[1980]

PROCEEDINGS OF
DOWNSTREAM RIVER CHANNEL CHANGES FROM DIVERSIONS OR RESERVOIR CONSTRUCTION

D. B. Simons, Director
Colorado State University

R. M. Li, Associate Director
Colorado State University

R. T. Milhous, Project Officer
U.S. Fish and Wildlife Service

RESEARCH INSTITUTE OF COLORADO
Fort Collins, Colorado

27-29 August, 1980

TABLE OF CONTENTS

DOWNSTREAM RIVER CHANNEL CHANGES FROM DIVERSIONS OR RESERVOIR CONSTRUCTION

INTRODUCTION

Daryl B. Simons
Director, Engineering Research Center and Professor, Civil Engineering,
Colorado State University, Fort Collins, Colorado

BACKGROUND

River systems are an integral part of the fluvial ecosystem. Streamflows, sediment transport rates, and channel morphology reflect the major responses resulting from river utilization activities. Knowledge of river mechanics, geomorphology, and watershed management is essential for formulating and selecting design alternatives by planners or engineers or both. The basic principles affecting the dynamics and response of streams to natural conditions or man-made alterations, or both, are not generally covered in college curricula, particularly at the undergraduate level. An understanding of stream mechanics is necessary for the proper planning and design of any channel change. This is particularly true of work in natural streams that carry heavy sediment loads. Analysis using principles of stream mechanics, that is a dynamic approach as compared to a static rigid-boundary approach, provides a more realistic understanding of channel response to man-induced changes. In response to this need, the U.S. Fish and Wildlife Service organized a workshop on the response of river systems to major impoundments or flow diversions.

This workshop assembled 20 of the world's most qualified individuals to discuss solutions to downstream problems stemming from hypothetical impoundments or diversions, or both, on three selected Western United States rivers. The participants were chosen from varied disciplines including geology, geomorphology, river mechanics, erosion and sedimentation, hydraulics, hydrology, fisheries and aquatic biology, and water quality. Each of the participants was an expert in one of these areas and possessed some understanding of all topics to facilitate a productive exchange of ideas.

Results of this workshop include this set of proceedings composed of reports prepared by the 20 participants along with reporters' comments and workshop summaries. These reports describe how the author perceives the problem of river response and determines a solution to a set of hypothetical man-induced changes. Reports were submitted before the workshop, reviewed within the group of workshop participants, and revised and resubmitted by the authors after the workshop.

The workshop offered a unique opportunity for a group of highly qualified people to present, exchange and discuss concepts, theories, and methodologies regarding the response of river systems to various types of development. The primary objective of the workshop was this set of papers which covers a wide spectrum of viewpoints and was prepared by experts in the area of river response and physical channel changes that result from man's activity.

Complexities and differing procedures involved in analyzing river response to works of man are often beyond the typical professional's expertise to assimilate into a usable form. This task is particularly difficult if the professional needing the information is not trained in the discipline that supports solutions. This is the situation, for example, when aquatic biologists investigating habitat dynamics require techniques for estimating channel changes caused by altered hydrologic and hydraulic processes. The workshop project was designed to provide information to the Water Resources Analysis Project (WRAP) from a large group of experts through a set of workshop proceedings.

WORKSHOP PHASE

River systems selected for analysis and discussion were Poplar Creek, a gravel and cobble stream in California, the Yampa River in Colorado, and the Elk River in Eastern Kansas. Participants were divided into three groups and requested to assess the importance of hypothetical development on one of the three river systems. After receipt of a data package containing information that might typically result from an initial reconnaissance and literature search, participants were requested to:

- Consider response of the river system to hypothetical development and alteration

- Present concepts, methods, and other aspects in a general way that you utilize and recommend for analysis of such channel problems

- Submit a paper including results of your analysis

Participants assembled at Colorado State University, Fort Collins, Colorado on 27 August, 1980 for the first of 3 days of workshop meetings. The first half day was devoted to an introduction by D. B. Simons and general discussion of workshop objectives and organization. C. R. Stalnaker provided a review of ecological and biological concerns in relation to instream habitat. R. T. Milhous supplemented the data provided to participants with a photographic reconnaissance of all three river study areas.

The next 3 half-day periods were devoted to presentation of papers by each of the participants for the Yampa River problem, Poplar Creek, and Elk River, respectively. A monitor for each group (K. Bovee--Yampa River, R. T. Milhous--Poplar Creek, and C. Thorne--Elk River) was responsible for the time schedule and organization of the presentations. During the final day the three groups met, separately, to discuss the results of the analysis of their particular problem area. A reporter for each group (C. Nordin--Yampa River, S. Schumm--Poplar Creek, and F. Theurer--Elk River) was assigned to insure that unanswered questions were addressed and to mediate unresolved issues. The reporter was assigned to identify key issues, and prepare a summary of problem perception and solution approach employed by the participants in each group.

The workshop concluded with a joint session to consider the reporter's summaries and complete any unfinished discussion. This final session concentrated on research needs in the area of river response and a discussion of possible alternative approaches to the problem of making the basic techniques of analysis of river response available to professionals not trained specifically in river mechanics or river engineering.

In organizing these proceedings an attempt has been made to adhere to the format of the workshop and, insofar as possible, convey the dynamics and "flavor" of the sessions. A brief statement of the workshop problems as posed to the participants is followed by a general summary of the results of the proceedings. Papers, revised and resubmitted after the workshop, are presented in the order discussed: Yampa River, Poplar Creek, and Elk River. Each set of papers is preceded by the reporter's summary presented at the final workshop session. Finally, a set of appendices contains detailed information drawn from the data packages provided to participants for each of the three rivers analyzed.

THE PROBLEMS[1]

YAMPA RIVER

The Yampa River is located in northwestern Colorado. The river is essentially a gravel-cobble bed stream above the confluence with the Little Snake River. Below the confluence the river is predominantly a sand-bed stream. Several reservoirs are proposed to be constructed on the Yampa River; one is the proposed Cross Mountain Reservoir and another is the proposed Juniper Reservoir. These reservoirs will impose changes in the flow and sediment regime of the river which will, in turn, cause possible alterations in the channel morphology.

The objective of this workshop problem was to discuss the short-and long-term changes of the following stream characteristics of the Yampa River as a result of the two reservoirs as follows:

1. Meander pattern
2. Configuration of the channel,
3. Substrate material, and
4. Pool-riffle sequence.

Data supplied by the U.S. Fish and Wildlife Service includes information on four small reaches of the river, but only two are to be considered in any detail: the Box Elder reach and the Lily Park reach. Lily Park reach is located just above the Little Snake River, and Box Elder reach is located just above the juncton of the Yampa River with the Green River.

POPLAR CREEK

Poplar Creek (not the streams true name) is a sand and gravel bed stream located in northern California. It is a tributary to the Sacramento River. Precipitation ranges from 70 inches in the headwaters to between 25 and 30 inches in the reach of interest below the proposed Dutch Gulch dam site. For purposes of discussion the reach of concern can be divided into two reaches as follows: Reach 1 between the dam and the junction of a major tributary, Dry Creek, Reach 2 below the junction of Dry Creek. Participants were asked: "What will happen to the morphology of the stream's channel as a result of the changes in streamflows and sediment discharge caused by the construction of a reservoir upstream of a reach of stream?" Specifically, for both a short and a long time after construction of the reservoir:

---

[1] For purposes of the Workshop the physical characteristics of the three river systems were simplified and altered to a degree. Because of this "academic license," the results of the Workshop should not be interpreted as representative of the response to be anticipated if the proposed development were to be implemented.

1. What will be the meander pattern?
2. What will be the configuration of the channel?
3. What will be the substrate material? and
4. What will be the pool-riffle sequence?

ELK RIVER

Elk River is a tributary of the Verdigris River in the Arkansas River basin in southeastern Kansas. The Elk River reach selected for evaluation is near Longton, Kansas. Participants were asked to analyze and evaluate expected response of this reach of river to the installation of 45 small floodwater retarding dams in the upstream reaches of the watershed under the U.S. Department of Agricultural Soil Conservation Service small watershed program. Again, the question relative to the Elk River was "What will happen to the morphology of the stream channel as a result of the changes in streamflows and sediment discharge caused by the construction of a number of small flood retention reservoirs upstream of a reach of stream?" Specifically, for both a short and a long time after construction of the reservoirs:

1. What will be the meander pattern?
2. What will be the configuration of the channel?
3. What will be the substrate material? and
4. What will be the pool-riffle sequence?

Acknowledgements: The assistance of the following individuals in providing data for the Workshop problems is gratefully acknowledged.

Yampa River: T. D. Steele & D. Bauer
U.S. Geological Survey
Denver, Colorado

Poplar Creek: M. Gee
Hydrologic Engineering Center (HEC)
Davis, California

E. F. Sing
U.S. Army Corps of Engineers
Sacramento District Office
Sacramento, California

Elk River: L. H. Wetter, Hydraulic Engineer
R. L. Hager, State Biologist
C. E. Deal, Civil Engineer
Soil Conservation Service
Lawrence, Kansas

SUMMARY

Daryl B. Simons
Director, Engineering Research Center; Professor, Civil
Engineering, Colorado State University,
Fort Collins, Colorado, U.S.A.

INTRODUCTION

Alluvial river systems such as the three examined in this workshop are very dynamic in nature and generally experience significant changes in depth, width, alignment, and stability with time. A systematic analysis is required to distinguish between changes due to the natural dynamic characteristics of the system and those due to man's activities. The changes may be defined as degradation, aggradation, and lateral migration. Degradation and lateral migration can endanger adjacent property, bridges, and other hydraulic structures while aggradation can reduce channel capacity, increase lateral erosion, and increase the flooding potential.

The dynamic nature of river and watershed systems requires that local problems and their solutions be considered in terms of the entire system. Natural and man-induced changes in a river frequently initiate responses that can be propagated for long distances both upstream and downstream (Simons and Senturk 1977). Successful river utilization and water resources development require a general knowledge of the entire watershed and river system and the processes affecting it. This goal can be achieved only through a basic understanding and application of physical processes governing channel response and the utilization of physical and numerical techniques.

In the past the emphasis of research and analysis has been on rivers with fine-grained alluvial beds and it is only recently that attention has been focused on flow in gravel-bed channels such as the Yampa River and Poplar Creek. In recent decades, though, increasing human involvement with upland and mountain regions, activities such as agriculture, forestry, recreation, gravel mining, reservoir construction, river regulation, and highway construction have affected the gravel-bed river environment. Gravel-bed rivers have therefore increasingly felt the impact of human activities and have themselves become the focus of engineering projects. As a result, there is an urgent need for the development of dynamic modeling techniques that can be applied to the management of gravel-bed rivers.

This summary is intended to highlight the major themes of the participants' papers regarding the scope, approaches, and data requirements for analyzing the general question of downstream river channel changes associated with diversions or reservoir construction. The summary will also relate these major themes to the instream aquatic habitat, a task not specifically assigned to the participants in their analysis. A careful reading of the papers which follow will reveal striking consistencies in these areas as well as several interesting digressions from what can be considered the usual thrust of river system analysis. One should keep in mind when reading these papers that given the techniques currently available for analysis of river channel change, the "science" of river engineering must be supplemented by subjective judgements based on years of field experience with rivers. The papers collected in these proceedings provide an exposure to the "art" of river system analysis that is not normally found in the technical literature.

MAJOR PROBLEMS THAT REQUIRE DETAILED ANALYSIS

The major effects imposed by diversions or reservoir construction that must be evaluated are as follows:

1. Determine conditions on the watershed such as climatology, hydrology, land use, possible land use changes, soil types, the geometry and topography of the system, and the existence of man-made or natural controls or both.

2. Determine the characteristics of the proposed reservoir including its volume, geometry, its stage-volume and stage-area curves, the operational plan for the reservoir, its trapping efficiency, and its uses such as irrigation, power, or recreation.

3. Evaluate the impact of the reservoir on flow in the study reach. The type of hydrographs normally experienced will depend on operation of the reservoir, probably reducing peak flows and increasing base or minimum flows

4. The water released from the reservoir will be transporting less sediment at the point of release than natural flows and this change in water quality may induce degradation, bank erosion, head cutting in tributaries, and possibly may induce growth of aquatic plants that may effect flow conditions, water losses, and water quality.

5. Evaluate the impacts of changed flow conditions on river form, the sequence of riffles and pools, lateral migration, and the bed material.

6. The modification of flows will cause changes in channel regime such that the aquatic habitat of the river may be affected, at least until a new equilibrium is established.

7. The storage and modified release of water from the reservoir may cause changes in the natural temperature conditions in the reach below the dam.

8. The reduction in peak flows and base flows will cause changes in the hydraulic characteristics and possibly in the stream morphology that may alter the fish spawning environment.

9. Impacts of the reservoir on groundwater conditions near the reservoir may be significant and should be investigated.

In order to evaluate the above-mentioned effects, an analysis of hydrological, hydraulic, morphological, and thermal changes is required. Hydrologic analysis will establish the flow occurrence frequencies for all of the main rivers and major tributaries. Hydraulic analysis will estimate the hydraulic parameters such as velocity, depth, top width, and wetted perimeter that are required to conduct the sediment and morphological studies and evaluate changes induced in the fish spawning capacity of the system. Sedimentation analysis will analyze the impact of siltation on the hydraulic parameters that govern fish habitat due to construction of the project. Careful scheduling of construction activities may be required to minimize impacts. The morphological studies will consider the changes that can be expected to occur over time in the river profile and cross section along a study reach. A thermal study should consider the thermal regime in the river resulting from selected withdrawal of water from a multilevel intake structure.

PROPOSED SCOPE OF WORK

The following general scope of work is suggested by the participants' papers in order to adequately analyze the responses of a reach below a dam or reservoir.

1. Conduct site visits to become familiar with the physical environment. All participants agreed that this is absolutely essential to any adequate analysis of the system.

2. Collect, collate, synthesize, and verify available hydrologic, hydraulic, thermal, topographic, sediment, cross-sectional, geological, structural, and fish habitat data pertinent to the study (see the data base section which follows).

3. Evaluate the data available for analysis, identify the immediate data gaps, and recommend an effective short-term in-field data collection program.

4. Conduct in-field data collection of cross-sectional data, velocity, depth, width, and bed material and suspended sediment samples in the river system of concern. Participants agreed unanimously that the data packages provided were not adequate for more than a preliminary qualitative assessment and must be supplemented to support quantititive analysis.

5. Compile and develop a spatial representation system that approximates the study area. This spatial design will provide a line diagram showing the watersheds, reservoir, river mile, cross-sectional numbers, location of structures, fish habitat reaches, bed material sampling points, geologic controls, and works of man such as construction roads.

6. Review and evaluate the hydrologic changes in the river system induced by the dam.

7. Estimate sediment loading and the associated impacts on the study reach during the construction phase (this requires site data).

8. Estimate sediment loading to the river system during the construction phase.

9. Establish the resistance to flow equations and sediment transport characteristics for the study reach.

10. Conduct a qualitative morphological analysis (degradation, aggradation, planform change, and bank stability) of the system considering the clear water release from the dam. The changes in flow over the long-term future should be assessed. The analysis would provide information on the expected bed profile and cross section and bed material distribution over time.

11. Evaluate the changes in the hydraulic parameters that affect the fish habitat utilizing a water-sediment routing program.

12. Conduct an initial thermal study of the temperature regime in the study reach and the impacts of the reservoir. If changes in thermal regime are found to be significant, a more detailed study will be necessary that considers the thermal routing in the system and selected withdrawal of water from multi-level intake structure from the reservoir to improve the thermal regime. This requires a mathematical model study.

13. Use a mathematical model if a more detailed study of the thermal regime is required to identify the potential thermal problem associated with fisheries. Suggestions to modify the position and openings of the multi-level intake should be made if the study shows that serious temperature effects occur.

14. Evaluate one proposed construction plan and, if required, recommend alternatives for evaluation.

15. Prepare reports documenting the results of analysis and recommendations.

PROPOSED APPROACH

Storage and release of water from a reservoir will have effects on in-stream flow, discharge rates, channel morphology, velocity, substrate, depth, top width, and temperature. The modification of flow in a reach below a reservoir also may have both beneficial and adverse effects on the fisheries over time. The hydraulic, morphological, and thermal changes, as well as channel stability, are functions of hydrologic changes. A systematic approach to the analysis of the hydrologic, hydraulic, sedimentation, morphological, and thermal changes is required to adequately evaluate the potential effects on the creek and its fish habitat.

The sediment transport capacity can be estimated by applying the modified Meyer-Peter, Muller equation using limited measured data. The sediment loading to the stream due to construction activities can be estimated by applying an on-site soil erosion model (Simons et al. 1977).

The morphological changes in the system are dynamic in nature and should be evaluated in both qualitative and quantitative terms. The altered water and reduced sediment flows downstream of the reservoir will probably induce degradation or aggradation depending on the sediment retention capacity of the reservoir. The altered flow and the clear water release from the reservoir will probably degrade the downstream channel; however, the extent of degradation is dependent on the flow rate, particle size, channel shape, and downstream controls.

The degradation or aggradation of the river system, or both, can be estimated by applying an acceptable water and sediment routing method such as the one developed by Li and Simons (1979). This method routes sediment by size fraction and has been verified in many field applications. The new equilibrium morphological conditions can be further checked by utilizing the Shields criteria (Simons and Senturk 1977) considering the armoring effect. After the morphological changes have been evaluated, the hydraulic parameters related to fisheries such as top width, velocity, flow depth, and substrate can be determined by applying an acceptable model.

An initial thermal study should be conducted. A more detailed analysis must be performed if significant changes in the thermal regime are detected by the initial study. This analysis would consider the thermal routing in the system. A mathematical model would be required to conduct this detailed analysis. A candidate for use is the Colonell (1976) model, which was developed by modifying the Massachusetts Institute of Technology model (MIT Model). The model was based on the simultaneous solution of appropriate equations for the conservation of mass and energy. Related hydrodynamic and thermodynamic processes include 1) internal radiation absorption, 2) heat sources and sinks, 3) advective heat transport, and 4) convection and diffusion. In order to account for cold region conditions, the model can be modified to consider ice cover during the winter months.

The general approach to the complicated problems involved in the study of downstream river channel change is 1) to consider the significance of the physical and biological environment, 2) to conduct sensitivity analysis for evaluating the relative importance of the physical processes and data, 3) to adhere to the project schedule, and 4) to provide a factual, practical, efficient, and effective solution.

DATA BASE

The data required to conduct the required hydrologic, hydraulic, sedimentation, and morphological analysis generally will include:

A. Watershed:

Geometry
Topography
Road location
Snowmelt rate
Soil type
Geology
Vegetation

B. Surface Water Hydrology:

Discharge records
Stage records
Stage-discharge relationships
Flood frequency curves
Flow duration curves
Design flood hydrograph
Sediment transport data (if available)
Tidal waves

C. Cross-sectional Data:

Location map
HEC-2 cross-sectional data covering the study area

D. Bed and Bank Material:

Size
Size distribution
Banks (stratified or homogeneous)

E. Structural Data:

Dam
Hydroelectric facility
Bridge
Construction plans

F. Geological Control Data:

Rock outcropping
Narrow section
Man-made control

The additional data requirements for a thermal study include:

Incoming solar radiation
Atmospheric radiation
Air temperature
Relative humidity
Wind speed
Water surface elevation
Upstream inflow rates to the reservoir and temperature

Outflow rates of the reservoir
Geometry of the reservoir
Water transparency to solar radiation
Water temperature
Time and periods of breaking and forming of the ice cover

As with the workshop data packages, the available data will seldom satisfy the requirements of this data list. However, appropriate methods of synthesis can be used to supply necessary data from a secondary data base. In general, these data can be classified as 1) data essential to conduct the proposed study, 2) data that are available on existing records, 3) data that can be synthesized by theory or extrapolated from adjacent basins, and 4) data that must be collected to supplement the existing data and proposed synthesized data to add to the validity and accuracy of the study.

CONCLUSIONS

There was general agreement among the workshop participants concerning the critical problems and data needs for assessing downstream channel change. The scope of the analyses provided in the papers which follow was influenced by the time available for study, the data provided, and the absence of a site visit to the study area. As a result participants generally attempted only a qualitative analysis, but many papers outline procedures for more detailed quantitative studies.

The details of the approaches selected by each participant vary based on the individual's training and experience. There are, however, striking commonalities which highlight the state-of-the-art of river system analysis.

Regime theory and concepts of dynamic equilibrium are used widely as a basis for qualitative assessment of river response to development. The concepts of fluvial geomorphology derived from Lane and Schumm are also pervasive. All participants relied heavily on experience, and many supplemented their analysis with case study data derived from comparable physiographic settings. It was generally agreed that hydraulic engineering projects can induce major changes in the hydrologic, hydraulic, and sediment regimes of river systems, and at present, theory alone is not capable of predicting this complex response. Research effort committed to producing documented case studies can provide an important resource for evaluating river response. Post-project monitoring and analysis should be supported by agencies responsible for river system development and control.

REFERENCES

Colonell, J. M. 1976. Field Evaluations of a Predictive Model for Thermal Stratification in Lakes and Reservoirs. Water Resources Research Center, University of Massachusetts, Amherst, Massachusetts.

Li, R. M. and D. B. Simons. 1979. Degradation and Aggradation Analysis. Chapter 18, presented at Analysis of Watersheds and River Systems, Colorado State University, Fort Collins, Colorado, May 28-June 1, June 4-8.

Simons, D. B., Li, R. M., and T. J. Ward. 1977. Estimation of Parameters that Describe Channel Geometry for Watershed Modeling. Colorado State University Report CER77-78DBS-RML-TJW12. Prepared for USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona, December. 807 p.

Simons, D. B. and F. Senturk. 1977. Sediment Transport Technology. Water Resources Publications, Fort Collins, Colorado.

YAMPA RIVER MORPHOLOGY

PROBABLE IMPACT OF PROPOSED RESERVOIRS ON SEVERAL REACHES OF THE YAMPA RIVER IN COLORADO: SUMMARY OF DISCUSSIONS

Carl F. Nordin
Hydrologist, U.S. Geological Survey
Denver, Colorado, U.S.A.

BACKGROUND

Two reservoirs are proposed by the Colorado River Water Conservation District for construction on the Yampa River in Colorado. According to information received from the District's Public Affairs Consultant (Lee Harris, personal communication, 1980), the upstream reservoir, Juniper, will have a capacity of about 1.08×10^6 acre-feet behind a 210 feet dam, at water surface elevation of 6125 feet. It will have a total rated generating capacity of 98×10^3 kw and will generate 134×10^6 kw-hrs/year under a schedule for peaking power. Juniper Dam will have a minimum release of 25 cfs (cubic feet per second) and the capability of going to a maximum discharge of 7000 cfs instantaneously.

The downstream reservoir at Cross Mountain is a re-regulating reservoir to smooth the flows from the peaking operaton at Juniper. It will have a capacity of about 142,000 acre-feet at water surface elevation of 5875 feet behind a 260-foot dam and will have generating capacity of 50×10^3 kw. It will generate about 165×10^6 kw-hrs/year. Maximum outflow is about 3000 cfs. Proposed operating criteria call for a minimum release of 200 cfs or a greater amount to provide a minimum flow in the Yampa River below its confluence with the Little Snake River of 500 cfs. During the rafting season, May through July, a minimum flow of 1800 cfs will be maintained. All the above data are preliminary and are subject to revision.

Of concern here is the question of what will happen to the morphology of the stream channel as a result of changes in streamflow and sediment discharge brought about by these reservoirs. In particular, the following questions were posed.

1. What will be the meander pattern?
2. What will be the configuration of the channel?
3. What will be the substrate material, and
4. What will be the pool-riffle sequence?

Cross section data were provided for four reaches of the river.

1. Maybell
2. Lily Park
3. Mantle Ranch
4. Box Elder

YAMPA RIVER

PAPERS AND PARTICIPANTS

Reporter: CARL F. NORDIN
Hydrologist
U.S. Geological Survey
Water Resources Division
Mail Stop 413, Box 25046
Federal Center
Lakewood, Colorado 80225

Monitor: KEN B. BOVEE
Hydrologist
Instream Flow Group
U.S. Fish and Wildlife Service
Fort Collins, Colorado

Participants: VICTOR GALAY
Northwest Hydraulic Consultants, Ltd.
4823 - 99 Street
Edmonton, Alberta, Canada T6E 4Y1

RAM GARDE
Professor of Hydraulic Engineering
Department of Civil Engineering
University of Roorkee
Roorkee (U.P.), India

ROLF KELLERHALS
Consulting Engineer
2533 Wallace Cr.
Vancouver BC, Canada

RUH-MING LI
Associate Professor
Department of Civil Engineering
Colorado State University
Engineering Research Center
Fort Collins, Colorado 80523

HSIEH WEN SHEN
Professor
Department of Civil Engineering
Colorado State University
Engineering Research Center
Fort Collins, Colorado 80523

TED YANG
Civil Engineer
Water & Power Resources Service
P.O. Box 25007
Denver Federal Center
Denver, Colorado 80225

Only two reaches, Lily Park and Box Elder, were to be considered in any detail. Additional information included excerpts of background material from Steel et al. (1978), a report by Andrews (1978) on sediment yield, monthly flow records from the gaging stations, Yampa River near Maybell and Little Snake River near Lily, for the period 1910-1976 and projected flows with the two reservoirs for both stations for the period 1927-1976. Peak flow records, copies of daily sediment loads, a couple of snowmelt hydrographs, and topographic maps were also furnished. Particle size distribution for only one sample of bed material was provided; it was collected near the Maybell gaging station.

