes were present.

What I interpreted as a mixed forest riparian cover type on the aerial photography was either *Pinus ponderosa/Cornus stolonifera* habitat types with *Populus trichocarpa* plants over 25 percent covers or polygons with ridge and swale topography and mixture of *Pinus ponderosa/Cornus stolonifera* and *Populus tremuloides/Cornus stolonifera* habitat types.

Some extremely disturbed high terraces were occupied by *Centaurea maculosa, Poa pratense, Phleum pratense* and other graminoids.

Lower Flathead River Successional Trends

From the above observations and following the Classification and management of riparian and wetland sites in Montana (Hansen et al., 1993), one can establish probable successional trends of the lower Flathead River's riparian zone and relative frequencies of pioneer species establishment. These frequencies, as shown before, depend on frequency of flood magnitudes sufficient to create new fluvial surfaces.

The mature to decadent *Populus trichocarpa* and *Salix exigua* early pioneer community types (always the same age class at a site) indicate that the fluvial surfaces now supporting them were indeed once fresh fluvial deposits; past discharges were sufficient to create environments suitable for the establishment of pioneer riparian species. However, the lack of seedling, sapling, and pole age classes plus the age of the *Pinus ponderosa* trees within the *Populus trichocarpa* community types indicate that no major recruitment has taken place within the last 110 years approximately. The relative paucity of the *Populus trichocarpa* -- 12.2 percent for the pre-dam and 7.6 percent for the post-dam aerial photography -- and *Salix exigua* community types within the lower Flathead River riparian zone implies low frequencies for the hydrologic events that created surfaces suitable for their recruitment.

The early successional *Cornus stolonifera* community type seems to be more successful in colonizing low terraces than both the *Populus trichocarpa* and the *Salix exigua* community types.

The natural climaxes as of the lower Flathead River floodplain are *Populus tremuloides/Cornus stolonifera, Pinus ponderosa/Cornus stolonifera*, and *Juniperus scopulorum/Cornus stolonifera* habitat types, which range respectively from wettest to driest sites. The relative abundance of the coniferous and mixed forest habitat types -- 16 percent for the pre-dam and 16.2 percent for the post-dam aerial photography -- indicate both a prevalence of secondary succession and a relative stability of the riparian zone.

CHAPTER II

HYDROLOGY AND GEOMORPHOLOGY OF THE LOWER FLATHEAD RIVER

Type of materials available for floodplain construction, channel energy gradient, and frequency of flows that can move the materials control frequency of creation of new fluvial surfaces. Thus, regeneration of pioneering riparian species depends hydrologic and geomorphic conditions of a catchment.

CATCHMENT OVERVIEW

The Flathead River catchment encompasses an area of 22,241 km^2 in western Montana and southeastern British Columbia (Figure 1). Glaciated mountainous landscapes of the Rocky Mountains trench control snowmelt-driven runoff with flood peaks in late May and June.

The North Fork, Middle Fork, and South Fork of the Flathead River join near the town of Hungry Horse, Montana, to form the upper Flathead River with mean annual discharge of 273 cubic meters per second. Flowing south, the river enters Flathead Lake, the largest fresh-water natural lake (496 km^2) west of the Mississippi River. Swan River, a smaller perennial tributary, has a mean annual discharge of 33 cubic meters per second. The lower Flathead River, the only outlet from Flathead Lake, flows south and west for about 115 kilometers before it joins the Clark Fork River of the Columbia River system.

KERR DAM AND HUNGRY HORSE HYDROPOWER FACILITIES

Two hydropower facilities regulate the flow of the Flathead River: Hungry Horse on the South Fork of the upper Flathead River and Kerr Dam on the lower Flathead River right below the natural outlet of Flathead Lake. Operation of both facilities is somewhat coordinated with 20 other downstream hydroelectric facilities in the Columbia basin. The federal government operates Hungry Horse, and Kerr Dam is operated jointly by the Montana Power Corporation (MPC) and the Confederated Salish and Kootenai Tribes (CSKT) of the Flathead Reservation.

Since 1938, Kerr Dam has been operating primarily as a load control facility (Jourdonnais, Hauer, 1993) supplying the instantaneous energy demands of the MPC's power distribution system. Load control operations result in numerous unpredictable daily fluctuations of the lower Flathead River.

Hungry Horse, completed in 1952, supplies regular peak power demands within the Boneville Power distribution system. Unlike the fluctuations caused by Kerr Dam, the daily outflow fluctuations from the Hungry Horse are more predictable.

STREAMFLOW RECORDS

Long-term streamflow records are the best indicators of the past hydrologic histories of streams. The United States Geological Survey (USGS) operates a gaging station on the mainstem of the upper Flathead River, and two gaging stations on the lower Flathead River, one directly below the Kerr Dam outlet and one near the mouth (USGS, 1992) (Table 8).

Table 8. USGS stations on the mainstem of the Flathead River.

Station name	Station #	Period of record	Mean ann. flow (m^3/s)
Flathead R. at Columbia Falls	12363000	1929-present	273
Flathead R. near Polson	12372000	1908-present	326
Flathead R. at Perma	12388700	1983-present	332

Upstream and Downstream Mean Annual Flow Comparison

When assessing changes in stream flow caused by artificial regulation, it is necessary to examine natural runoff trends. Since mean annual flows largely mask the influence of reservoirs on annual flow variations, they are a convenient variable to analyze long-term natural runoff trends. They can be also used to determine relative contributions of individual sub-catchments.

The mean annual flow at Columbia Falls is about 84 percent of the mean annual flow near Polson and the mean annual flow at Perma is about 108 percent. The gage near Polson covers a sufficiently long period to be used for flow analysis of the lower Flathead River. The regulated (1952 to 1991) mean annual flow at the Columbia Falls was 103 percent of the period of record (1929 to 1991) flow, and the natural (1929 to 1951) mean annual flow was 94 percent of the period of recorded flow.

The mean annual flow at the gage near Polson for the pre-Kerr-Dam interval (1908 to 1937) was 99 percent of the period of record (1908 to 1991) flow; the mean annual flow for the pre-Hungry-Horse interval (1938 to 1951) was 94 percent of the period of record flow, and post-Hungry-Horse (1952 to 1991) mean annual flow was 100 percent of the period of record flow. The numbers show that no significant annual runoff change has occurred during the measurement periods. Basic statistics for the three gages during the pre- and post-regulation periods are compared in Tables 9 to 11.

Table 9. Mean annual flow: Flathead River at Columbia Falls.

Period	Average (m^3/s)	Maximum (m^3/s)	Minimum (m^3/s)	St. deviation (m^3/s)
1929-1951	258	365	136	69
1952-1991	282	389	191	51
1929-1991	273	389	136	59

Table 10: Mean annual flow: Flathead River near Polson.

Period	Average (m^3/s)	Maximum (m^3/s)	Minimum (m^3/s)	St. deviation (m^3/s)
1908-1937	322	488	212	76
1938-1951	306	450	147	97
1952-1991	336	464	214	62
1908-1991	326	488	147	74

Table 11. Mean annual flow: Flathead River at Perma.

Period	Average (m^3/s)	Maximum (m^3/s)	Minimum (m^3/s)	St. deviation (m^3/s)
1984-1991	332	455	250	66

Tributary Contributions

Four small perennial tributaries enter the lower Flathead River between the Polson and Perma gages: Crow Creek (1.2 m^3/s mean annual discharge, CS&K Tribes data), Little Bitterroot River (0.8 m^3/s mean annual discharge, CS&K Tribes data), Mission Creek (4.5 m^3/s mean annual discharge, USGS and CS&K Tribes data) and Jocko River (6.4 m^3/s mean annual discharge, USGS and CS&K Tribes data). They, together with groundwater inflow and intermittent tributaries, contribute about eight percent of the mean annual flow at Perma; the remainder of the lower Flathead River flow at Perma comes from Flathead Lake.

Flood Frequency Analysis

Regulation of rivers by dams often results in lowering flood magnitudes. Usually, creation of new fluvial surfaces happens during flood stages; certain amounts of energy are needed to entrain, transport, and deposit bed materials. The three highest and lowest annual floods and their recurrence intervals at the Polson gage for the pre-dam, Kerr-Dam and Hungry-Horse periods are shown in Table 12. Recurrence interval for floods of similar magnitudes has increased, and flood magnitudes decreased following the regulation.

Table 12. Three highest and lowest annual discharges at Polson.
a) pre-dam period (1908 to 1937)

Max. annual discharge (m^3/s)	Magnitude	Recurrence interval (years)
2296.51	1	31.00
2169.08	2	15.50
2135.10	3	10.33

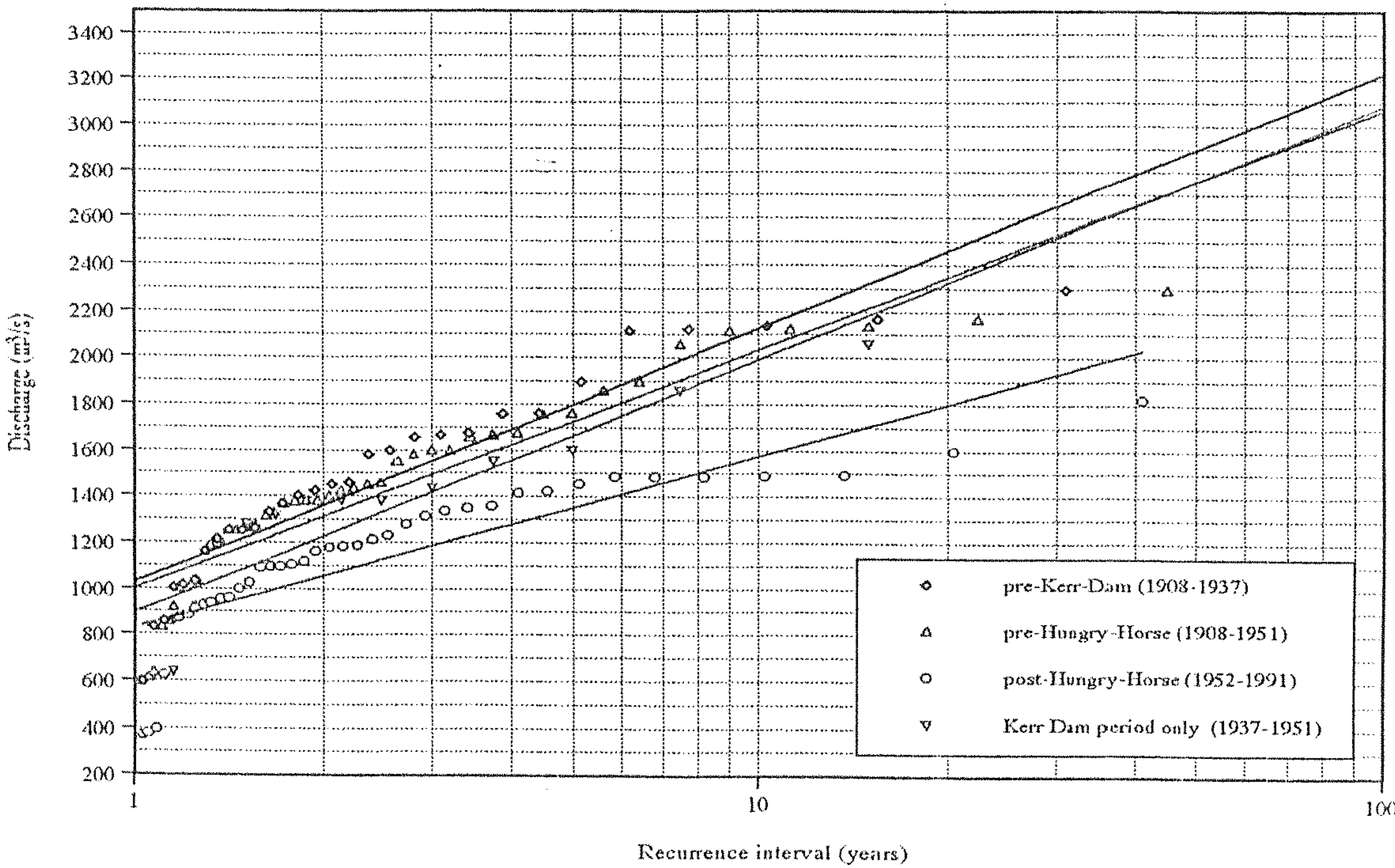
Cont. Table 12. Three highest and lowest annual discharges at Polson.
a) pre-dam period (1908 to 1937)

Max. annual discharge (m^3/s)	Magnitude	Recurrence interval (years)
858.01	28	1.11
829.69	29	1.07
594.66	30	1.03
b) post-Kerr-Dam-pre-Hungry-Horse period (1938 to 1951)		
2058.65	1	15.00
1854.76	2	7.50
1599.91	3	5.00
920.30	12	1.25
634.30	13	1.15
611.65	14	1.07
c) post-Hungry-Horse period (1952 to 1991)		
1820.78	1	41.00
1599.91	2	20.50
1495.14	3	13.67
393.61	38	1.08
376.62	39	1.05
368.12	40	1.03

The annual flood frequency analysis uses the standard USGS formula, where recurrence interval R= n+1/m, n is the number of years of record and m is the rank of the each flood's magnitude.

An annual flood frequency distribution graph (Figure 13) shows that Kerr Dam operations reduced the 10-year flood magnitude by approximately 7 percent and the 100-year flood magnitude by approximately 4 percent. The combined effect of both dams reduced the 10-year flood by approximately 27 percent and the 100-year flood by approximately 29 percent. This means that larger floods, responsible for new fluvial surfaces creation, have lower frequency in the post-dam era.

Figure 13. Annual flood frequency distribution: Flathead River near Polson.



Significance of Large Floods in the Lower Flathead

Estimation of the flood magnitudes necessary for creating conditions favorable for *Populus trichocarpa* and *Salix exigua* establishment is one of the central objectives of this study. Given the estimated age of the existing larger *Populus trichocarpa* stands (90+ years), the largest and least frequent floods on record are likely responsible for the creation of new fluvial surfaces. The highest recorded flood at Polson for the 1908 to 1937 period was 2,296 m^3/s (20-year pre-dam recurrence interval), 2,059 m^3/s (15-year pre-dam recurrence interval) for the 1938 to 1951 and 1,821 m^3/s (21-year pre-dam recurrence interval) for the 1952 to 1991 periods. The highest estimated discharge in the lower Flathead was 3,120 m^3/s (80-year pre-dam recurrence interval) in 1894. Later, I will show the relationship of flood magnitudes to the erosional competency of the river and to existing fluvial surfaces.

Differences between highest annual floods at the Polson gage and at the Perma gage for the common period of record are small (Table 13).

Table 13. Highest annual floods in m^3/s for at Perma and near Polson gages.

Year	Perma	Polson	Statistics	Perma	Polson
1984	1030.74	954.28	Mean an. flood	921.36	891.63
1985	931.63	937.29	Max. an. flood	1220.46	1161.00
1986	1141.18	1095.87	Min an. flood	404.93	376.62
1987	611.65	622.97	St. deviation	282.95	267.75
1988	404.93	376.62			
1989	891.99	883.49			
1990	1138.34	1161.00			
1991	1220.46	1101.53			

A logical inference is that the gage near Polson fairly represents the entire river. The difference in annual flood magnitudes between the two gages ranges from minus two percent in 1990 to 11 percent in 1991, with a three percent difference in the mean annual floods.

Flood Attenuation by Flathead Lake and Dams

Magnitudes of floods directly influence the amounts of material entrained, moved, and deposited. Flathead Lake attenuates (lowers magnitudes but prolongs durations) flood flows coming from the upper Flathead River. The degree of attenuation has been increased by operations of Kerr Dam and Hungry Horse (Figures 14, 15 and 16). The dates of the three highest recorded overlapping floods (1933, 1948, 1964) happen to fall within the three different dam regulation periods. The 1933 curves show classic pre-regulation snowmelt-driven runoff and the smoothing influence of the lake on the lower Flathead River hydrograph; the lake decreased the flood by about 13 percent. The 1948 curves reveal a somewhat greater reduction in flood magnitude when compared to the pre-regulation period, and they also reveal cutting-off of the flood recession limb by Kerr Dam; the dam reduced the flood by about 26 percent. The 1964 curves show ~~not only a runaway peak caused by a faulty operation of the Hungry Horse~~ dam, but also an overall decrease in the spring runoff caused by the two dams. Lower floods mean less chance of new fluvial surfaces creation. Most of the current attenuation does not result in increased durations of the spring floods; instead, the water is stored and released during winter.

containment of the South Fork flows by Hungry Ho.

Mean Daily Annual Flow Impacts

Lack of new fluvial surfaces, attributable to low floods, and ice scour have been identified as being detrimental to successful *Populus trichocarpa* and *Salix exigua* reproduction. Mean daily annual hydrographs (Figure 17) for the three regulation periods illustrate decreases of spring runoff and increases of winter flows -- classic effects of dam operation. Operation of Kerr Dam alone reduced average spring runoff magnitudes by about 11 percent; operation of Kerr Dam and Hungry Horse together reduced average spring runoff magnitude by about 34 percent.

Significant increases in average winter flows also result from dam operations. Higher winter stages lead to ice covers on the low bars, which causes subsequent shearing and plucking of existing black cottonwood and sandbar willow plants.

Operation of Kerr Dam alone resulted in an average increase of winter flow magnitudes by approximately 133 percent, and the

Figure 14. The 1933 flood hydrograph for the Flathead River above and below the Flathead Lake.

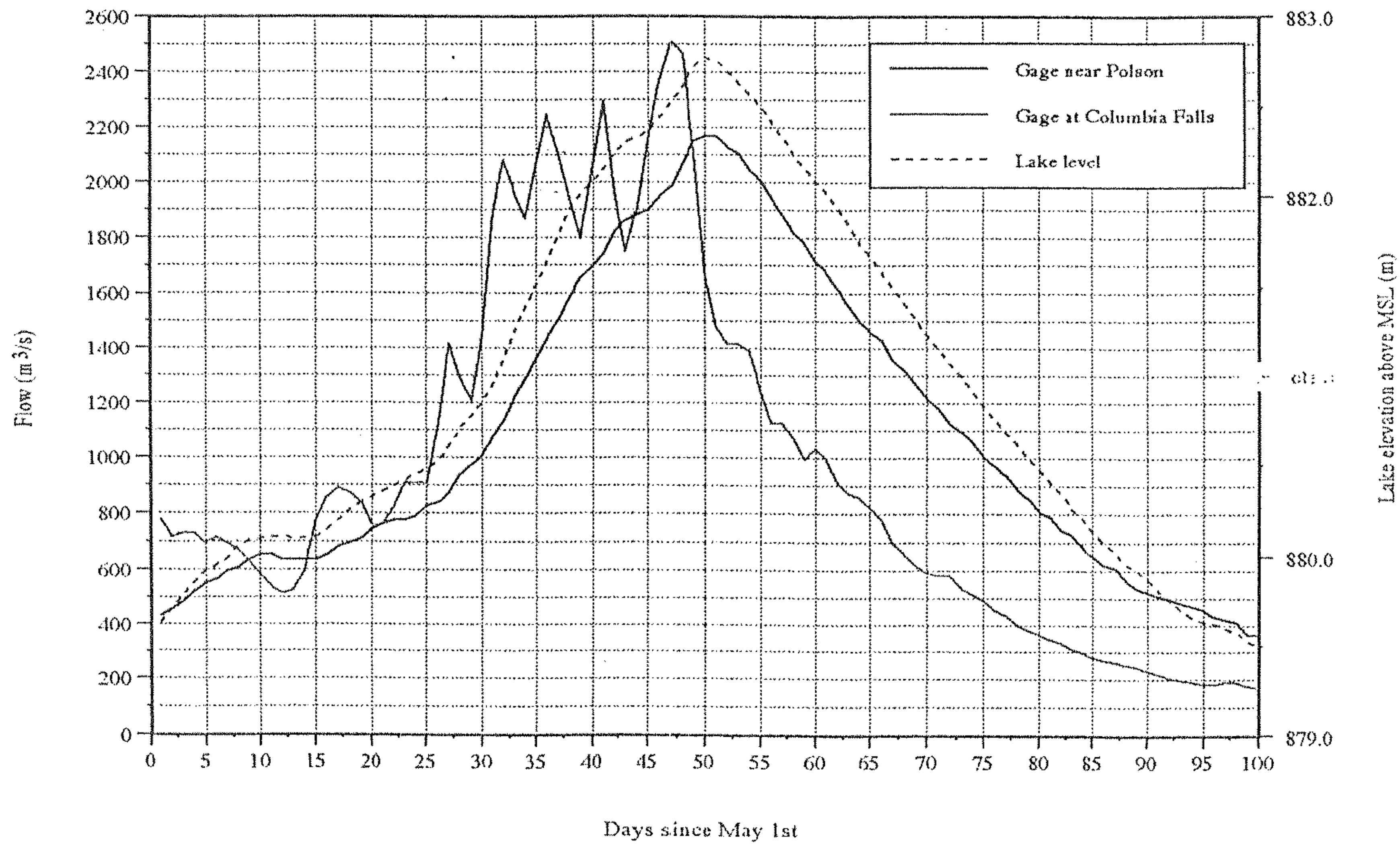


Figure 15. The 1948 flood hydrograph for the Flathead River above and below the Flathead Lake.