APPROACH

Introductory sessions of the workshop included an overview by D. B. Simons, a review of ecological concerns with particular attention to in-channel habitat, by C. B. Stalnaker, and a summary of the characteristics of each river by R. T. Milhous.

After the preliminary discussions, R. M. Li presented a general review of the Yampa River problems with a summary of available data and a careful exposition of the three basic levels of analysis: 1) qualitative involving geomorphic concepts, 2) quantitative involving geomorphic concepts and basic engineering relationships, and 3) quantitative involving sophisticated mathematical modeling concepts. He presented some qualitative assessments and outlined steps leading to a few results from the second level approach. He concluded by emphasizing the importance of a field site investigation and of the need for more complete data before any detailed computational modeling could be undertaken.

Dr. Li's introduction was followed by the participants' presentations and informal discussions by the group to finalize concepts regarding the approach. The level of analysis by the participants varied from fairly complex computations to qualitative discussions of the general geomorphology and of the data needs both for preliminary assessment and for detailed evaluations.

A number of aerial photographs and slides of the critical reaches of the river were reviewed during the course of the workshop. Most of the participants plotted the river profile from topographic maps provided. Consideration of the profile, the topographic maps, slides and photographs, and the background information led to the following conclusions regarding the nature of the river.

1. The Yampa River is not an alluvial channel; its slope is controlled by the bedrock through which it is cutting its major canyons. Its pattern and behavior are controlled mostly by geology rather than by the quantity of water and sediment it is required to convey.

2. The channel has a pool-riffle configuration over much of the reach considered. Most of the riffles are formed by cobbles and boulders fed into the channel from steep, mostly ephemeral tributaries.

3. Some reaches of the river are alluvial in nature. The bed is armored with cobbles the size of which corresponds roughly to the size for critical tractive force at bankfull discharge.

4. These gravel-armored reaches are relatively stable.

5. Small quantities of sand and fine gravel are available for transport in the Yampa River above the Little Snake confluence; these sediments move over the armored gravel bed and accumulate in pools, on point bars, and in certain reaches with mild slopes.

6. Much of the sediment transported to the Box Elder reach is sand from the Little Snake River.

7. The reservoirs will trap most of the sediment of the Yampa River now passing the Maybell gage.

Much of the discussion centered around data needs. It was generally agreed that the data provided were not adequate. In particular, it was pointed out that meander pattern and channel configuration in the alluvial reaches of the river would likely depend on some dominant or "channel forming" discharge that might occur only a few days a year. The only information on reservoir releases were average monthly flows, whereas specific operating rules were needed, along with information on the outlet structures, their elevation, whether or not they would release sediments, and so on. There also was general concensus that extensive bed samples and at least some general information on the nature of the bank material were essential to any quantitative analysis.

One critical question emerged. What would happen in the vicinity and downstream of the confluence of the Little Snake and Yampa Rivers? The Little Snake River contributes heavy sediment loads. Would the regulated flows be able to transport this sediment, or would there be aggradation in the reach? Would the transport capacity of the sustained sediment-free reservoir releases exceed the supply of sediment, resulting in degradation? Only one of the participants, Dr. R. J. Garde, presented any calculations on transport capacities. He concluded that there would be minor degradation and armoring at Deerlodge Park, and that "once the surface is paved the material that comes in from the Little Snake River would be safely carried down the Yampa River." He was careful to point out that his analysis was based on some "simplified assumptions" and a careful reading of his paper will show that these simplifications were necessary because of the lack of data.

It was generally agreed that more detailed flow and transport calculations would be necessary to resolve the question of what would happen in the vicinity of the confluence of the Little Snake River, and that this would require the collection of field data to provide cross sections and bed material size distributions. In addition, it was stressed by Dr. Shen that future flows were stochastic processes; the distribution of these flows would have to be determined and hydraulic calculations should be carried out to cover that distribution. The future conditions in the reach cannot be predicted precisely; they should be specified in terms of their probabilities of occurrence.

Several other important concerns were identified and discussed by the group. These may be summarized as follows.

1. The method of analysis will depend to a large extent on whether or not the river system is stable, so a historical perspective is important. Any old maps, aerial photos, geological maps, or historical reports would be useful.
2. There is a potential in the basin for drastic land-use changes in connection with coal mining and other energy-related industries. These could have appreciable impact on the flow and sediment discharge of the Little Snake River, so they need to be considered.
3. Channel configuration downstream of reservoirs is influenced in many circumstances by the encroachment of vegetation. Not much is known about this; it is an area in which additional research is needed.
4. The sites should be inspected by aerial reconnaissance and on the ground.

SUMMARY AND CONCLUSIONS

In summary, the participants of the workshop presented a variety of approaches, from qualitative geomorphic assessments to quantitative calculations. A number of important concerns were raised during the group's discussion; most of these revolved around the need for additional data. There was general agreement on the following three major points.

1. The question of whether or not future flows would be able to transport the sediment delivered by the Little Snake River is critical to the analysis.
2. To answer this question, some computations of the hydraulics and the sediment transport will have to be carried out.
3. Additional field data are needed to provide a basis for reliable computations, and in fact, additional data are needed even for a qualitative assessment of the impacts of reservoir construction on the system.

REFERENCES

Andrews, E. D., 1978. Present and potential sediment yields in the Yampa River basin, Colorado and Wyoming. U.S. Geological Survey Water Resources Investigations 78-105, 33 pp.

Steele, T. D., Baver, D. P., Wentz, D. A., and J. P. Warner, 1979. The Yampa River basin, Colorado and Wyoming. A preview to expanded coal resource development and its impact on regional water resources. U.S. Geological Survey Water Resources Investigation 78-126, 133 pp.

YAMPA RIVER

Dr. V. J. Galay
Northwest Hydraulic Consultants Ltd.,
North Vancouver, British Columbia, Canada

INTRODUCTION

Several small flood control reservoirs are to be constructed on the Yampa River, one at Cross Mountain and one at Juniper. These reservoirs will impose changes on the flow and sediment regime of the river which will, in turn, cause changes to the stream channel. More specifically, this study is concerned with short- and long-term changes to the following stream characteristics:

1. Meander pattern,
2. Channel configuration,
3. Substrate material, and
4. Pool-riffle sequence.

The reaches that are treated in detail are the Box Elder Reach and the Lily Park Reach which are located 2 miles and 52 miles from the confluence with Green River, respectively.

In order to assess the short- and long-term changes to various river characteristics, several levels of study should be undertaken. For the Yampa River, the levels of study proceed as follows.

Level 1. Preliminary appraisal of river processes.

Level 2. Assessment of the scope of the problem.

Level 3. Additional data requirements.

Level 4. Analysis of river processes and prediction of changes.

The forthcoming comments will treat each of the above levels.

PRELIMINARY APPRAISAL OF RIVER PROCESSES

A preliminary appraisal can only be undertaken if the following data are available.

Topographic maps

Geologic maps

Air photos

Site inspection or ground photos

River cross sections

Hydrologic information

For the Yampa River problem, topographic maps were supplied and air photos of the Lily Park Reach were obtained during the workshop. A general appraisal of the two reaches follows.

Box Elder Reach

The river channel may be described as having an irregular meander pattern, deeply entrenched in a 1000 foot deep canyon, with a thin layer of alluvium on the bed. The banks are essentially bedrock. There are no air photos, consequently it is difficult to assess the river processes, but it appears that the river is stable and is not expected to change its pattern.

Lily Park Reach

As noted from the topographic maps and the air photos, the Yampa River changes character several times as it emerges from the Cross Mountain Canyon; in fact this reach can be further subdivided into three distinct reaches as follows (see Figure 1 for details of reaches as traced from air photos).

Reach No. 1. The Yampa River is confined within stable steep banks, has a pool and riffle sequence with some mid-channel bars composed of gravel and boulders. The channel pattern is irregular with some bends and straight reaches. It appears that the sediment load brought into this reach from the Cross Mountain Canyon would be transported through the Reach and that the channel is relatively stable (see Figure 2 for river profile).

Reach No. 2. The Yampa River becomes wider with a regular meander pattern. The banks consist of a high terrace on the left which appears stable and a low floodplain on the right which is susceptible to erosion. This reach has several point bars and could be aggrading due to the confluence at the bottom end of the reach.

Reach No. 3. The Yampa River widens significantly and flows within low unstable banks. The bed has large mid-channel bars as well as wide point bars indicating that material is depositing throughout the reach and that the bed is aggrading.

With the various reaches described, we can now discuss the scope of the problem to be studied.

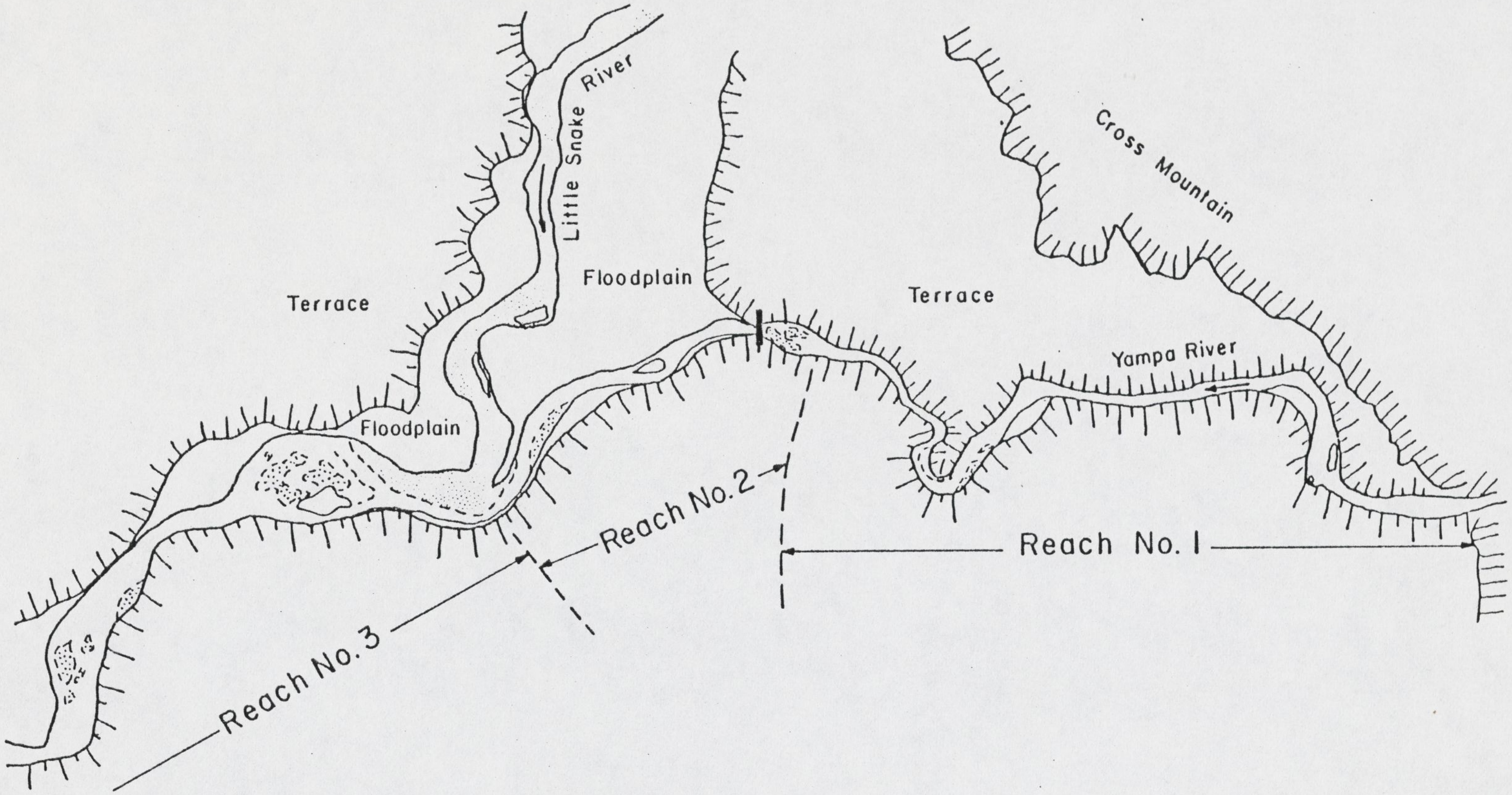


Figure 1. Yamper River at Lily Park.

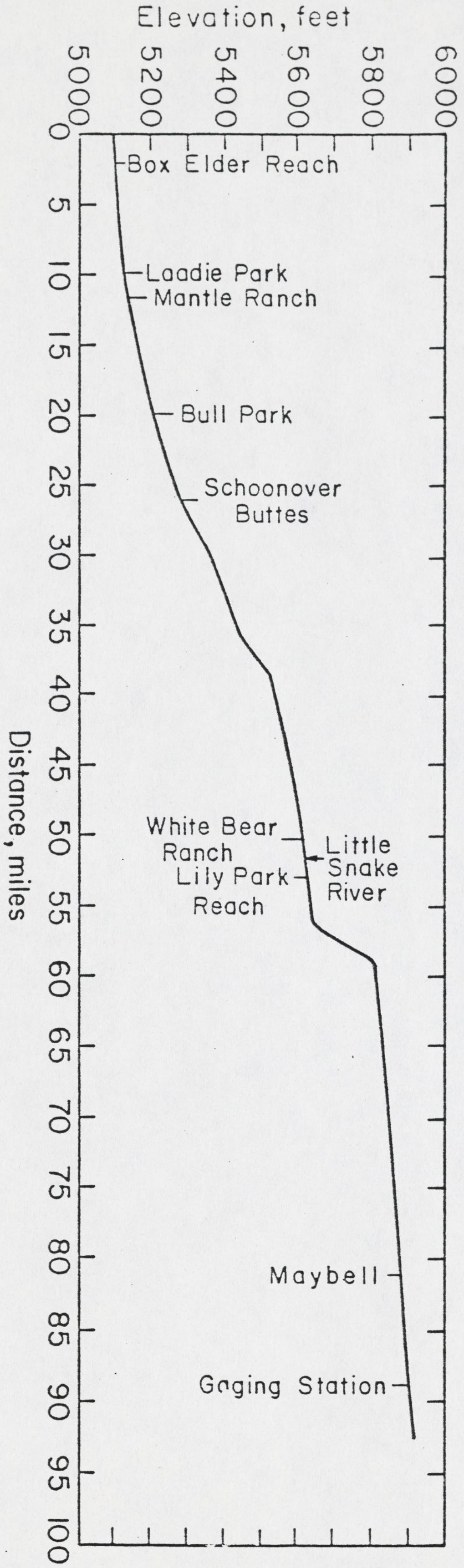


Figure 2. Yampa River profile.

ASSESSMENT OF THE SCOPE OF THE PROBLEM

Box Elder Reach

Examination of the cross sections in this reach, for three distinctly different discharges, shows no changes. This indicates that the bed and banks are primarily composed of resistant material and, further, that the stream characteristics of concern will not be significantly altered by the construction of upstream reservoirs. Since the channel is deeply entrenched in bedrock its configuration and its meander pattern should not change markedly, at least not within the engineering time scale. The pool and riffle sequence as well as substrate material will also not be affected since reservoir release flows will have smaller magnitudes than historical floods.

Therefore, there is probably no additional data or analysis required for this reach.

Lily Park Reach

In terms of fish-spawning grounds, it is not certain which of the three distinct reaches are of most interest to biologists; therefore, all three reaches will be discussed briefly.

The problem consists of predicting the changes to meander pattern, channel configuration, substrate material and pool and riffle sequence. We can consider these changes for each reach.

	Reach No. 1	Reach No. 2	Reach No. 3
a) Meander Pattern	No change, stable	Some change	Minor changes possible
b) Channel Configuration	No change, bed-material stable	Some change, depends on backwater	Some change, depends on reservoir releases
c) Substrate	No change	Some change, depends on backwater	Some change, depends on reservoir releases
d) Pool & Riffle	No change	Some change	Uncertain

It appears that Reach No. 1 will not undergo major changes. A reservoir upstream will probably reduce flood peaks and the existing pool and riffle sequence will probably not be disrupted.

As for Reach No. 2, there may be some changes to the meander pattern and the channel configuration if there is significant bank erosion, which could be occurring along the right bank. In regard to substrate, pools, and riffles, there may be some infilling of the pools with sand and gravel depending upon the extent of backwater from the Little Snake River.

For Reach No. 3, significant changes could occur. The construction of dams on the Yampa River will result in reduced bed material transport capacity. Because the supply of bed load from the Little Snake will not change, the Yampa may aggrade at the confluence. Also, if the peak flows on the Yampa are reduced significantly, then upstream progressing degradation will occur on the Little Snake during corresponding high flows (Figure 3). Therefore, it is probable that the Yampa River will aggrade in Reach No. 3, this would create backwater effects up the Yampa and drown out the riffles. With this flow situation, sands and gravels moved into the pools will probably stay there, at least until high flows are released from the reservoirs. In regard to channel configuration and meander pattern in Reach No. 3, it is difficult to predict changes that may occur. The maps are inadequate to clearly ascertain historical shifting of the channel. Air photos over a time span are essential to evaluate the lateral stability of the river. Also, the magnitude, frequency and duration of releases from the reservoirs must be known in order to attempt to predict future channel configuration. In qualitative terms, it appears that the channel pattern is controlled by boulders along the river banks and reduced flows will produce relatively little change. However, if aggradation takes place at the confluence, then the build-up of channel bars will deflect currents into the banks resulting in some change to the channel pattern. The pattern below the confluence is likely to have several distinct channels flowing adjacent to bars and islands.

In order to carry out further detailed analysis, however, more data are required.

ADDITIONAL DATA REQUIREMENTS

The following data are required in order to analyze the various river reaches and to predict river changes.

Data	Reach No. 2	Reach No. 3	Little Snake River
Cross sections	X	X	X
Bed material samples	X	X	X
Bank material samples	X	X	-
Water levels at various flows	X	X	X
Stage-discharge measurements	X	X	X
Reservoir Releases	X	X	-
Bed forms during high flows	X	X	-

ANALYSIS OF RIVER PROCESSES AND PREDICTION OF CHANGES

With the availability of more data it may be possible to make use of available mathematical models to predict the changes to the river.

The use of the HEC-6 scour and deposition computer model developed by the U.S. Army Corps of Engineers should enable one to compute the response of the river to changes in sediment loads due to reservoir construction. It would be necessary to operate the model for a number of releases from the reservoir in order to evaluate the possible aggradation through Reach No. 3 and its possible backwater effects on Reach No. 2.

Changes to the pool and riffle sequence as well as to meandering cannot be evaluated with a mathematical model, it may be necessary to obtain data from other similar rivers that have undergone major changes in order to predict what will happen to the Yampa River.

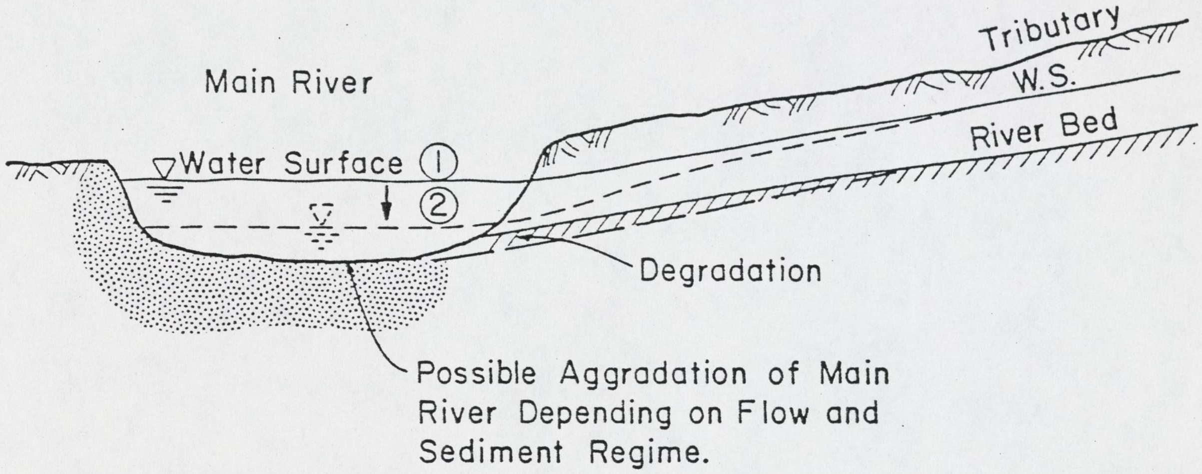


Figure 3. Upstream progressing degradation on tributary caused by base level lowering on main river.

STUDIES ON THE MORPHOLOGICAL CHARACTERISTICS OF THE YAMPA RIVER

Dr. R. J. Garde
Professor and Head of Civil Engineering Department,
University of Roorkee, ROORKEE-247672, India

INTRODUCTION

The data concerning the Yampa River were made available to the author by the organizers of the workshop for carrying out a detailed morphological analysis of this river. A close scrutiny of these data and the questions posed led the author to study the following aspects of the problem.

1. Morphological characteristics of the Yampa River from Maybell to its confluence with the Green River in the absence of flood control reservoirs, with particular reference to plan-form and longitudinal slope.
2. Response of the Yampa River to the construction of flood control reservoirs with reference to bed level variations.

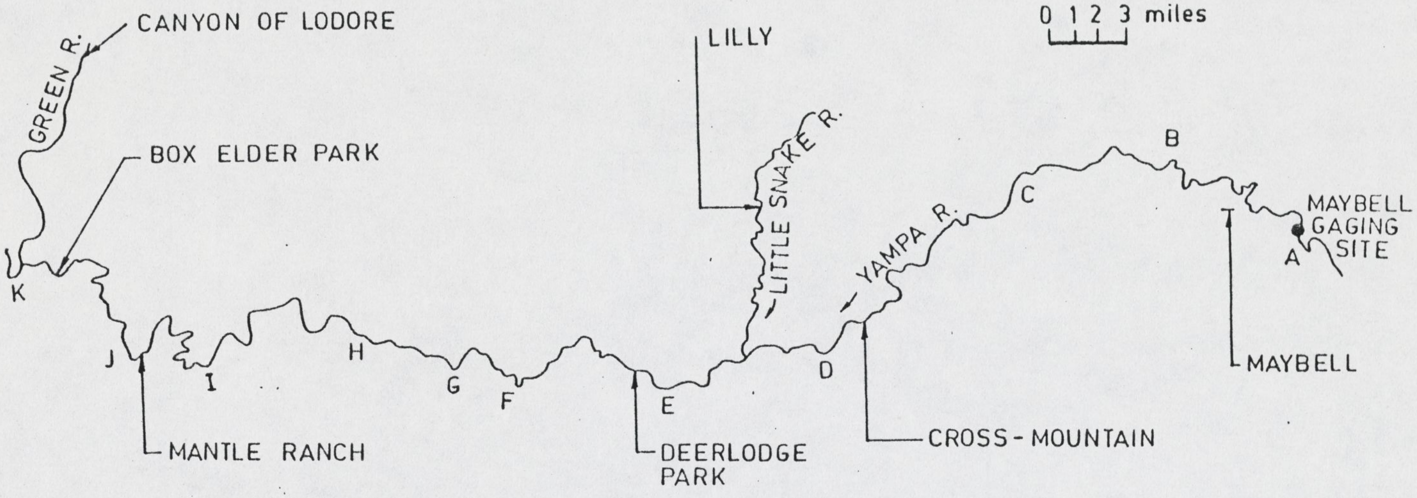
The results of the analysis are reported in the present paper; details of the data, and other information made available to the participants are omitted to avoid repetition. It would not be out of place to mention here that owing to the paucity of time and the difficulties in getting clarifications or informaton on telephone over such a long distance, the author was constrained to make several assumptions, either intuitively or on the basis of certain deductions.

PRESENT CHARACTERISTICS OF THE YAMPA RIVER

In dealing with a river, a thorough understanding of its morphological characteristics is the first essential step in the analysis of its response to man-made changes. Accordingly, several interesting features of the Yampa River are studied first.

Meander Pattern of the Yampa River Between the Little Snake and the Green River

The plan view of the Yampa River along with the longitudinal bed slope for the various reaches is shown in Figure 1. The slopes have been calculated from the knowledge of elevations and distances obtained from the contour maps. It can be seen that the slope varies from 60.90×10^{-4} to 4.84×10^{-4} and that the reach under consideration is a meandering one. It was thus thought desirable to study these meander patterns in terms of meander length M_L, meander belt M_B, and the radius of curvature R. Thus, for the meander pattern shown in Figure 1, the values of M_L, M_B, and R were actually measured. In the measurement of R, it was assumed that the meander loop is a segment of a circle of equivalent radius and the best possible fit of this segment for the curved surface of the meander was used to calculate R.