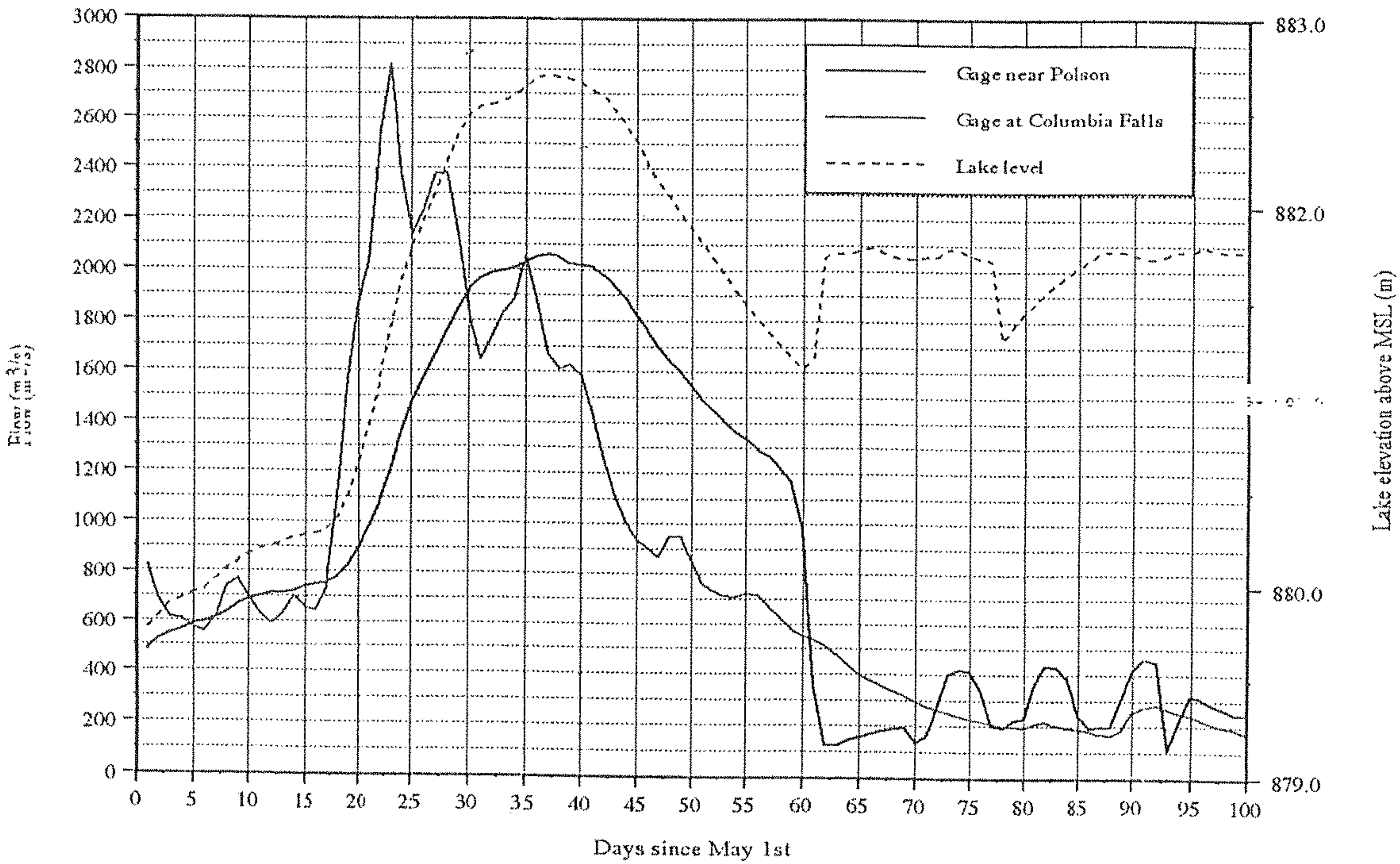
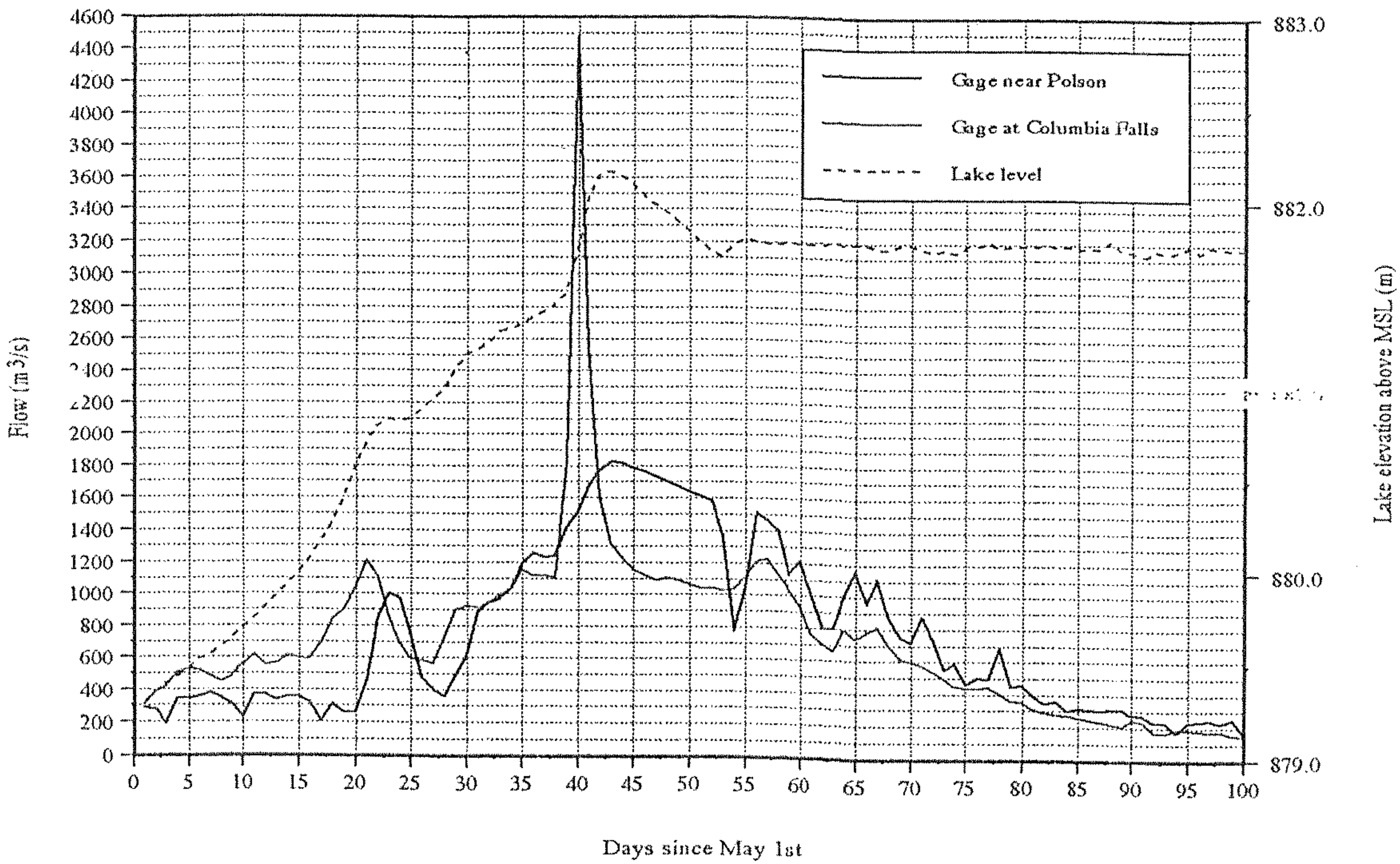


Figure 16. The 1964 flood hydrograph the Flathead River above and below the Flathead Lake.



combined effects of both dams increased average winter flow magnitudes by about 233 percent. Later I will show the relation of the high winter stages to the elevations of low gravel bars in the river.

Daily Flow Reversals

Large and frequent water stage fluctuations adversely affect water supplies to fluvial surfaces that could support denser stands of *Populus trichocarpa* and *Salix exigua*. Sudden power demands on Kerr Dam cause frequent hourly discharge fluctuations. Figure 18 presents an hourly discharge record at the Polson gage during the end of June (approximate black cottonwood seed dispersal period) 1990. The frequent changes in water levels (up to 1.5 meters) associated with the water releases create both a fluctuating alluvial groundwater table under low bars and frequent inundation and drying of the bars, conditions unfavorable for cottonwood and sandbar willow seed germination and growth. This area, called the varial zone (Stanford and Ward, 1992), undergoes hourly inundation and dewatering and thus provides neither aquatic nor terrestrial habitat. Width of the varial zone along the lower Flathead River ranges from 5 to 10 meters along steep banks to over 100 meters in less incised reaches (Jourdonnais and Hauer, 1993).

GEOLOGIC SETTING OF MISSION VALLEY

After it leaves Flathead Lake, the lower Flathead River flows south through broad Mission Valley. The valley is bordered by high, gaciated Mission Mountains on the east and low, hilly Salish Mountains on the west. Quaternary glaciation shaped the Mission Valley. The valley fill consists mainly of deposits of glacial Lake Missoula, created by the Purcell Trench lobe of the Cordilleran ice sheet that blocked the course of the Clark Fork River (Pardee, 1910; Baker and Nummedal, 1978; Breckenridge, 1989). At the same time, the Flathead lobe of the Cordilleran ice sheet advanced south through the Flathead Valley into the Mission Valley.

At present, the terminus of the southern advance of the Flathead lobe and the genesis of the valley fill is open to doubt (Levish et al.,1993). Noble (1952) and Alden (1953) explained the diamict

Figure 17. Average daily flows: lower Flathead River near Polson

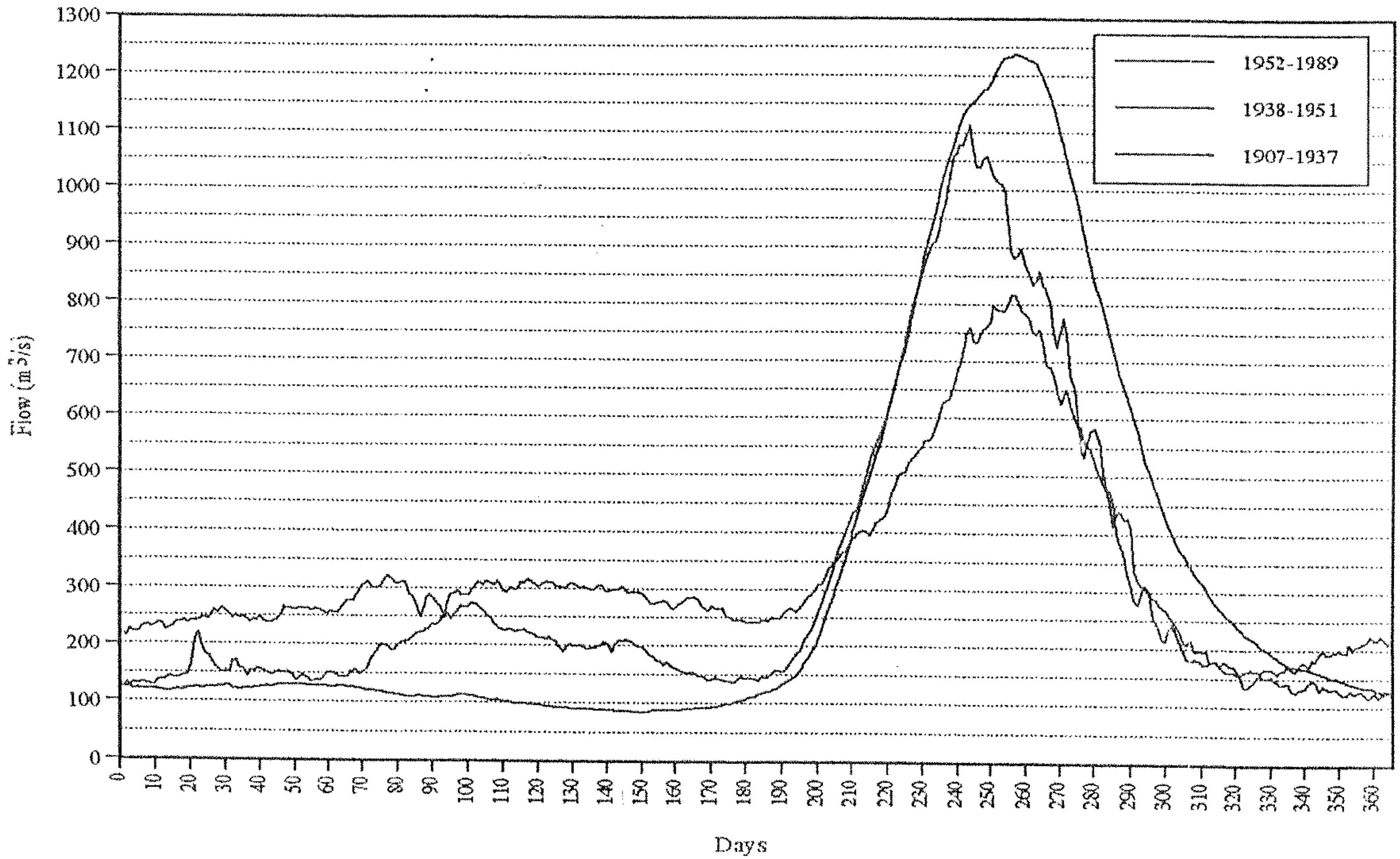
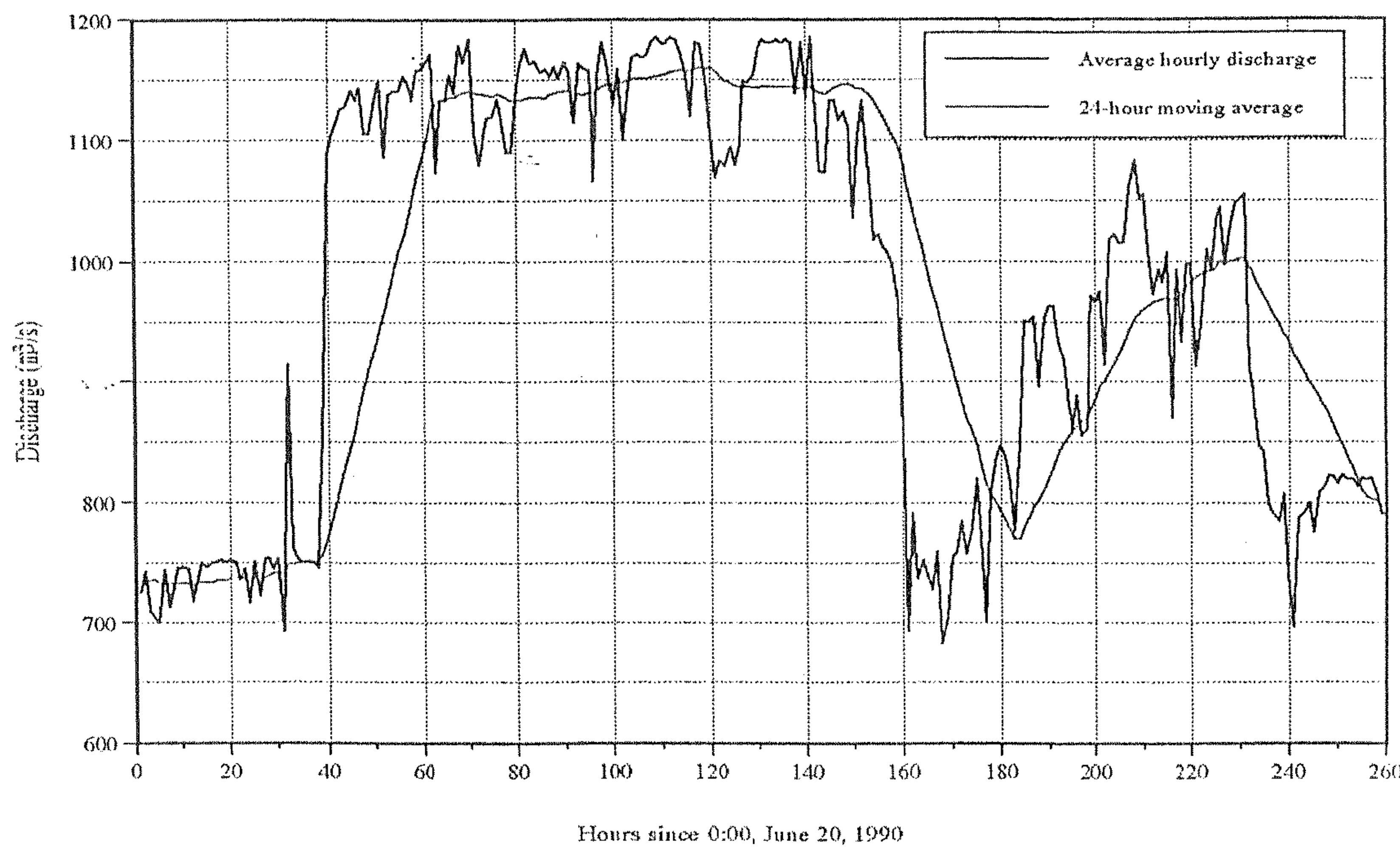


Figure 18. Mean hourly discharge: Flathead River near Polson; June 20 to June 30, 1990



layers within the lake beds as glacial till and, thus, assumed that the Flathead lobe covered much of the Mission Valley, advancing and retreating with complete drainings of the Lake Missoula. Levish (1993) asserts that the Polson terminal moraine at the southern end of Flathead Lake marks the southernmost margin of the Flathead lobe and that the Mission Valley was not covered by the Cordilleran ice sheet. He attributes the presence of gravels and diamicts to a Mission Mountains alpine iceberg "rain-out," outwash from the Polson moraine, and re-deposition by lake currents.

However, since the characteristics of the available substrate, and not its genesis, affect the erosional and depositional potential of the lower Flathead River, the Flathead lobe terminus argument is marginal to this work.

Flathead River Profile

Besides mean channel depth (determined by discharge magnitude and channel width), stream gradients affect the magnitudes of shear stress available to move channel-bed materials. At the same discharge, lower gradient means less shear stress available to move substrates needed for new fluvial surface creation. An explanation of the Flathead River profile roughly indicates where greater or lesser channel bottom stresses occur.

After it leaves Flathead Lake at Polson (Figure 2), the lower Flathead River flows about 16 kilometers over a series of resistant bedrock ledges of the Ravalli group of the Belt Supergroup of metasediments (Soward, 1965). These ledges controlled lake levels before Kerr Dam construction. The dam stands in the middle part of the bedrock section at river kilometer 115.9. Below the dam, the river falls over the bedrock down to kilometer 108.8 with an average gradient of 2.83 m/km (computed from 5-foot vertical relief longitudinal profile map; USGS, 1947).

At kilometer 108.8, the river follows the axis of an anticline in the Ravalli group. To kilometer 56.3, the gradient of the river drops an average of 0.70 m/km. Poorly consolidated Tertiary conglomerate and Pleistocene outwash, diamicts, and glacial lacustrine materials fill the valley. The river is deeply incised in the deposits; the heights of canyon walls range from 50 to 150 meters (Levish et al., 1993). Occasional massive landslides reveal the stratigraphy of various lake beds (Figure 19). The river channel level is controlled by several bedrock outcrops that slightly affect the average gradient. Gravel, sand, and silt characterize recent alluvium, which is underlain by tight lacustrine sediments. The average size of the channel gravel presented in Bonneville Power Administration (BPA) studies (Payne, 1986) ranges from 7 to 15 centimeters. A few high gravel-fill terraces and lake-fill cut terraces document post-Lake-Missoula downcutting of the river.

From kilometer 108.8, the river is mostly a straight run to kilometer 56.3, located just above its confluence with Mission Creek. Besides a few bedrock-controlled bends and associated older, inactive point bars deposited mostly in incised lake sediments, there is very little floodplain or bar development in this reach.

From river kilometer 56.3 to its confluence with the Jocko River at kilometer 40.2, the lower Flathead River forms a transitional reach with an average gradient of 0.38 m/km. At the end of this reach, the river enters an old, well-graded Proterozoic fault valley and is suddenly forced to turn west. The downstream half of this transitional reach exhibits ten mid-channel vegetated islands separated from the uplands during higher flows. Here the lower Flathead River anastomoses.

From kilometer 40.2, where it turns west, to the Clark Fork River at kilometer 0, the lower Flathead River river flattens to an average gradient of 0.24 m/km. The valley walls are mostly Prichard metasediments of the Belt Supergroup; a few diorite sills crop out at the river level near Perma. In this reach, the river flows over glacial lake beds and gravelly, sandy, and silty alluvium. Up to 10 meters of alluvium sit on the glacial lacustrine deposits (Soward, 1965). Small terraces cut in the lacustrine deposits cling to bedrock walls. The lake beds fill hollows within several bedrock controls. A layer of gravel lines the channel and was also present under mid-channel islands that I augered. Twelve tree-covered mid-channel islands and numerous mid-channel gravel bars impart to the river its anastomosing character. The occurrence of the islands corresponds to the sudden decrease in river gradient and the associated entrainment power. The presence of the islands also indicates past large floods that moved material from the steeper part of the river.

Sources of Bedload

To construct new fluvial surfaces for *Populus trichocarpa* and *Salix exigua* to colonize, a stream must have a suitable supply of materials. Such materials can be transported by the stream from a source upstream or be supplied by tributaries, bed and banks.