REACH	AB	BC	CD	EF	FG	GH	HI	IJ	JK
SLOPE $\times 10^4$	6.77	4.73	31.65	17.50	60.90	28.60	29.70	15.90	4.84

Figure 1. Plan-View of the Yampa River.

It is obvious from the geology of the area that these meanders are entrenched meanders different from the conventional meanders in alluvial plains. This contention was also supported by the finding that the observed meander characteristics did not show any correlation with the dominant discharge at Deerlodge Park. The hydrograph at Deerlodge Park was prepared by adding the mean monthly discharges of the corresponding months from the Little Snake River and the Yampa River, and the dominant discharge was taken as 8900 cfs.

The meander data were then compared with some of the available relationships for entrenched meanders. According to Bates, M_B is given by Equation 1 while Inglis suggested the use of Equation 2 for M_B.

$$M_B = 30.8\ W_s \tag{1}$$

$$M_B = 27.30\ W_s \tag{2}$$

The relationships for M_L given by Inglis and Dury are given by Equations 3 and 4 respectively.

$$M_L = 11.45\ W_s \tag{3}$$

$$M_L = 7 \text{ to } 10\ W_s \tag{4}$$

In the above equations W_s is the bankful width of the river.

In estimating the values of M_B and M_L from the above relationships, the value of W_s was taken as the width of the river. The values of M_B obtained from Equations 1 and 2 were in general 3 to 4 times larger than the actual values; on the other hand, the values of M_L obtained from Equations 3 and 4 were comparable with the actual values only for a few meander loops. Figure 2 shows the variation of M_L with R for the observed values. On this figure, the relationship between M_L and R for entrenched meanders proposed by Young (1974) has also been plotted for comparison. It can be seen that, on the average the Yampa River data follow Young's relationship.

The study of the topographic features of the Yampa River also indicates the presence of cliffs more than a thousand feet high especially on the inside bends of the entrenched meanders. Thus, the meanders are more or less confined within the high vertical walls of the river with little possibility of their lateral migration. The general meander pattern is, therefore, unlikely to be affected by any variations in discharge.

Hydraulic and Sediment Characteristics at Maybell

The data regarding the mean monthly discharges and the maximum annual discharges of the Yampa River at Maybell have been collected since 1910. However, the gage heights are known only for the maximum annual discharges and even in this situation it is not known how these gage heights are related with the depths of flow. The sediment data include the size distribution of bed and suspended material along with the mean monthly concentration of the suspended load from 1951 to 1957 and 1977 to 1978. These data have been used to study the hydraulic and sediment characteristics of the Yampa River at Maybell.

Stage-Discharge Relationship. Figure 3 shows the stage-discharge relationship at Maybell. A close examination of this figure indicates that the gage heights corresponding to the same discharge are different for different years. Such a variation in the gage height would imply that the stream is not in true equilibrium and is either aggrading or degrading. To examine this aspect more thoroughly, the gage heights were plotted against time for different ranges of discharge as shown in Figure 4. It is interesting to note that gage heights increased continuously up to 1950 and have stabilized at constant values since then. This may be taken to be an indication of aggradation until 1950 and subsequent attainment of equilibrium conditions at its present slope.

Relation between Stage and Depth of Flow. In the absence of any definite relationship between the stage and the depth of flow, it was necessary to estimate the depth of flow for the given discharge and the slope. The size distribution of the bed material of the Yampa River is shown in Figure 5 which shows that the size of the bed material ranges from 4.0 mm to 128.0 mm with a median size of 40.0 mm. Considering the coarseness of the bed material, the bed was assumed to be flat and the value of Manning's roughness coefficient n, was computed using Equations 5 and 6 proposed by Bray (1979) and Strickler (see Garde and Ranga Raju, 1977) respectively

$$n = .104\ S^{0.177} \tag{5}$$

$$n = \frac{(d_{65})^{1/6}}{21.0} \tag{6}$$

Here S is the bed slope and d_{65} is the size of the bed material in meters such that sixty-five percent of the material is finer than this size.

The values of n obtained from Equations 5 and 6 were 0.0285 and 0.029 respectively and thus a constant value of $n = 0.03$ was adopted in the subsequent calculations.

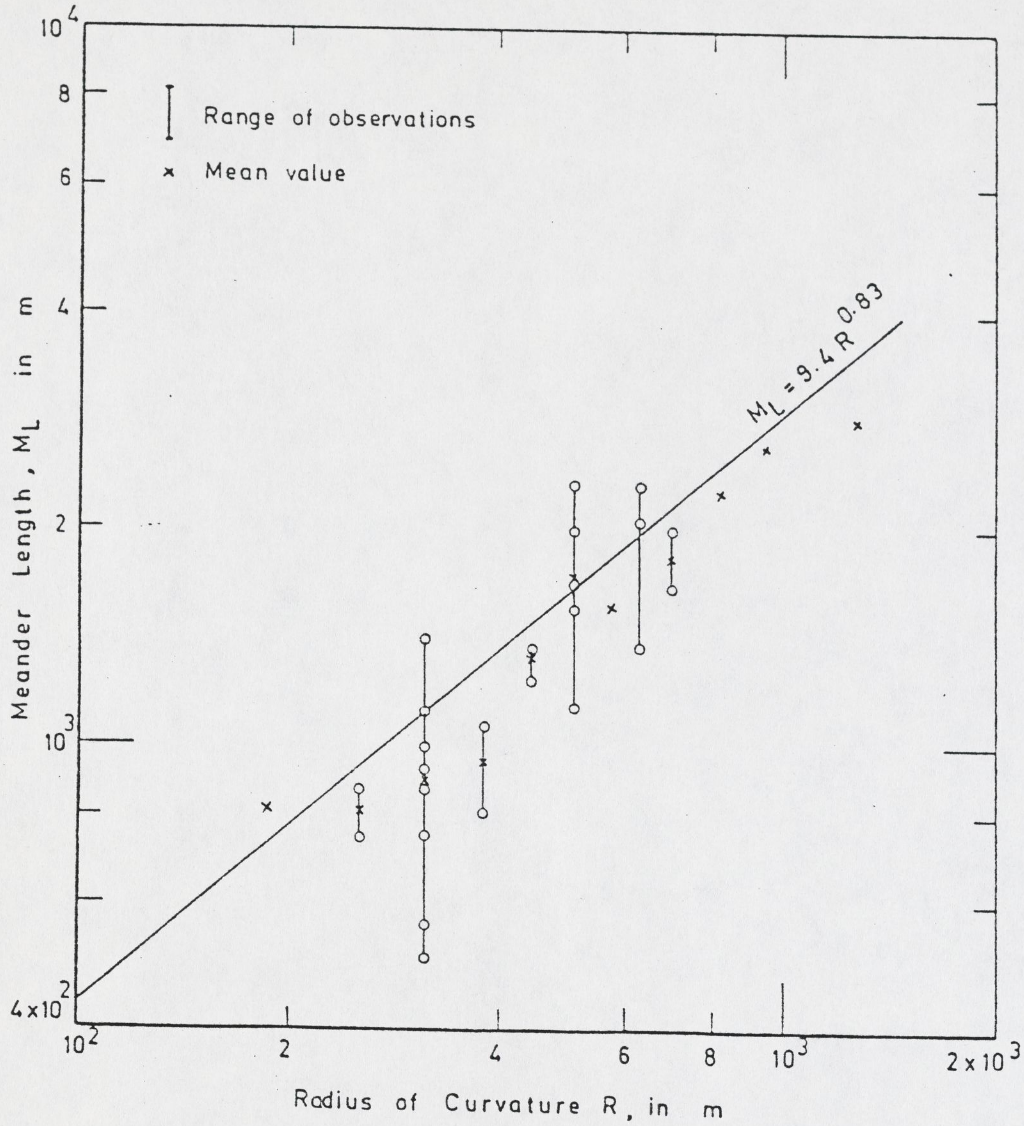


Figure 2. Variation of M_L with R for the meanders in the Yampa River.

Garde 4

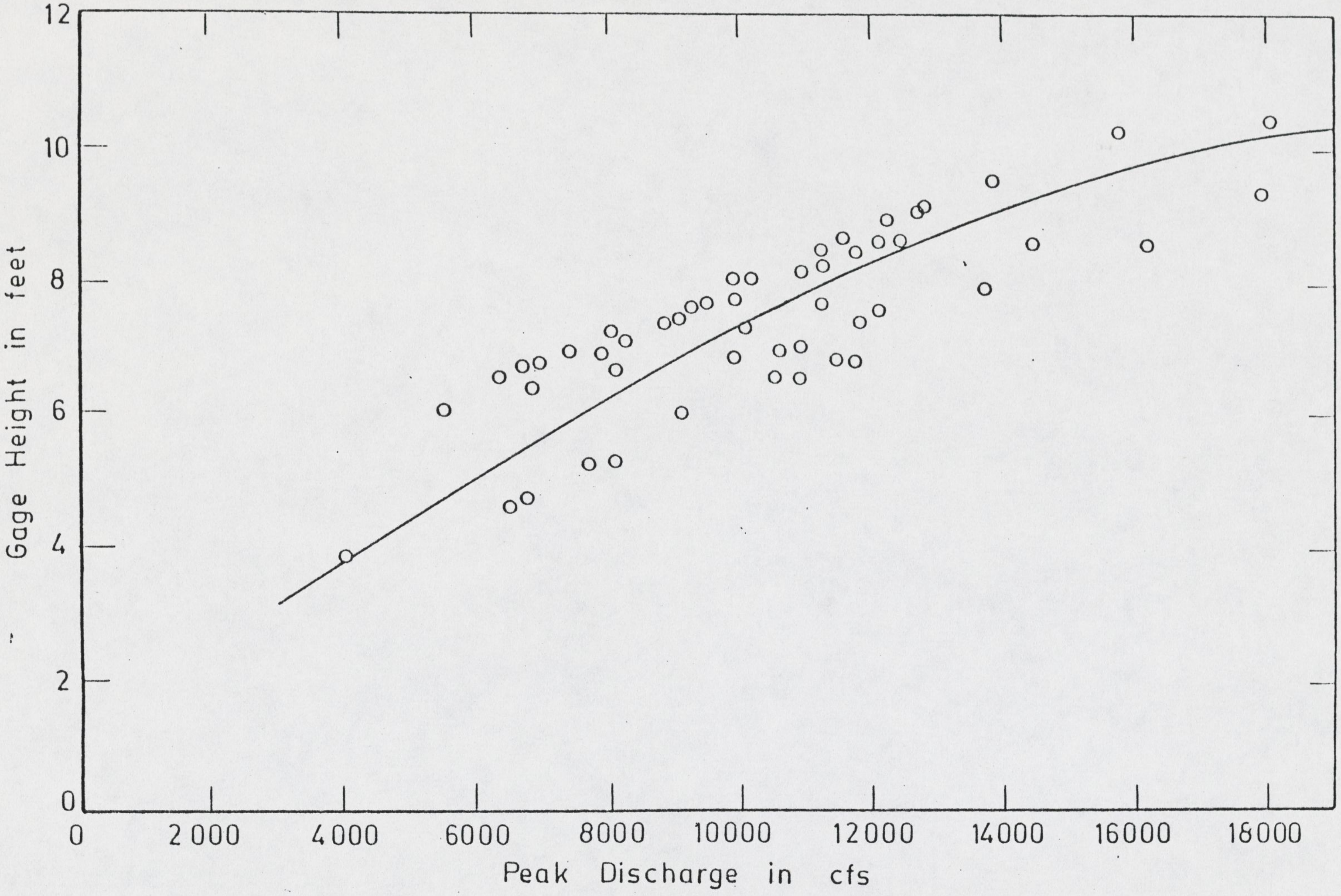


Figure 3. Relationship between stage and discharge for annual-maximum flows at Maybell.

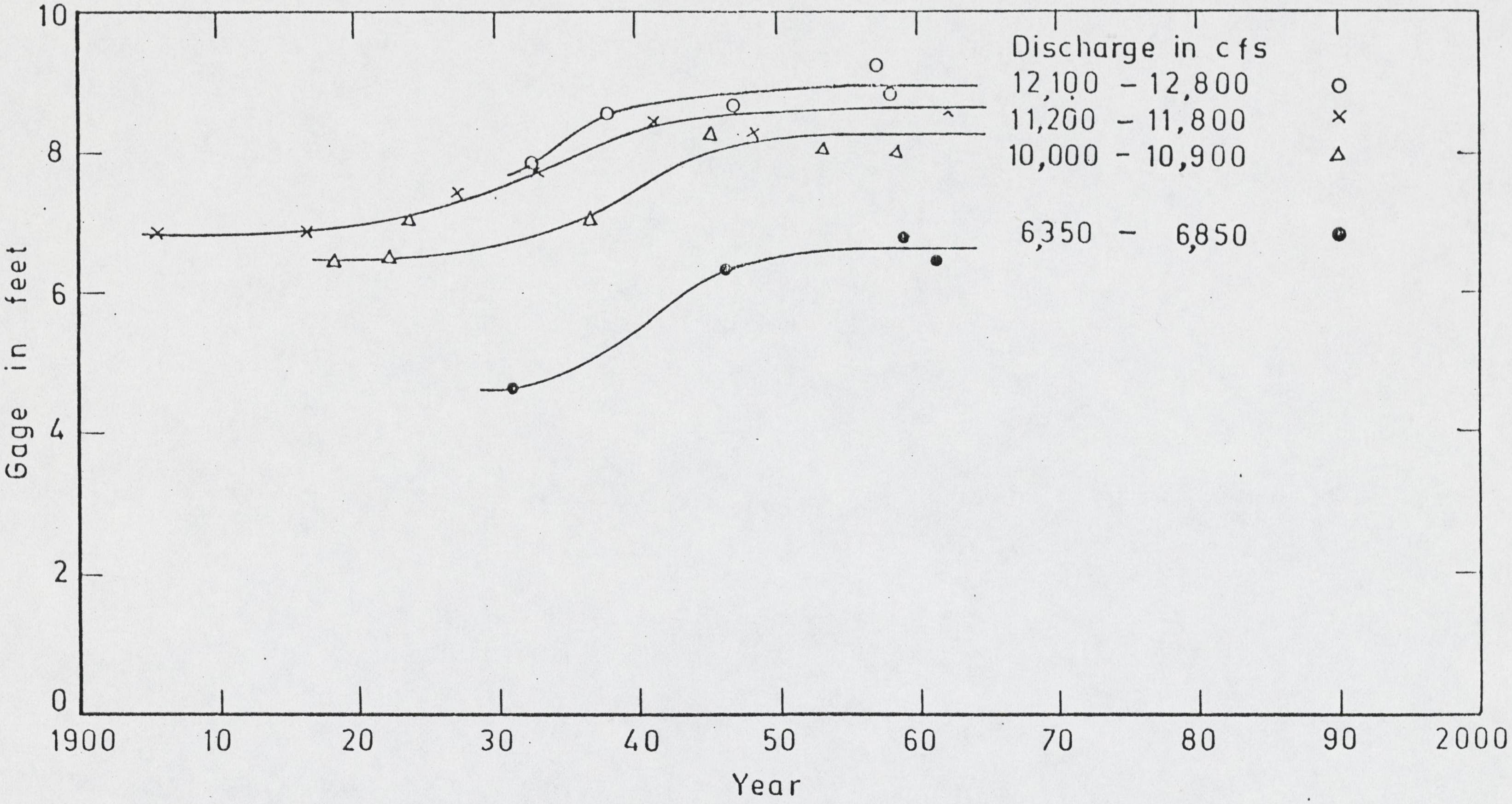


Figure 4. Variation in river stage with time for different discharges.

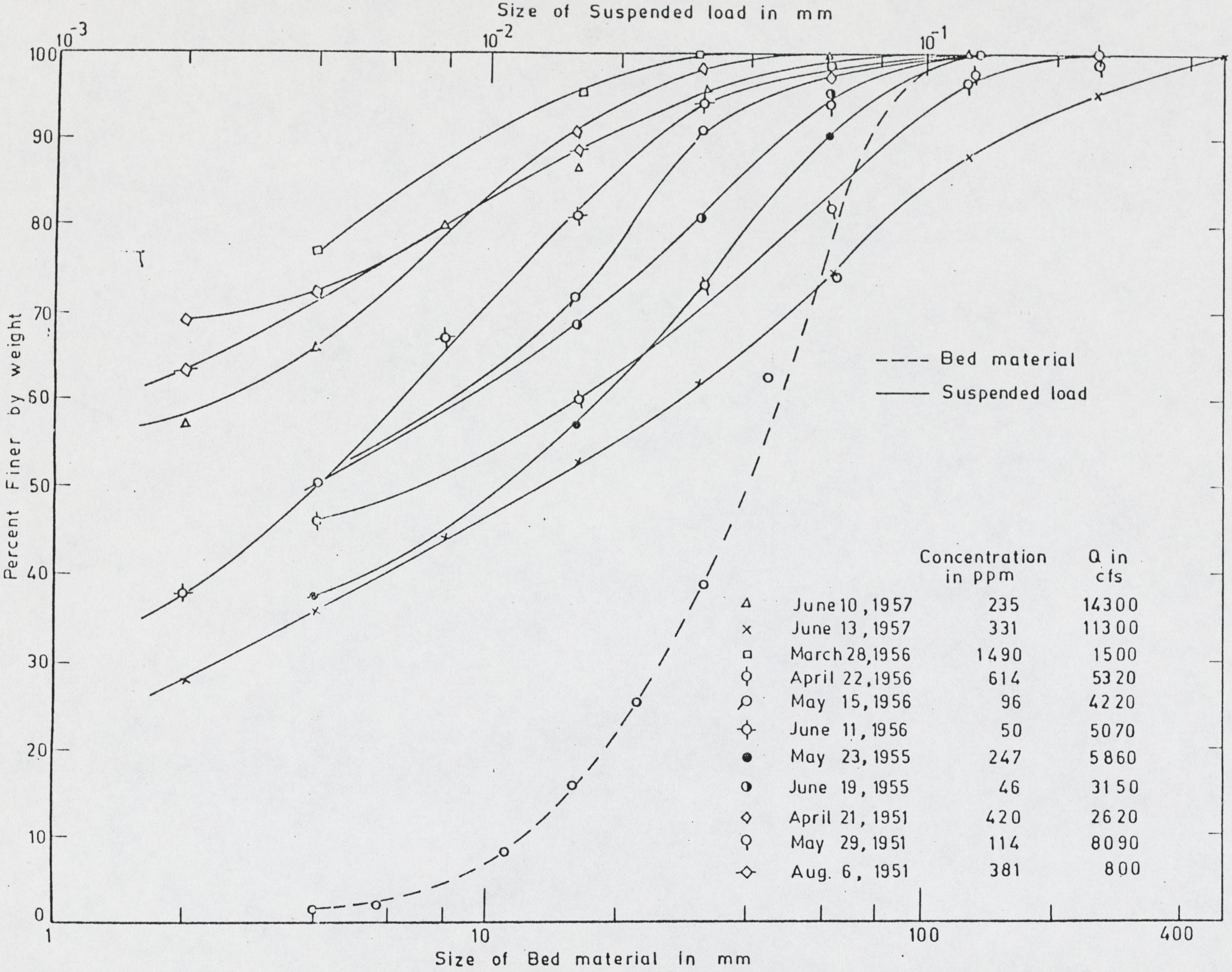


Figure 5. Size distribution of suspended load and bed material in the Yampa.

The Manning's equation was used to calculate the depths of flow for the peak flows. The river cross section was taken to be a wide rectangle with an average bed width equal to 326 ft. The depths so computed were compared with the corresponding gage heights. This comparison showed that around the 1920's the gage heights and the depths of flow were more or less the same; however, after 1950 the indicated gage heights were consistently 1.40 feet higher than the estimated depths.

The foregoing finding substantiates the conclusion that aggradation of the stream stopped after 1950.

Sediment Load Computations. Figure 5 shows the size distribution of the suspended load for the years for which the data were available. On this plot the size distribution of the bed material is also shown. It is evident from Figure 5 that the suspended material is much finer than the bed material. Further, with increase in shear stress or discharge the concentration of the suspended load and its median size normally increase when the suspended load happens to be a part of bed material load. However, such is not the situation in Figure 5 and this is taken to indicate that the observed suspended load is, in fact, wash load.

For the estimation of bed load, one can use either Meyer-Peter and M≠ller's equation or follow Einstein's (see Garde and Ranga Raju 1977) procedure of computation. Recently some work has been carried out by Misri (1980) concerning the partial transport of bed load in case of highly non-uniform material and this has been used to estimate the bed load. According to Misri the parameter i_B/i_b is related to τ_o/τ_{ci} as shown in Figure 6. Here i_b is the fraction of the bed sediment in the given size range d_i, i_B' is the fraction of the bed load transport of size d_i, τ_o is the grain shear, and τ_{ci} is the critical shear corresponding to d_i. In the present study Figure 6 in conjunction with Meyer-Peter's Equation 7 has been adopted to estimate the bed load.

$$\phi_i = 8(\tau_{*i} - .047)^{3/2} \tag{7}$$

In Equation 7, parameters ϕ_i and τ_{*i} are defined as,

$$\phi_i = \frac{q_{B_i}}{\delta s} \frac{1}{\sqrt{(\frac{\rho_s}{\rho_f} - 1) g d_i^3}} \text{ and } \tau_{*i} = \frac{\tau_o'}{(\Delta\gamma_s)\, d_i}$$

Here q_{B_i} is the bed load transport rate in lb/ft of size d_i, γ_s is the unit weight of sediment, $\Delta\gamma_s = (\gamma_s - \gamma_f)$, γ_f is the unit weight of water, ρ_s and ρ_f are the mass densities of sediment and water respectively, and g is the acceleration due to gravity.

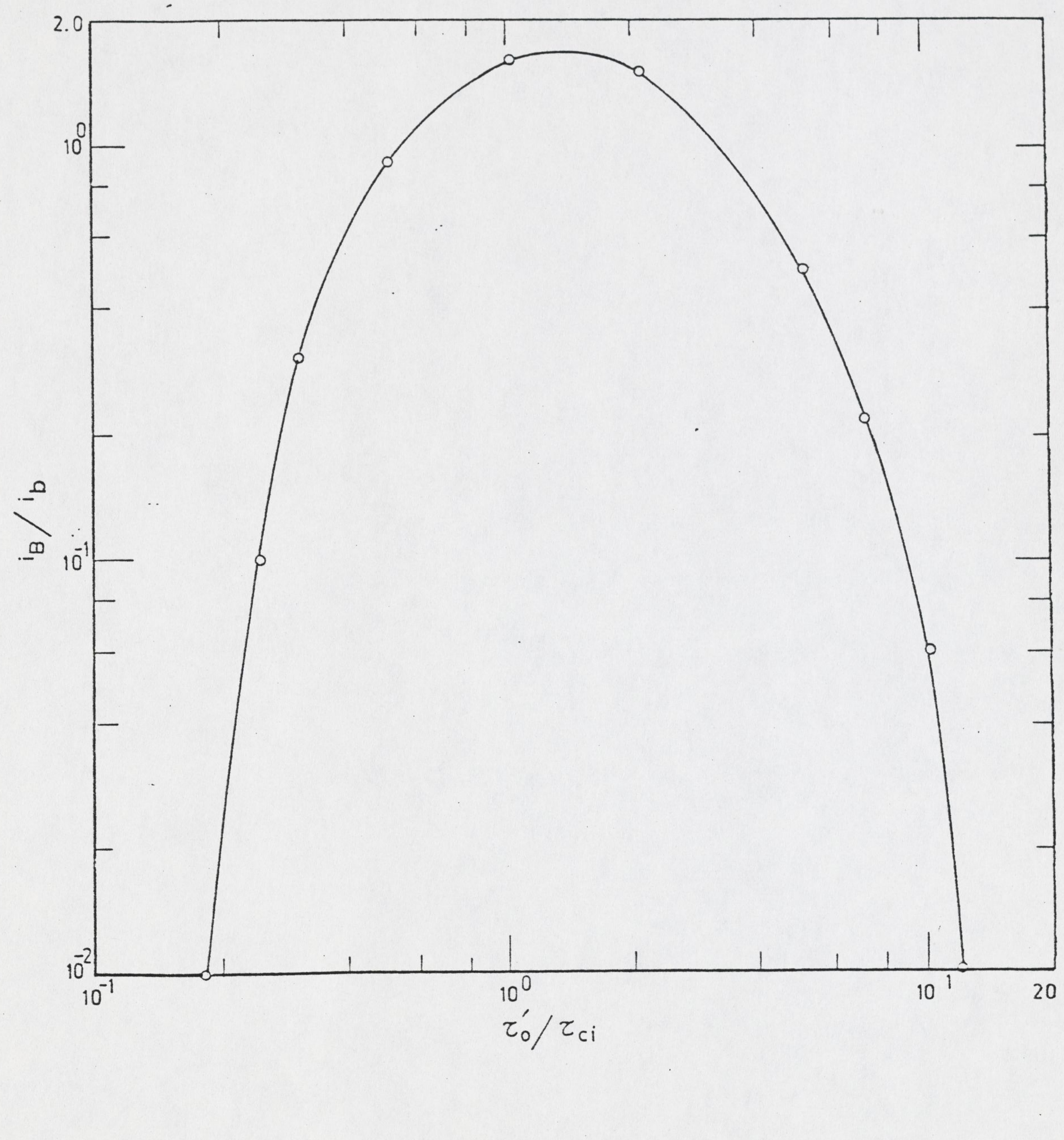


Figure 6. Variation of i_B/i_b with τ'_o/τ_{ci}.