Lake and Reservoir Traps

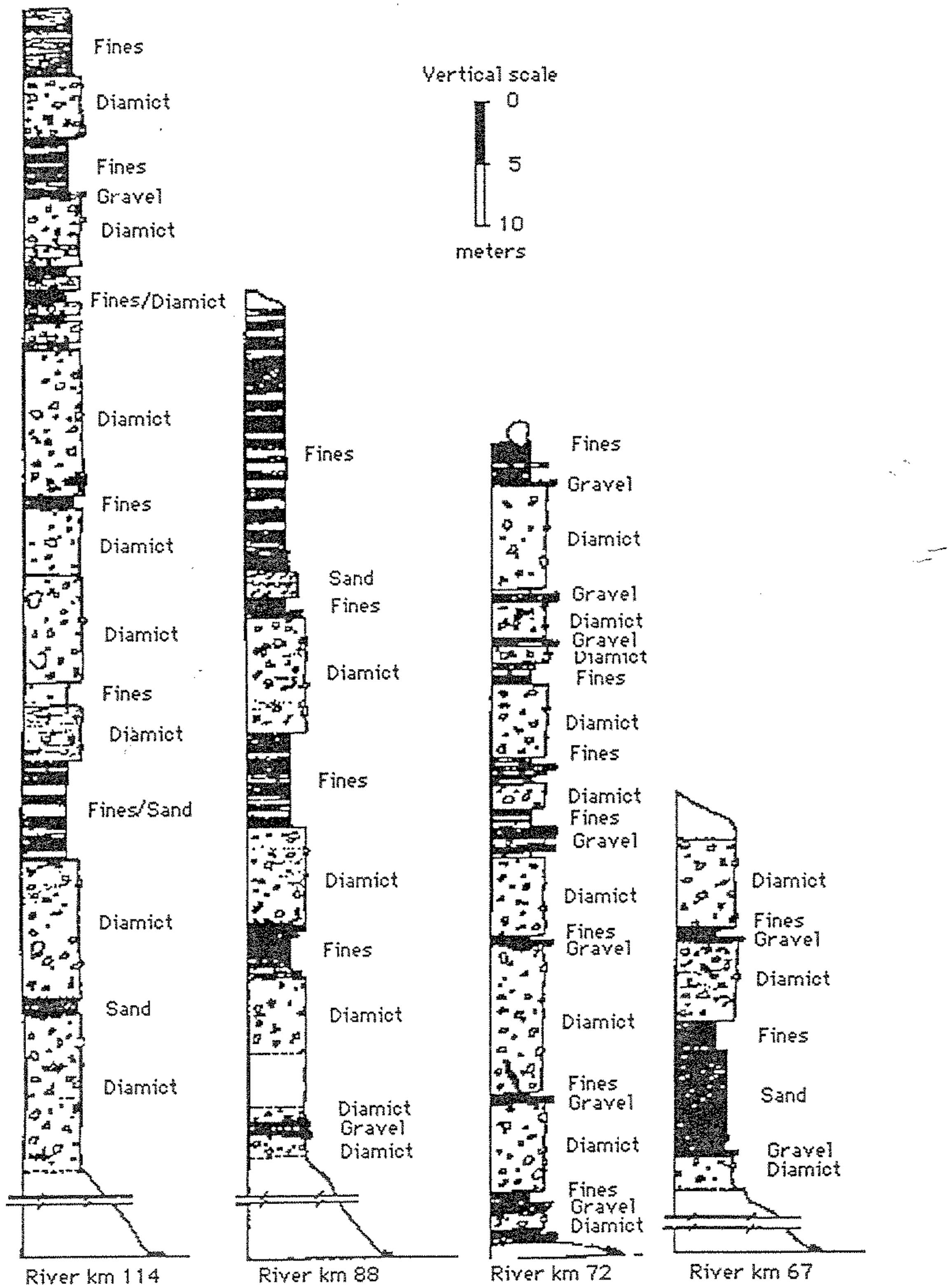
Damming rivers usually decreases peak flows and sediment loads downstream. Flathead Lake must have always functioned as a natural trap for sediment delivered by the upper Flathead River, especially for the coarse bedload. A large, forested delta existed at the mouth of the upper Flathead River before being eroded by artificially high lake levels maintained by Kerr Dam (Lorang, 1992). Hence, Kerr Dam has probably not significantly affected sediment load of the lower River. Although a spring turbidity plume, due to different densities of inflowing warm stream water and cold lake water (Zackheim, 1983), develops in the lake, it is safe to assume that the plume particles are so small that they could not settle out in the more competent transport environment of the lower Flathead River. The impact of Kerr Dam and Hungry Horse Reservoir on the hydrologic-geomorphic system of the lower Flathead River can be thus narrowed to manipulation of streamflows only.

Suspended Sediment

Relationships between suspended sediment concentrations and discharges can provide clues to erosional behavior of streams. Positive correlation between suspended sediment concentration and discharge in the lower Flathead River implies higher sediment availability with higher flows, a fact pointing to importance of high flows in channel-forming processes.

At low and medium discharges, suspended sediment loads of the Flathead River are relatively small. Table 14 shows the three highest and lowest measurements of suspended sediment concentrations and associated instantaneous discharges at the USGS station at Perma. The highest concentration, 65 mg/L, is due to an

Figure 19. Valley fill stratigraphy: lower Flathead River (after Levish et al., 1993)



extremely high water and sediment discharge of the Little Bitterroot River on that day. Figure 20 shows a suspended sediment concentration rating curve synthesized from measurements at the USGS Perma station. Within the recorded range, the curve shows a weak correlation between discharge magnitudes and suspended sediment concentrations. Even though no large flood figures in the measurements, it is logical to assume increases in suspended sediment load with larger discharges. However, once the flow stages reach above the gravel level of the wider channel, availability of fine materials increases dramatically.

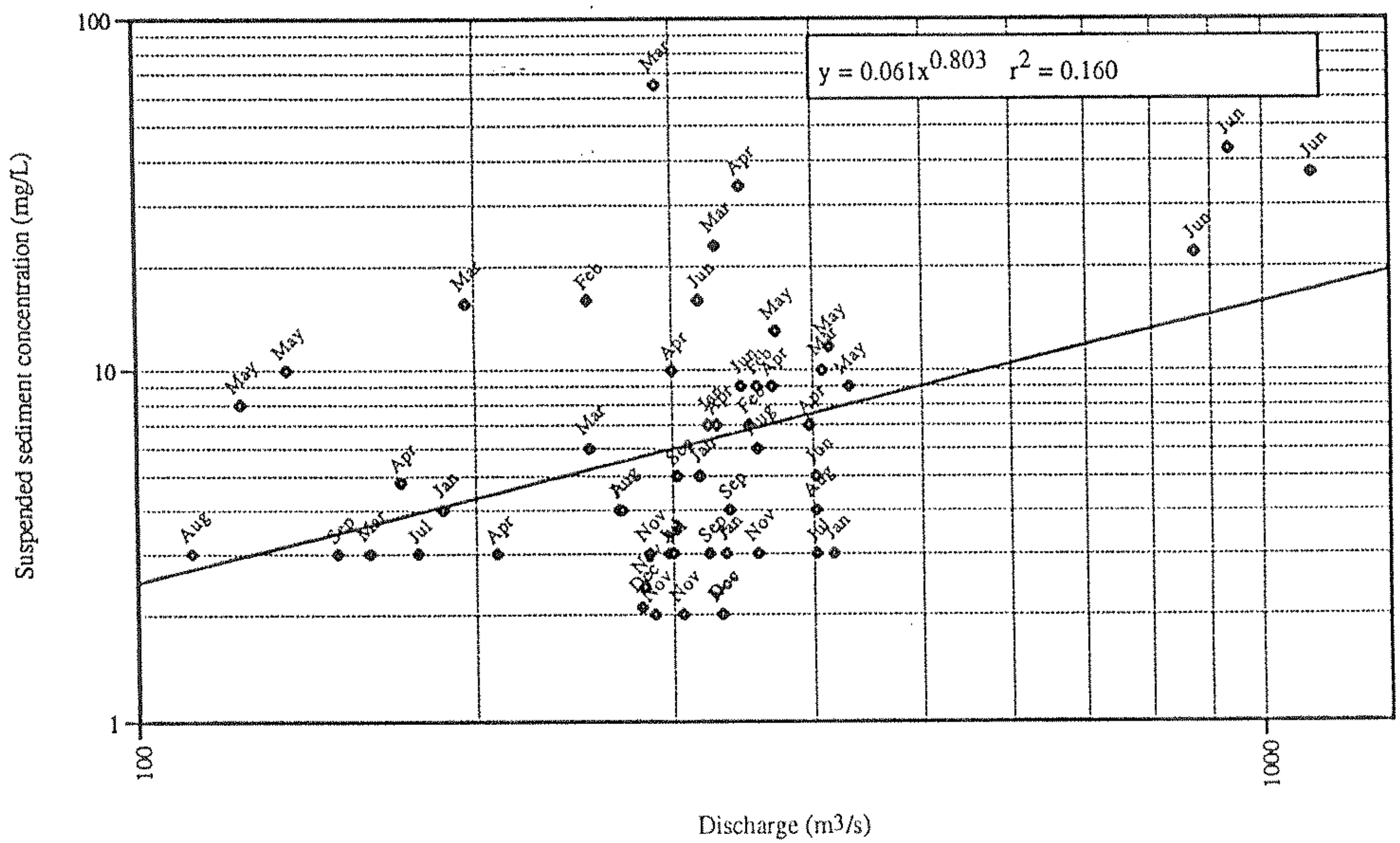
Table 14. Suspended sediment concentration: lower Flathead River at Perma

S.s. concentration mg/L	Month	Inst. discharge (m^3/s)
65	Mar	291.67
43	Jun	934.46
37	Jun	1107.19
2	Nov	288.83
2	Nov	331.31
2	Dec	331.31

Mission Valley Fill as Source of Bedload

Since Flathead Lake prevents bar-size materials from entering the lower Flathead River, the source of such materials must occur downstream of Polson. Any new deposition would largely be derived from the same unconsolidated sources. Levish et al. (1993) describes vertical lithofacies at seven different sites along the river (Figure 19). The sections show diamict and gravel layers as components of the lake beds. The gravel layers are thick at the Crow Creek, one of the perennial tributaries of the river. The diamict disappears near Bison Range. Levish et al. (1993) explain the presence and disappearance of the diamicts by the distance from the Polson moraine and the Mission Mountains front. Soward (1965) estimated that gravel makes up about 30 percent of the diamict volume. A tremendous amount of material was removed during deep incision of the Flathead River into the glacio-lacustrine deposits and outwash. Gravels from the diamicts and outwash ended up in the

Figure 20. Sediment concentration/discharge relationship: Flathead River at Perma



river's channel. At present, large landslides and active gully erosion, apparent on the aerial photos, contribute silt, sand, and some gravel to the river when activated by events of large magnitudes.

Tributaries as Source of Bedload

Lower Flathead River tributaries also provide bedload for bars and other channel forms. In addition to the already mentioned four perennial streams, nine intermittent flashy tributaries enter the east-west portion of the lower Flathead River from the south and two from the north. Three of them, Revais Creek, Magpie Creek and Seepay Creek, contribute significant amounts of gravel to the river. These three streams formed large gravel alluvial fans, and there is a worked gravel pit at the mouth of the Seepay Creek. Some of the tributary fans have grown since the building of Kerr Dam. Relatively, the tributaries are an important source of gravel.

Lower Flathead River Fluvial Dynamics

Since the pioneer cottonwoods and sandbar willows depend on periodic disturbances and bar creation for their establishment, knowledge of fluvial stratigraphy of the islands and of the floods can shed some light on the past frequency of such depositions. Different combinations of sizes and availability of the bar-forming materials and necessary shear stresses (flood magnitudes and channel gradient) result in different frequency of pioneer riparian species establishment.

Fluvial Stratigraphy of Mid-Channel Islands in the Lower Flathead River

In trying to estimate conditions necessary for new fluvial surface creation, one can examine existing islands and bars that once supported or now support *Populus trichocarpa* and *Salix exigua* community types. Fluvial silts and sands comprise the mid-channel islands within the anastomosing floodplain of the lower Flathead River (Figures 4, 5, 6, 7, 8, 9, 19, 11, 34, 36, 38, 40 and

42). Almost all terraces sampled show fining upward sequences of fluvial gravels and sands topped by silt. I found gravels or coarse fluvial sands underlying the mid-channel islands wherever they were within reach of a 1-meter or 2-meter auger. The augered sequences show that the mid-channel islands formed from fluvially deposited silts and sands on top of a gravel foundation. Cut banks along island edges reveal the same depositional sequence. The lack of laterally deposited point bars and the presence anastomosing channels, levees, splays, abandoned side-channels, and flood basins, together with the fining sequence of the deposits suggest overbank deposits dropped during flood recession (Ritter, 1979; Petts and Foster, 1985; Gregory and Walling, 1973). Since Flathead Lake traps almost all sediment of sizes found in the river's floodplain, the substrates must have come from the lower river's banks and tributaries.

Channel Gravel Particle Size Distribution

Gravel forms all current channel bars and appears to underlie the mid-channel islands. To estimate the flows that moved these gravels and created the bars, one has to analyze the gravel particle distribution. Following a procedure described by Dunne and Leopold (1978), I sampled nine upstream points (Figure 21) of mid-channel islands and bars. The surfaces were all gravel bars supporting sparse covers of sprouting black cottonwoods and sandbar willows. I assumed the mid-channel bars to be depositional features created by floods of some magnitude and thus of finer gravel than the thalweg. That was the case, as I will show later.

A 50-foot measuring tape was stretched across a bar, and then, with my eyes averted, I touched and picked a rock approximately every half-foot. In the laboratory, I then measured the intermediate axis of each rock and divided the rocks into size classes with $\sqrt{2}$ interval (Dunne and Leopold, 1978); this class interval is commonly used in stratigraphic analysis and is considered fine enough for percent-by-weight distribution analysis. All rocks in each size class were then weighed to find out the distribution by weight.

To account for the higher probability of picking up larger rocks, I corrected by dividing each class' total weight by the square of the mean diameter of the particle size (Dunne and Leopold, 1978). I did not sample any particle smaller than two millimeters. Table 15 and Figure 22 show the percentile size distribution of the nine samples.

Figure 21. Locations of gravel sampling points

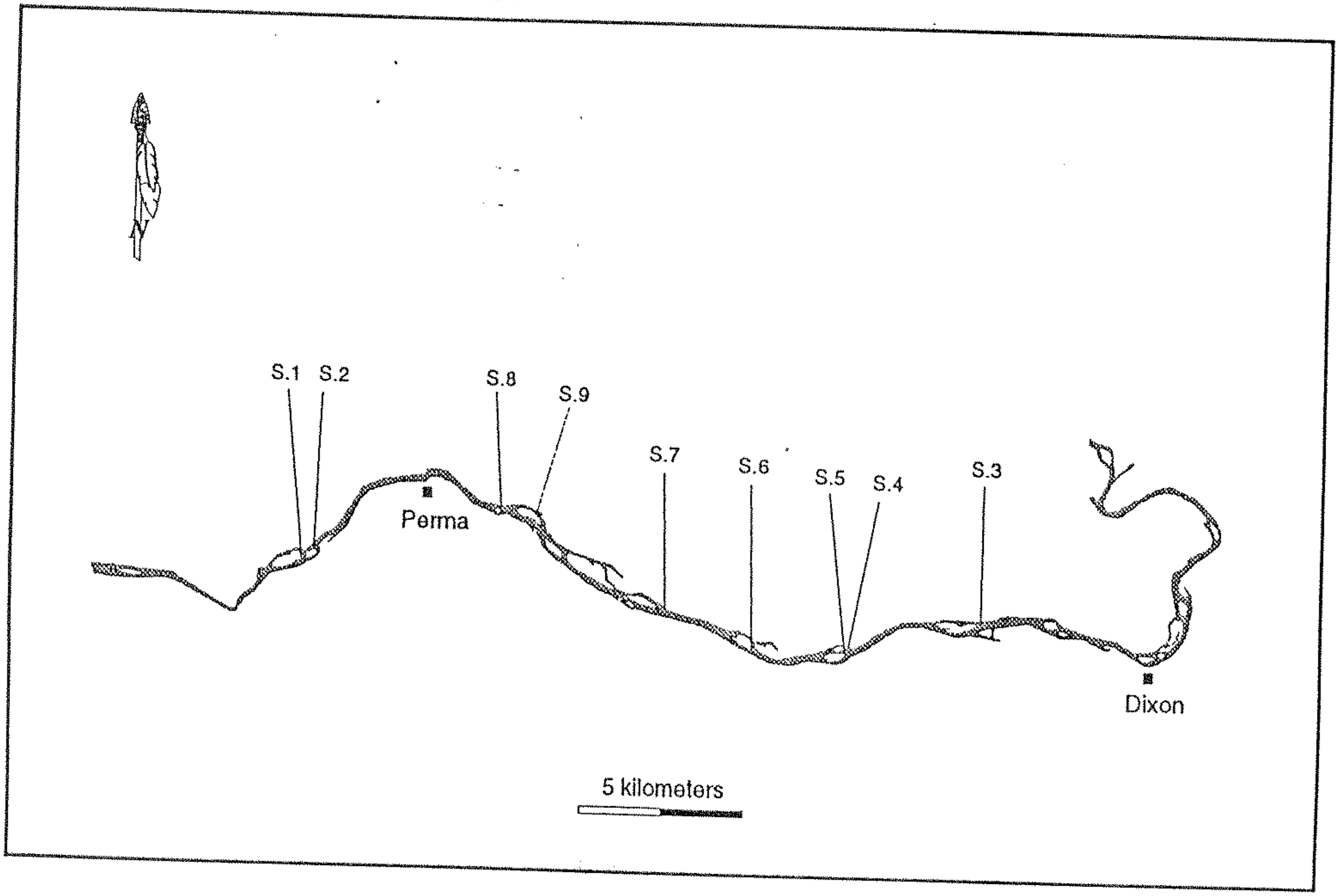


Table 15. Substrate weight distribution by size class in percent

Class interval (mm)	Sample Identification Number 1	2	3	4	5	6	7	8	9
2.1 - 4.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4.1 - 6.0	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.1 - 8.0	1.0	0.2	0.0	0.2	0.0	0.0	0.0	0.0	0.0
8.1 - 11.0	3.0	2.5	0.9	0.6	0.0	1.8	2.9	8.4	10.6
11.1 - 16.0	5.7	5.8	4.3	1.5	6.5	7.7	8.0	13.8	8.4
16.1 - 23.0	20.1	8.8	11.5	7.0	15.3	20.7	30.6	13.0	48.9
23.1 - 32.0	22.1	24.9	28.2	23.5	23.0	21.2	44.1	36.9	21.5
32.1 - 45.0	26.8	27.8	26.6	26.9	36.9	22.0	14.4	22.5	10.6
45.1 - 64.0	14.8	12.6	12.1	27.5	18.0	21.7	0.0	5.2	0.0
64.1 - 90.0	6.0	10.1	9.7	12.9	0.0	4.8	0.0	0.0	0.0
90.1-128.0	0.0	7.1	6.8	0.0	0.0	0.0	0.0	0.0	0.0
Total	99.8	99.9	100.1	100.1	99.7	99.9	100.0	99.8	100.0

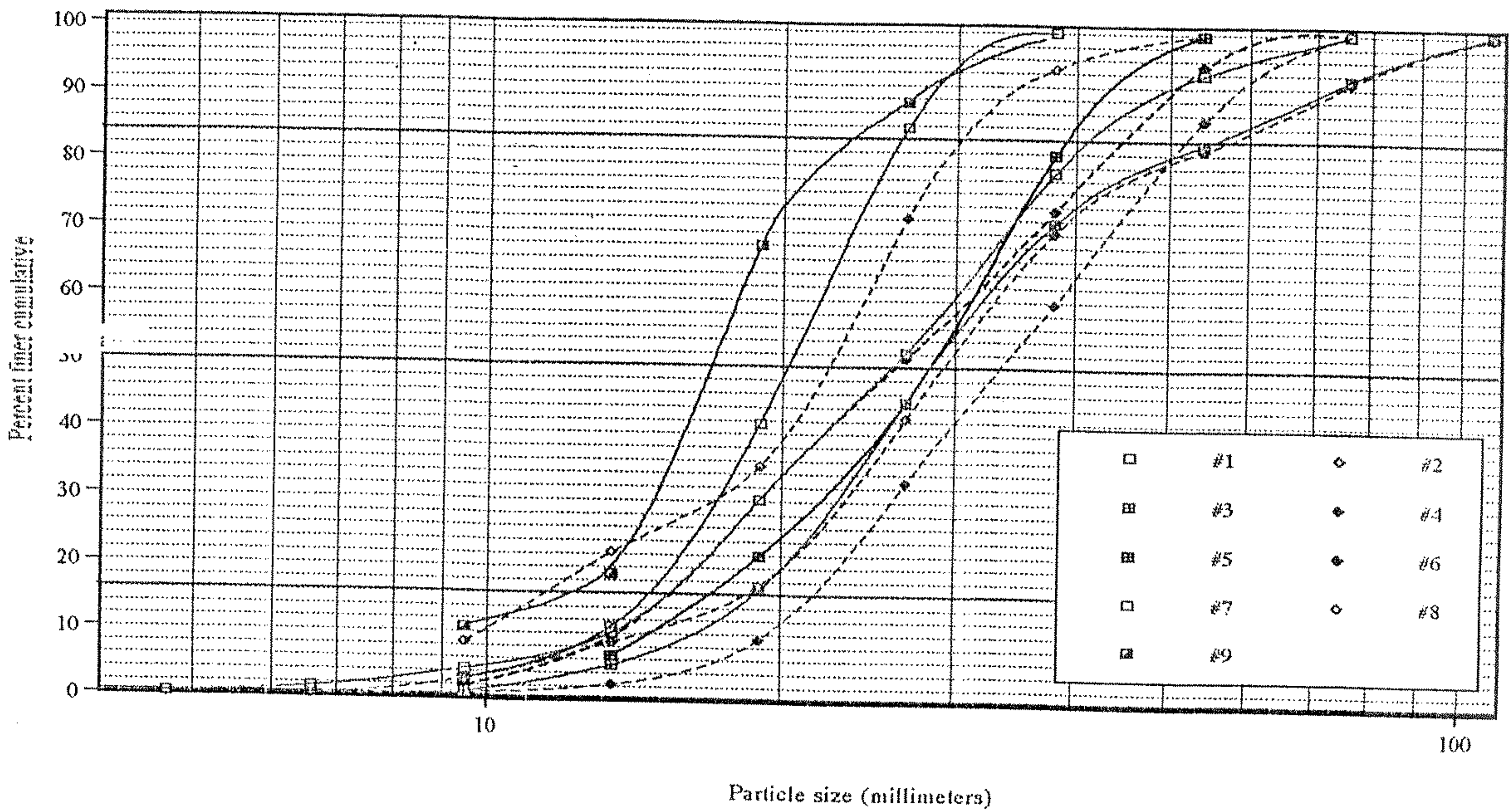
Sample 9 with the smallest median particle size (17 mm) came from a gravel bar in a small side-channel and thus does not represent transport competency of the main channel. Leaving sample 9 out, the median particle size of the eight samples ranges from 20 millimeters to 33 millimeters (Table16), and the average median particle size of the eight samples is 26 millimeters. I will use both end-range values (20 and 33 mm) to compute the flows necessary to entrain the gravels that now form the low-level bars.

Table 16. Basic percentiles* of the nine gravel samples in millimeters

Sample #	16%	50%	84%
1	16	26	40
2	19	29	55
3	19	28	54
4	22	33	51
5	17	28	38
6	16	26	44
7	14	20	26
8	11	22	30
9	12	17	23

* assumed to represent one standard deviation from the mean at 50%

Figure 22. Particle cumulative frequency distribution



Payne (1986) reports that the majority of bed gravels along channel transects in the anastomosed reach lie in the range of 2.5 to 7.6 centimeters; he also notes some cobbles in the range of 7.6 to 15.2 centimeters. The bed substrate thus appears to be coarser than the mid-channel bars. Most bed material along transects of the incised reach range from 7.6 to 15.2 centimeters (Payne, 1986), which seemingly reflects a higher competency of the steeper incised reach.

Relative Stability of Anastomosed Flathead River Floodplain

Stable floodplains have larger proportions of climax riparian community types to pioneer ones. The following lines of evidence point to relative stability of the Flathead River's floodplain: 1) the aerial photo interpretation of the riparian zone of the lower Flathead River, 2) the stability of the channel gravel (as will be shown later in shear stress calculation), 3) the low gradient of the lower anastomosed portion of the lower Flathead River, 4) the lack of new bar creation and associated sandbar willow/cottonwood establishment, and 5) the cohesive nature of the glacial and lacustrine silt and clay banks.

Smith (1973,1983), and Petts and Foster (1985) describe stable, anastomosed streams as rapidly aggrading low-energy channel and wetland complexes, which require for their formation a rather unusual combination of geomorphic and climatic conditions. The channels of anastomosed rivers are characterized by lateral stability (low gradients and cohesive banks). However, they may move laterally with major events, which results in overbank and levee deposits, rapid filling of abandoned channels, and splays prograding into floodplain wetlands.

Anabranch Formation

Knighton and Nanson (1993) regard formation of anabranches as a response to a flow regime dominated by isolated events of relatively large magnitude. They document two case studies of anastomosing streams, the Magdalena River in Colombia and Columbia River in Canada, where aggradation is related in part to abrupt decreases in gradient. After presenting examples of anastomosing rivers from around the world, Knighton and Nanson (1993) conclude that anastomosing rivers are found in a wide variety of climates ranging from cool warm, from humid to semi-arid. The factors that unite such rivers are low gradients (0.0039 to 0.000096 from the published data) and relatively stable banks due to cohesive fine materials and/or binding root mats. Channel deposits result mostly from vertical aggradation during low frequency, high magnitude floods.

Harwood and Brown (1993) describe three micro-processes they found responsible for creating the anastomosing pattern of the Gearagh River in Ireland: 1) localized bank protection by root masses and concentration of both bank and overbank erosion between them, 2) dissection of islands by flows caused by channel backing-up behind debris dams, and 3) distribution of flood waters throughout the system, onto the islands and dead-water zones. These processes reduce stream power available for lateral channel migration.

Harwood and Brown also found that islands in the Gearagh River were underlain by gravel at some absolute level. They attributed this to damming of some faster channels and opening of some fast channels during a competent flood.

Indeed, all of these observations apply to the lower portion (downstream from the confluence with the Mission Creek) of the lower Flathead River. The average gradient of that reach of the river is 0.00038 to 0.00024 (abrupt decrease from 0.0007), the mid-channel islands are well vegetated with woody plants and composed of fine (silt and sand) materials derived from the glacial Lake Missoula sediments, and the river morphology did not change noticeably even after a 2,059 m^3/s 1948 flood (approximately a 9-year flood). The rich assortment of various erosional and depositional environments, as apparent from the riparian zone transects, provide varied localized energy environments in floods large enough to entrain and transport the sediments.

Gravel Entrainment Analysis

Fluvial gravels form the channel and bars of the lower Flathead River. Relative stability of floodplains and thus importance of either primary or secondary riparian plant succession depends on frequencies of flows capable of moving such gravels. There is a relationship between the channel profile, channel geometry, flood magnitude, and sizes of entrainable bed and bank materials.

Shear Stress Theory

One indirect way to estimate discharges competent to move large particles through transects of known dimensions is to calculate the lowest threshold of shear stress capable of moving the particles. Estimating stresses causing incipient motion of a particle in turbulent flow in a natural channel is quite difficult. The concept of critical shear stress (T_c) introduced by Shields (1936) has been used in many studies to estimate discharges necessary to entrain and transport bed particles and is accepted as a useful approximation (Wiberg and Smith, 1987; Wilcock, 1988; Harvey et al., 1993; Andrews, 1983; Gordon at el., 1992). The Shields' equation computes the incipient motion as a set of conditions expressed as:

$$T_c = T_* (\gamma_s - \gamma_w)\, dg \qquad (1)$$

where T_c = critical shear stress (N/m^2), T_* = dimensionless critical shear stress, γ_s = specific weight of sediment (N/m^3), γ_w = specific weight of water (N/m^3), g = gravitational acceleration (m/s^2) and d = diameter of bed particles (m).

The critical shear stress equation assumes that when a bed particle is about to begin motion, the combined shear forces (drag and lift) are in balance with the effective gravitational and resistance forces.

The dimensionless critical shear stress (T_*) is a function of particle shape, arrangement (angle of repose), protrusion, and fluid properties (viscosity and type of flow). Reported values for T_* range from 0.03 (Meyer-Peter and Mueller, 1948; Parker et al., 1982; Andrews, 1983) to 0.06 (Shields, 1936; Kondolf, 1987), with 0.047 widely used in engineering practice. Gordon et al. (1992) present 0.035 to 0.065 as a range for mixed, settled, random grain arrangement bed sediments. I will compute the incipient motion conditions using T_* values of 0.035 and 0.065 to address the range of possible conditions and uncertainties associated with variable conditions of natural channels.

Representative Grain Size

Computing bed shear stress as a function of grain size poses the question of which grain size to use to represent a coarse gravel mixed-size sediment. Wilcock and Southard (1988) and Wilcock (1992) present a model of bulk flow competence where median grain size (d_{50}) is used to represent the mixture. After analyzing 11 different mixed-size sediments (d_{50} = 0.18 to 2.1cm) of varied sorting and distributions, they concluded that d_{50} provides a reliable minimum estimate of the shear stress necessary to initiate general movement of a mixed-size sediment, with the possible exception of strongly bimodal distributions. All nine samples from the lower Flathead River are unimodal. The d_{50} representation assumes that the whole substrate begins to move within a small shear stress range. Their conclusion is supported by Parker et al. (1982) and Andrews (1983), and d_{50} has been widely used to represent natural channel gravel mixtures.

Shear Stress as Function of Flow and Energy Gradient

Magnitude of a flow controls active channel mean depth. The depth and channel (energy) gradient then control the bottom shear stress. Shear stress as a function of a flow of a certain magnitude can be computed using DuBoys equation (2):

$$T = \gamma_w D S \qquad (2)$$

where T = bottom shear stress (N/m^2), γ_w = specific weight of water (N/m^3), D = mean depth of water (m) and S = water surface or energy slope. The mean depth substitutes for hydraulic radius in a wide, rectangular channel such as shown by the lower Flathead River transects used in this analysis.

Channel Transects Used in the Calculations

Payne (1986) presents nine surveyed transects of the first anastomosed reach of the river (Figure 2) and six surveyed transects of the third incised reach of the river. He also includes their stage-discharge rating tables. Of the nine transects from the anastomosed reach, only two cross single channels. Since the potential error in generating rating curves at the multiple channel transects may be large (no hydraulic model was used to calculate backwater effects and the flow at some of the individual channels was arrived at by proportioning the flow from the single-channel transects), I will use only the two single-channel transects (Figures 23 and 24) to calculate the shear stress generated by a 2-year flood (1,291 m^3/s) from the pre-dam annual flood frequency distribution (Figure 13). A 1.5 to 2-year flood is a useful approximation of bankfull or channel-forming discharges in most meandering streams flowing in their own alluvium (Dunne and Leopold, 1978), though, as I will show later, not the case for the lower Flathead River. To show what the difference in gradient between the anastomosed and the incised reach means in terms of power to entrain and move different sizes of gravel, I will also calculate shear stresses for two incised-reach transects (Figures 29 and 30).

The rating curves for the transects end at discharge 1,699 m^3/s, which is at the upper stage limit of the survey. The rating curves for the first transect were developed from three stage-discharge relationships at 1,110 m^3/s, 303 m^3/s and 143 m^3/s, and the rating curves for the second transect were developed from three stage-discharge relationships at 1,110 m^3/s, 323 m^3/s and 136 m^3/s (the range of stage-discharge relationships was limited by the time of the survey) by fitting a power equation curve to the three discharge measurement points and subtracting the point of zero flow from the stage (Herschy, 1985). Figures 25 and 26 show the discharge-depth relationships for the two anastomosed-reach transects. Use of the developed stage-discharge relationships for discharges larger then 1,700 m^3/s would underestimate the flows, since the stage-discharge relationship changes dramatically once

Figure 23. Profile: Reach I; channel transect #1; (river km 27.5)

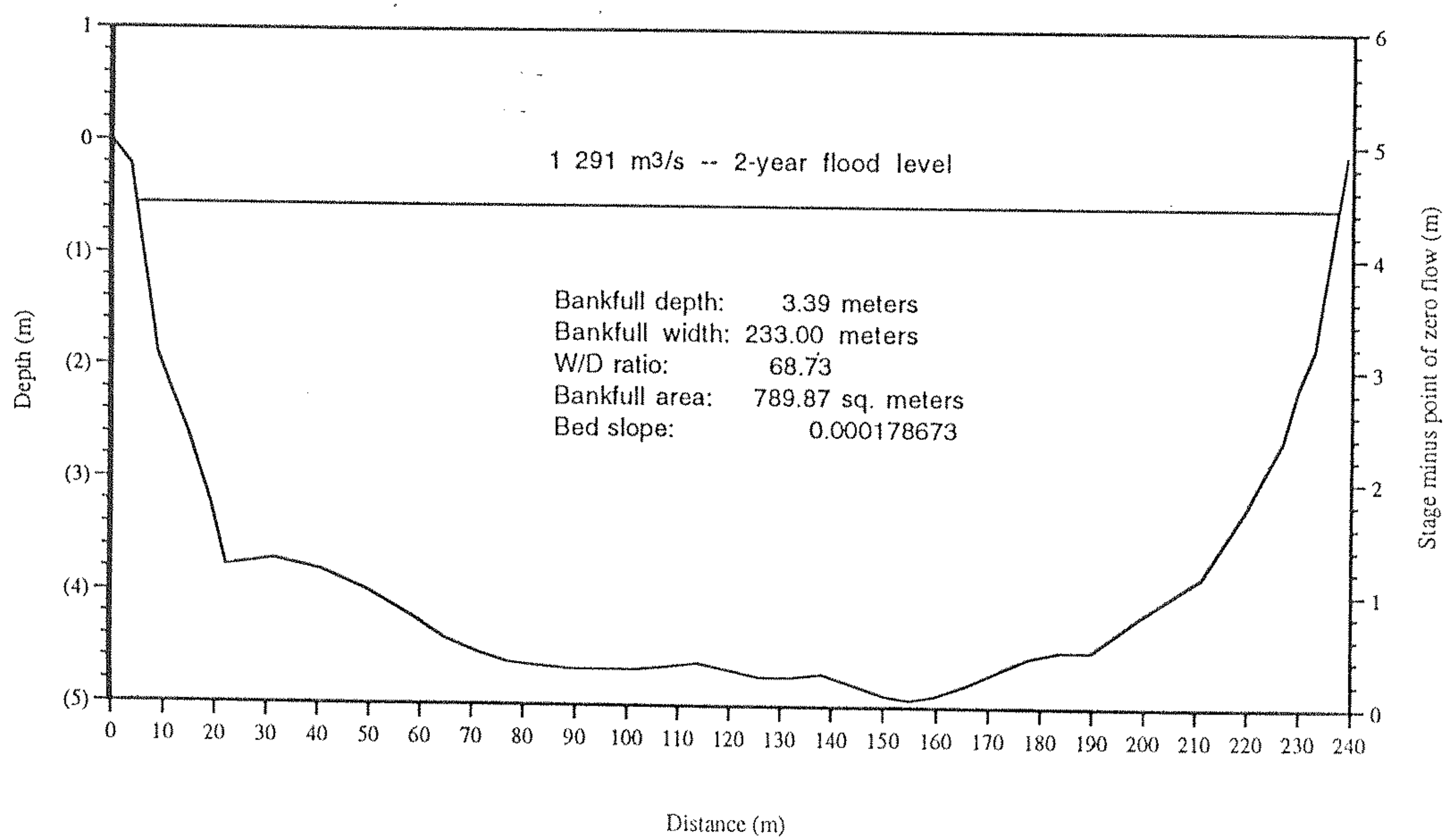


Figure 24. Profile: Reach I; channel transect #2; (river km 32)

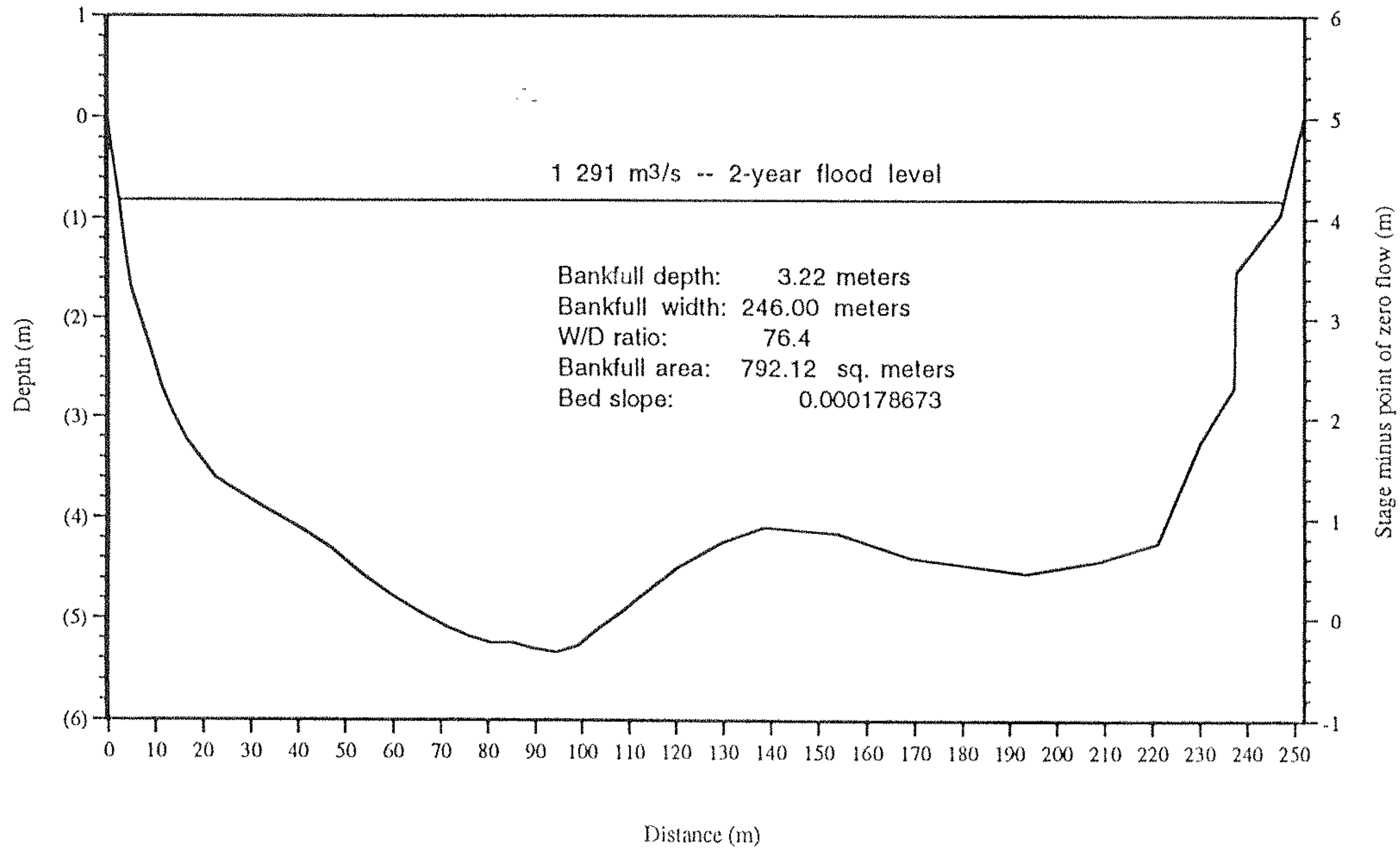


Figure 25. Rating curve for channel transect #1

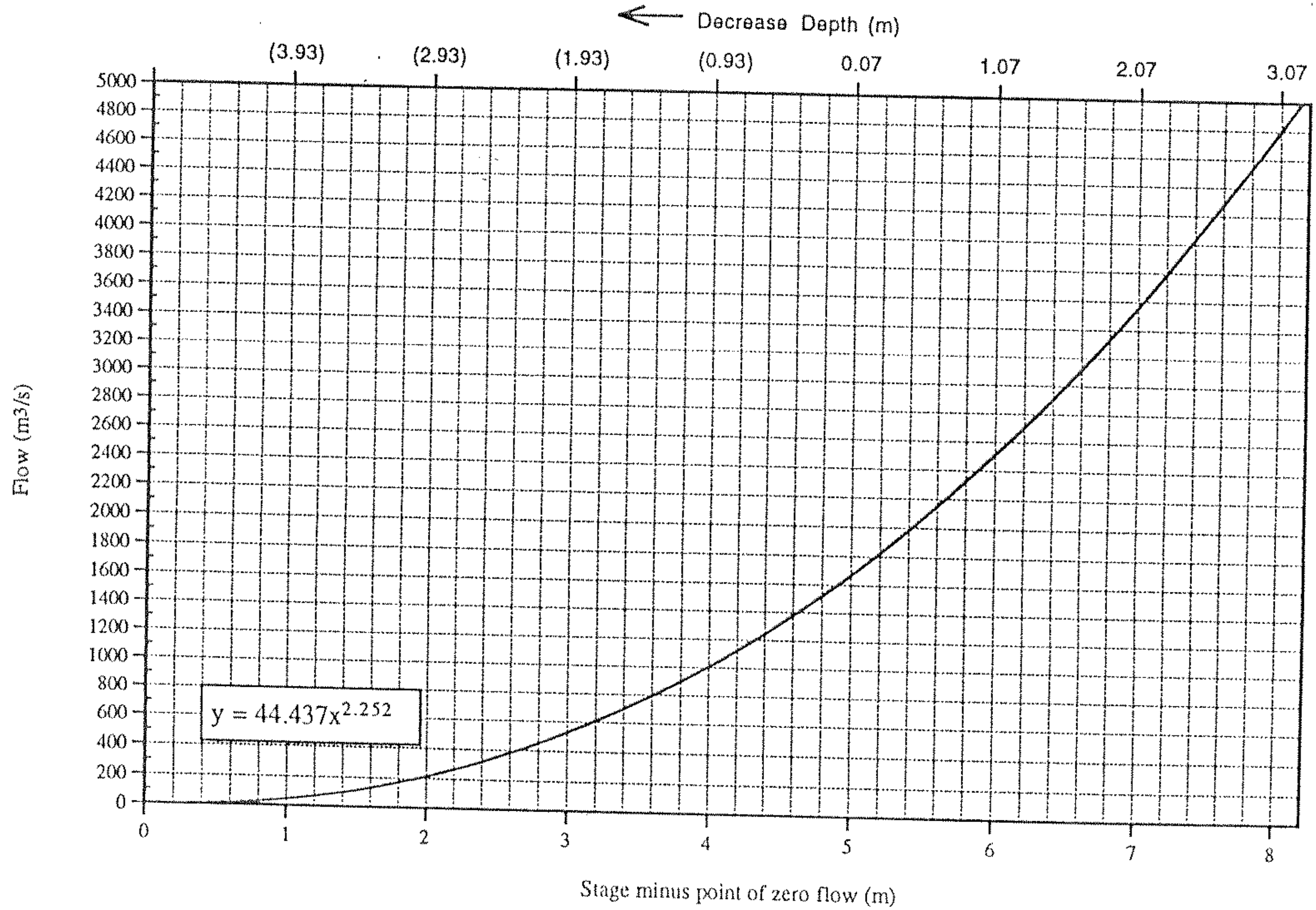
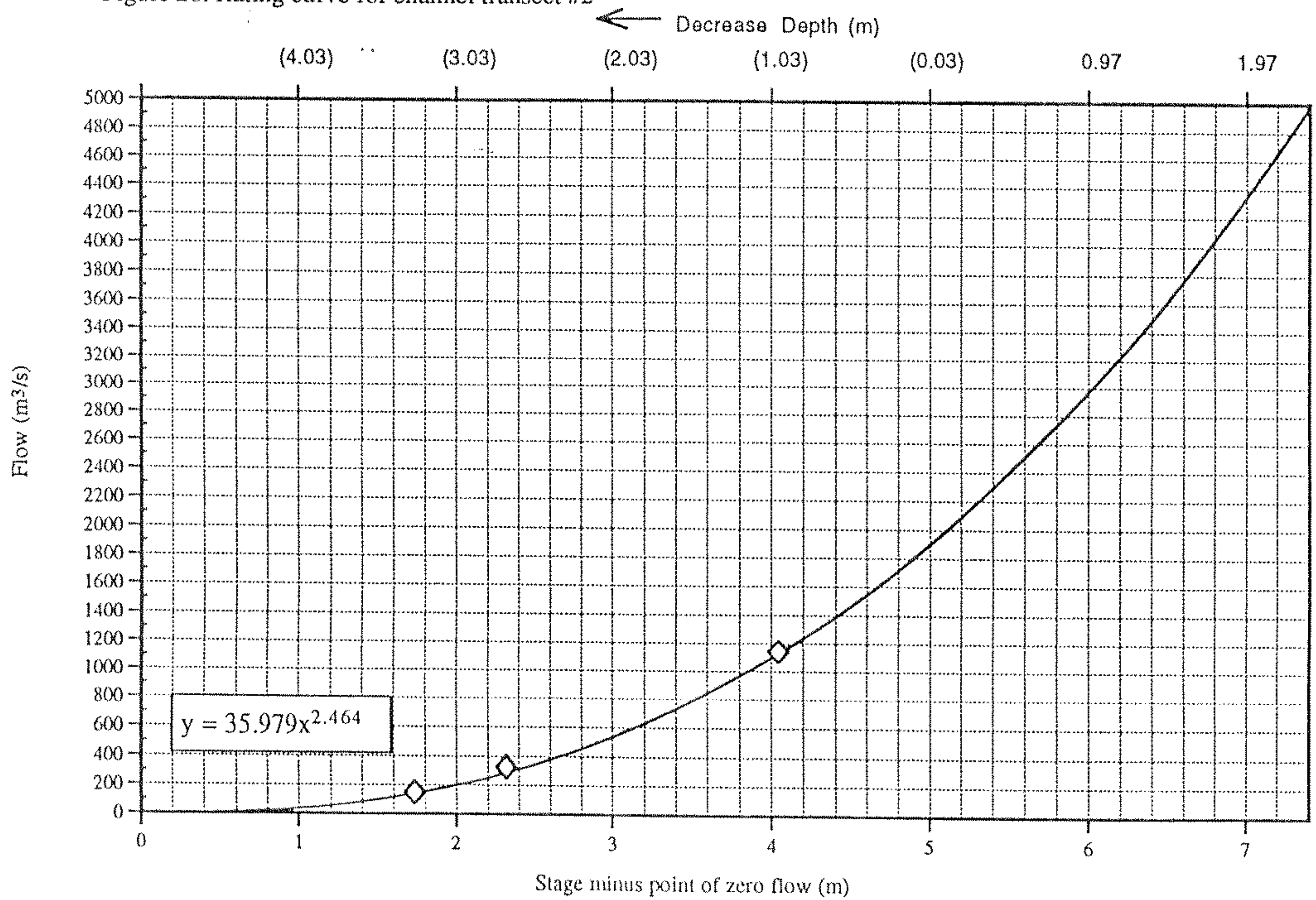


Figure 26. Rating curve for channel transect #2



the flows go overbank. The lack of accurate surveys across the whole floodplain will limit the analysis of the flows required to move the bar gravels.