The values of τ_{c_i} were determined from Shields' (see Garde and Ranga Raju, 1977) and τ_o was taken as the total shear τ_o in view of the earlier assumption of flat bed.

Using Figure 6 in conjunction with Equation 7, the bed load transport for each size range d_i was calculated as $i_B\, q_{B_i}$ in lb/ft s. The total bed load Q_B in T/day was then determined in the following manner.

$$Q_B = \Sigma\, i_B\, q_{B_i} \text{ x width of the channel in ft x } 38.57.$$

The bed load transport rates thus obtained are shown in Table 1.

Table 1. Transport rates of the Yampa River at Maybell.

Average shear stress τ_o in lb/ft²	0.104	0.137	0.163	0.208	0.239	0.307	0.400
Bed load Q_B in T/day	6.35	54.30	135.7	341.6	625.0	1358	2000

The above hydraulic and sediment computations have been used to study the longitudinal bed profile of the Yampa River at Deerlodge Park. Following is a brief description of this study.

Longitudinal Bed Profile of the Yampa River Near Deerlodge Park

The longitudinal bed slope of the Yampa River near Deerlodge Park is 1.75×10^{-3} as indicated in Figure 1. This slope is much steeper than the slope of 6.77×10^{-4} at Maybell. In general the stream slope decreases in the downstream direction. The converse situation prevailing here led the author to examine the possible reasons. Since the Little Snake River brings in about 70% of the total sediment load (mostly fine suspended load) of the Yampa River downstream of the confluence, occurrence of aggradation downstream of the Little Snake is a possibility. In making the necessary computations the following assumptions have been made.

1. Bed load of the Little Snake River has been taken from the available relationship at Dixon, while discharges and the suspended load data have been taken from the records at Lily.

2. The river cross section and the bed material characteristics at Deerlodge Park have been assumed to be the same as at Maybell.

3. Variations in discharges and the sediment load in the Yampa River from Maybell to its confluence with the Little Snake

River have not been considered in the absence of any relevant information in this regard.

4. The median size of the suspended load is taken as 0.04 mm.

The total discharge, bed load, and suspended load at Deerlodge Park were then estimated by adding the corresponding values for the Yampa and the Little Snake Rivers.

Aggradation in the Yampa River near Deerlodge Park will take place if the incoming sediment load exceeds the equilibrium transport rate. As mentioned earlier, the suspended load from Maybell as well as from the Little Snake River is, in fact, wash load. Therefore, one could use Pullaiah's (1978) results for determining the slope required to transport the incoming wash load without objectionable deposition. According to Pullaiah, the limiting concentration C in ppm is related to $u_{*b}\ S/w_o$ as shown in Figure 7. Here u_{*b} is the shear velocity corresponding to bed, S is the bed slope, and w_o is the fall velocity for the median size of the wash load. In the present case, since the river is wide, u_{*b} is taken as u_*. Using Manning's equation $u_* S/w_o$ may be expressed as

$$\frac{1}{w_o}\left(\frac{Q\ n\ g^{5/3}}{1.49\ B}\right)^{0.30} S^{1.35}$$

Available data for the year 1977-1978 indicate that the Little Snake River had a maximum concentration of wash load on September 22, 1978. The concentration was 17,300 ppm with a discharge of 123 cfs. For the corresponding period, the values of wash load concentration and discharge for the Yampa River were 91 ppm and 226 cfs respectively. Thus, a total discharge of 349 cfs with a wash load concentration of 6161.52 ppm was considered at Deerlodge Park.

For $Q = 349$ cfs, $S = 6.77 \times 10^{-4}$, and median sediment size of 0.04 mm for the wash load, Figure 7 gives the limiting concentration as 3500 ppm. Since the combined concentration from the Little Snake and the Yampa River is 6161.52 ppm, the river would need a steeper slope to carry this load. Figure 7 gives the value of this slope as 1.315×10^{-3} for $C = 6161.52$ ppm. Thus, the Yampa River near Deerlodge Park would aggrade until this slope is attained.

The slope estimated above is smaller than the present slope of the reach. While the approximate nature of Figure 7 could be partly responsible for this difference, the possibility that the Little Snake River carried higher sediment loads in the past (leading to steeper slopes in the Yampa River) cannot be ruled out. With aggradation in the Yampa River, some of the wash load would start depositing in the Little Snake River itself, thus causing a reduction in wash load entering the confluence.

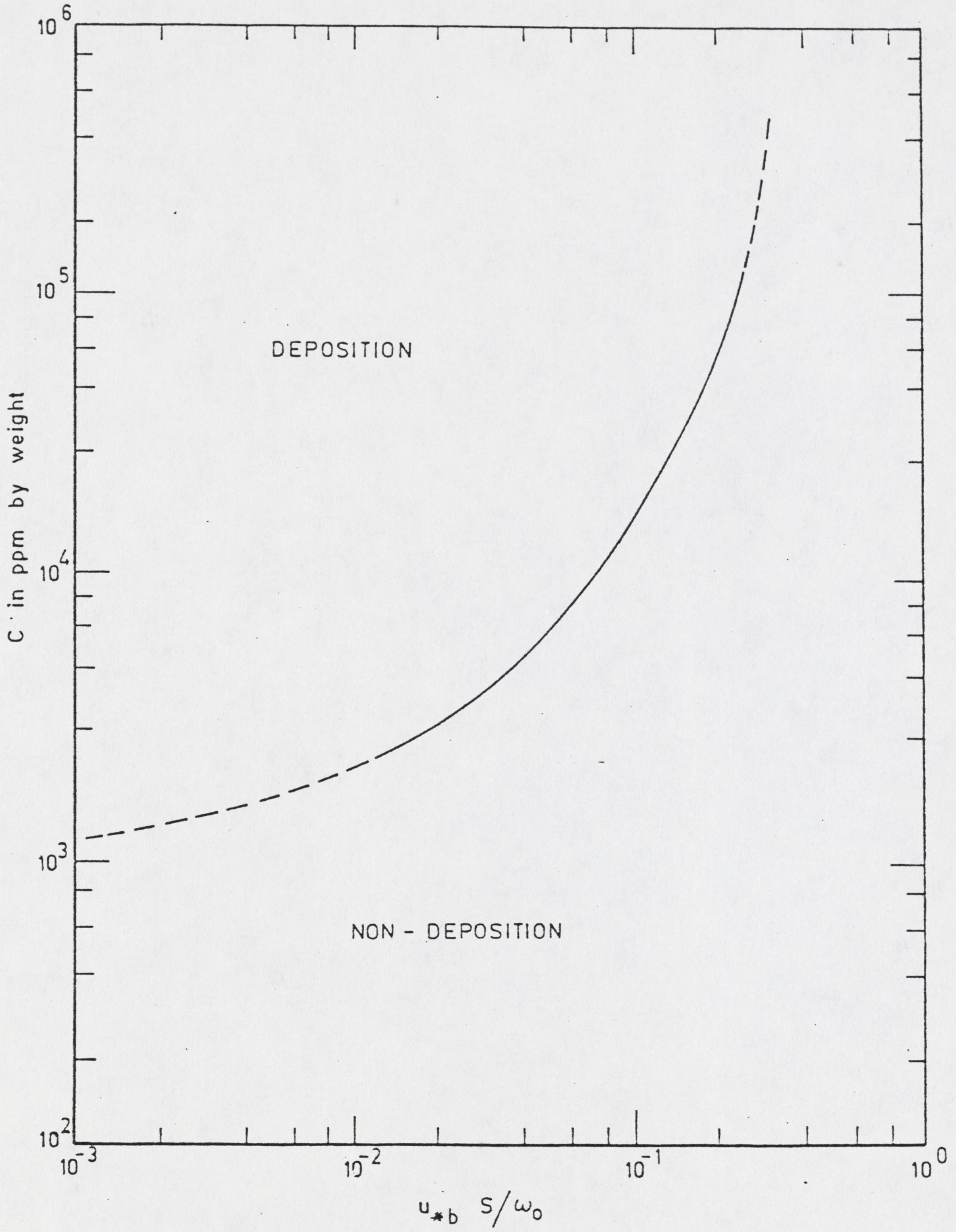


Figure 7. Variation of C with $u_{*b}S/w_o$.

Table 2. Hydraulic and sediment characteristics at Deerlodge Park during 1977-1978.[a]

S. No.	Period	Total mean monthly Q cfs	Bed load Q_B T/day		Wash load Q_S T/day		Max. size of bed material likely to move in mm
			Incoming	Carrying Capacity	Incoming	Max. carrying capacity without deposition	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	Oct 1977	199.44	-	-	94.89	5385.0	-
2	Nov 1977	243.50	-	-	69.56	6903.0	-
3	Dec 1977	306.12	-	-	256.48	9340.0	-
4	Jan 1978	323.87	-	-	82.20	10056.0	-
5	Feb 1978	401.22	-	-	85.86	14083.0	-
6	Mar 1978	1125.02	-	80.0	8666.00	57714.0	9.30
7	Apr 1978	4070.60	80.0	1500.0	7615.66	417643.0	20.10
8	May 1978	9672.0	2320.0	5000.0	22529.54	1984700.0	33.80
9	June 1978	11917.66	2730.0	6000.0	9684.00	2960300.0	38.30
10	July 1978	3442.81	58.0	1000.0	1048.38	316000.0	18.20
11	Aug 1978	612.55	-	-	693.12	25100.0	-
12	Sept 1978	265.90	-	-	1216.26	7753.0	-

[a] (2) Addition of mean monthly flows of the Yampa and Little Snake Rivers.
(3) Addition of bed loads rates from the two rivers at Dixon and Maybell respectively.
(4) Computed using Figure 6 and Equation 7.
(5) Addition of observed suspended loads at Lilly and Maybell.
(6) Computed using Equation 7.

Conceding that a slope of 1.75×10^{-3} downstream of the confluence is a result of deposition of fine sediment brought in by the Little Snake River, it would now be interesting to examine the effects of the varying discharges and sediment loads on the stability of this reach. The data for the year 1977-1978 were used in this analysis and these are listed in Table 2.

It is evident from this table that during 1977-1978, the total sediment load supplied at Deerlodge Park was less than the corresponding carrying capacity. One would thus expect degradation to occur provided the composition of the bed does not change.

Table 2 also shows that the bed material is likely to move from March 1978 to July 1978 because during this period shear exceeds the critical value based on Shields' criterion. The maximum size that is likely to move during this period is 38.0 mm. Thus, due to the removal of finer sizes from the bed, the bed would eventually become armored.

From the above qualitative analysis, it appears that the present top surface of the Yampa River near Deerlodge Park is a paved one and the sediment load supplied from the upstream is being carried through without any bed level variations.

The analysis so far presented deals with the present characteristics of the Yampa River. However, these characteristics are likely to be modified if flood control reservoirs are constructed on the upstream reach. In fact construction of a large number of small flood-retaining reservoirs on the Yampa River is envisioned. Obviously, one would then like to know the response of the Yampa River to the construction of these reservoirs with particular reference to bed level variations. Therefore, the subsequent discussion deals with the change in bed characteristics at Deerlodge Park as a result of construction of Cross Mountain reservoir the location of which is shown in Figure 1.

RESPONSE OF YAMPA RIVER DOWNSTREAM OF CROSS MOUNTAIN RESERVOIR TO THE CONSTRUCTION OF THE DAM

The available data indicate a dam of about 360 ft. height with a capacity of 10.64×10^{6} acre ft located at Cross Mountain on the Yampa River immediately upstream of its confluence with the Little Snake River (Figure 1). This reservoir is likely to trap all the bed and wash load that is supplied to it by the Yampa River at Maybell. Therefore, the releases from this reservoir will be sediment free. These releases along with the inflow from the Little Snake River will affect the present bed levels at Deerlodge Park.

The data for the year 1977-1978 were once again used to study the bed characteristics at Deerlodge Park as discussed above. Table 3 shows the hydraulic and sediment characteristics at Deerlodge Park considering the sediment free releases from Cross Mountain reservoir.

As was the circumstance before the construction of the reservoir, the wash load would be safely transported by the stream without any deposition (Table 3). The bed material load is, however, slightly smaller than the carrying capacity. This indicates the possibility of degradation downstream of the Cross Mountain reservoir. For reasons mentioned earlier, this degradation will also not result in any significant bed level variation; the surface will be paved after enough fine material has been picked up by the flow. But after the surface is paved the material that comes in from the Little Snake River would be safely carried down by the Yampa River at Deerlodge Park.

The Cross Mountain Dam would also cause aggradation on its upstream side. The amount and the extent of aggradation would depend on the capacity of the reservoir, the length of the back water profile, the amount and the nature of the total sediment load supplied to it from Maybell. The process of aggradation in the reservoir would be accelerated as a result of surface mining which is contemplated upstream of Maybell. The data indicate that the net effect of surface mining will be to increase the total sediment load of Maybell by 7%. With available methods, it would have been interesting to study the deposition profiles upstream of dam; however, due to paucity of time, the process of aggradation could not be studied in this paper.

CONCLUSIONS

The available data on the Yampa River have been analyzed to study the morphological characteristics of the river. The analysis reported in this paper is based on some simplified assumptions made either intuitively or on the basis of certain deductions. The main findings are as follows.

1. The meanders in the Yampa River are entrenched and are unlikely to be changed by the variations in discharge and sediment load brought about by the construction of dams.

2. The Yampa River at Maybell was an aggrading river until 1950 and appears to have attained equilibrium conditions after that.

Table 3. Bed level variations at Deerlodge Park after construction of Cross-Mountain Reservoir.[a]

S. No.	Period	Total mean monthly discharge Q in cfs	Bed load Q_B T/day		Wash load Q_S T/day	
			Incoming	Carrying capacity	Incoming	Max. carrying capacity without deposition
	(1)	(2)	(3)	(4)	(5)	(6)
1	Oct. 1977	471.70	-	-	40.0	17830.26
2	Nov. 1977	402.60	-	-	59.0	14131.26
3	Dec. 1977	398.80	-	-	250.0	13998.0
4	Jan. 1978	334.00	-	-	77.0	10821.60
5	Feb. 1978	324.30	-	-	80.0	10507.32
6	Mar. 1978	801.25	-	24.0	8550.0	37859.0
7	Apr. 1978	1100.30	-	87.0	3760.0	56445.0
8	May 1978	4790.0	1900	2000.0	15426.0	620784.0
9	June 1978	5705.0	1940	2700.0	5555.0	739368.0
10	July 1978	3122.2	-	864.0	393.0	252898.0
11	Aug. 1978	1182.2	-	102.0	505.0	60646.0
12	Sept. 1978	698.0	-	7.00	936.0	30153.6

[a] (2) Addition of mean monthly flows of the Little Snake River and the corresponding releases from the Cross Mountain reservoir.
(3) From the Little Snake River only as releases from the Cross Mountain reservoir are assumed to be sediment free.
(4) Computed using Figure 6 and Equation 7.
(5) From the Little Snake River only as releases from the Cross Mountain reservoir are assumed to be sediment free.
(6) Computed using Figure 7.

3. The slope of the Yampa River near Deerlodge Park is steeper than in the upper reaches on account of aggradation caused by the high influx of sediment from the Little Snake River.

4. The Cross Mountain reservoir is unlikely to affect the bed levels in the Yampa River downstream of the dam.

ACKNOWLEDGEMENT

Mr. M. K. Mittal, Dr. B. Prakash, Dr. K. G. Ranga Raju, and Mr. V. C. Agarwal rendered valuable assistance in the analysis of data. This help is gratefully acknowledged.

REFERENCES

Bray, D. I. 1979. Estimating Average Velocity in Gravel Bed Rivers. Journal of Hydraulic Division, Proceeding ASCE, Vol. 1C5, No. HY9, September.

Garde, R. J., and K. G. Ranga Raju. 1977. Mechanics of Sediment Transportation and Alluvial Stream Problems. Wiley Eastern Limited, New Delhi.

Misri, R. L. 1980. Partial Bed Load Transport of Coarse Non-Uniform Material. Ph.D. Thesis to be submitted to the University of Roorkee, Roorkee.

Pullaiah, V. 1978. Transport of Fine Sediment in Smooth Rigid Bed Channels. Ph.D. Thesis, University of Roorkee, Roorkee.

Young, R. W. 1974. The Meandering Valleys of the Shoalhaven River System: A Case Study of Stream Adjustment to Structure and Changed Hydrologic Regime. Ph.D. Thesis, University of Sydney, Sydney.

YAMPA RIVER

Rolf Kellerhals
Professional Engineer, Heriot Bay, British Columbia, Canada

INTRODUCTION

The objective of this study is to comment on the downstream effects on channel morphology of the Yampa River due to two proposed flood retaining reservoirs. The prediction is to be made on the basis of a package of background material provided by the U.S. Fish and Wildlife Service. Two short reaches of the Yampa River, for which some survey data are available, are to be considered specifically.

A quick review of the data package indicated that only a relatively small part of the information that one would need for any kind of quantitative prediction is presently available. Before the workshop, it was therefore only possible to state some general, qualitative conclusions and to list the types of data needed for more refined estimates. The present text was revised after the workshop to take data obtained there (e.g., air photos) into account and to refer to some important references seen since completion of the preconference text.

DEFINITION OF THE PRESENT RIVER REGIME

Discharge

The Yampa River appears to have a strongly seasonal discharge regime, dominated by snowmelt runoff during spring and early summer. Low flows prevail during the rest of the year, with the annual low occurring either in late summer or in mid-winter.

For proper impact assessment the following discharge data should either be available or be estimated for each reach of interest.

1. Flood frequency.
2. Low flow frequency.
3. Typical hydrographs.
4. Flow duration curve.
5. Flow probability curves, giving the estimated distribution of flow for every day of the year.
6. Tabulation of mean monthly flows.

In the present case only items 1, 2, and 3 are available and only for one of the two reaches (Lily Park).

Sediment Transport

Long-term suspended data are available for the upper reach and for the Little Snake River, a major tributary between the two test reaches. The computed bed load estimates given by Andrews (1978) are, in the writer's view, probably considerably too large. The size distribution of the suspended load is reasonably well defined. It appears to consist predominantly of clay and silt. Concentrations of 1000 mg/l, or higher, are being observed occasionally, indicating a potential for density currents in the proposed reservoirs. The bed load size distribution is not given.

As in the case of discharge, it would be desirable to have better site specific data. Bed load computations in particular cannot be transposed from reach to reach. They should be carried out for all the reaches of interest.

Bed and Bank Materials

A single bed material sample is provided for the Yampa River, but it was not taken within either study reach and no information is provided about sampling method or the details of the sample site. Indirect evidence, such as a map profile, air photos, and reports by others indicate that the Lily Park Reach has basically a gravel bed, but with extensive sand deposits within the channel zone. The bed materials of the Box Elder Reach are probably also mainly gravel, but there may also be some cobbles and boulders.

Extensive site-specific bed and bank material sampling is required for proper definition of the existing conditions. For each sample both the sampling method and the sedimentary environment of the sample site should be documented carefully. Kellerhals and Bray (1971) discuss sampling procedures and a check list developed by Bray (1972) for identification of the sedimentary environment of bed material samples is appended to this report (Appendix A). The list was developed for a general morphologic study of rivers in Alberta and may need to be modified depending on local conditions and on study objectives.

If there is a possibility of degradation, as in the present case, sub-bed materials are of interest. Any drill logs from within or near the study reach should be examined.

Hydraulic Geometry

The cross sections provided for the two study reaches are of little use as they cover only very short reaches and do not include water levels. The location of the sections is also not shown on any plan. Based on a rough map profile (Figure 1) the two reaches appear to have slopes of approximately 0.001.

Five to 10 cross sections along a reach of at least one, but better, two to three meander cycles, are needed for a reasonable definition of hydraulic geometry. At least five water level observations covering a wide range of discharge should be available at each section

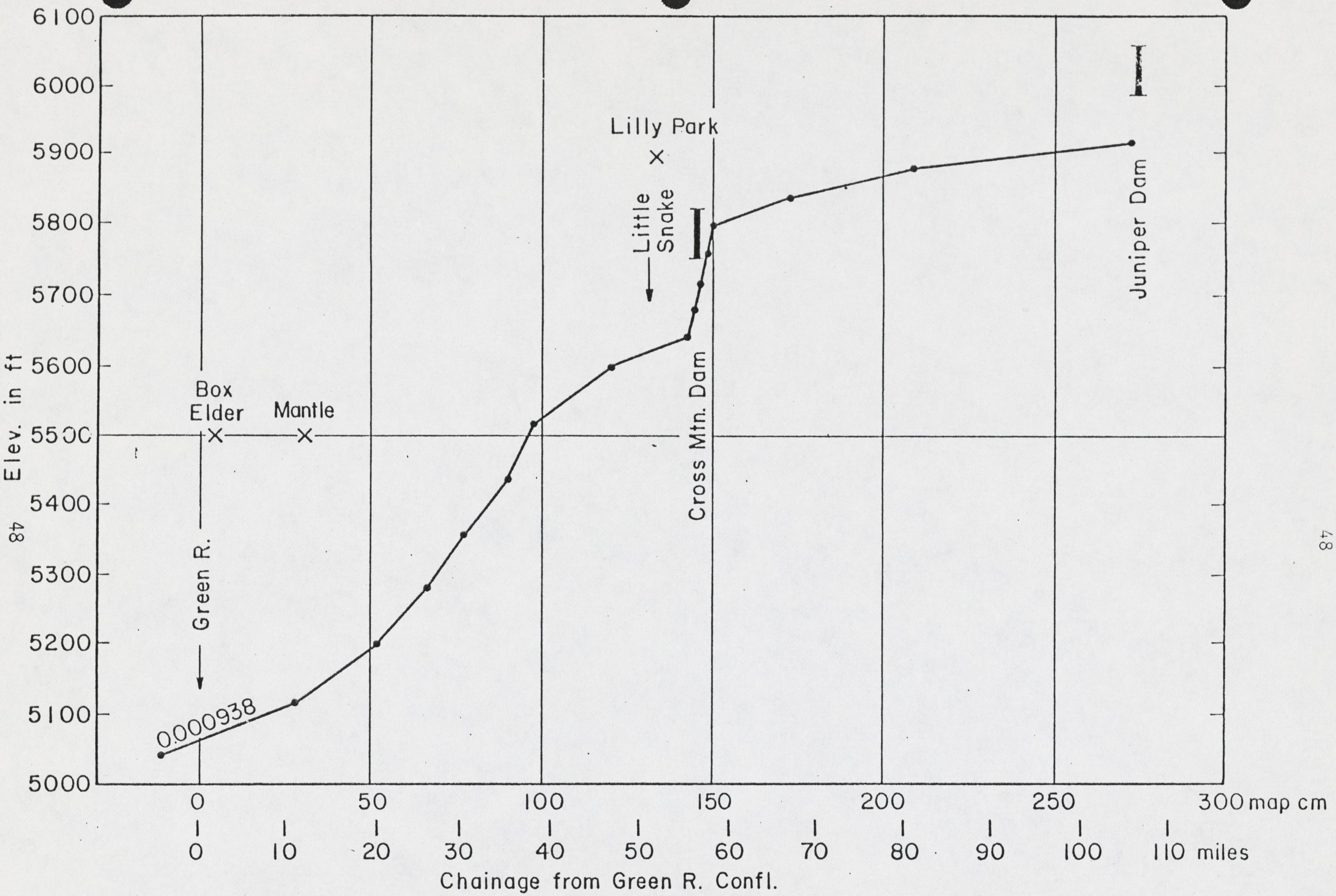


Figure 1. Yampa River profile.

so that the information on the time-distribution of flows can be converted to stage.

Channel Morphology and Fluvial Processes

With only topographic mapping at 1:62500 little could be said about the detailed channel morphology. The channel profile at Figure 1 indicates strong bedrock control along much of the lower Yampa River, although the two surveyed reaches are probably alluvial. Air photos seen during the course of the workshop confirm that the Lily Park Reach is essentially alluvial. It is partially confined, with an irregular meander pattern and occasional islands.

For an adequate morphological assessment air photo analysis and field inspection are essential. Kellerhals, et al. (1976) discuss in detail the types of information that one looks for and provide check lists to help assure that nothing of importance is missed.

Fluvial process rates (e.g. channel shifting, bar migration rates), and any nonequilibrium trends (e.g., channel zone widening, entrenchment,) can often be obtained from comparative analysis of old and recent air photos or maps.