Particle Sizes Movable by 2-Year Floods

The average specific weight of Belt Supergroup metasediments is 2,670 N/m^3 (Sheriff, 1986). The channel slope at the two transects of the anastomosed reach is 0.000178673 (USGS, 1947). The channel slope can serve as an approximation of an average energy gradient at higher flows; in reality, there will be somewhat different (lower) local energy gradients at lower flows imposed by local hydraulic controls. The mean 2-year-flood depths (calculated as an average depth from all measurements) for the two transects are 3.39 and 3.15 meters respectively (Figures 23 and 24). Gravitational acceleration is 9.807 m^2/s, and specific weight of water is 1000 N/m^3.

Then, according to equation (2), a 2-year flood at transects #1 and #2 generates bed shear stresses of 5.94 and 5.64 N/m^2 respectively (Table 17).

Table 17. Bed shear stress generated by 2-year flood at channel transects #1 and #2

Transect number	2-year flood mean depth (m)	Bed shear stress (N/m^2)
1	3.39	5.94
2	3.15	5.64

According to a rearranged equation (1)

$$d = T_c / T_* (\gamma_s - \gamma_w) g$$

Figure 27. Mean depth/stage relationship channel transect #1

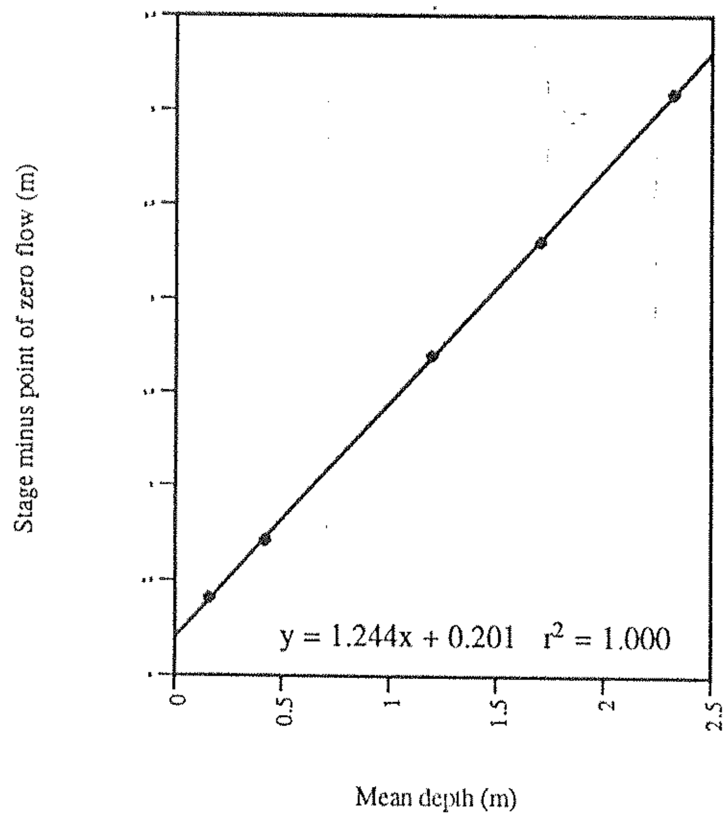
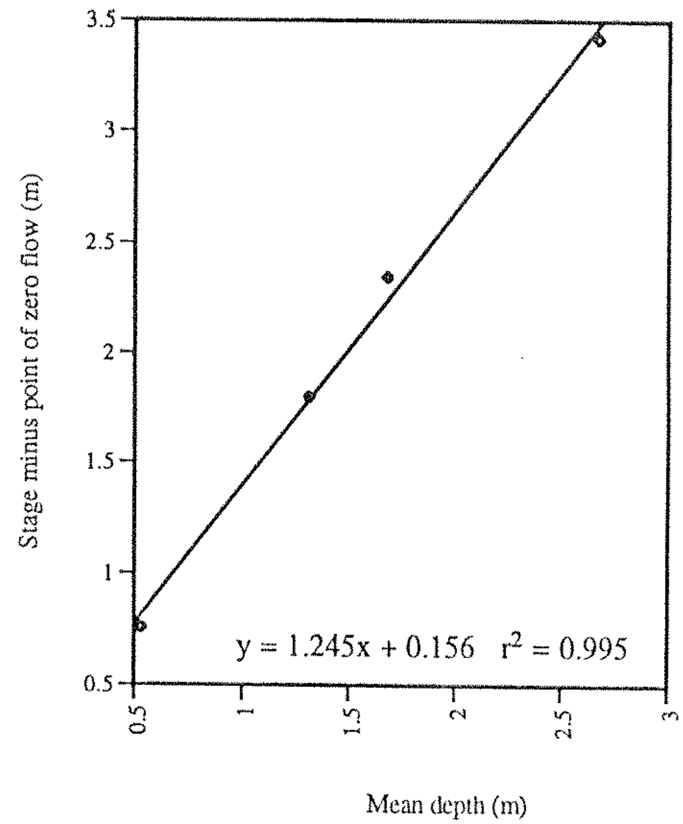


Figure 28. Mean depth/stage relationship channel transect #2



and using 0.035 as the dimensionless critical shear stress, the 2-year flood at transects #1 and #2 can entrain particles with 9.6 and 9.8 millimeters diameter respectively. With 0.065 as the critical dimensionless shear stress, particles between 5.1 and 5.3 millimeters diameter can be entrained and moved by a 2-year flood at the two transects (Table 18).

The calculated diameter values are less then the 16th percentile of any of the nine gravel bars sampled.

Table 18. Diameter of particles entrainable by 2-year flood at channel transects #1 and #2

Transect #1

Dimensionless critical shear stress	Particle diameter (mm)
0.035	9.6
0.065	5.1

Transect #2

Dimensionless critical shear stress	Particle diameter (mm)
0.035	9.8
0.065	5.3

Rating curves for transect #3 and transect #4 of the incised reach (Figures 31 and 32) were developed from three discharge measurements of 1,051 m^3/s, 251 m^3/s and 91 m^3/s (Payne, 1986). The transects have 0.000728438 channel bed slope (USGS, 1947) and mean 2-year-flood depth of 3.02 and 2.85 meters respectively. They correspond to bed shear stress of 21.57 and 20.36 N/m^2. A 2-year flood at transect #3 can then entrain and move particles between 20.26 (dimensionless critical shear stress 0.065) and 37.62 (dimensionless critical shear stress 0.035) millimeters diameter.

The results are similar for the transect #4; the diameters of particles that can be entrained range between 19.12 and 35.52

millimeters. The median size of the eight samples from the mid-channel bars from the first reach ranges between 20 and 30 millimeters. These sizes are within the range of the bar gravels from the anastomosed reach.

Mean Depth Entrainment Thresholds for the Anastomosed Reach

If the median gravel size distribution, d_{50}, from the eight sites sampled (excluding the side-channel) is used to represent the mixed-size substrate, one can calculate the mean depths that would generate shear stress necessary to entrain and move the gravels.

With d_{50} = 20 millimeters and dimensionless critical shear stresses of 0.035 or 0.065, bed shear stresses of 11.46 or 21.29 N/m^2 respectively would be needed to entrain and move the gravel mixture (Table 19).

Using d_{50} = 33 millimeters and dimensionless critical shear stresses of 0.035 or 0.065, bed shear stress of 18.92 or 35.13 N/m^2 respectively would be needed to entrain and move the gravel mixture.

Table 19. Bed shear stress entrainment threshold for 20 mm particles at channel transects #1 and #2

Dimensionless critical shear stress	Bed shear stress (N/m^2)	Mean depth (m)
0.035	11.46	6.54
0.065	21.29	20.05

Rearranged equation (2)

$$D = T_c / \gamma_w S$$

and the smallest and largest value of the bed shear stress needed

Figure 30. Profile: Reach III; channel transect #4; (river km) 73.8

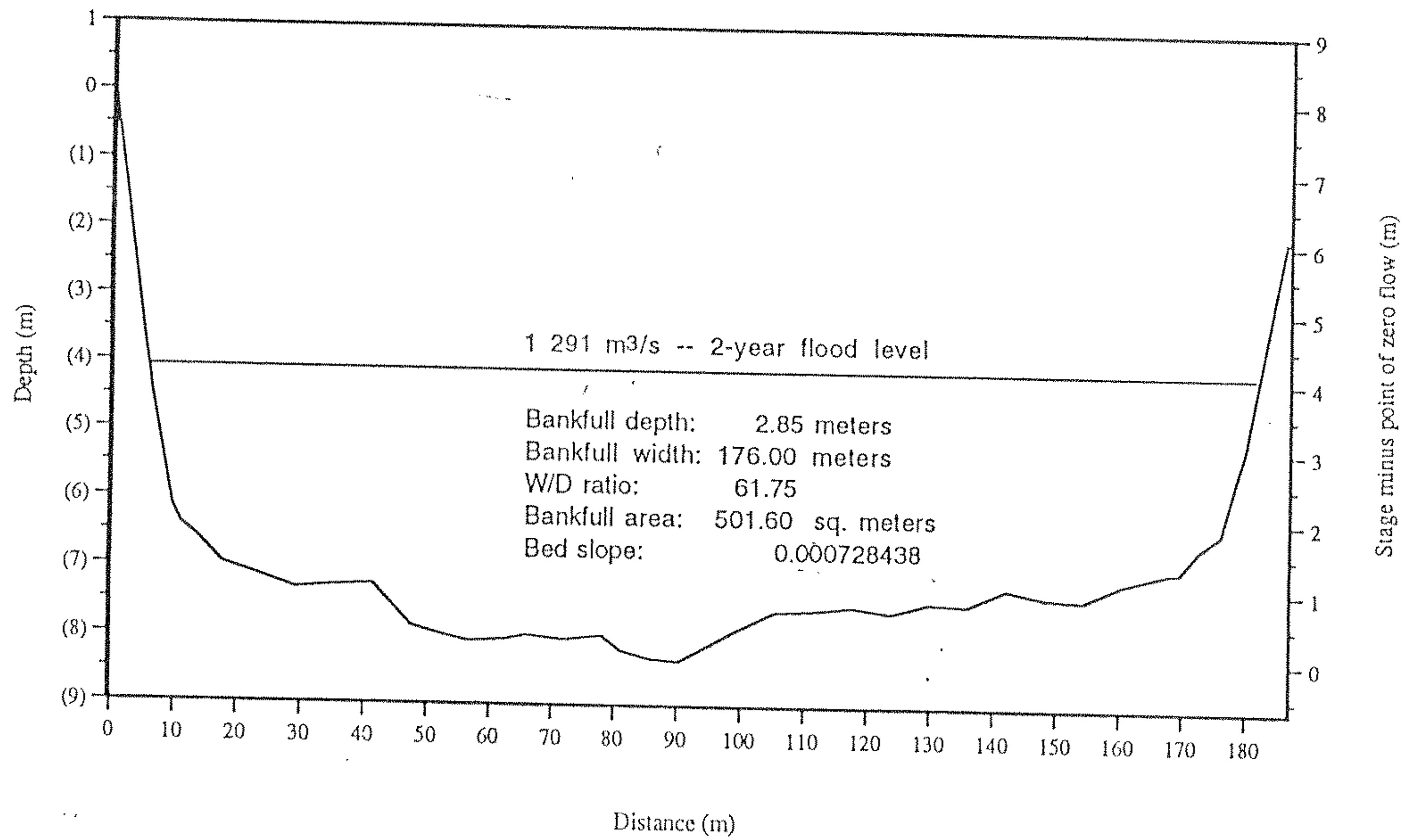


Figure 29. Profile: Reach III; channel transect #3; (river km) 73.7

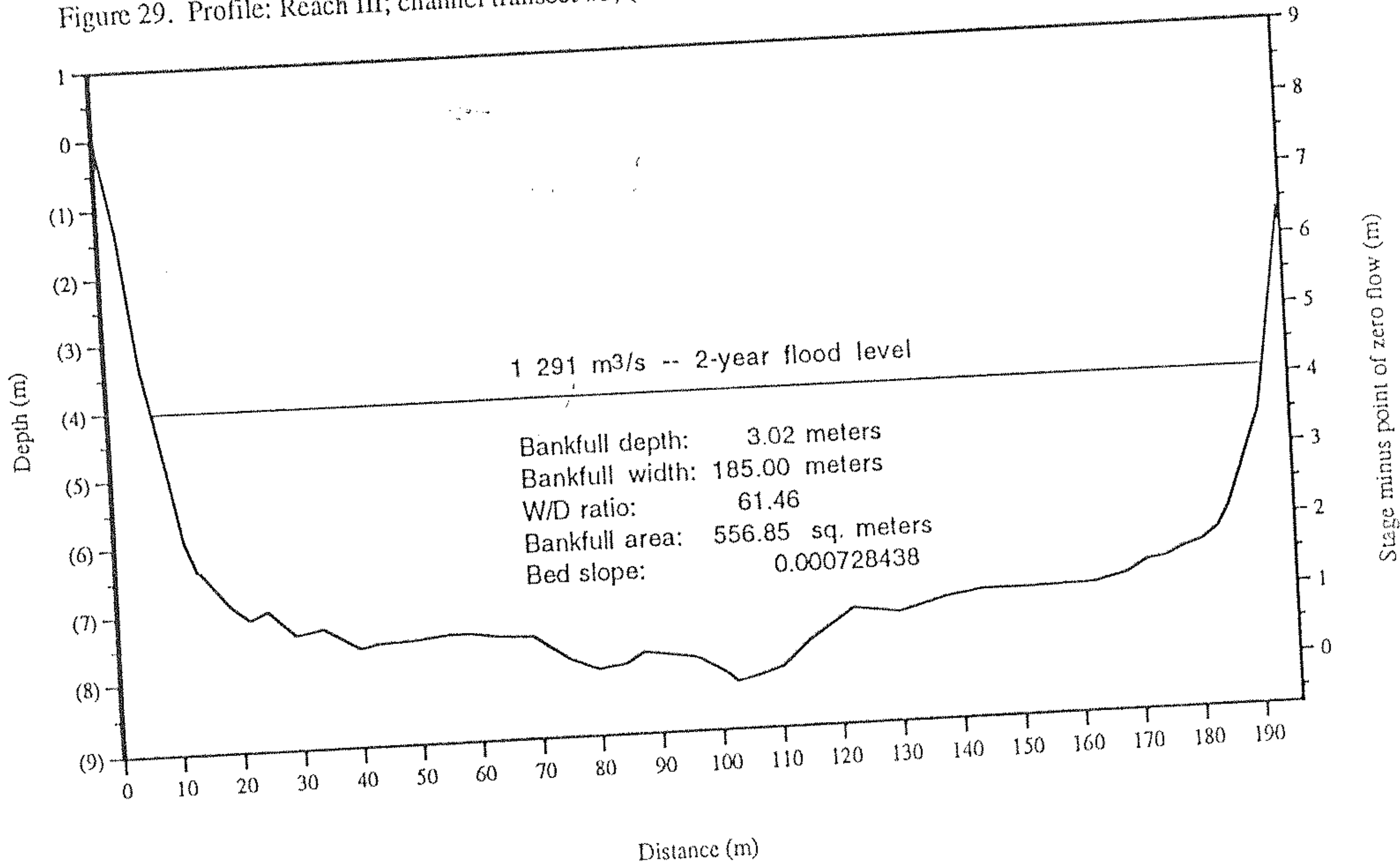


Figure 31. Rating curve for channel transect #3

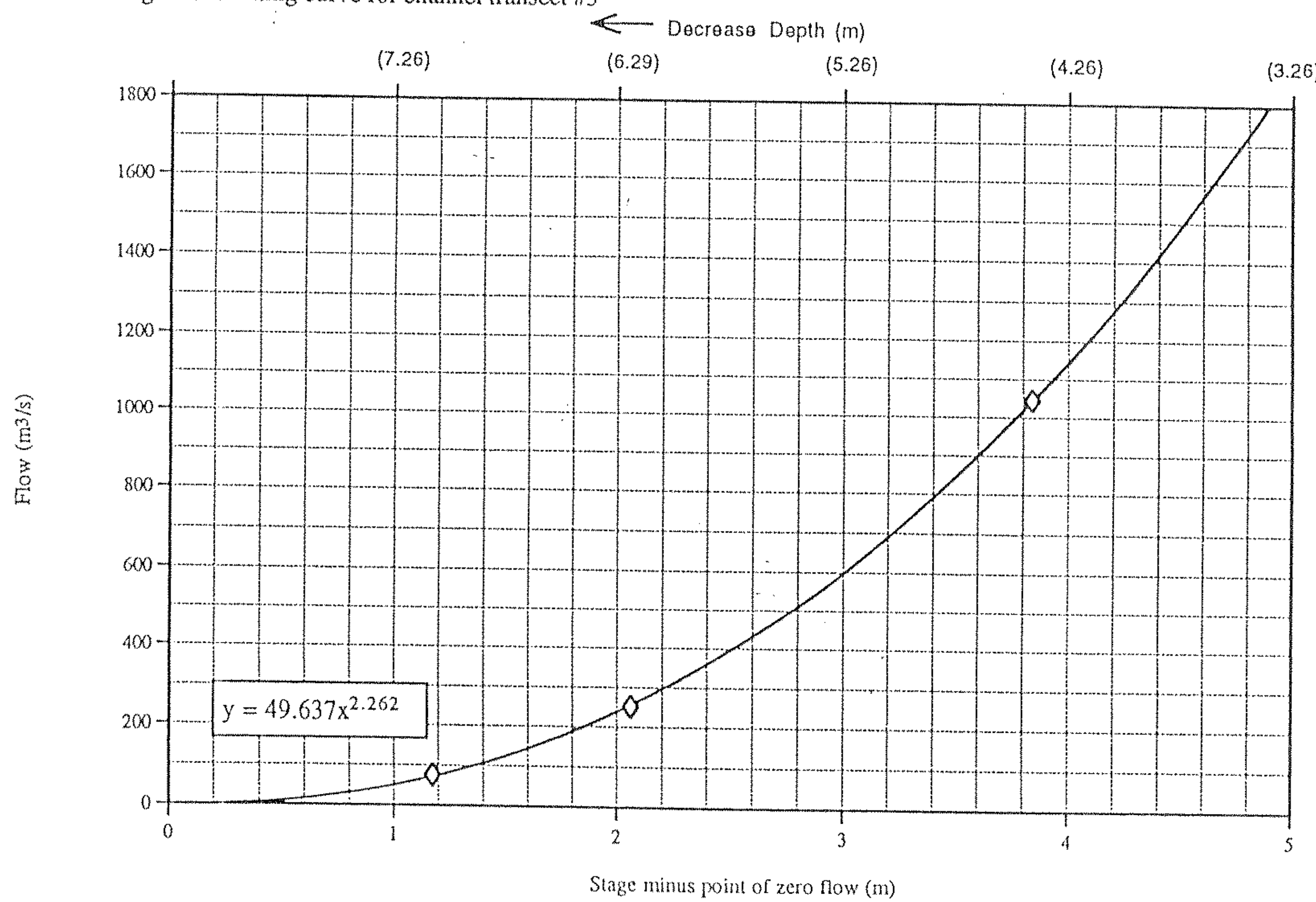
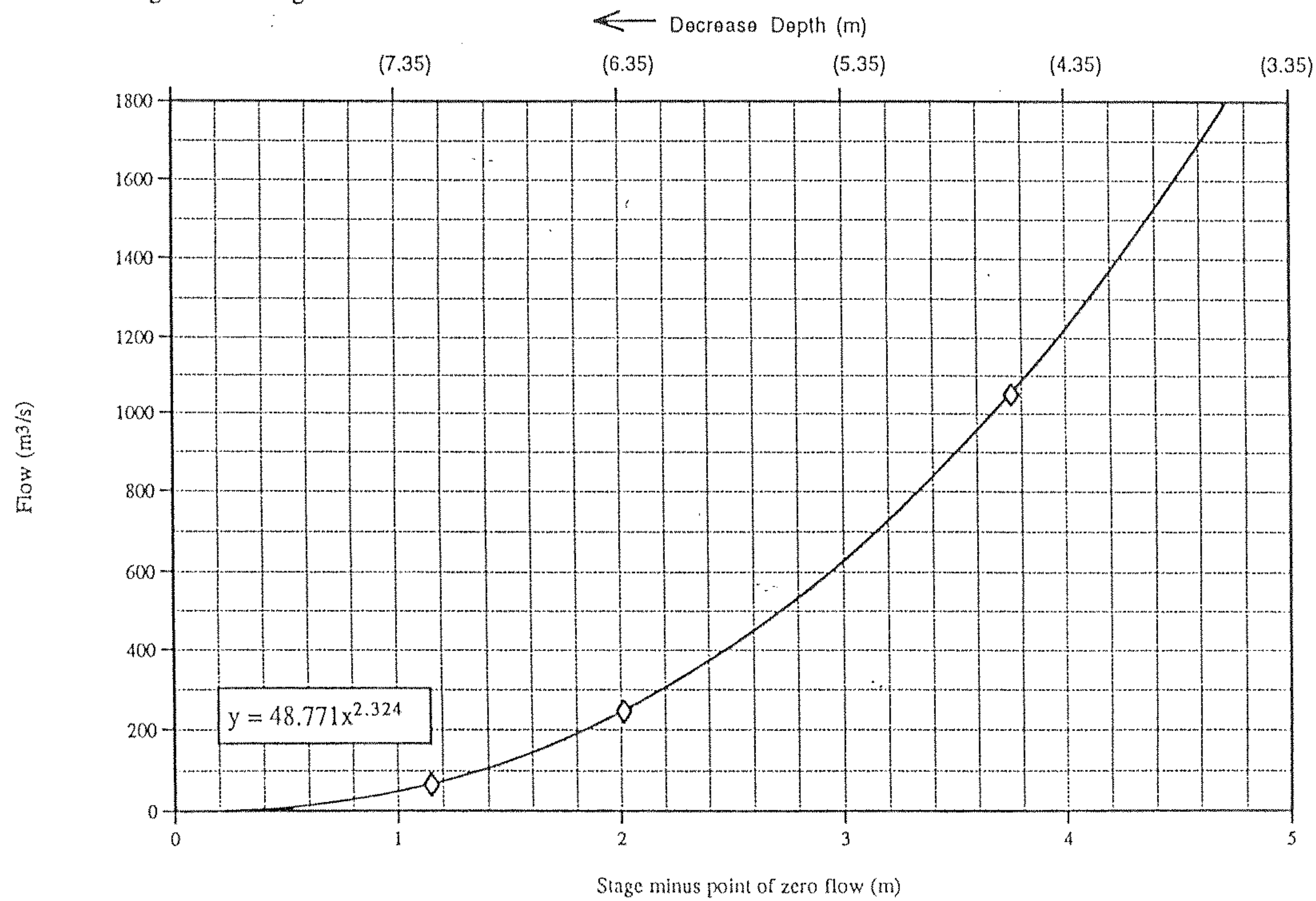


Figure 32. Rating curve for channel transect #4



to entrain and move the sampled gravel mixtures result in the necessary mean depth between 6.54 and 20.05 meters (Table 19). The smallest of the two numbers, 6.54 meters, is about two times larger than the 2-year-flood mean depths at transects #1 and #2.

Discharge Entrainment Threshold for the Anastomosed Reach

Lacking detailed transectal data across the whole river valley, one can back into the flood magnitude necessary to move the gravel mixture with median size 20 millimeters through the two anastomosed-reach single channel transects by figuring mean depth to stage relationship and then deriving the required flow from the rating curves. This assumes that the hydraulic relationships stay the same even as the flood waters enter the floodplain. In reality, increase in mean depth with increase in discharge will be probably less once the floodplain is inundated.

Figures 27 and 28 show mean depth to stage relationship for channel transect #1 and #2. Using 6.54 meters as the mean depth required to move the sampled gravels results in 8.34 meters stage minus point of zero flow and 5,274.86 m^3/s discharge at channel transect #1, and 8.30 meters stage minus point of zero flow and 6,616.94 m^3/s discharge at channel transect #2 (Table 20). Both floods would have return periods greater than 1,000 years on any of the flood frequency curves. The large magnitudes of the flows are probably due to the low bed slope used in the calculations; actual energy gradients may be somewhat higher.

Table 20. Flood magnitudes at 6.54 meters mean depth at channel transects #1 and # 2

Transect number	Mean depth (m)	Stage minus point of zero flow (m)	Discharge (m^3/s)
1	6.54	8.34	5,275
2	6.54	8.30	6,617

However, the results suggest that only infrequent floods of very large magnitudes can move the gravel found on mid-channel bars in the first reach of the river. The finding reinforces the interpretation of the lower Flathead River as an anastomosed stream.

U.S. GEOLOGICAL SURVEY MEASUREMENT TRANSECT

Remeasurement of the same transect over a period of years can show profile changes resulting from erosion or deposition. The USGS measures flows for the Perma gage from the bridge that crosses the lower Flathead River at Perma (Figure 12). The section was altered by construction of the 3-pier bridge and is not suitable for shear stress calculations.

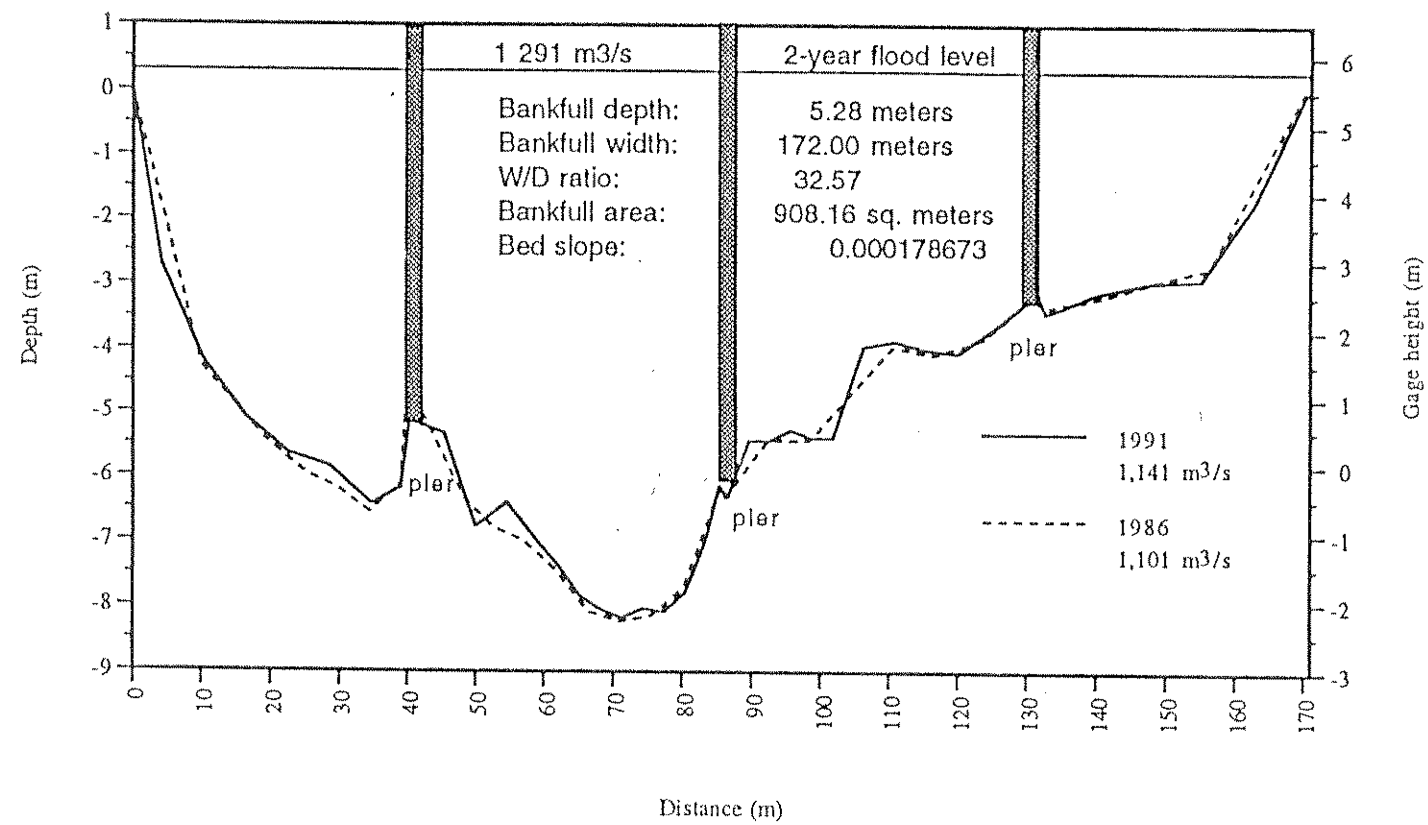
Two transectal profiles, one from June 3, 1986 and one from May 30, 1991; (USGS Discharge Measurement Notes), are compared (Figure 33) to see if transectal geometry changed during the five years. The channel bed profile is essentially unchanged; minor differences can be attributed to different measurement points. The highest flood during the period between the measurements was 1,138 m^3/s in 1990; about 1.5 or bankfull year flood. Lack of change in the transectal geometry tends to support the idea that the lower Flathead River floodplain is stable and that fluvial-surfaces-forming flows have high magnitudes.

MID-CHANNEL FLUVIAL SURFACES AND ASSOCIATED DISCHARGE MAGNITUDES

Bedrock ledges and gravel movable by only very large floods control base of the lower Flathead River; it can be hypothesized that the river has not incised appreciably since the last large scale fluvial deposition. Thus the relative relief of the islands in the river must have resulted from flood magnitudes; different flood stages should correspond to different relative elevations of the river islands.

Calculating discharges that can inundate fluvial surfaces of known elevation can shed some light on how often these surfaces

Figure 33. Profile: USGS measuring transect at Perma: Reach I; channel transect #5



may be re-worked by the stream. Parret (1986) presents 10 lower Flathead River channel transects and their rating tables. The ratings were developed using the Manning uniform flow equation and flows at the USGS gage at Perma recorded at the time of the transect surveys. Thus, rating errors grow with the distance of transects from the Perma gage. For that reason, I will use only five transects, numbered from 6 to 10 (Figures 34, 36, 38, 40, 42). Parret estimated the rating error for transects 6, 7, 8, and 9 to be ±5% and for transect 10 ±15%. Figures 35, 37, 39, 41, 43 show rating curves constructed from Parret's rating tables.

Again, to ascertain the depositional origin of the islands and to determine relationships between different riparian community types and discharges, I have identified riparian community or habitat types and soil textures of the upper two meters of individual fluvial surfaces along the transects. Soil textures were recorded at approximately 20 cm intervals, and their general sequence again indicates overbank deposition with a possible exception of the highest surface along transect number 6 (Figure 34). Surface textures of all terraces were silts or silty loams -- easily transported materials.

The climax *Pinus ponderosa* and *Juniperus scopulorum* habitat types dominated fluvial surfaces reachable by 4,000 to 6,000 m^3/s discharge stages (more than 900 years return period). Along transect 6, a stand of *Populus trichocarpa* over 90 years old (estimated from *Pinus ponderosa* core) along transect number 6 stood at about 3,800 m^3/s discharge level. The gravel bars with sparse cover of *Populus trichocarpa* and *Salix exigua* plants were between 300 to 400 m^3/s discharge level (the average daily winter discharge magnitudes and ice-up levels).

The initiation of the *Populus trichocarpa* stand along transect 6 matches fairly well the 1894 flood, which was estimated at 3,120 m^3/s. Such a flood would have an 80-year pre-dam return interval. During my field work along the lower Flathead River, I checked all larger *Populus trichocarpa* stands; none appeared to be younger than the transect 6 stand. Since recent incision of the lower Flathead River can be ruled out (bedrock controls), the findings again indicate that channel-forming floods are infrequent and of large magnitudes.

CONSTRUCTION OF MID-CHANNEL ISLANDS

Available evidence shows that the mid-channel islands were constructed by the river, most likely as overbank deposits. Discharges responsible for their creation probably had recurrences of over 80-years. As shown by aerial photos, no large new fluvial surfaces were created between 1937 and 1991; the highest flood in that period was 2,059 m^3/s (8-year pre-dam return period). Only floods of extreme magnitudes can reach the older fluvial terraces of the mid-channel islands and only extreme floods can move the channel gravels. The lower Flathead River base level is bedrock controlled; thus, a recent incision can be ruled out.

Large floods can cause landslides and slumping of the glacial Lake Missoula sands, silts, and clays along the third reach of the lower Flathead River. The increased silt and clay concentrations, through greater fluid density and viscosity, can enhance capacity to transport sands and gravels. The sudden drop in gradient at the merger of the second and first reach results in a loss of transport competence, aggradation, channel widening and anastomosing. The channel itself may temporarily aggrade; subsequent smaller floods may then remove excess fines from the active channels and reconstruct the banks. The presence of fluvial gravels under the islands tends to support this notion.

The relatively high percentage of climax coniferous and mixed forest stands (16%) to purely deciduous forest stands (12.3%) as shown in the pre-dam aerial photos also points to a stable floodplain dominated by secondary successional processes on the islands.

Figure 34. Profile: Reach I; channel transect #6; (river km 13.2)

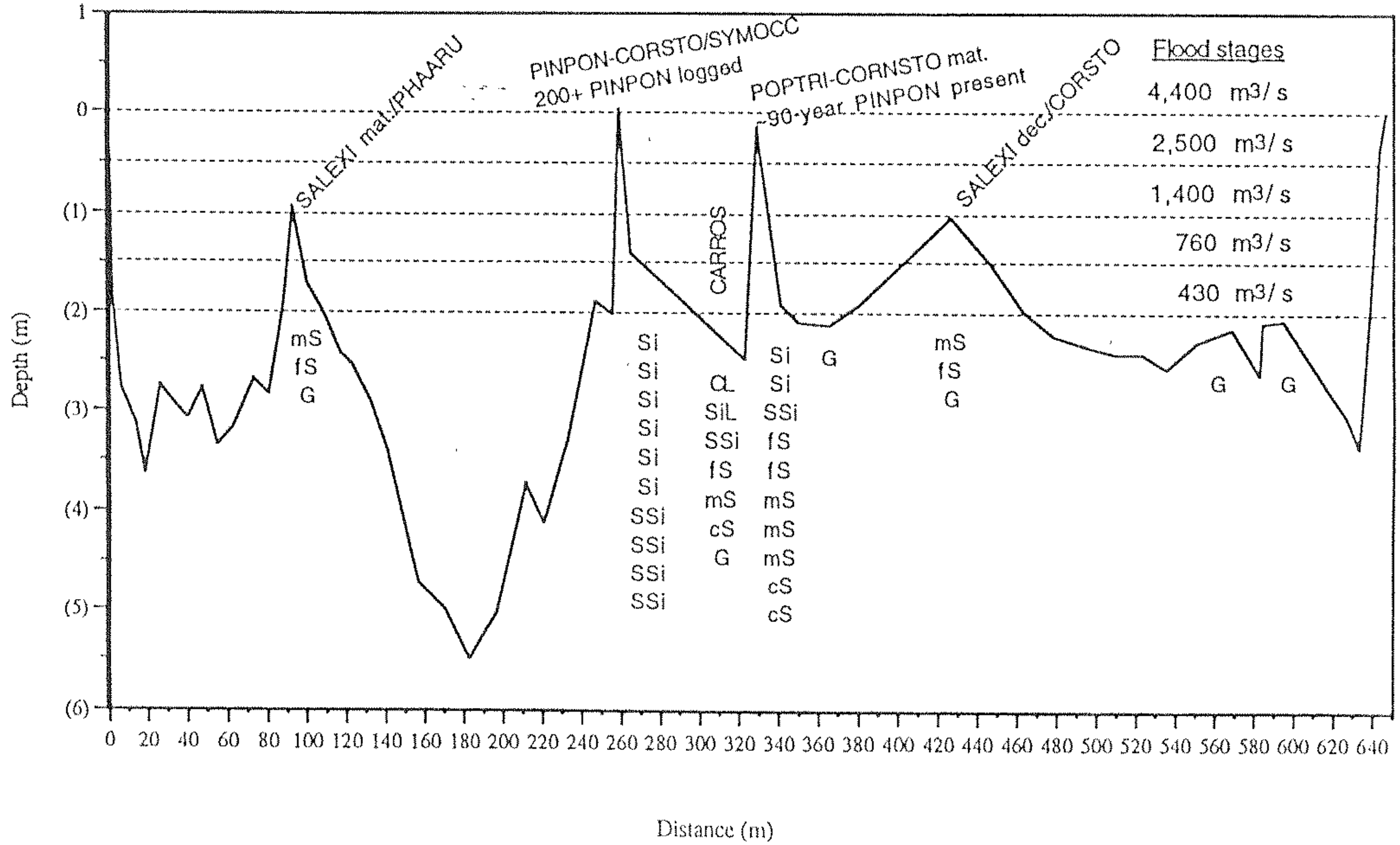


Figure 35. Rating for channel transect #6

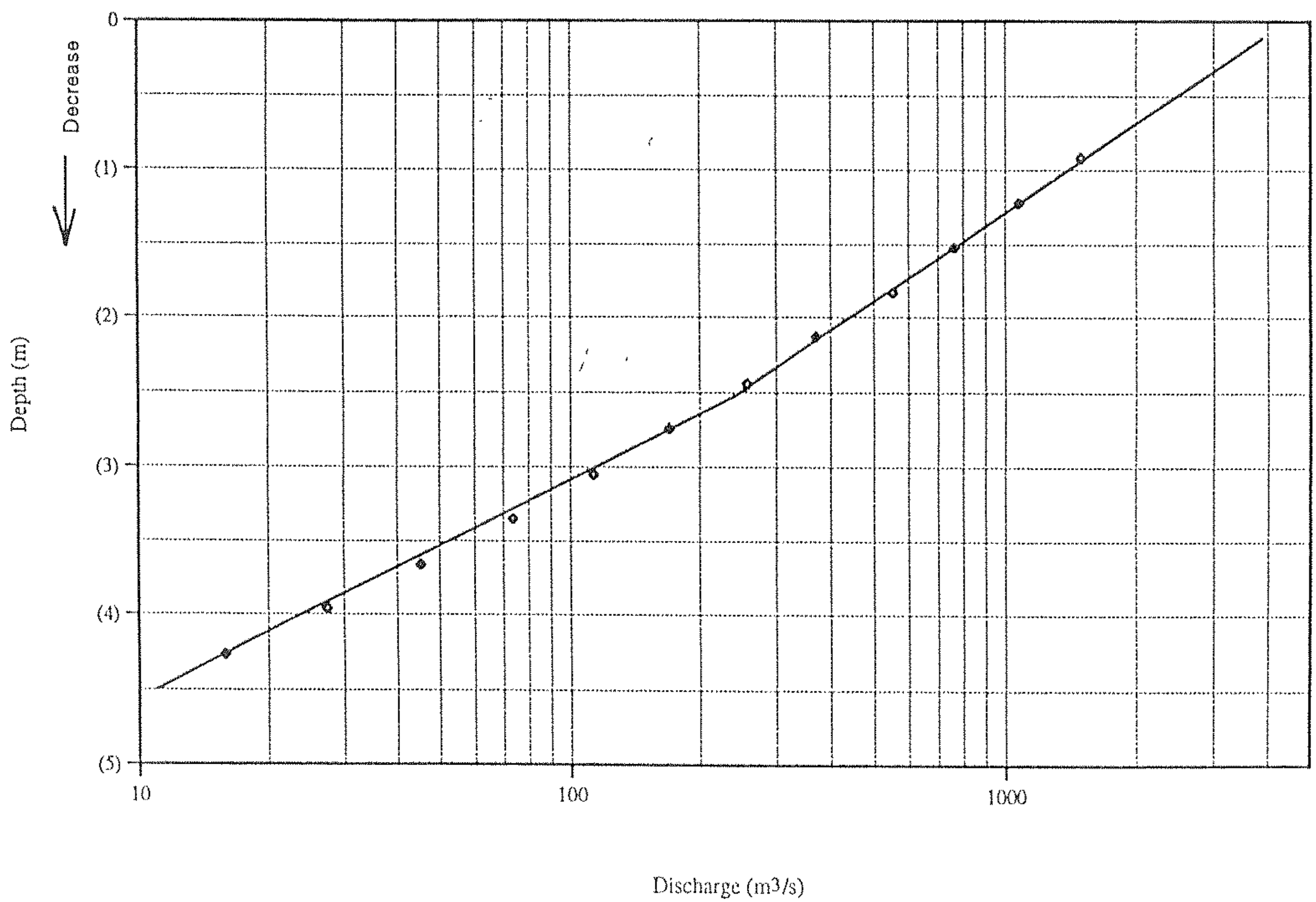


Figure 36. Profile: Reach I; transect #7; (river km 13.8)