Other Matters

A wide range of water quality parameters is obviously of interest but falls outside the objectives of the present workshop. One needs to be aware, however, that there are linkages between water quality and channel morphology. Water temperature, for instance, can be greatly affected by changes in channel zone width or by changed bank vegetation.

Bank vegetation also affects channel stability, fisheries, recreational values, flood stages and others. The existing bank vegetation should be carefully documented and checked for long-term trends. Comparative analysis of old and recent air or ground photos and possibly local interviews are needed to detect long term trends.

In northern climates the ice regime may have a major influence on channel morphology (Kellerhals and Gill 1973, Kellerhals and Church, in press). Since dams can drastically alter the existing ice regime, this becomes a matter of great importance.

The water exchange between a stream channel and the surrounding valley aquifer can be important for fisheries and for water users. Since it, also, is potentially affected by dams, the existing situation needs to be documented as best as possible.

PROJECT DESCRIPTION

The two proposed dams are only described in a very general manner and the data on future, regulated flows are not consistent with the natural flow data. Tables of average monthly reservoir releases for the period 1927-1976 are provided and indicate considerable regulation. The highest monthly flows are reduced by around 50. The effect on flood flows is unknown but a significant reduction appears probable.

For a detailed impact assessment it would be desirable to have the regulated flow regime defined in a similar manner as the natural regime. In the case of peaking plants, hourly rather than daily flow distributions may be needed. The physical limits on flow releases are also of interest. Experience has shown that, regardless of what a water license says, projects will occasionally be operated at their limits due to emergency situations (e.g., a transmission line failure might result in zero discharge unless there is a fail-safe minimum release system). The reservoir filling schedule may also need to be considered.

The thermal structure of the proposed reservoir and the elevation of the various outlet works are important because they will determine whether significant amounts of suspended load might pass through the reservoir. They naturally also determine the downstream water temperature and ice regimes.

DOWNSTREAM EFFECTS

Basis for prediction

The interrelations between an imposed flow regime with sediment supply and the resulting channel morphology are only very poorly understood at present, and what little quantitative information is available is generally based on empirical analysis of field data rather than on an understanding of the basic physical processes involved. However, river regulation has now been going on for such a long time that, when considering a new project, it is generally possible to find comparable case histories. They are needed primarily to identify potentially significant impacts. After the basic morphological impacts have been identified, quantitative estimates are sometimes possible (e.g., degradation between rigid banks, vegetation encroachment into a stable channel zone), but in many situations an empirical analysis of case histories remains the only basis for quantitative prediction (e.g., change in channel pattern, change in bar morphology).

Effects on the Yampa River

Assuming that the main structure of the Yampa River channel consists of gravel or coarser materials, combined with local bedrock outcrops, the dams are unlikely to cause major morphological changes. The material in the major bars and riffles probably moves only infrequently now and it might never move under regulated conditions.

Along the Lily Park Reach which lies upstream of the Little Snake River confluence, the river bed surface will be winnowed of fines and transformed into a very stable, coarse armor layer. There may be some minor degradation if the highest flood releases can move some of the bed gravel.

If the seepage gradient at the channel bed is predominantly downward (out of the channel), the stability of the armor layer, combined with minor amounts of fines passing through the reservoir could lead to a totally sealed channel. This could be detrimental to fish spawning.

Reduced floods generally lead to a tendency towards reduced channel size. Upstream of the Little Snake River, the Yampa River lacks the sediment supply needed for a fast reduction in channel size. On some of the higher bar surfaces and parts of the river bank trees and shrubs will grow and might then very slowly silt in. With the high suspended sediment load of the Little Snake River, areas of vegetation encroachment downstream of the confluence will quickly aggrade to flood plain level. The canyon reaches of the Yampa Rver are probably too steep for any significant suspended load deposition, but there will still be extensive vegetation encroachment, as shown in a recent, well documented study of the Colorado River below Glen Canyon Dam (Turner and Kariscak 1980). Vegetation encroachment reduces solar energy input to the water, increases water losses, and increases flood levels for any given discharge.

The most visible morphological changes are likely to occur in the vicinity of the Little Snake River confluence. Any alluvial confluence region represents a delicately balanced equilibrium between the long-term sediment transporting capacities of the various channels. In the present situation it appears reasonably certain that the reduced gravel transport capacity of the Yampa River will be the dominant effect, outweighing any effect due to reduced gravel inflow to the confluence from the Yampa River. The confluence area will gradually aggrade until the downstream Yampa River has enough slope to move the incoming load. Initially the Little Snake River might degrade somewhat due to reduced backwater from the Yampa River.

Aggradation at tributary confluences is a general result of regulation or flow reduction (Kellerhals, et al. 1979) and it will eventually result in a more irregular profile for the Yampa River. In a recent paper Graf (1980) shows how regulation of the Green River is gradually making rafting more difficult due to increasing severity of the rapids. Vegetation encroachment and winnowing of fines in the remaining channel zone are also making it more difficult to find campsites in the Green River canyon.

REFERENCES

Andrews, E. D. 1978. Present and Potential Sediment Yields in the Yampa River Basin, Colorado and Wyoming, U.S. Geological Survey, Water Resources Investigations, 78-105, December.

Bray, D. I. 1972. Generalized Regime-Type Analysis of Alberta Rivers. Ph.D. Thesis, University of Alberta, Department of Civil Engineering, Edmonton.

Graf, W. L. 1980. The Effect of Dam Closure on Downstream Rapids. Water Resources Research, Vol. 16, No. 1, pp. 129-136.

Kellerhals, R., and D. I. Bray. 1971. Sampling Procedures for Coarse Fluvial Sediments. ASCE Proceedings Journal of the Hydraulics Division, Vol. 97, No. HY8, pp. 1165-1180.

Kellerhals, R., and D. Gill. 1973. Observed and Potential Downstream Effects of Large Storage Projects in Northern Canada. 11th Congress of the International Commission on Large Dams, Madrid, pp. 731-754.

Kellerhals, R., M. Church, and D. I. Bray. 1976. Classification and Analysis of River Processes. ASCE Proceedings, Journal of the Hydraulics Division, Vol. 102, No. HY7, pp. 813-829.

Kellerhals, R. M. Church, and L. B. Davies. 1979. Morphological Effects of Interbasin River Diversions. Canadian Journal of Civil Engineering, Vol. 6, No. 1, pp. 18-31.

Kellerhals, R., and M. Church. in press. Effects of Channel Enlargement by River Ice Processes on Bankfull Discharge in Alberta, Canada by D. G. Smith, a discussion. Water Resources Research.

Turner, R. M., and M. M. Karpsicak. 1980. Recent Vegetation Changes Along the Colorado River between Glen Canyon Dam and Lake Mead, Arizona. U.S. Geological Survey Professional Paper 1132, Washington, D.C., USA, 125 pp.

RESEARCH COUNCIL OF ALBERTA
HIGHWAY AND RIVER ENGINEERING DIVISION
UNIVERSITY OF ALBERTA
NO. DES 2/71
DEPARTMENT OF CIVIL ENGINEERING

RIVER DATA SHEET

DESCRIPTION OF BED-MATERIAL SAMPLING SITE, CODES

Sample No.	Type	Location to W.S.	Geomorphic Unit	Loc. on Geo. Unit	Lateral Location	Longitudinal Location	Direction	Pavement	Activity	Representa-tiveness	Particle Shape	Particle Lithology

NOTE: Use -1 for "unknown" and use multiple codes where necessary.

SAMPLE NO.: Station - Year - Type - No.
(e.g.): 10 70 N 3
(10-70-N3)

TYPE: Grid-by-number = N
Photo = P
Sieve = S

Sample Type
Lateral Location in Channel
1 tape grid
applicable
2 stepping (toe) grid
bank
3 grid photo
quarter point
4 sieve, including surface
5 sieve, excluding surface
quarter point

bank

Location in Relation to Water Surface
0 at edge of water
1 (n) n ft above water surface
2 (n) n ft below water surface

Geomorphic Unit
0 no particular feature
1 side bar
2 point bar
3 mid-channel bar
4 island
5 in pool
6 at riffle
7 at cross-over

Location on Geomorphic Unit
0 not applicable
1 near upstream end
2 near centre
3 near downstream end

0 not
1 near left
2 near left
3 near centre
4 near right
5 near right

Longitudinal Location
1 relatively straight reach
recent movement
2 bend to left
minor movement
3 bend to right
major movement

Direction of Linear Grid Samples
0 not applicable
1 parallel to flow
2 perpendicular to flow
3 (d) at d degrees to flow

Pavement Code
0 no apparent pavement
1 only fines removed from surface
2 obviously larger material at surface

Activity Code
0 no indication of
1 indication of recent
2 indication of recent

Representativeness Code
0 not representative of site
1 estimated average for site
sandstone
2 coarsest material at site
3 finer than average

Predominant Particle Shape
1 spherical and rounded
2 elongate and rounded
3 angular
4 platy

Predominant Particle Lithology
1 granite
2 gneiss
3 basalt
4 quartzite
5 slate
6 schist
7 limestone
8 dolomite
9 conglomerate
10
11 shale

DOWNSTREAM RIVER MORPHOLOGICAL CHANGES FROM PROPOSED RESERVOIR CONSTRUCTION ON THE YAMPA RIVER, COLORADO

Ruh-Ming Li
Associate Professor, Department of Civil Engineering,
Colorado State University, Fort Collins, Colorado, U.S.A.

INTRODUCTION

River system processes are closely related to the dynamics of the ecosystem. Streamflows, sediment transport rates, and channel morphology all effect the instream habitat and each can be altered by river utilization activities. Man's activities, such as diversions or reservoir construction, can alter the channel morphology enough to affect fisheries and other aquatic biology. For a proper river utilization plan, possible morphological changes in both short- and long-terms should be anticipated. This paper reviews the data needs, suggests the methods of analysis, and presents a qualitative assessment of the downstream river morphological changes from proposed reservoir construction on the Yampa River, Colorado.

The Yampa River is located in northwestern Colorado. The river is essentially a gravel-cobble bed stream upstream of the confluence with the Little Snake River. Below the confluence the river is a mixture of sand and gravel bed stream. Several small flood control reservoirs are to be constructed on the Yampa River; one is the proposed Cross Mountain Reservoir and another is the proposed Juniper Reservoir. These reservoirs will impose changes in the flow and sediment regime of the river which will, in turn, cause possible alterations in the channel morphology. More specifically, the objective established for Workshop Problem Number 1 is to discuss the short- and long-term changes of the Yampa River to the following stream characteristics: 1) meander pattern, 2) configuration of the channel, 3) substrate material, and 4) pool-riffle sequence. The data supplied by the U.S. Fish and Wildlife Service include four small reaches of the river, only two of which are to be considered in any detail. They are 1) the Box Elder reach and 2) the Lily Park reach. The Lily Park reach is located just above the Little Snake River and the Box Elder reach is located just above the junction of the Yampa River with the Green River.

DATA SUMMARY

Available Data

Available data supplied by the U.S. Fish and Wildlife Service include:

I. General Information
   1. Maps of Yampa River basin, showing locations of gaging and sediment monitoring stations, proposed reservoir locations, and existing channel geometry stations.

2. Key to USGS gaging and sediment monitoring stations.
3. Description to physiography, geology, and precipitation characteristics of Yampa basin.
4. Present and potential sediment yields in the Yampa River basin by E. D. Andrews, U.S. Geological Survey.

II. Data for Yampa River near Maybell, Colorado
  1. Present cross-sectional profiles for Maybell reach.
  2. Streamflow data.
    A. Average monthly discharges from 1910 to 1976.
    B. Projected average monthly discharges at Maybell, with Juniper reservoir.
    C. Peak flow data.
      1. Peak flows for period from 1904 to 1962.
      2. Peak flows, 1904-1978, with Weibull plotting positions and annual exceedence probability.
    D. Average monthly discharges, October 1975 to September 1978.
    E. Snowmelt hydrographs for 1976, 1977 and 1978.
  3. Sediment load data for Maybell reach.
    A. Suspended sediment loads and particle size analyses, Yampa River near Maybell, for the period November 1950 to September 1957.
    B. Suspended sediment discharge, Yampa River near Maybell, for the water year October 1977 to September 1978.
    C. Miscellaneous sediment discharge data for stations upstream from Maybell, for the water year October 1977 to September 1978.
      1. Williams Fork at mouth (2497.5).
      2. Yampa River below Craig (2476).
      3. Wilson Creek near Axial, CO (2506).
      4. Stokes Gulch near Hayden, CO (2444.7).
      5. Yampa River below Elkhead Creek (2465.5).
    D. Particle size analysis of bed material, Yampa River near Maybell.
  4. Area - elevation and capacity - elevation tables for Juniper Reservoir.

III. Data for Lily Park reach, Yampa River.
  1. Map of study area.
  2. Present cross sections measured at a discharge of 800 cfs.
  3. Present cross sections measured at a discharge of 5000 cfs.
    A. Average monthly discharges at Lily, for the period 1910 to 1976.
    B. Projected average monthly discharges at Lily, with Juniper and Cross Mountain.
    C. Projected average monthly discharges, Little Snake River at mouth, with Juniper - Cross Mountain.
    D. Peak flows, Little Snake River.

4. Suspended sediment discharge, Little Snake River at Lily, October 1977 to September 1978.
5. Area and capacity data for Cross Mountain Reservoir.

IV. Cross-sectional data for the Yampa River at Mantle Ranch.

V. Cross-sectional data for the Yampa River at Box Elder Campground.

Topography

Figure 1 gives a general location map of the study area. U.S. Geological Survey maps were utilized to approximate the channel bed profile. Figure 2 indicates that the bed slope of the study area changes from 2 ft/mile to 80 ft/mile (4×10^{-4} to 152×10^{-4}). The steepest reach is near the Cross Mountain Canyon where the Cross Mountain Dam is proposed. Variation of bed slope with river distance is given in Figure 3. It is important to note that the bed slopes of Maybell reach, Lily Park reach, and Box Elder reach are comparable. Excluding the special geological condition near the Cross Mountain Canyon area, the channel bed slope steepens below the confluence with the Little Snake River. Then the bed slope flattens in the downstream direction. The steepening of the slope below the Little Snake River may be due to significant sediment inflow from the Little Snake River.

Cross-sectional Data

Available cross-sectional data cover only four isolated and short reaches. These short reaches are Maybell, Lily Park, Mantle Ranch, and Box Elder. Representative cross sections for these four reaches are given in Figures 4 to 7. Average top widths for approximately bank full flows for these four reaches are 280, 409, 200, and 379 ft respectively. The cross sections are practically unchanged for the range of measured flow conditions. Available cross-sectional data may be enough to represent the subject reaches for study of fish habitat. However, they are not sufficient to conduct any quantitative evaluation of river response.

Proposed Reservoirs

Elevation-capacity curves for the two proposed reservoirs are available. Only the proposed Cross Mountain Reservoir will be considered in the analysis. The main purpose of the proposed reservoir is for flood control. This capacity would provide a significant reduction of flood peaks. Information related to reservoir operation is unavailable.

Hydrology

Streamflow records of the Yampa River near Maybell, Colorado (USGS Station No. 09251000) and Little Snake River near Lily, Colorado (USGS Station No. 09260000) are available. In addition, the projected monthly

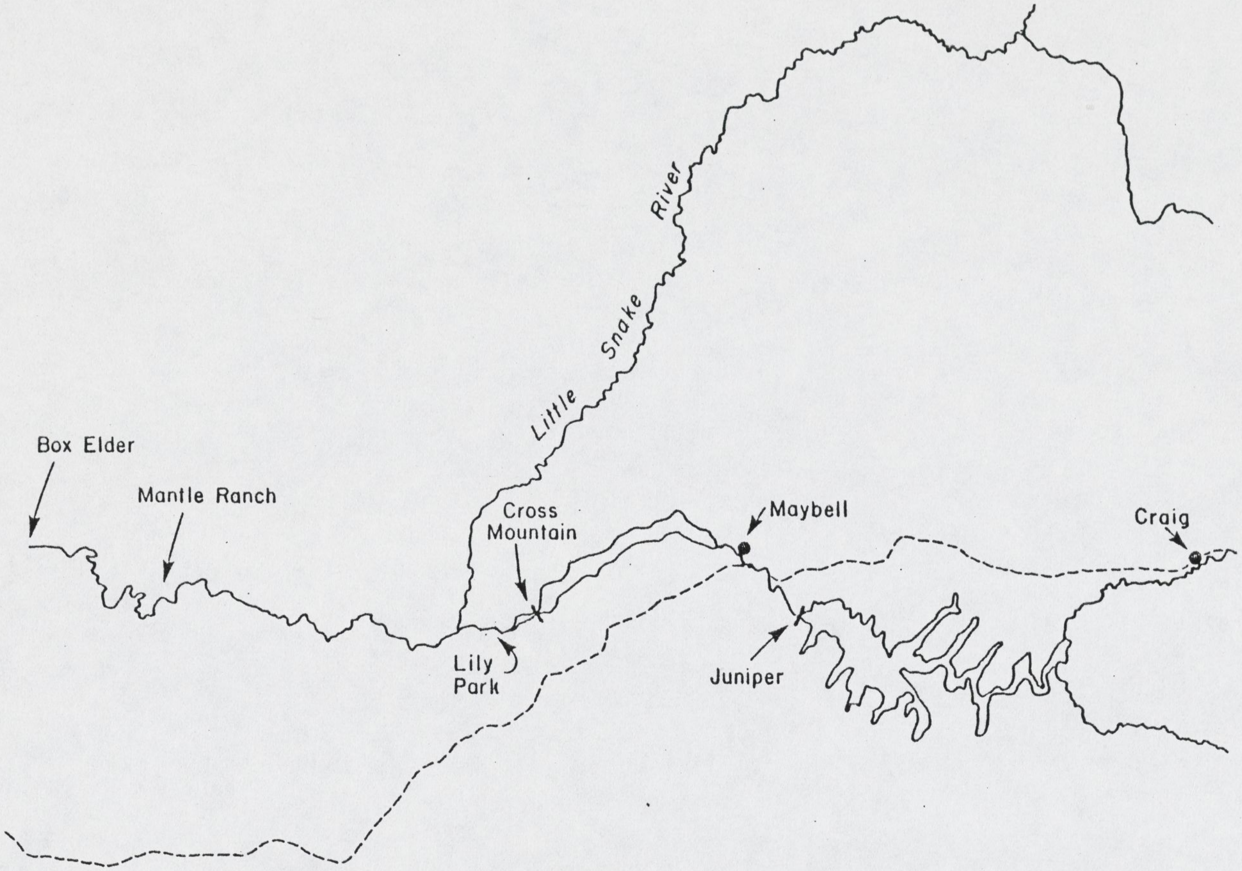


Figure 1. General location map.

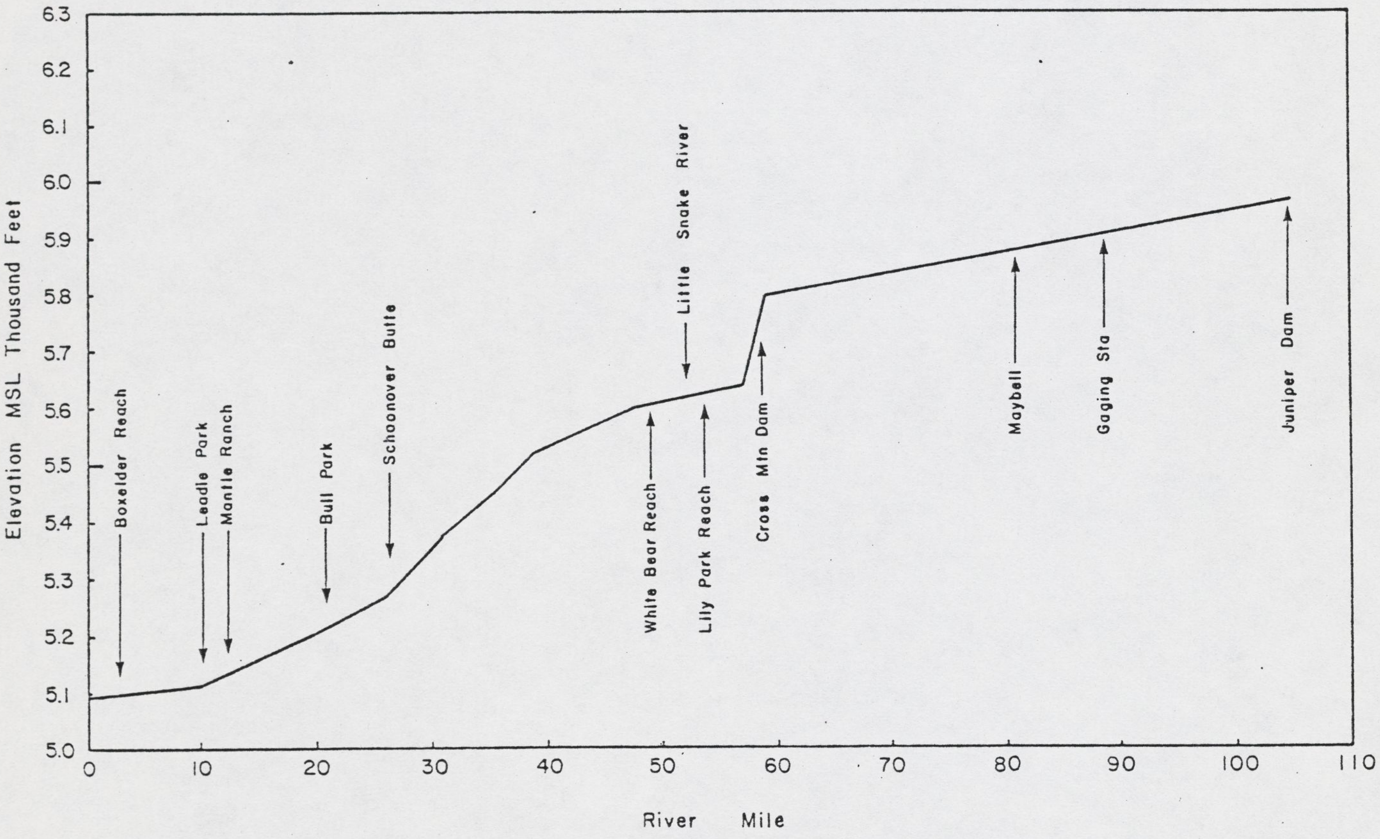


Figure 2. Yampa River bed profile.

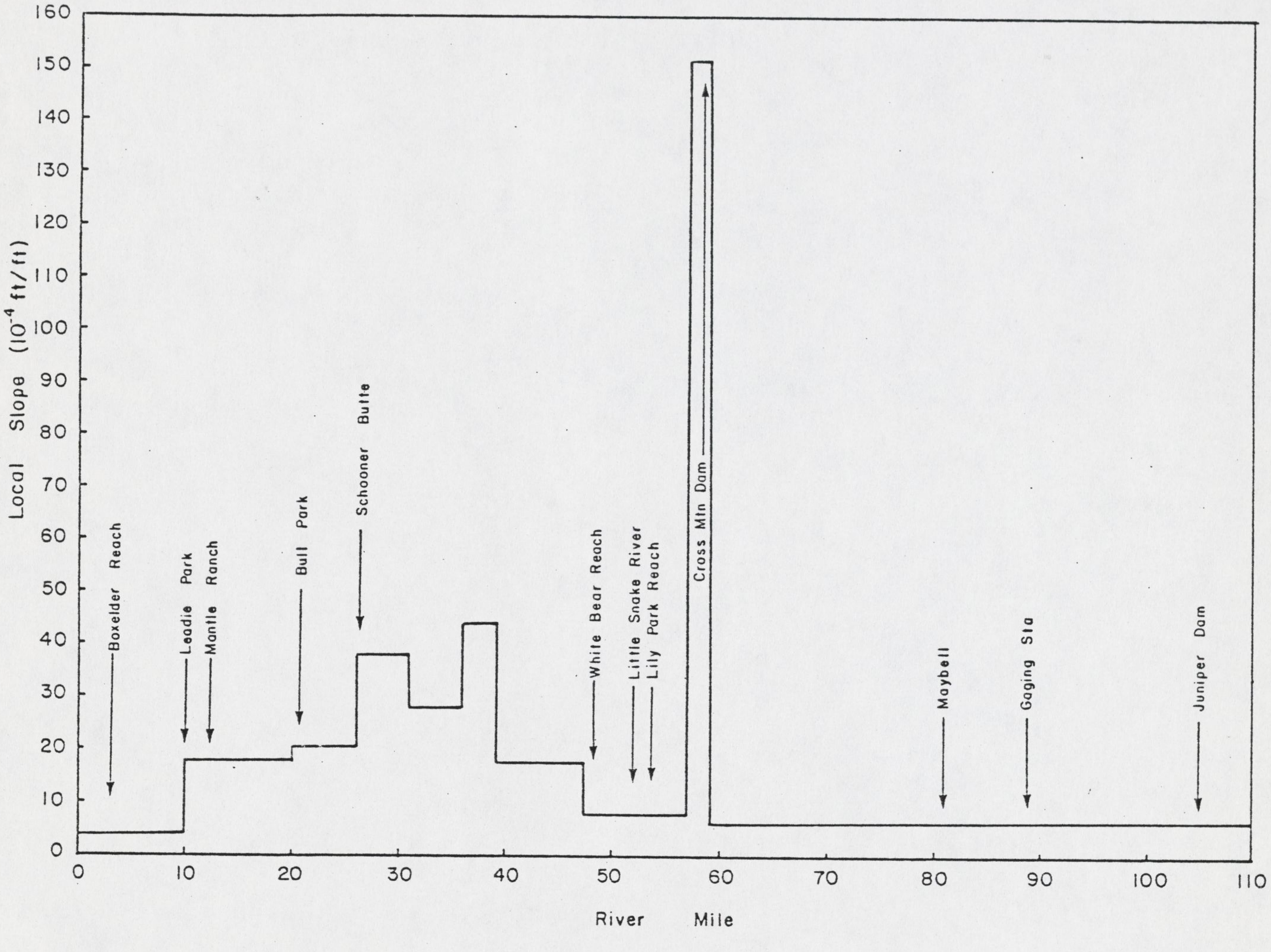


Figure 3. Variation of slope with river distance.