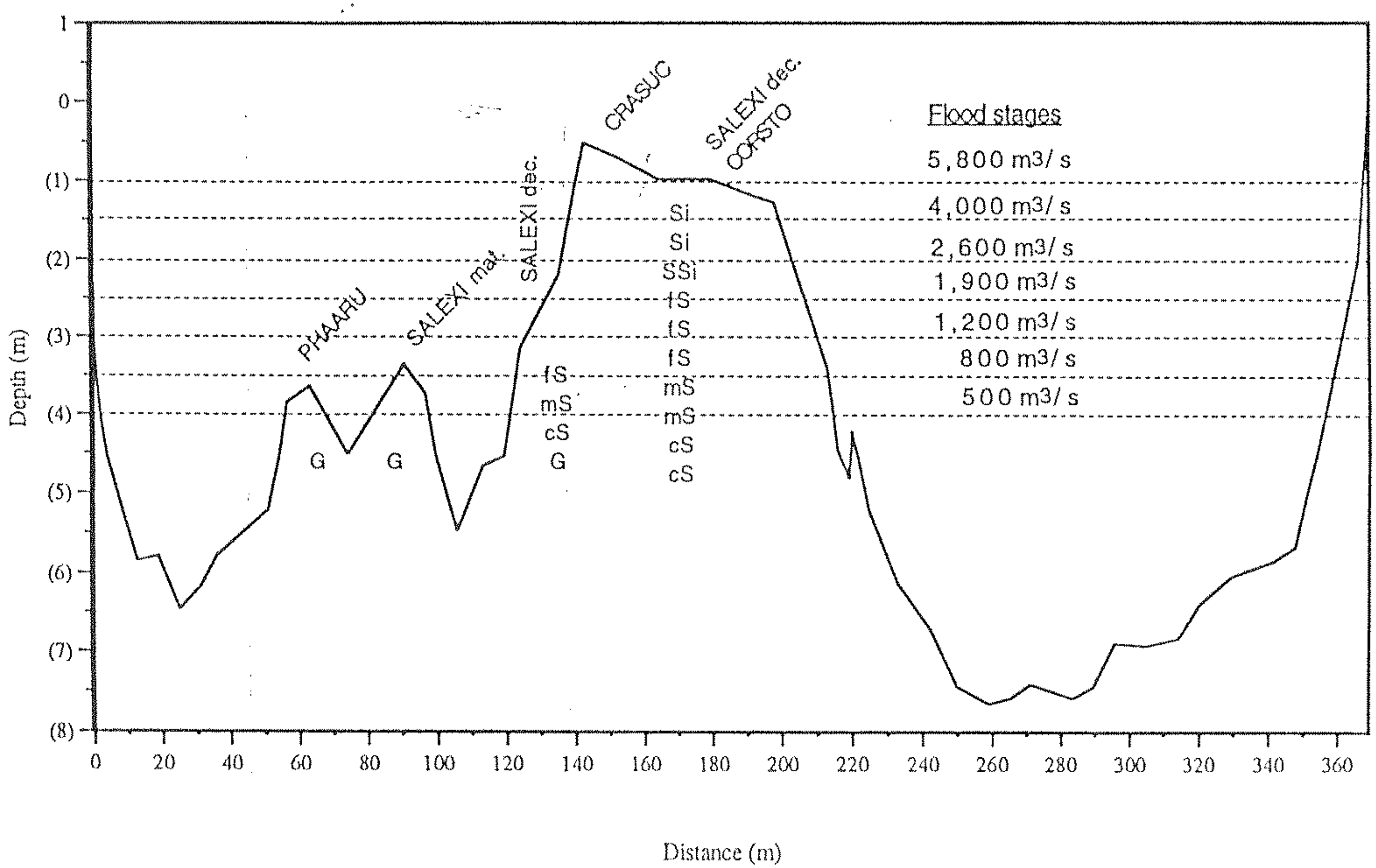


Figure 37. Rating for channel transect #7

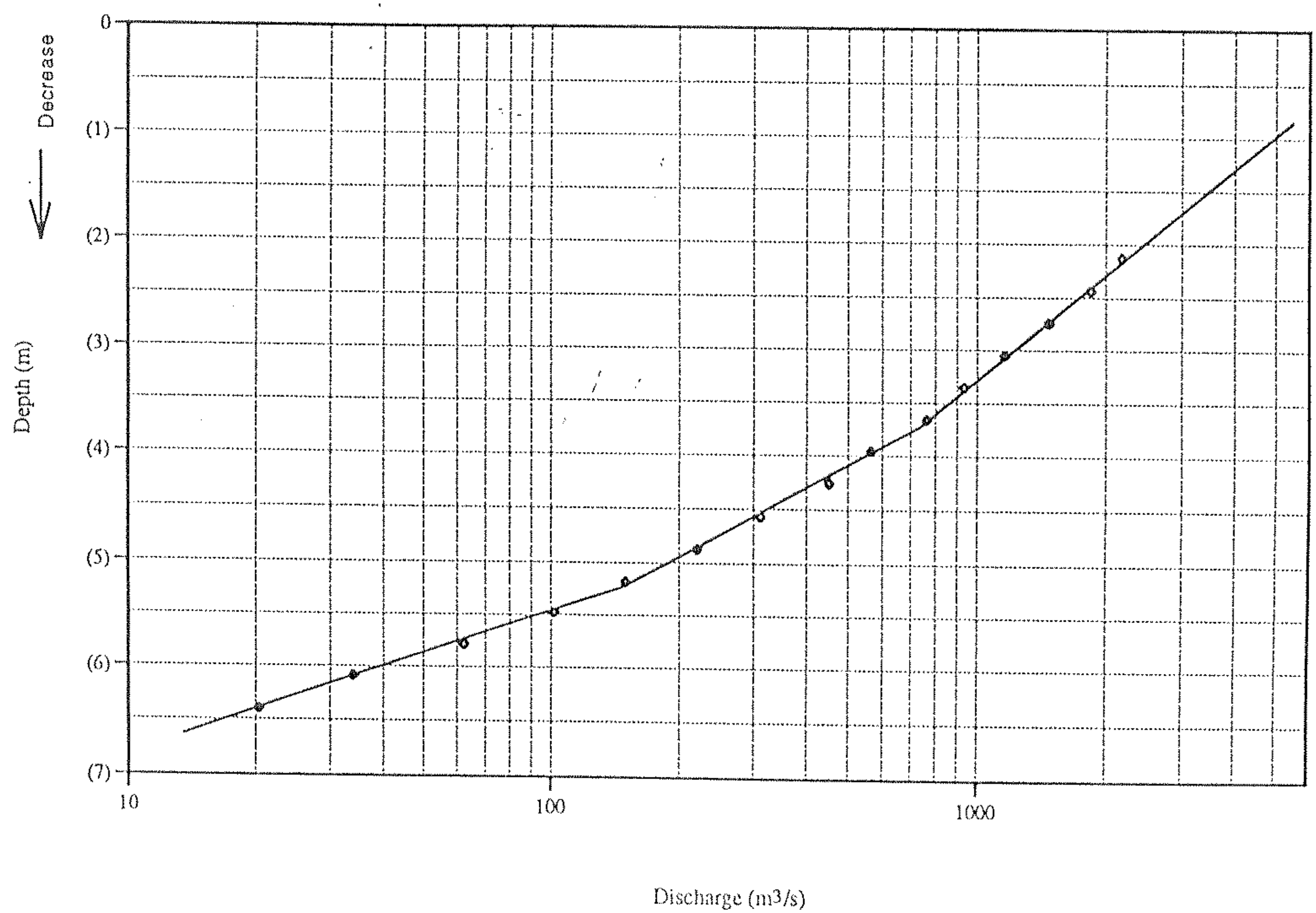


Figure 38. Profile: Reach I; channel transect #8; (river km 21.2)

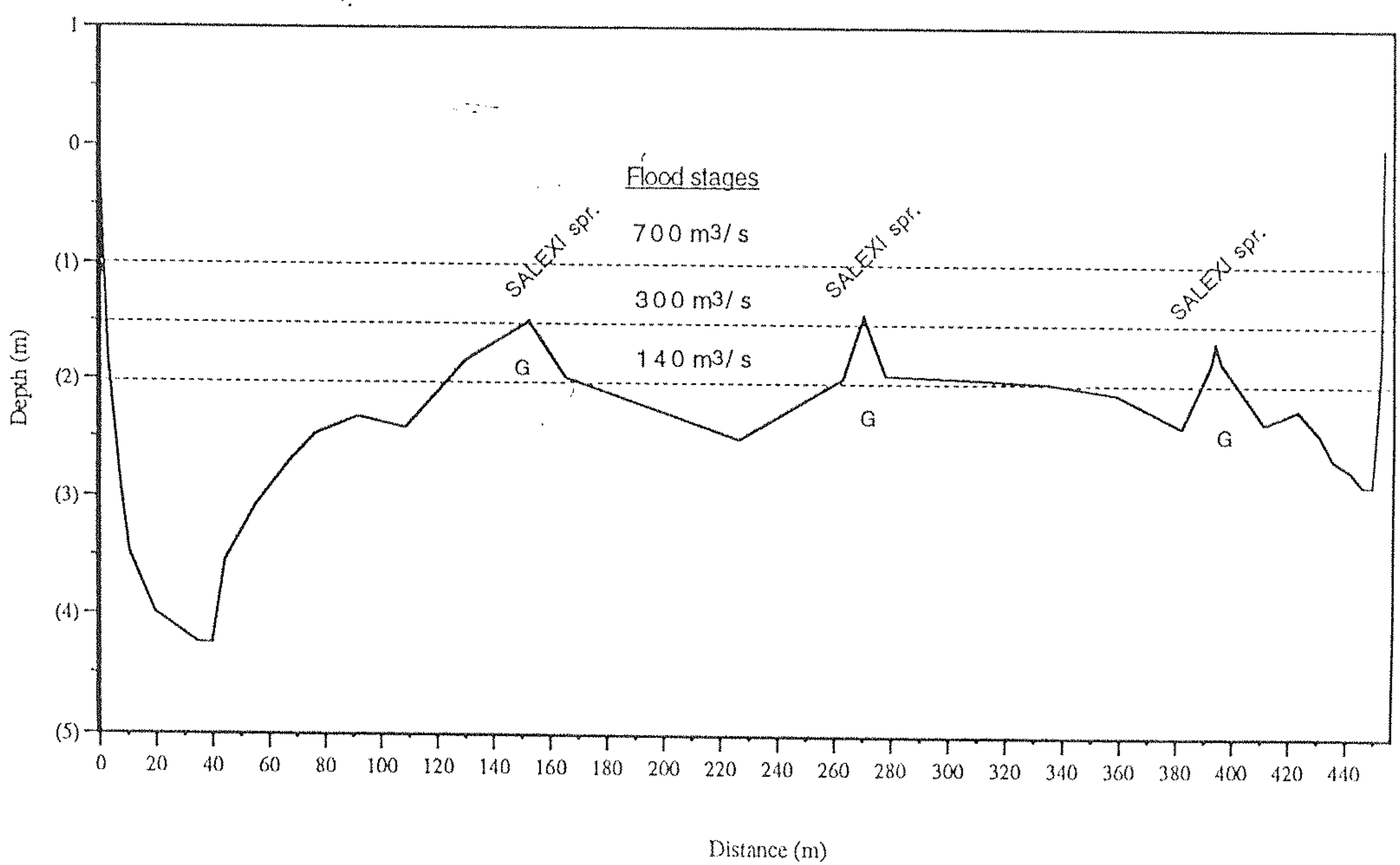


Figure 39. Rating for channel transect #8

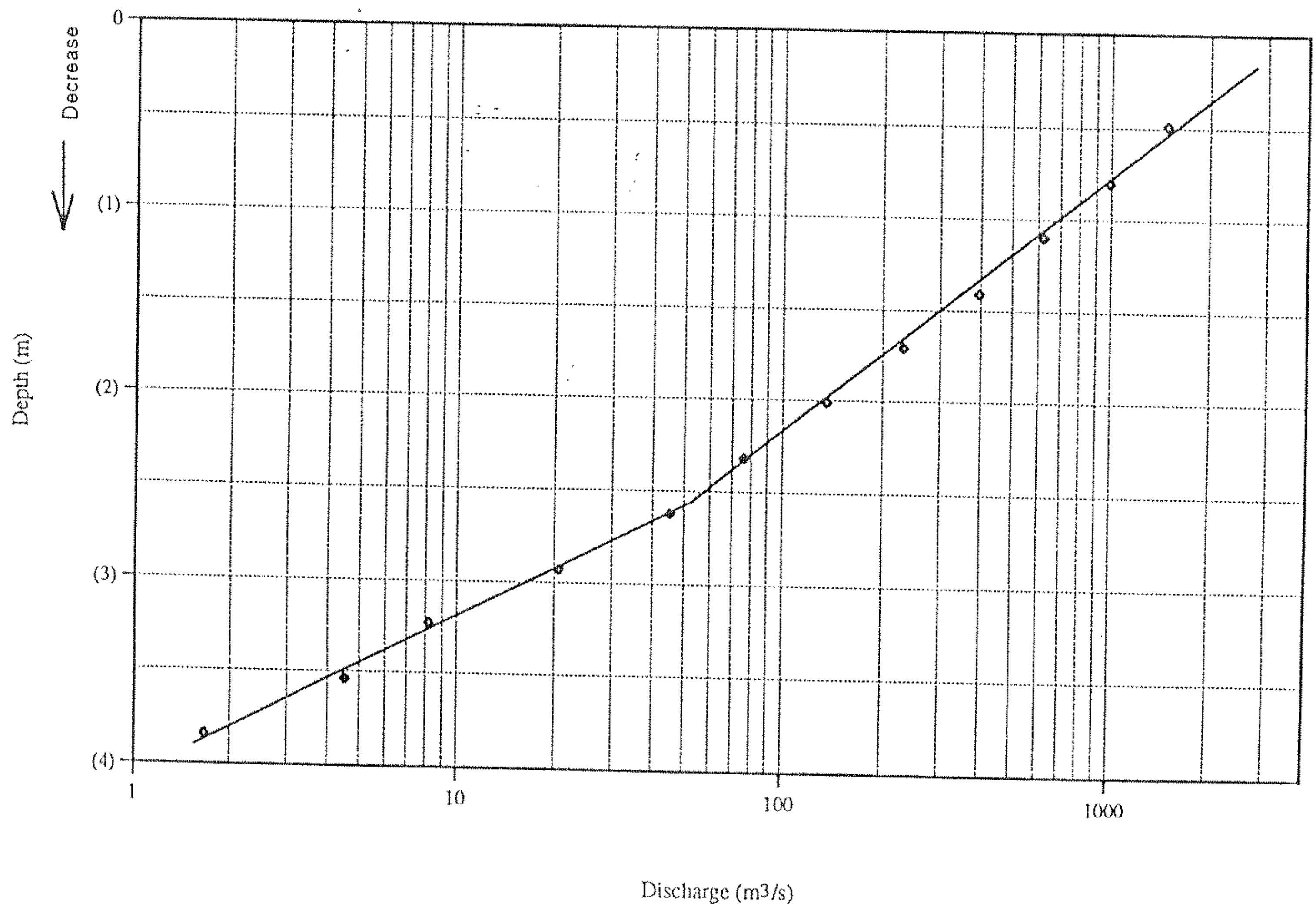


Figure 40. Profile: Reach I; channel transect #9; (river km 21.7)

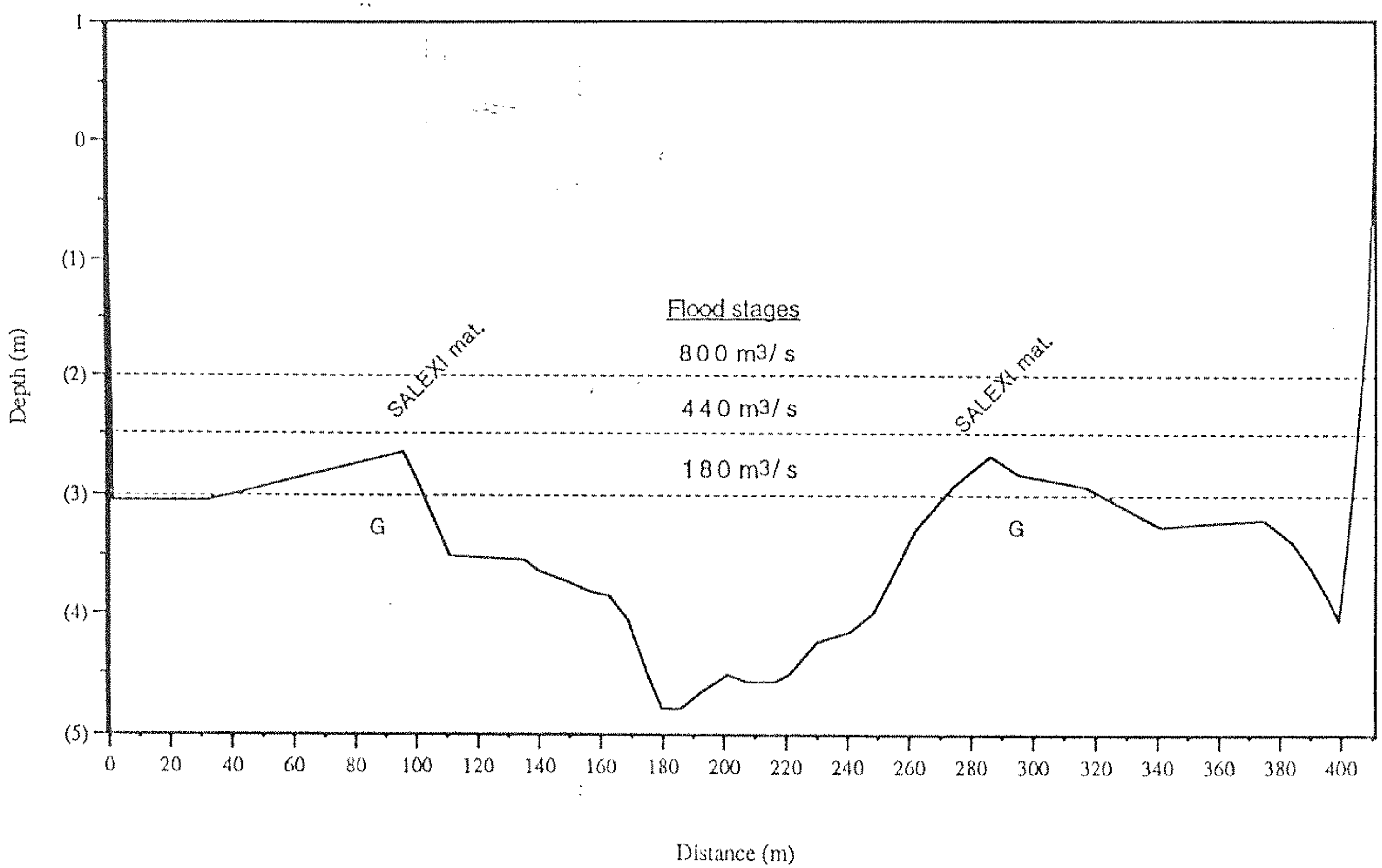


Figure 41. Rating for channel transect #9

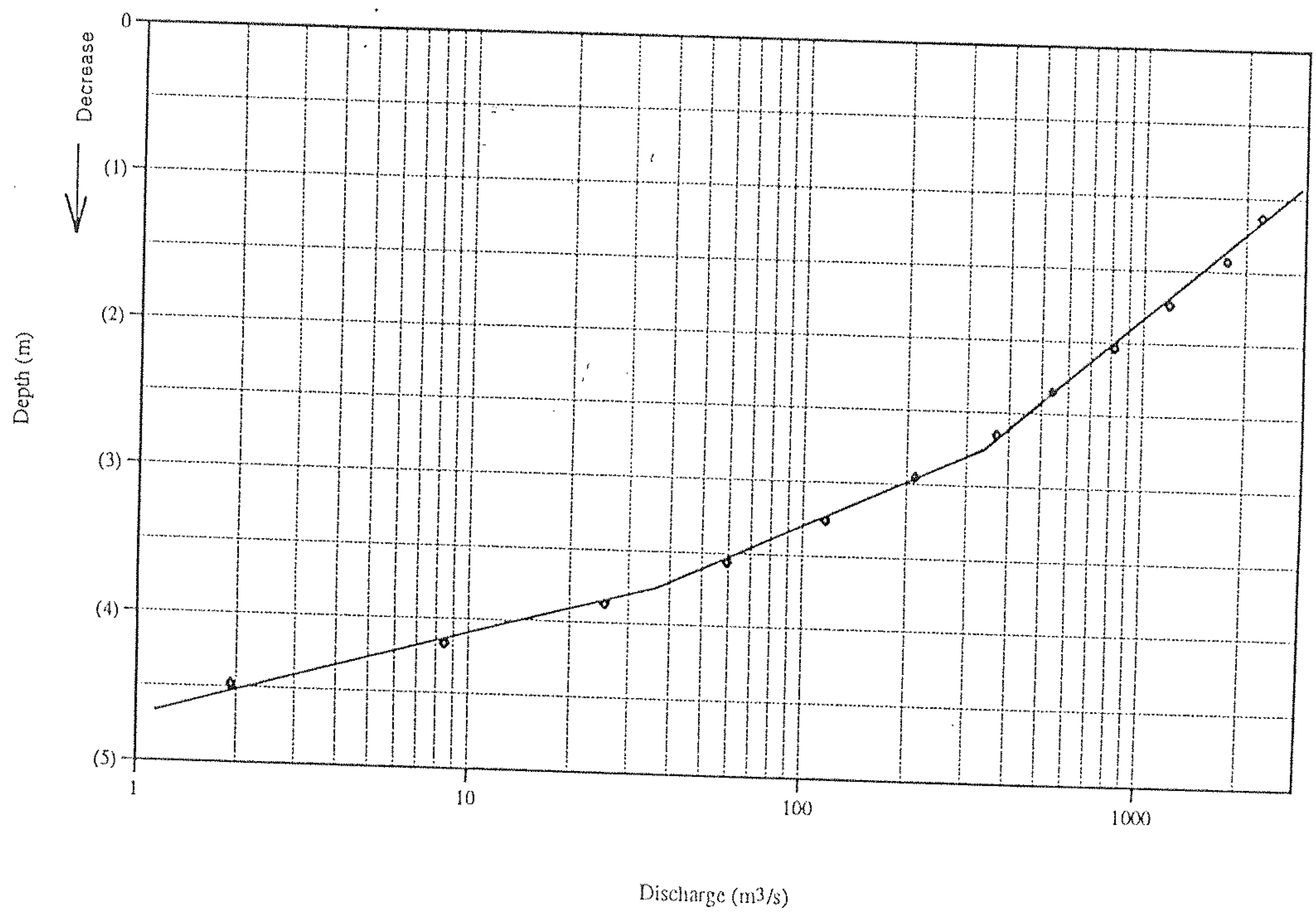


Figure 42. Profile: Reach I; channel transect #10; (river km 35.1)