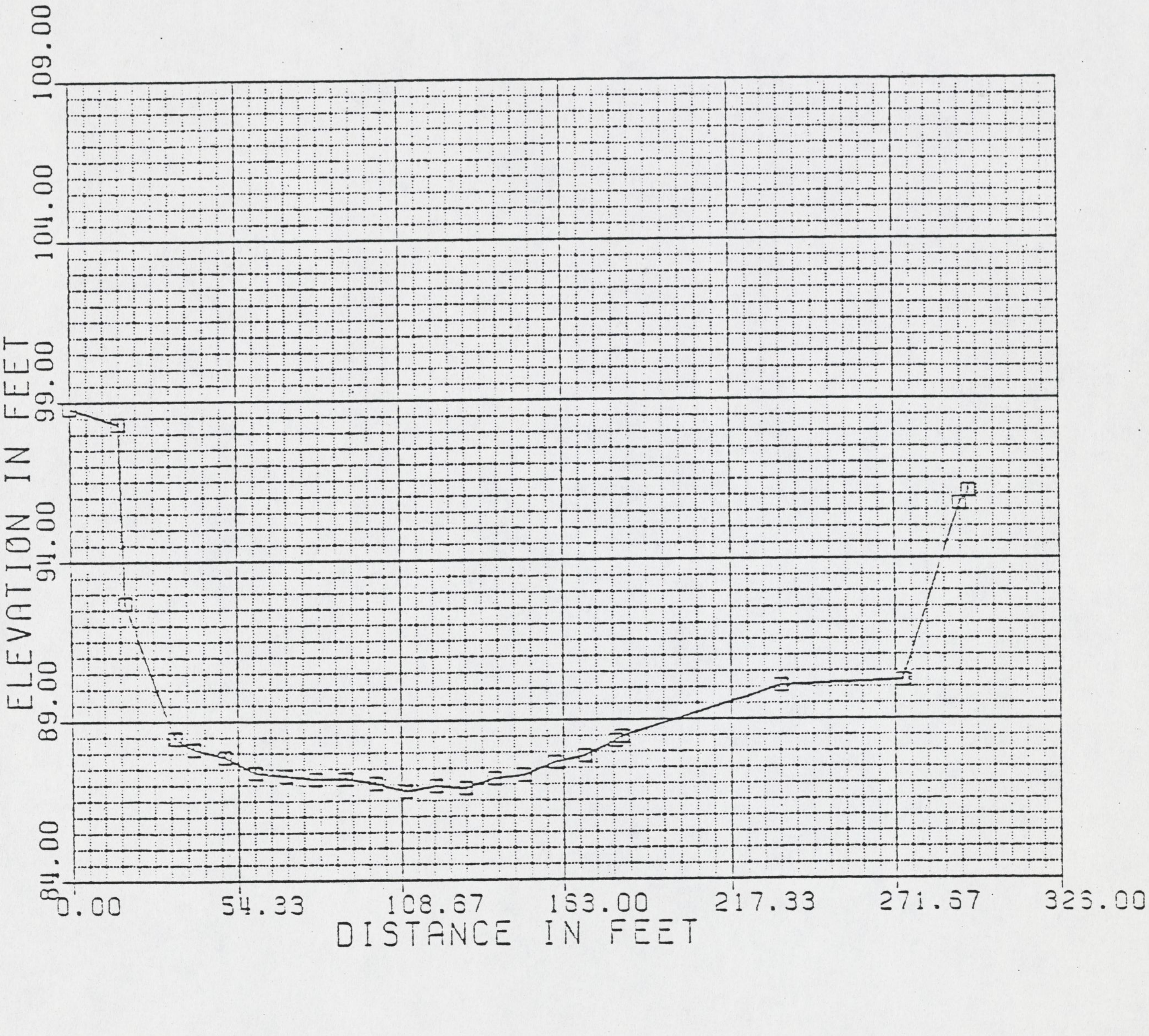


Figure 4. Maybell reach cross section 21.

Li 7

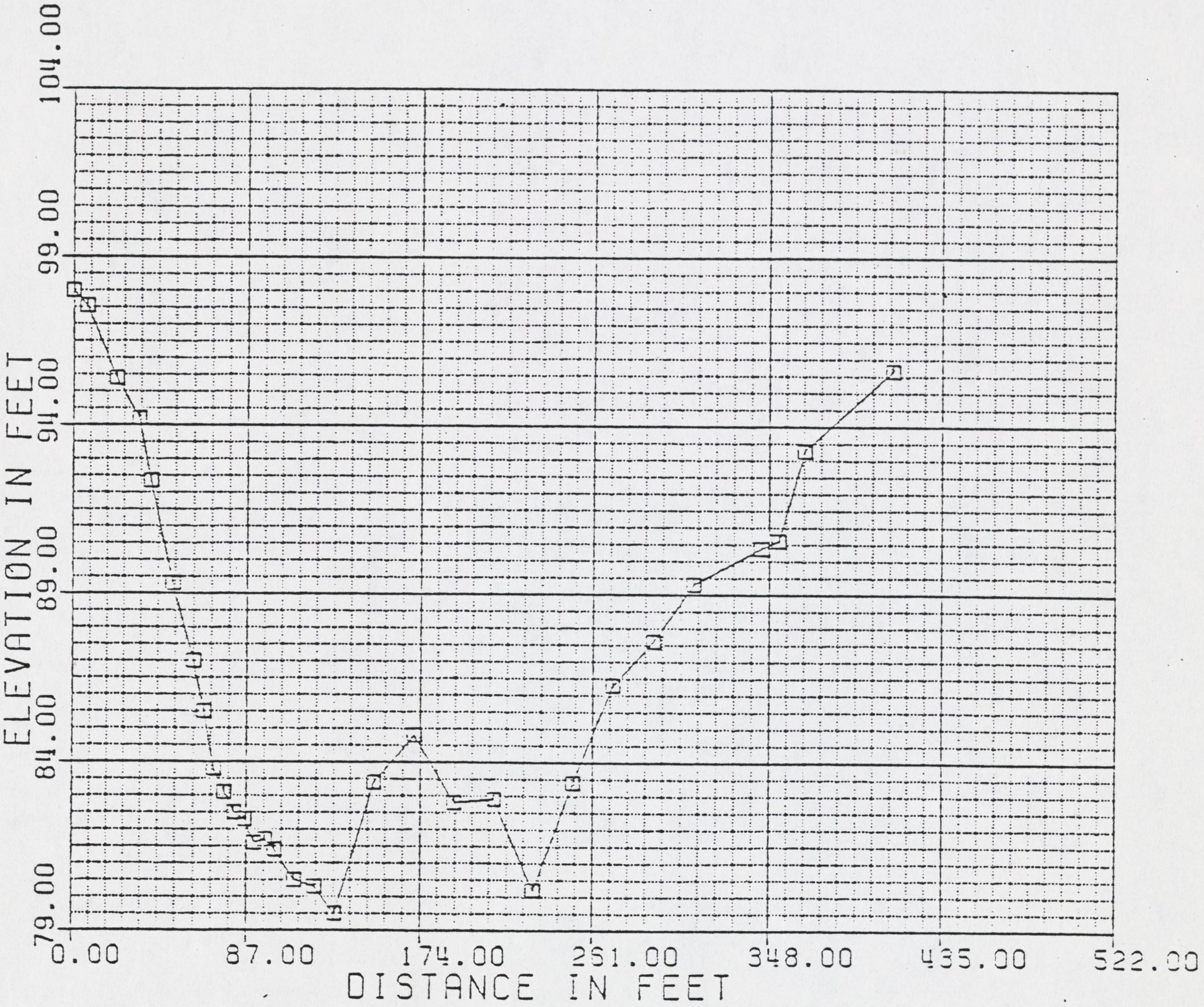


Figure 5. Yampa River at Lily Park, cross section 338.

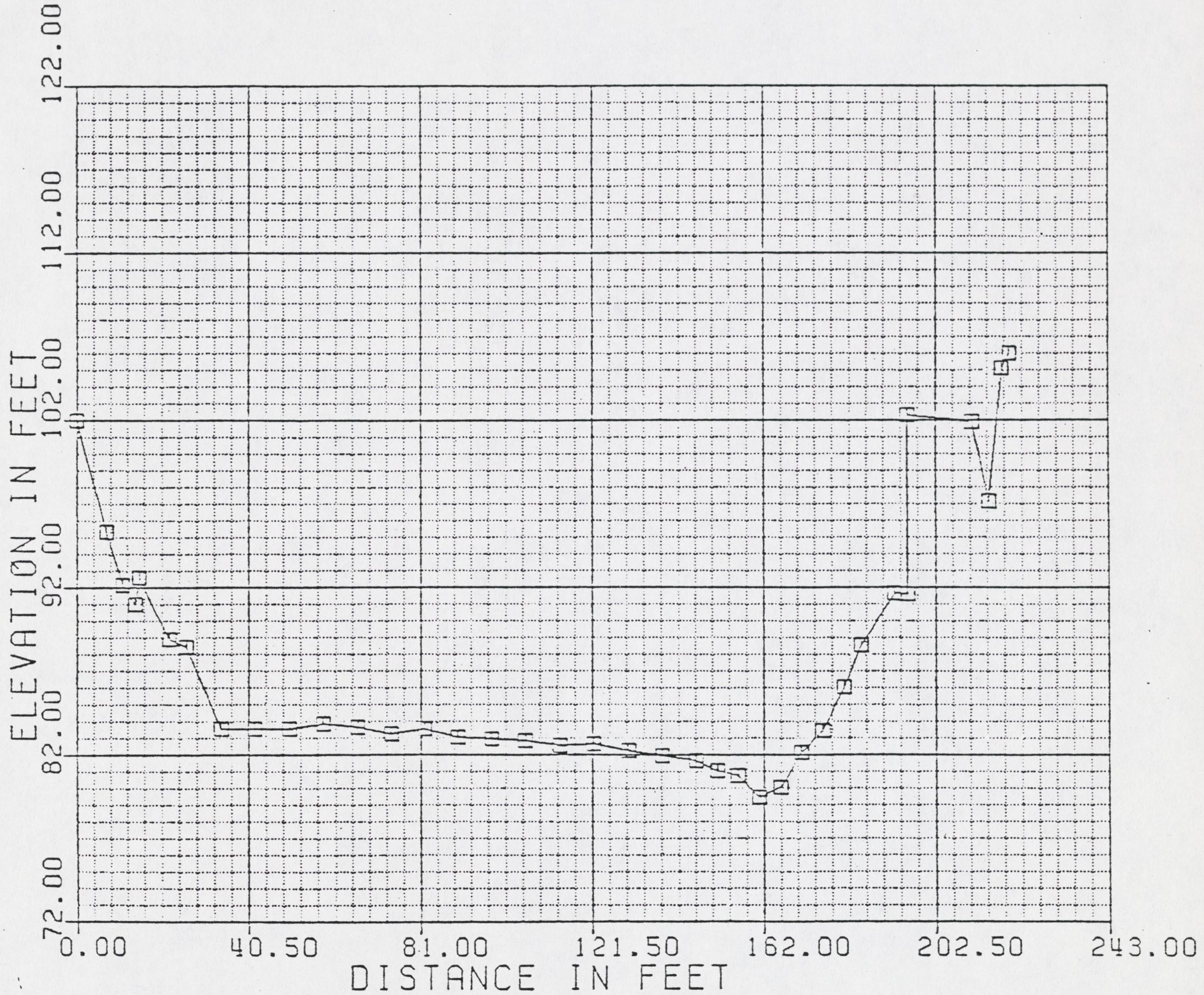


Figure 6. Dinosaur National Monument near Mantle Ranch, cross section 150.

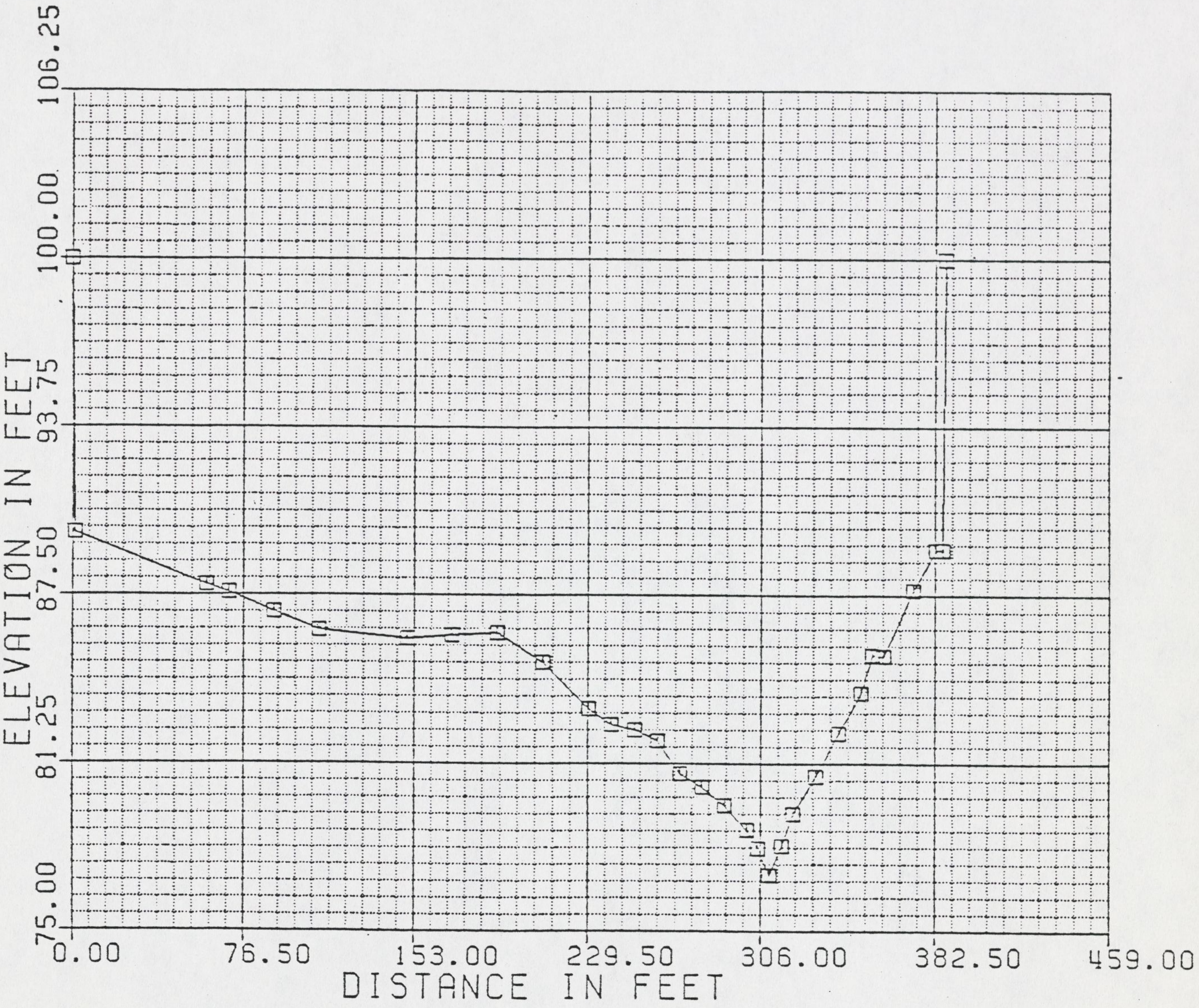


Figure 7. Dinosaur National Monument, Box Elder reach, cross section 24.

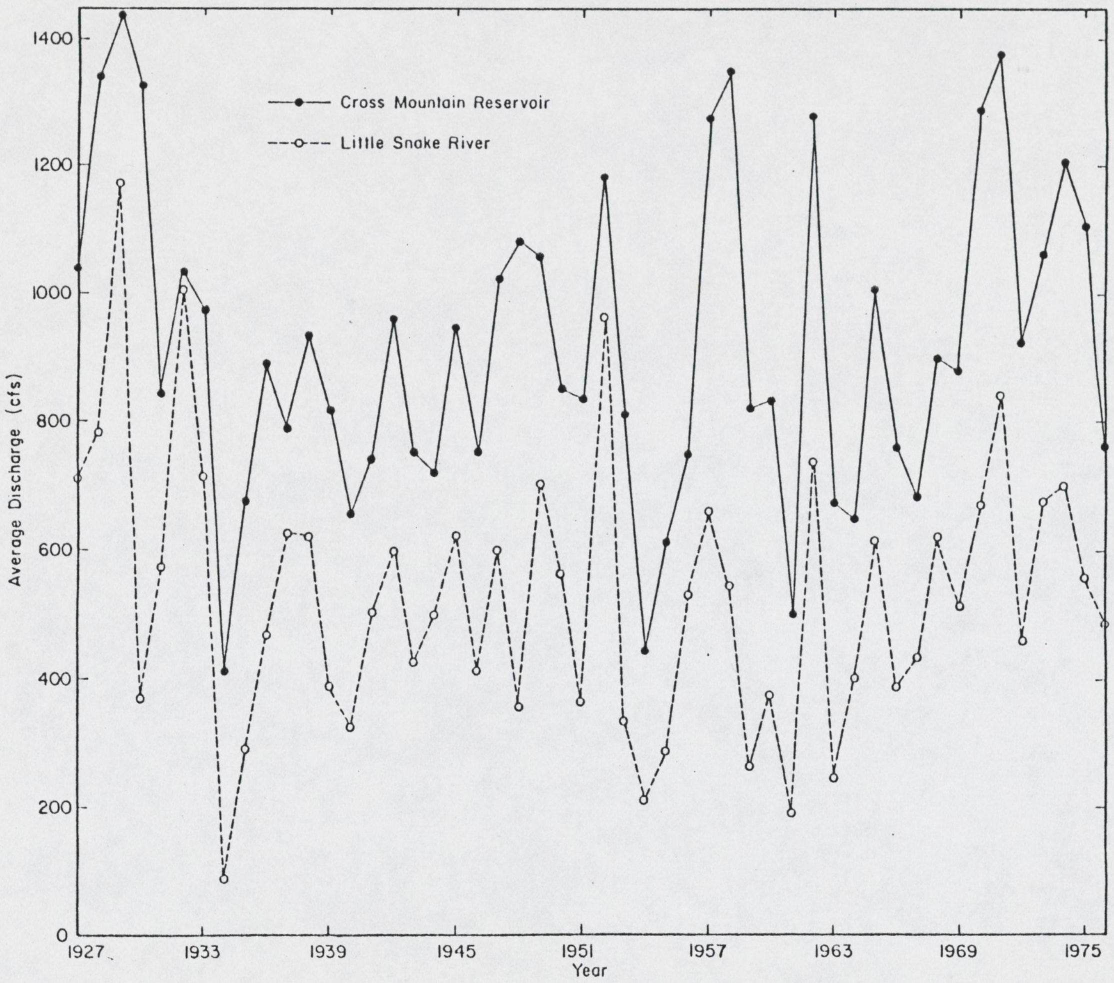


Figure 8. Comparison of flow from Cross Mountain Reservoir release and the Little Snake River.

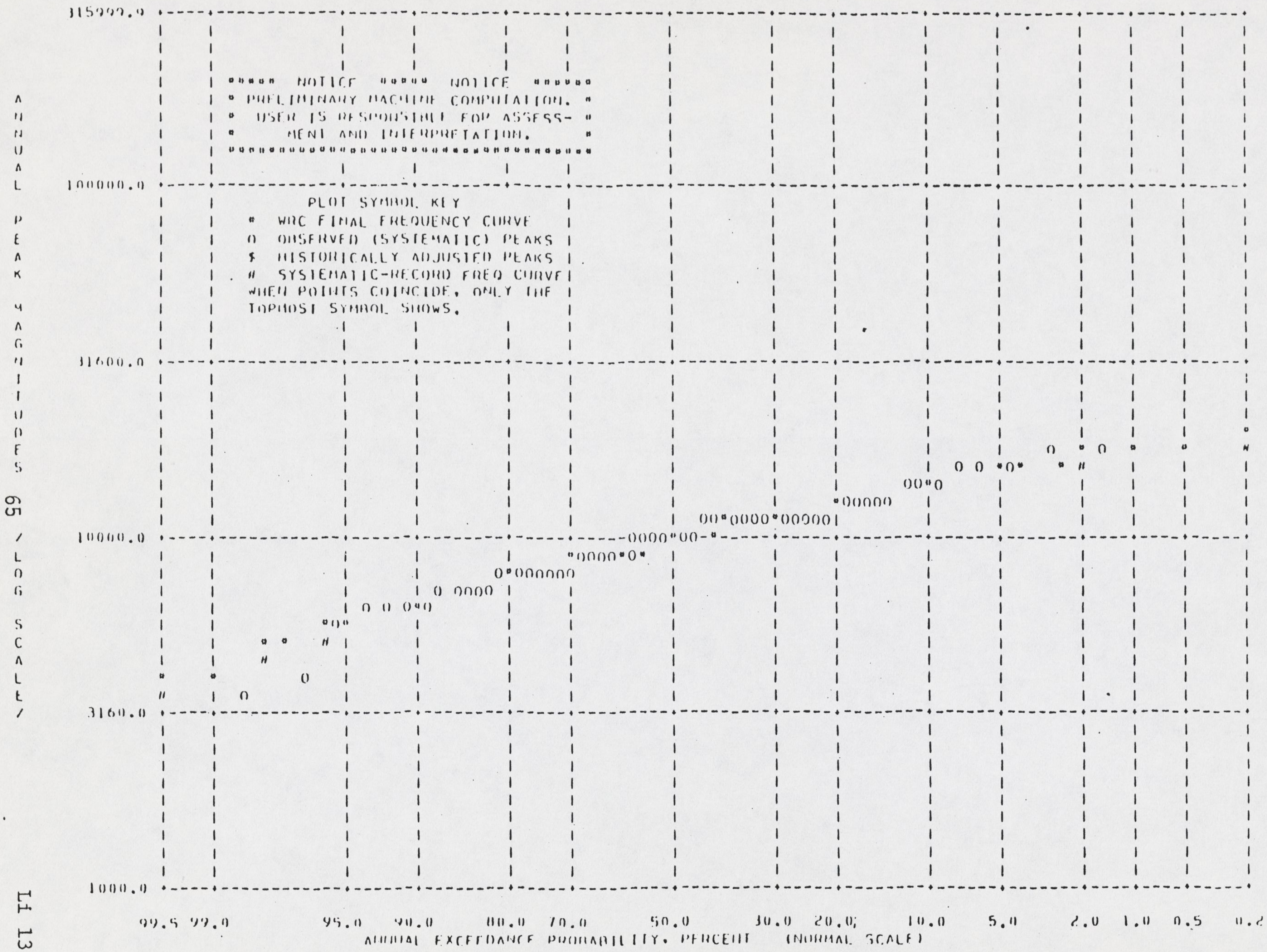


Figure 9. Annual peak flow frequency analysis for Yampa River near Maybell, Colorado.

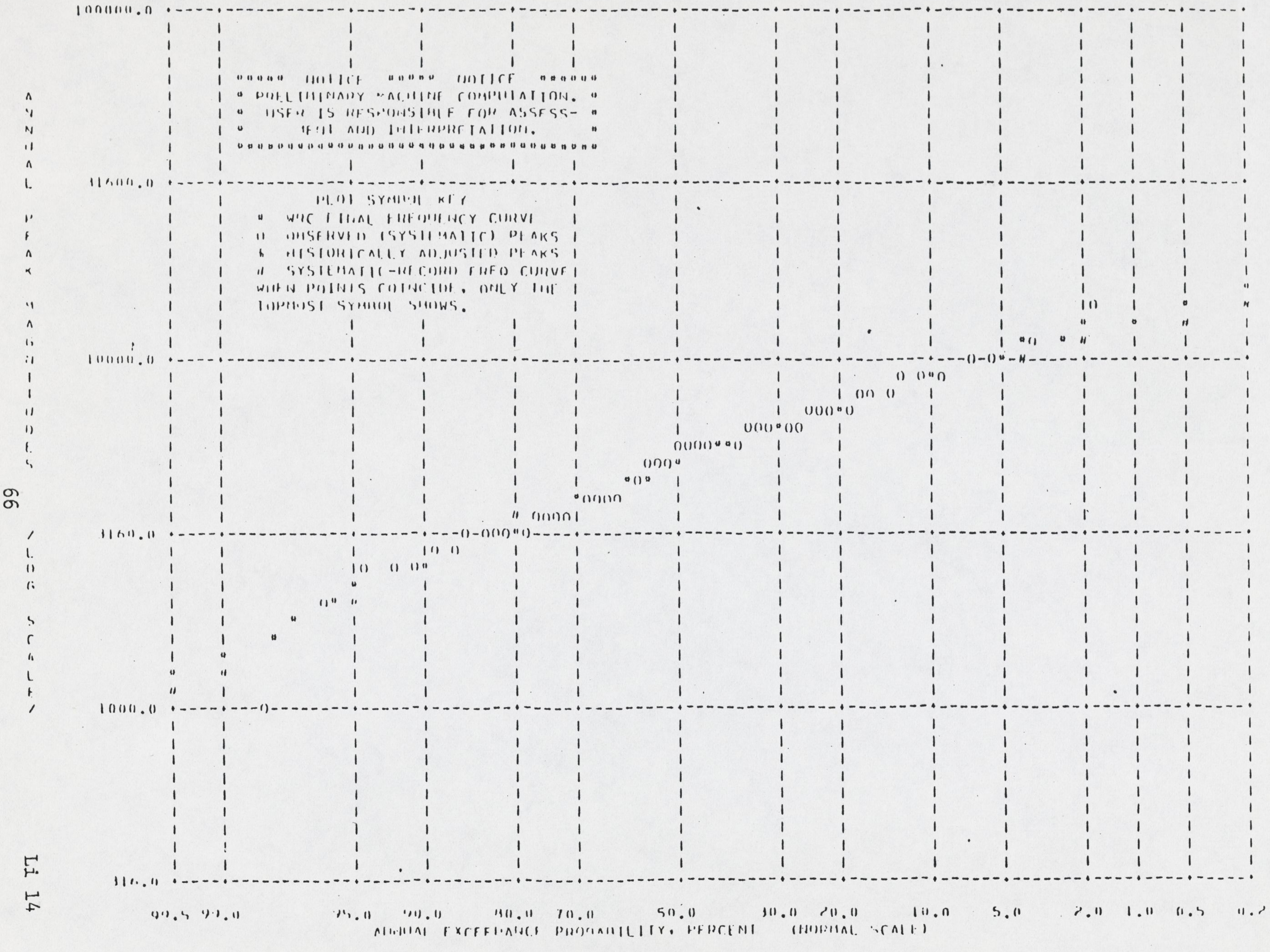


Figure 10. Annual peak flow frequency analysis for Little Snake River near Lily, Colorado.

Li 14

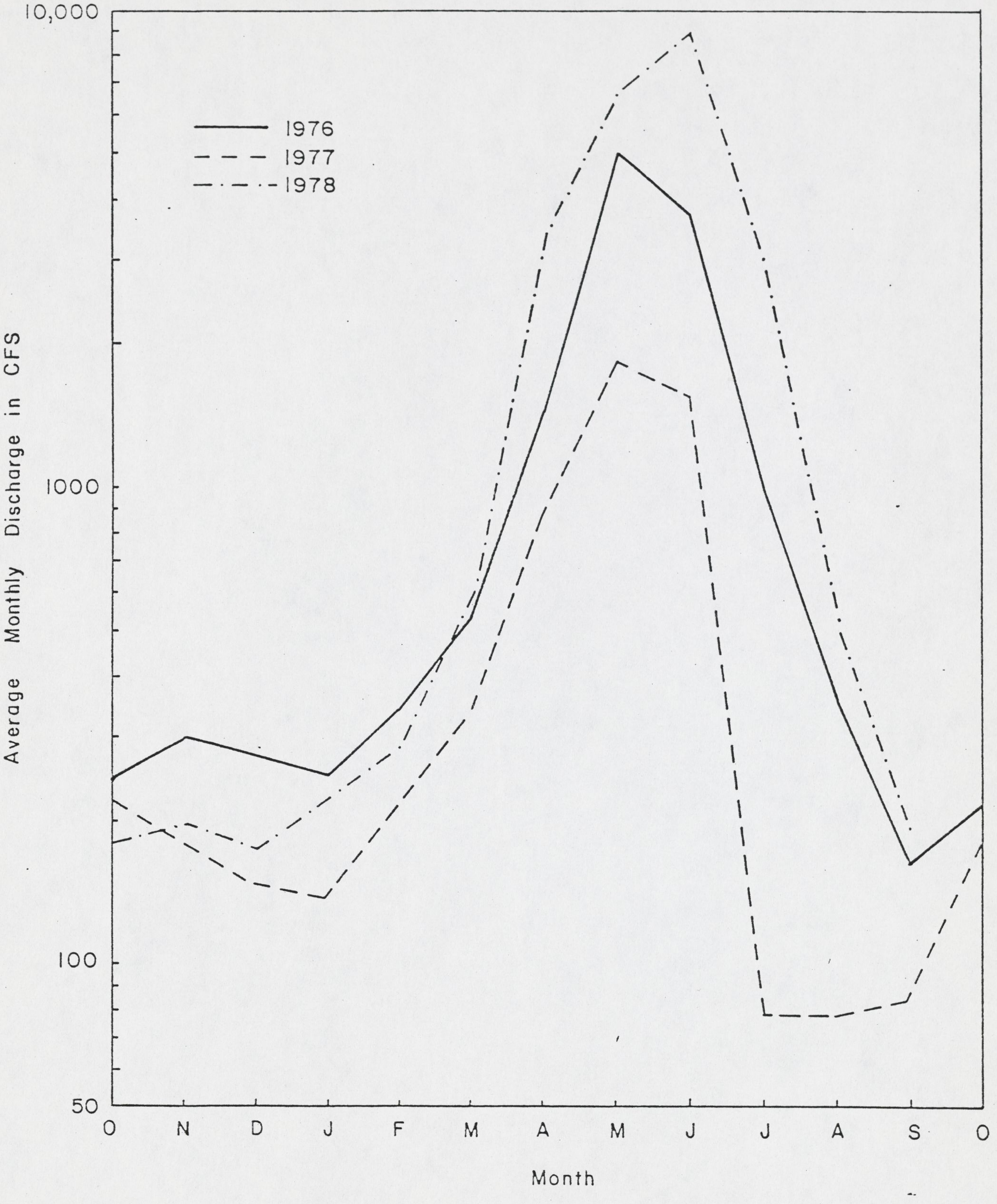


Figure 11. Monthly variation of flow on the Yampa River.

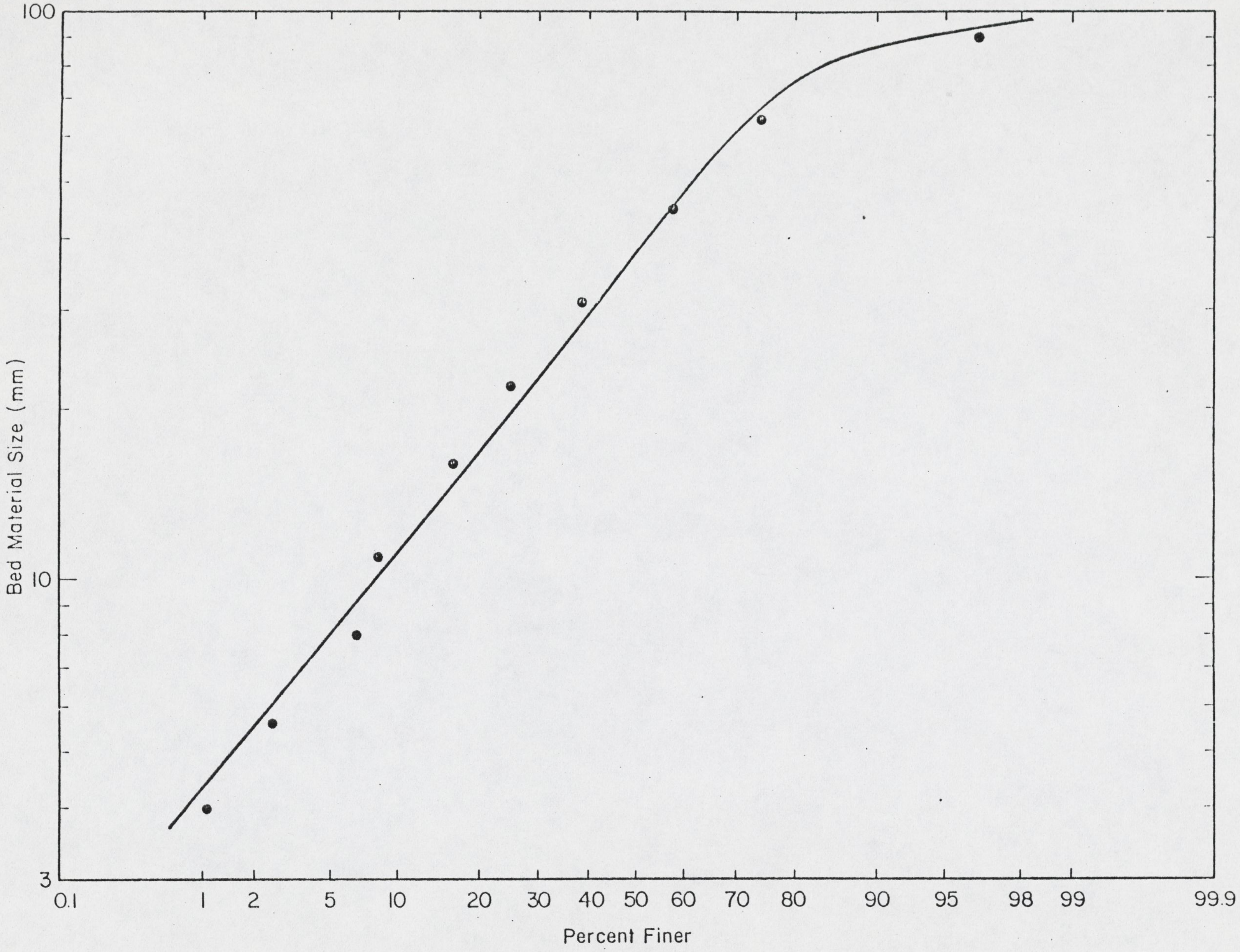


Figure 12. Bed material size distribution of Yampa River near Maybell, Colorado.

streamflows considering the Cross Mountain Reservoir are given. However, effects of the proposed reservoir on reducing the flood peaks are not provided. The proposed Cross Mountain Reservoir will reduce some of the annual streamflows and the reduction of flood peak will be more significant. Figure 8 gives the annual average daily discharge of the Yampa River near Maybell with the effect of the Cross Mountain Reservoir and the Little Snake River near Lily. It is important to note that flow released from the Cross Mountain Reservoir is on the average only about 1.5 larger than the flow from the Snake River. Furthermore, the Snake River will not be regulated and will probably produce higher flood peaks than those released from the Cross Mountain Reservoir.

Figures 9 and 10 show the flood frequency analysis of the flows at stations of the Yampa River near Maybell and the Little Snake River near Lily. No information is available about the flood frequency of the Yampa River modified by the operation of the Cross Mountain Reservoir.

The Yampa River has a strong seasonal discharge trend, dominated by snowmelt runoff during spring and early summer (Figure 11). Many high peaks were produced by events involving rain on snow pack. Many measured stage-discharge records are available. Records show that the stages for 4,000, 10,000 and 18,000 cfs are approximately 4, 7, and 10 ft, respectively.

Bed and Bank Material

A single bed material sample is available for the Yampa River near Maybell, Colorado. The size distribution curve is given in Figure 12. Personal communication with John Andrew indicates that the bed material size distributions from Maybell to Lily Park reach upstream of the confluence with the Little Snake River are similar. This reach is essentially a gravel-cobble bed stream. With high sediment load from the Little Snake River, the Yampa River below the confluence with the Little Snake is predominantly a sand bed stream. Extensive bed and bank material samples would be required to align the data to describe the as is condition. Exploratory drill results if available would also be helpful.

Sediment Transport

Long-term suspended sediment data are available for the upper reach and for the Little Snake River. According to E. D. Andrews of the U.S. Geological Survey, the lower Little Snake River sub-basin contributes about 60% of the total Yampa River basin sediment yield, although it represents less than 35% of the area and supplies less than 3% of the stream flow. However, it is suspected that most of the sediment from the Little Snake River is fine sediment in the range of silt, clay and fine sand.

Examination of the available suspended sediment data indicates that there is no correlation between measured suspended concentration and discharge. Concentration ranges from 40 to 1500 ppm, and the predominant size of suspended sediment is silty and clay. More sediment transport investigation is required.

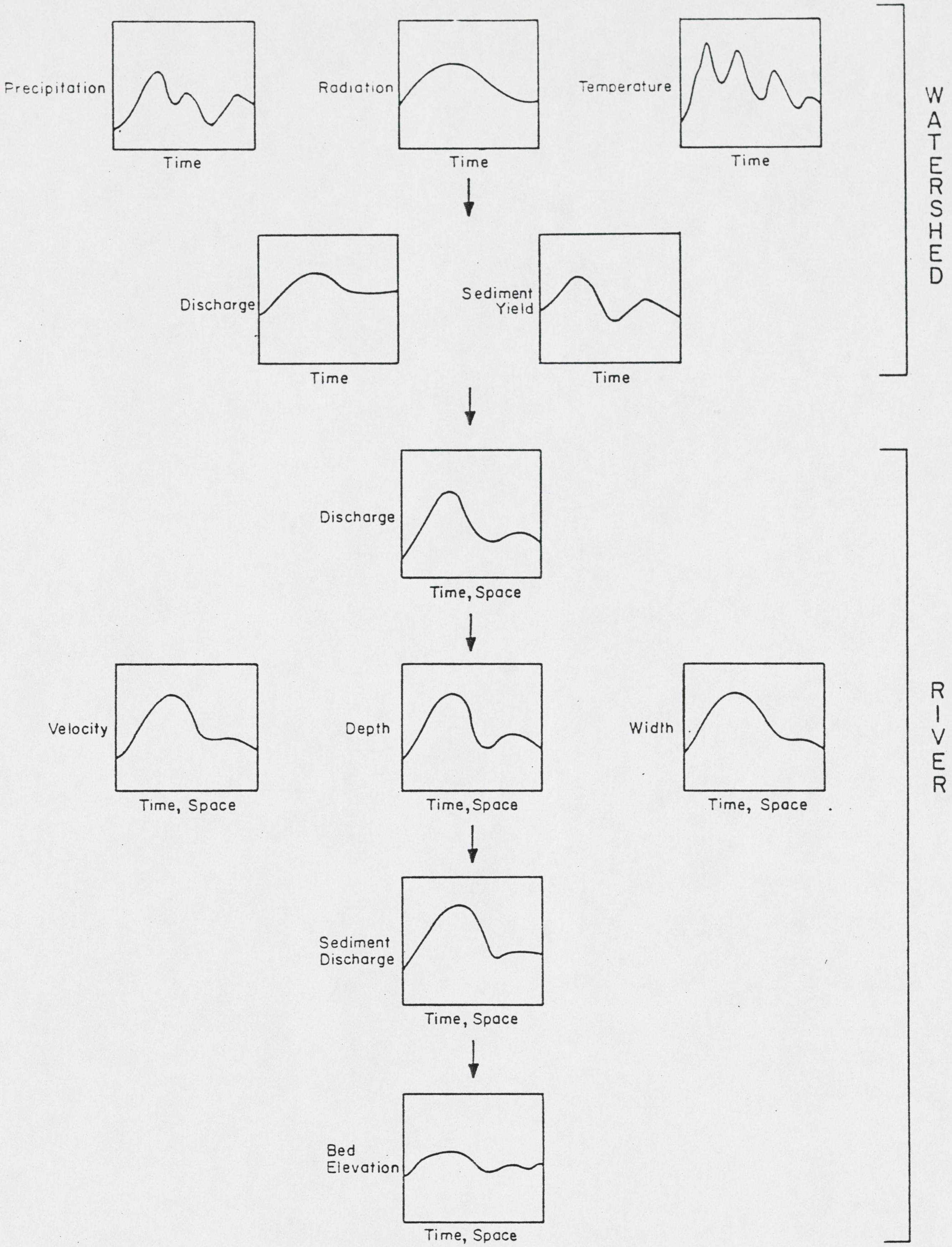


Figure 13. Key elements in the watershed and river analysis.

Morphology

Time-lapsed aerial photographs are not available. With only topographic mapping at 1:62500, little can be derived for the channel morphology. Personal communication with John Andrew reveals that the Yampa River may be in the transition regime. Parts of the river are braided and others are meandering.

ANALYSIS

General Approach

There are three basic levels of approach for predicting the downstream morphology changes: 1) qualitative involving geomorphic concepts, 2) quantitative involving geomorphic concepts and basic engineering relationships, and 3) quantitative involving sophisticated mathematical modeling concepts. A mathematical model is simply a quantitative expression of a physical process or phenomenon. The physical processes governing watershed and river responses are very complicated. Figure 13 illustrates some key elements in the mathematical modeling of watershed and river responses.

A qualitative analysis can provide insight and direction to an analysis of complicated river response problems. Investigation of complex problems with many variables usually requires a massive amount of data. Application of a strict quantitative analysis under these conditions results in many tables and charts summarizing the results of many calculations. Understanding and applying these results to the problem solution is extremely difficult. A qualitative analysis applied before or during the quantitative effort indicates those variables and relationships that are actually significant to the given problem. Furthermore, the qualitative analysis will aid in the selection of the level of quantitative analysis.

Available data on the workshop problem are not sufficient to obtain a conclusive answer. Only a qualitative statement can be obtained based on the data that are currently available.

Qualitative Analysis

Based on the hydrology and bed slope information, it can be determined that the Yampa River is in the transition regime. This determination was based on the work of Lane (Simons and Senturk, 1977) by noting that the product of $SQ^{1/4}$ (bed slope and one-fourth power of dominant discharge) is 0.006 for the Yampa River. The transition regime (or intermediate stream) is capable of braiding or meandering or both depending on the local condition.

Qualitative geomorphic analysis of morphology changes is based on the concept of equilibrium. The qualitative approach assumes that rivers strive, in the long run, to achieve a balance between the product of water flow and channel slope and the product of sediment discharge and size. The most widely known geomorphic relation embodying the equilibrium concept is known as Lane's principle. The Lane relation is

$$Q_s \, d_{50} \propto Q_w \, S \tag{1}$$

where Q_s is sediment discharge, d_{50} is particle size, Q_w is water discharge, and S is bed slope.

Application of the relation in Equation 1 to the workshop problem will indicate that there is a potential for degradation in the Lily Park reach if the reach is not armored due to the clear water release from the proposed Cross Mountain Reservoir. Or

$$Q_s^- \, d_{50}^0 \alpha \, Q_w^0 \, S^- \tag{2}$$

where S^- indicates the potential for degradation. However, an examination of the bed material in the Maybell reach indicates that there is a strong possibility for an armoring effect in the Lily Park reach, and therefore the degradation may be minimal. The armored material in the major bars and riffles probably moves only during large flows and it may never move under regulated flow conditions. Only some of the fine sediment will be gradually cleaned out of the system. Furthermore, assuming that the bank material is either armored or consists of bed rock, lateral migration would also be curtailed. Therefore, the morphology of the Yampa River in the Lily Park reach will likely be unaffected by the construction of the Cross Mountain Reservoir. The meander pattern, channel configuration, and pool-riffle sequence will be essentially unchanged. The substrate material will become slightly coarser and will not affect fish and other aquatic biota significantly. The change in the flow regime and possibly the temperature regime may have some effect.

Below the Little Snake River, the Yampa River may experience aggradation due to the large sediment load of the Little Snake River and the reduced capacity of the Yampa River due to the construction of the dam. This can be concluded from the Lane relation as follows.

$$Q_s^0 \, d_{50}^0 \alpha \, Q_w^- \, S^+ \tag{3}$$

Box Elder reach is in the lower reach and most likely will experience aggradation. This aggradation process will steepen the slope and may alter the stream regime from the transition to the braided stream. Current bed material in the Box Elder reach is predominantly from the Little Snake River and the substrate material is likely to remain the same for the post-project condition. Meander pattern, channel configuration, and pool-riffle sequence will likely be altered significantly. The stream is likely to become braided with more pronounced multiple channels. Width-depth ratio will tend to increase and the channel will be more unstable. Due to the confinement of the bluff lines existing on both banks, the braided channel will be confined in width from bluff line to bluff line. Degree of alteration is dependent on the extent of changes in sediment supply, hydrograph and others. Only a quantitative approach can provide a meaningful answer, but the qualitative analysis indicates that this level of effort should be made in the Box Elder reach.

Quantitative Geomorphic Analysis

As mentioned earlier in the qualitative analysis, the key to predicting the potential change in the Lily Park reach is an examination of the armoring effect. Utilizing the Shields criteria coupled with the Manning equation, an analysis of incipient motion was conducted for the Lily Park reach. Figure 14 gives the relation between incipient particle size and discharge. For a one percent flow (or 100-year flood), discharge is approximately 20,000 cfs. Average particle size that will be in motion is about 21 mm. According to Figure 12, material of this size corresponds to the size that is 30% finer by weight. This implies that on the average, 70% of the particles will not be in motion during a 100-year flood. This supports the assumption of armoring effect made in the qualitative analysis. Due to the unavailability of the bed material size distribution in the Lily Park reach, the above conclusion is at best semi-quantitative.

Equilibrium bed slope in the lower reach below the Little Snake River confluence can be approximated by knowing sediment supply rate, flow rate, the sediment transport equation, and considering any man-made or natural control points. A procedure for estimating equilibrium bed slope is outlined below.

Equations of sediment transport and Manning's equation applied to a unit width of channel form a basis for the analysis. The sediment transport equation (bed load) can be written as

$$q_b = a\ V^b\ D^c \tag{4}$$

where q_b is the unit width bed material transport rate; a, b, and c are constants at each site, V is mean velocity, and D is hydraulic depth. The unit width Manning's equation and the flow continuity equation are written as

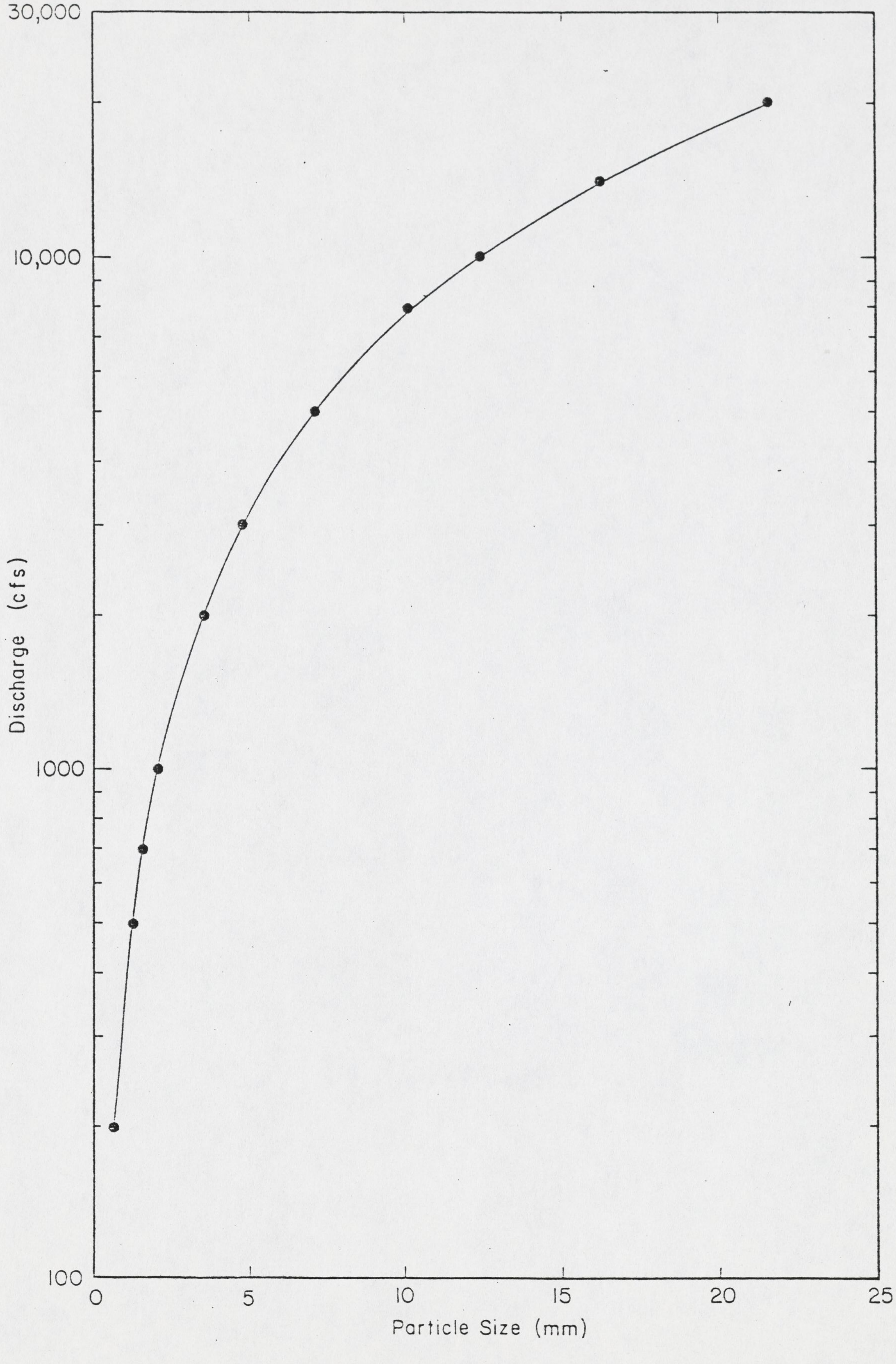


Figure 14. Incipient motion analysis for the Lily Park reach.

$$q = \frac{1.49}{n} D^{5/3} S^{1/2} \qquad (5)$$

and

$$q = VD \qquad (6)$$

where q is the unit width discharge, n is Manning's roughness coefficient, D is depth of flow, and S is slope.