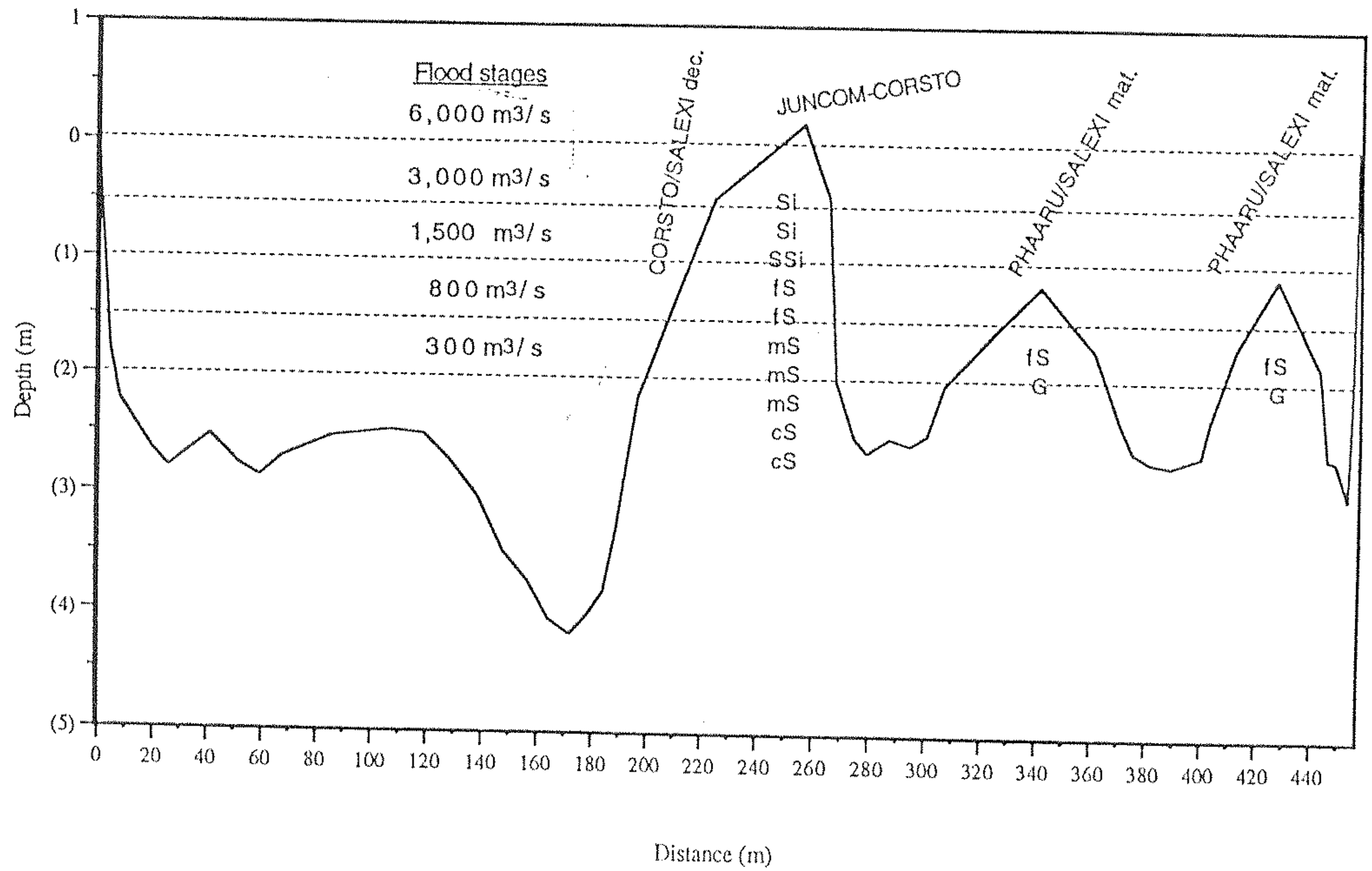
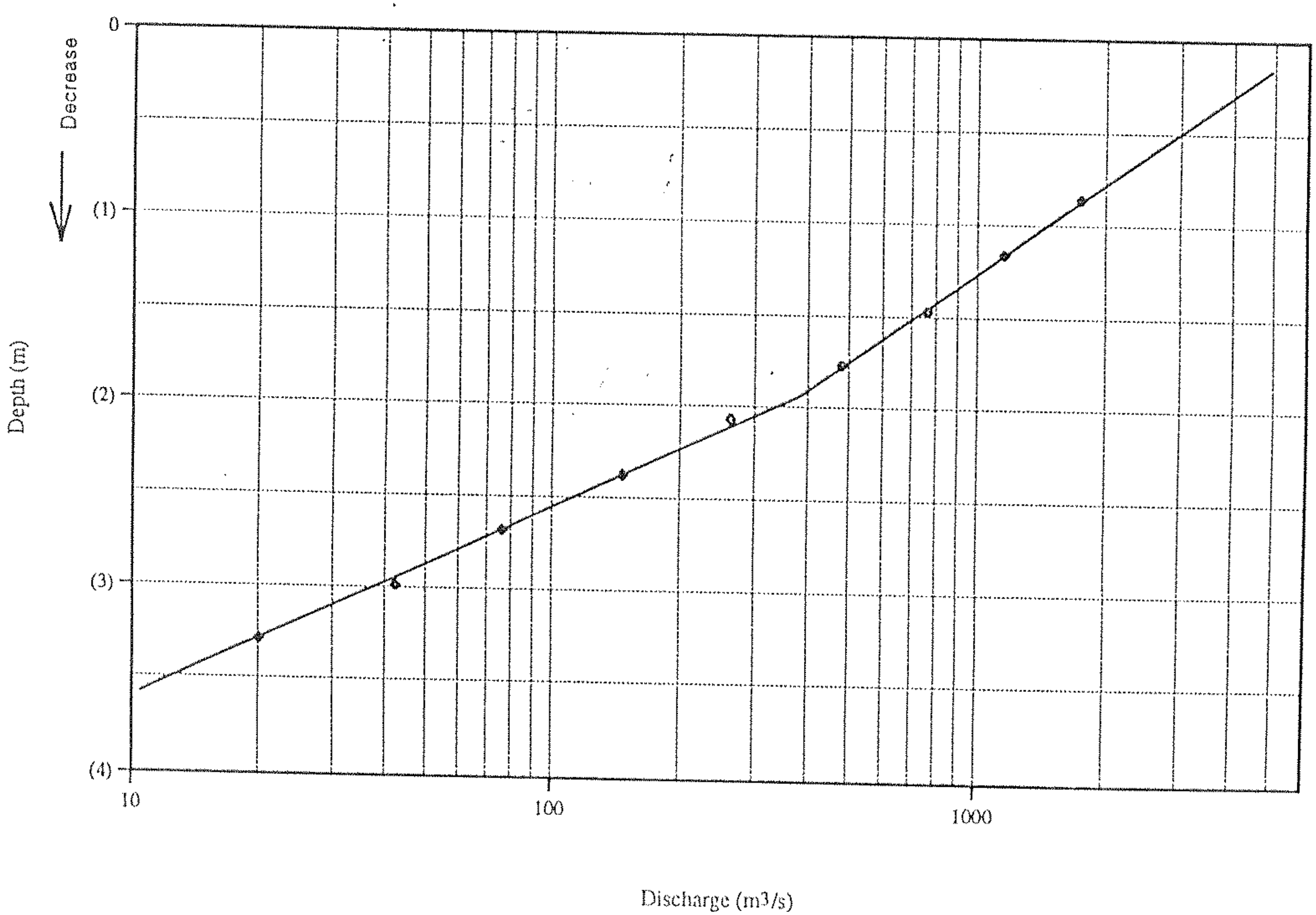


Figure 43. Rating for channel transect #10



CHAPTER III

CONCLUSIONS

The pioneer *Populus trichocarpa* and *Salix exigua* need fresh fluvial deposits to germinate their seeds. Past floods of the lower Flathead River created several islands and many bars within an anastomosed reach downstream of the confluence with Mission Creek. No new major fluvial deposition has occurred along the river floodplain since 1935 and possibly before. Climax *Pinus ponderosa* stands dominate most of the islands; a few remaining mature to decadent stands of *Populus trichocarpa* and *Salix exigua*, are being replaced by later successional riparian community types. Geomorphic and vegetational evidence indicates that only very large infrequent floods can rework the anastomosed reach of the river and create new fluvial surfaces necessary for *Populus trichocarpa* and *Salix exigua* establishment. Such floods would now be controlled by Kerr Dam and Hungry Horse Reservoir, two major facilities that regulate flows of the lower Flathead River. In addition to decreased spring floods, the operation of the two facilities results in increased winter flows and associated ice scour and in large hourly water stage fluctuations, both unfavorable to *Populus trichocarpa* and *Salix exigua* regeneration.

LIKELIHOOD OF FUTURE BLACK COTTONWOOD AND SANDBAR WILLOW REGENERATION ALONG THE LOWER FLATHEAD RIVER

Given the evidence, *Populus trichocarpa* and *Salix exigua* in the riparian zone along the lower Flathead River will continue to decline: 1) the river's regulated flows cannot create new fluvial surfaces, 2) its present bars have unstable water regime and undergo ice scour, and 3) *Pinus ponderosa, Juniperus scopulorum,Populus tremuloides* , and *Cornus stolonifera* dominated climax types are replacing existing stands of *Populus trichocarpa* and *Salix exigua.*

Low Potential for Creation of New Fluvial Surfaces

Because Kerr Dam and Hungry Horse Reservoir reduce its peak floods, the lower Flathead River does not experience channel-forming discharges sufficient to create significant fluvial surfaces. The fluvial geomorphology and riparian vegetation composition of the river show that infrequent floods of large magnitudes formed the river's channels and floodplain. It appears that the 1894 flood (3,120 m^3/s) created the last major fluvial surfaces suitable for *Populus trichocarpa* and *Salix exigua* regeneration. The return period of that flood is 80 years on the pre-dam flood frequency distribution. The largest flood during the regulation period (since 1938) occurred in 1948, and its magnitude was 2,059 m^3/s. The event did not cause any noticeable erosion or deposition. Its return period was 8 years on the pre-dam flood frequency distribution. In the post-Hungry-Horse period, the largest flood of 1,821 m^3/s occurred in 1964, and its return period on the pre-dam flood frequency distribution was 5 years. Again, this flood did not result in any noticeable erosion or deposition.

Agricultural and residential development has encroached on the floodplain of the upper and the lower Flathead River and would be threatened by high floods. If runoff capable of producing a large flood similar to the 1894 one would occur, Kerr Dam and Hungry Horse Reservoir would be operated for flood control. Therefore, channel forming flows cannot be expected barring a dam failure.

Adverse Conditions on Gravel Bars

Manipulation of daily flows by Kerr Dam and releases of stored water by both dams during winters make existing fluvial surfaces unfavorable for *Populus trichocarpa* and *Salix exigua*. The few gravel bars of the lower Flathead River annually undergo strong ice shearing and large water stage fluctuations. The bars do not provide hospitable environments for *Populus trichocarpa* and *Salix exigua* regeneration, as is evident by their present cover. Under normal circumstances, the lower Flathead River does not carry enough sediment to build-up these bars. These deposits have not noticeably changed their appearance since 1937. Plucking and shearing by river ice cakes and large fluctuations of stream stage will continue to suppress the plant cover on the bars. Winter flows less than 200 m^3/s (which do not reach the bars) may prevent ice scour and promote growth of the existing *Populus trichocarpa* and *Salix exigua* plants. Elimination of stream stage fluctuations would result in more stable water regime of the bars and perhaps increase *Populus trichocarpa* and *Salix exigua* coverage.

Replacement of Existing Cottonwoods and Sandbar Willows

In the absence of new fluvial surfaces creation, climax stands dominated by *Pinus ponderosa, Juniperus scopulorum,* and to a lesser degree by *Populus tremuloides,* in consequence of secondary succession, will replace the remaining cottonwoods on the floodplain of the lower Flathead River. In a same way, the remaining stands of *Salix exigua* will be replaced by *Cornus stolonifera* stands. Some small scale *Populus trichocarpa* and *Salix exigua* regeneration will occur on channel margins and backwater areas. Large scale regeneration of the riparian pioneering species -- requiring new fluvial surfaces created by large floods -- is not likely to happen under the present circumstances.

APPENDIX A

Riparian community and habitat type indicator species encountered on the field survey transects.

Abbreviation	Scientific name	Common name
AGRSMI	*Agropyron smithii*	western wheatgrass
POPTRI	*Populus trichocarpa*	black cottonwood
CARROS	*Carex rostrata*	beaked sedge
CENMAC	*Centaurea maculosa*	spotted knapweed
CORSTO	*Cornus stolonifera*	red-osier dogwood
CRASUC	*Crataegus succulenta*	succulent hawthorn
EQUFLU	*Equisetum fluviatile*	water horsetail
JUNSCO	*Juniperus scopulorum*	Rocky Mountain juniper
PHAARU	*Phalaris arundinacea*	reed canarygrass
PINPON	*Pinus ponderosa*	Ponderosa pine
POAPAL	*Poa palustris*	fowl bluegrass
POAPRA	*Poa pratensis*	Kentucky bluegrass
POPTRE	*Populus tremuloides*	quaking aspen
PRUVIR	*Prunus virginiana*	common chokecherry
SALEXI	*Salix exigua*	sandbar willow
SALLUT	*Salix lutea*	yellow willow
TYPLAT	*Typha latifolia*	common cattail

APPENDIX B

Flathead River at Columbia Falls mean annual flows

Year	Mean annual flow (m^3/s)
1929	214.05
1930	202.01
1931	181.74
1932	302.85
1933	345.33
1934	365.20
1935	273.60
1936	229.06
1937	195.95
1938	266.63
1939	246.64
1940	176.58
1941	136.43
1942	251.12
1943	316.98
1944	142.94
1945	212.01
1946	291.41
1947	322.93
1948	319.70
1949	229.85
1950	348.13
1951	362.26
1952	241.71
1953	214.39
1954	327.60
1955	269.18
1956	338.10
1957	270.74
1958	212.75
1959	377.38
1960	314.32
1961	285.55
1962	267.94
1963	248.91
1964	313.33
1965	343.37
1966	273.60

1967	311.35
1968	251.94
1969	318.23
1970	249.36
1971	335.33
1972	348.70
1973	221.75
1974	388.59
1975	- - -
1976	320.29
1977	191.08
1978	243.44
1979	260.88
1980	221.81
1981	301.83
1982	291.95
1983	256.47
1984	240.50
1985	279.60
1986	266.12
1987	219.03
1988	210.59
1989	261.99
1990	330.18
1991	388.79

Flathead River near Polson mean annual flows

Year	Mean annual flow (m^3/s)
1908	344.73
1909	317.58
1910	344.53
1911	332.61
1912	282.75
1913	387.69
1914	261.88
1915	242.31
1916	462.36
1917	357.81
1918	343.54
1919	246.92
1920	259.89

1921	392.28
1922	307.78
1923	331.96
1924	283.40
1925	432.77
1926	212.38
1927	487.56
1928	- - -
1929	265.56
1930	234.66
1931	215.95
1932	338.33
1933	398.76
1934	443.42
1935	323.72
1936	272.32
1937	225.63
1938	272.89
1939	284.76
1940	191.73
1941	147.16
1942	304.01
1943	383.89
1944	167.41
1945	246.73
1946	350.56
1947	385.73
1948	402.72
1949	278.67
1950	422.12
1951	449.93
1952	320.10
1953	270.97
1954	387.52
1955	326.30
1956	404.68
1957	308.63
1958	269.01
1959	463.66
1960	403.21
1961	352.66
1962	323.86
1963	295.66
1964	374.52

1965	431.04
1966	338.95
1967	373.36
1968	304.69
1969	388.06
1970	300.50
1971	401.65
1972	413.51
1973	251.31
1974	457.21
1975	344.16
1976	384.26
1977	213.99
1978	307.83
1979	308.57
1980	262.10
1981	362.43
1982	348.81
1983	296.73
1984	278.36
1985	311.12
1986	304.35
1987	246.41
1988	230.67
1989	290.70
1990	381.15
1991	429.00

Flathead River at Perma mean annual flows

Year	Mean annual flow (m^3/s)
1984	304.61
1985	331.62
1986	337.51
1987	269.04
1988	249.93
1989	316.30
1990	396.15
1991	454.77

APPENDIX C

Max. annual discharge (m^3/s)	Magnitude	Recurrence interval (years)
2296.51	1	31.00
2169.08	2	15.50
2135.10	3	10.33
2123.78	4	7.75
2115.28	5	6.20
1897.24	6	5.17
1758.49	7	4.43
1755.65	8	3.88
1673.53	9	3.44
1665.04	10	3.10
1653.71	11	2.82
1597.08	12	2.58
1582.92	13	2.38
1458.33	14	2.21
1449.83	15	2.07
1421.51	16	1.94
1401.69	17	1.82
1364.88	18	1.72
1330.90	19	1.63
1262.94	20	1.55
1251.61	21	1.48
1251.61	22	1.41
1211.97	23	1.35
1161.00	24	1.29
1033.57	25	1.24
1013.75	26	1.19
1002.42	27	1.15
858.01	28	1.11
829.69	29	1.07
594.66	30	1.03
b) post-Kerr-Dam-pre-Hungry-Horse period (1938 to 1951)		
2058.65	1	15.00
1854.76	2	7.50
1599.91	3	5.00
1551.77	4	3.75
1430.01	5	3.00
1379.04	6	2.50

1379.04	7	2.14
1373.37	8	1.88
1313.91	9	1.67
1279.93	10	1.50
1186.48	11	1.36
920.30	12	1.25
634.30	13	1.15
611.65	14	1.07

c) post-Hungry-Horse period (1952 to 1991)

Max. annual discharge (m^3/s)	Magnitude	Recurrence interval (years)
1820.78	1	41.00
1599.91	2	20.50
1495.14	3	13.67
1486.64	4	10.25
1483.81	5	8.20
1483.81	6	6.83
1483.81	7	5.86
1452.66	8	5.13
1421.51	9	4.56
1415.85	10	4.10
1359.22	11	3.73
1350.72	12	3.42
1336.56	13	3.15
1313.91	14	2.93
1277.10	15	2.73
1228.96	16	2.56
1211.97	17	2.41
1186.48	18	2.28
1180.82	19	2.16
1177.99	20	2.05
1161.00	21	1.95
1115.69	22	1.86
1101.53	23	1.78
1095.87	24	1.71
1095.87	25	1.64
1090.20	26	1.58
1025.08	27	1.52
999.59	28	1.46
959.95	29	1.41
954.28	30	1.37
937.29	31	1.32

928.80	32	1.28
908.98	33	1.24
883.49	34	1.21
872.16	35	1.17
858.01	36	1.14
622.97	37	1.11
393.61	38	1.08
376.62	39	1.05
368.12	40	1.03

APPENDIX D

Measured suspended sediment concentrations and associated discharges at Perma

S.s. concentration mg/L	Month	Inst. discharge (m^3/s)
65.00	Mar	291.67
43.00	Jun	934.46
37.00	Jun	1107.19
34.00	Apr	345.47
23.00	Mar	328.48
22.00	Jun	872.16
16.00	Jun	317.15
16.00	Feb	252.59
15.60	Mar	196.8
13.00	May	370.95
11.70	May	413.43
10.00	May	136.2
10.00	Mar	407.76
10.00	Apr	300.16
9.00	May	430.42
9.00	Jun	345.47
9.00	Feb	356.79
9.00	Apr	368.12
8.00	May	123.75
7.00	Jan	322.81
7.00	Feb	351.13
7.00	Apr	396.44
7.00	Apr	328.48
6.00	Mar	253.15
6.00	Aug	356.79
5.00	Sep	302.99
5.00	Jun	402.1
5.00	Jan	317.15
4.80	Apr	171.6
4.00	Sep	336.97
4.00	Jun	269.01
4.00	Jan	187.18
4.00	Aug	270.71
4.00	Aug	402.1
3.00	Sep	322.81
3.00	Sep	150.65
3.00	Nov	356.79
3.00	Nov	286
3.00	Mar	160.84
3.00	Jul	297.33
3.00	Jul	402.1
3.00	Jul	177.55
3.00	Jul	300.16
3.00	Jan	416.26

3.00	Jan	334.14
3.00	Aug	111.85
3.00	Apr	208.98
2.40	Nov	283.17
2.10	Dec	281.47
2.00	Nov	305.82
2.00	Nov	288.83
2.00	Nov	331.31
2.00	Dec	331.31

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