In simultaneous solution with the estimated sediment inflow rate, the new bed slope can be determined by the following procedure. For a selected design flow, this unit width sediment supply rate is set equal to Equation 4. This equation is a function of V and D along with the unit width water continuity equation. These two equations are solved simultaneously for V and D. Computed depth is then substituted into the unit width Manning's equation in order to solve for the new equilibrium slope. This new slope can be compared with bed slope or another computed slope under other flow conditions to indicate possible river response under various conditions.

The above procedure is only for approximations and is presented for illustration of the steps involved. For a more accurate analysis, channel geometry equations established using cross-sectional data should be utilized.

Mathematical Modeling

It is recommended that the dynamic nature of the Box Elder reach be studied by applying the mathematical modeling technique involving the elements outlined in Figure 13. Due to the short study reach involved, a known discharge sediment routing method is recommended. Because of the heterogeneous distribution of the bed material, a procedure for routing sediment by size fraction should be utilized. As outlined in Figure 13, the procedure involves estimation of sediment inflow from watersheds. Transporting capacity of each reach is determined utilizing the hydraulic conditions that can be determined by a backwater profile computation. The sediment routing procedure is accomplished by applying the sediment continuity equation and considering the size distribution of the upstream sediment supply and the bed material. The unsteady flow nature of the problem can be approximated by a series of semi-steady flow conditions.

CONCLUSIONS

This paper reviews the data needs, suggests methods of analysis, and presents a qualitative assessment of downstream river morphological changes from the proposed reservoir construction on the Yampa River, Colorado.

Available data are not sufficient to obtain a conclusive answer; therefore, only a qualitative statement can be obtained. It is imperative that a site visit be conducted before attempting to draw any conclusions related to the analysis of river response. Time-lapse aerial photographs are often useful in identifying river behavior. Based on the available data, qualitative conclusions regarding possible response of the downstream channel follow.

Morphology of the Yampa River in the Lily Park reach upstream of the confluence of the Little Snake River will likely be unaffected by the construction of the Cross Mountain Reservoir. The meander pattern, channel configuration, and pool-riffle sequence will be essentially unchanged. Substrate material will become slightly coarser and will not affect aquatic biota significantly.

Below the Little Snake River, the Yampa River may experience aggradation due to the large sediment load introduced by the Little Snake River and reduced transport capacity of the Yampa River due to construction of the dam. The Box Elder reach is in the lower reach and most likely will experience aggradation. This aggradation process will steepen the slope and may alter the stream regime from a transition to a braided stream. Thus, the meander pattern, channel configuration, and pool-riffle sequence will likely be altered significantly. Current bed material in the Box Elder reach is predominantly from the Little Snake River and the substrate material will largely remain the same for the post-project condition.

Additional data that are required to reach a more conclusive answer include:

1. Time-lapse aerial photographs,
2. Cross-sectional data for the entire study area,
3. Bed and bank material data covering the entire study area and the Little Snake River,
4. More detailed sediment transport data,
5. Reservoir operation data and related structural work, and
6. Modified flood peak frequency affected by construction of the dam.

Level of analysis chosen could be different for different study reaches. A qualitative and quantitative geomorphic analysis will be sufficient to analyze the Lily Park reach. A more detailed study is recommended involving use of mathematical modeling to analyze the more complex reach below the Little Snake River.

POSSIBLE EFFECTS OF CROSS MOUNTAIN AND JUNIPER RESERVOIRS ON LILY PARK AND BOX ELDER REACHES ON YAMPA RIVER, COLORADO

Hsieh Wen Shen
Professor of Civil Engineering, Colorado State University,
Fort Collins, Colorado, U.S.A.

INTRODUCTION

The Cross Mountain and Juniper Dams may be constructed in the future. The Colorado Squaw Fish designated as an endangered species in the Lily Park and Box Elder Reaches downstream from the two reservoirs may be adversely effected by these two dams. The purpose of this paper is to present a preliminary analysis based on available hydrologic data to evaluate the potential effects of the two dams on the Colorado Squaw Fish.

DESCRIPTION OF THE AREA

Figure 1 shows the location of this area. Lily Park Reach is located a) immediately above the junction between the Little Snake River and the Yampa River and b) immediately downstream from the Cross Mountain Dam. The distance between the Box Elder Reach and the Cross Mountain Dam is approximately 59 miles.

As indicated by Figure 1, two main U.S. Geological Survey gaging stations, the Maybell Station on the Yampa and the Lily Station on Little Snake River, are in this region.

GENERAL ANALYSIS

Before a detailed analysis of the hydrologic data, it would always be useful to inspect the field situation and obtain an overview of the morphology of the river. Since field investigation is not possible in this case, one must examine the morphology of the river from given data. Both the Yampa River and the Little Snake River are meandering rivers. However, Yampa River below the junction of Little Snake and Yampa River appears to exhibit a braided pattern. This indicates that the flow there has not been able to carry out all the sediment carried into the reach. This is an extremely important point to be considered later in more detail.

The longitudinal bed slopes for different reaches of the Yampa River are given in Table 1.

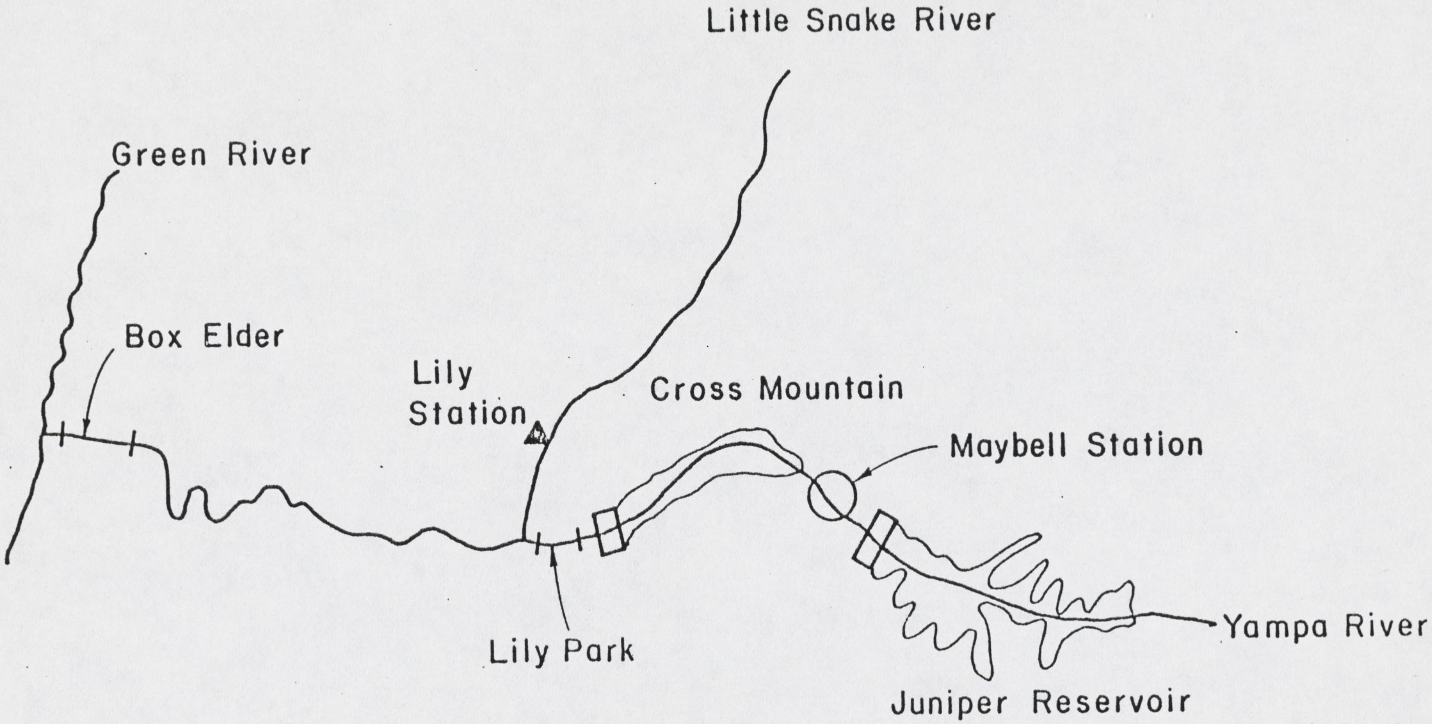


Figure 1. General location (not to scale).

Table 1. Longitudinal bed slopes for Yampa River downstream from Cross Mountain Dam (0 miles is at Box Elder).

Reach	Approximate Length (miles)	Bed Slope (ft/ft)
0 (Box Elder) to 20 miles	20	0.00085
20 miles to 38 miles	18	0.003
38 miles to Lily Park (56 miles)	18	0.0013
Lily Park (56 miles) to Cross Mountain Dam (59 miles)	3	0.01

The junction between Little Snake and Yampa River is at a distance of approximately 52 miles from Box Elder.

If both dams should be completed, the effects of Juniper Dam on both Box Elder and Lily Park Reaches are through the regulation of reservoir flow and potential erosion between the two dams. Both of these effects are minor. Thus it can be assumed that one needs to examine the river reach below Cross Mountain Dam.

As shown in Table 1, the variations of bed slope at different river reaches below Cross Mountain Dam are rather significant. These large differences indicate that the following two river reaches: a) river miles 20 to 38 and b) river miles 56 to 59 are rather stable with steep slopes. After the construction of the two dams, the river peak flows would be reduced and thus it is reasonable to assume that these two reaches would be stable in the future. The most critical reach to be examined should be the reach between river mile 38 to Lily Park. This is the river reach that the Little Snake River enters and that also exhibits a braided pattern.

HYDROLOGIC ANALYSIS

Reservoir Releases

The closest station on the Yampa River is at Maybell and flow data for this station provided to us are between 1910 and 1978. The maximum daily flow discharge within that period was 17,900 cubic feet per second (cfs) and occurred in 1917. The minimum daily flow discharge was 3620 cfs and occurred in 1977. The 50-year flood was estimated to be 19,730 cfs. The annual release from the Juniper Reservoir was given by the Instream Flow Group to be 68 cfs. From my calculations, 84 percent of the flow was diverted from the reservoir and not released downstream. From the data provided by the Instream Flow Group, it was found that the annual average release of flow was much more than the annual average inflow to the reservoir. It appears that a significant amount of flow would be diverted from Juniper Reservoir directly into the Cross Mountain Reservoir without entering the Yampa River Reach between the two reservoirs. This point should be examined rather closely. Maybe several reservoir diversion streams were used.

Change of Lily Park Reach

This reach is situated immediately downstream from the Cross Mountain Dam and thus the flow released from the reservoir will directly affect this reach. Since no detailed flow regulation for this reservoir is given, one can only discuss this problem qualitatively. For low flow, one must investigate the provision of flow depths for the fish. A great deal of vegetation growth may alter the channel shape. A botanist is needed to provide information on the relationship between flow and vegetation growth. The flood storage of the Cross Mountain Reservoir is not known, but the total storage volume appears to be rather large. The analysis of sediment samples collected at Maybell indicates that there are two types of sediment: very fine wash load and coarse material which formed the bed. In any case, it is difficult to use the cross-sectional areas of Lily Park provided by the Instream Flow Group without a field inspection and some information about its upstream and downstream conditions.

As stated previously, the major critical point of the stability of Lily Park is the stability downstream from the junction between the Little Snake River and Yampa River. Since the junction is located immediately downstream from the Lily Park section, the behavior at the junction would greatly affect the behavior of Lily Park Reach.

Table 2 shows the flow discharges and sediment loads for both the Yampa River at Maybell and Little Snake River at Lily, just upstream from its junction with the Yampa River.

Table 2. Flow discharges and sediment loads for both the Yampa River at Maybell and Little Snake River at Lily.

River	Years of Record	Drainage area (mile^2)	Annual discharge (cfs)	100 Years flood (cfs)	Suspended Load (Tons)	Bed Load (Tons)
Yampa (Maybell)	1904-1978	3910	1550	17110	0.42	0.12
Little Snake (Lily)	1923-1978	3730	575	12333	1.3	0.07

As shown in Table 2, although the drainage areas for both Yampa River and Little Snake River at the two respective stations are approximately the same, the annual flow in Yampa is much greater than that for the Little Snake River. On the other hand, the Little Snake River carries much more sediment than the Yampa River. From this, one may conclude that the Little Snake River carries a great deal of sediment to its junction with the Yampa River and the flow from the Yampa River is needed to carry these sediment deposits downstream to Green River. If one reduces the flow peaks and the annual flows through the regulation of Cross Mountain Reservoir releases, the Yampa River Reach immediately downstream from its junction with the Little Snake River may even aggrade.

All of these analyses indicate the need of a detailed analysis at the junction between Yampa River and Little Snake River. The correlation of flows between the two rivers must also be investigated. A mathematical model for this junction would be rather useful to study the various combinations of conditions.

Change of Box Elder Reaches

The effect of the two dams on Box Elder Reach probably would be minimum because the peak flows and the annual flows would be reduced and the Box Elder Reach is located downstream from a relatively steep reach.

CONCLUSIONS

1. A field inspection is needed before any detailed analysis can be made.
2. The flow regulation plans for both reservoirs should be investigated. The effects of the two dams on the two reaches may be reduced by an effective reservoir regulation plan.
3. The effect of Juniper Dam on the two reaches probably would be minor.
4. The most critical reach that should be investigated thoroughly is the Yampa River Reach immediately downstream from its junction with the Little Snake River.
5. The river bed at the Lily Park Reach may either degrade, aggrade, or remain the same depending mainly on the condition at its junction with the Little Snake River.
6. The effect of the two dams on the Box Elder Reach would probably be minimal.

RESERVOIR CONSTRUCTION AND YAMPA RIVER MORPHOLOGY

Chih Ted Yang
Civil Engineer, Water and Power Resources Service
Engineering and Research Center, Denver, Colorado, U.S.A.

INTRODUCTION

The Yampa River Basin lies within the southern part of Wyoming and the western part of Colorado. It was proposed that the Cross Mountain Reservoir and Juniper Reservoir be constructed on the Yampa River above Lily Park and Maybell, Colorado, respectively, as small flood retention reservoirs. The objective of this paper is to provide some preliminary assessments of the impacts of the proposed reservoirs on Yampa River morphology.

Quantitative assessment of a river's response to the construction of a reservoir can be made provided that detailed information on reservoir size and operation, flow, and sediment data collected near the reservoir, channel pattern and cross sections immediately above and downstream of the reservoir, and bed and river bank material size distribution are available. Because this information is rather limited, only qualitative assessments will be made under some assumed or hypothetical conditions. The assessments made in this paper are the author's personal opinions only and are not expressive of official policy or opinion by the Water and Power Resources Service or the United States Government.

BACKGROUND INFORMATION

The Yampa River flows through an area underlain by widespread deposits of relatively soft sedimentary rocks, bordered in part by abrupt mountain slopes, and containing isolated ridges. The most outstanding feature of this area is the meandering river cut through the mountain range to form canyons to depths of as much as 3,000 feet along the lower Yampa River. The river channel deposits along the Yampa River consist of clay, silt, sand, gravel, and boulders. Associated with the meandering river is the distinct pool and riffle sequence. The study reach is located between Lily Park and Box Elder, Colorado as shown in Figure 1. The longitudinal bed profile of the Yampa River is shown in Figure 2.

Good suspended sediment data are available at U.S. Geological Survey gaging station No. 2600 along the lower Little Snake River near Lily Park and No. 2510 along the Yampa River at Maybell between the proposed Cross Mountain Reservoir and the Juniper Reservoir. A study made by Andrews (1978) indicates that the lower Little Snake River subbasin contributes about 60% of the total Yampa River basin sediment yield, although it represents less than 35% of the area and supplies less than 3% of the streamflow. In contrast, the subbasin above Maybell, Colorado, which covers one-third of the Yampa River Basin, contributes only about 14% of the sediment yield but 76% of the streamflow. The interbed sandstones, mudstones, and shales in the study reach are relatively erodible. Based on the suspended sediment data at Maybell, the suspended loads are mainly made of materials finer than 0.062 mm. However, the bed material at Maybell has a median diameter of about 38 mm. The significant difference in size between suspended and bed material is an indication of the existence of armor layers on river bed.

The average monthly discharge from 1910-1976 and the projected average monthly discharge at Maybell with Juniper Reservoir in operation is shown in Table 1. The 10, 50, and 90 percent flows of the Yampa River at Maybell are about 14,000, 10,000 and 7,000 cfs, respectively.

The field survey data on channel cross sections as shown in Figure 3 and thalweg elevation of the Maybell reach indicates that the cross sections are rather symmetrical in shape and there is not a distinct pool and riffle sequence. However, the U.S. Geological Survey topographic maps indicate that the reach near Maybell is a sinuous river with sand bars. It is possible that the surveyed cross sections are not representative of the reach, and the pool-riffle sequence does exist.

The projected monthly average discharges at Cross Mountain Reservoir are shown in Table 2.

Table 1. Monthly streamflow of the Yampa River near Maybell, Colorado.

Mohth	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Average Flow 1910-1976 (in cfs)	21.6	20.8	18.1	16.8	18.1	41.3	156.2	380.0	323.5	80.9	23.2	14.5
Projected Average flow with Juniper Reservoir (in A.F.)	31	33	63	143	123	181	283	200	192	108	60	28

Table 2. Projected average monthly flow at Cross Mountain Reservoir, in cubic feet per second.

Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Discharge	452	357	266	234	202	235	356	1804	2705	2666	1091	633

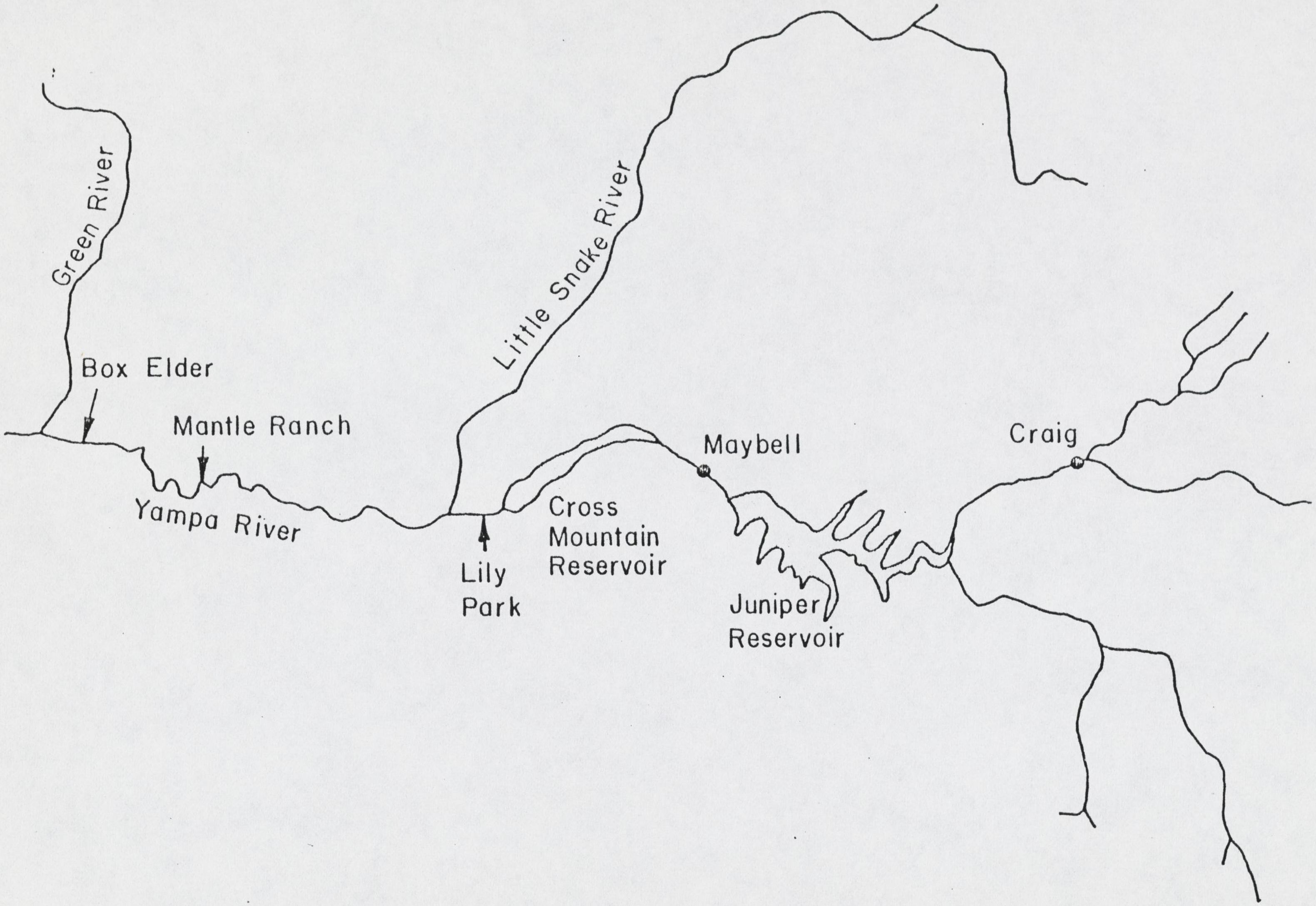


Figure 1. General location map of the Yampa River Basin.

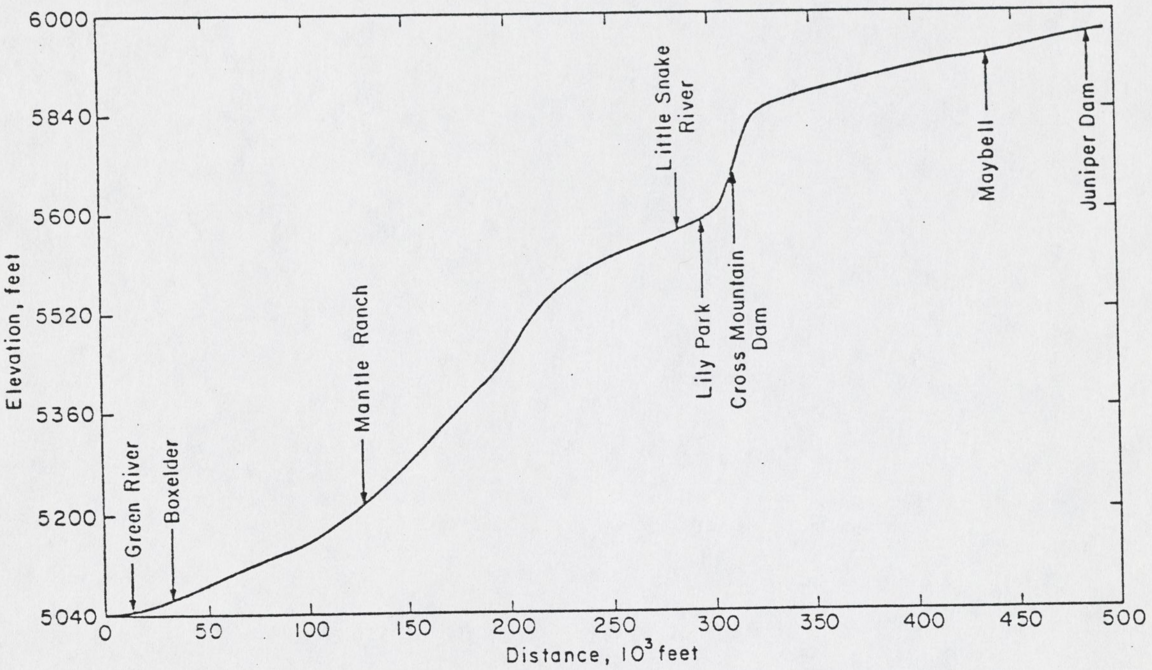


Figure 2. Longitudinal bed profile of the Yampa River.

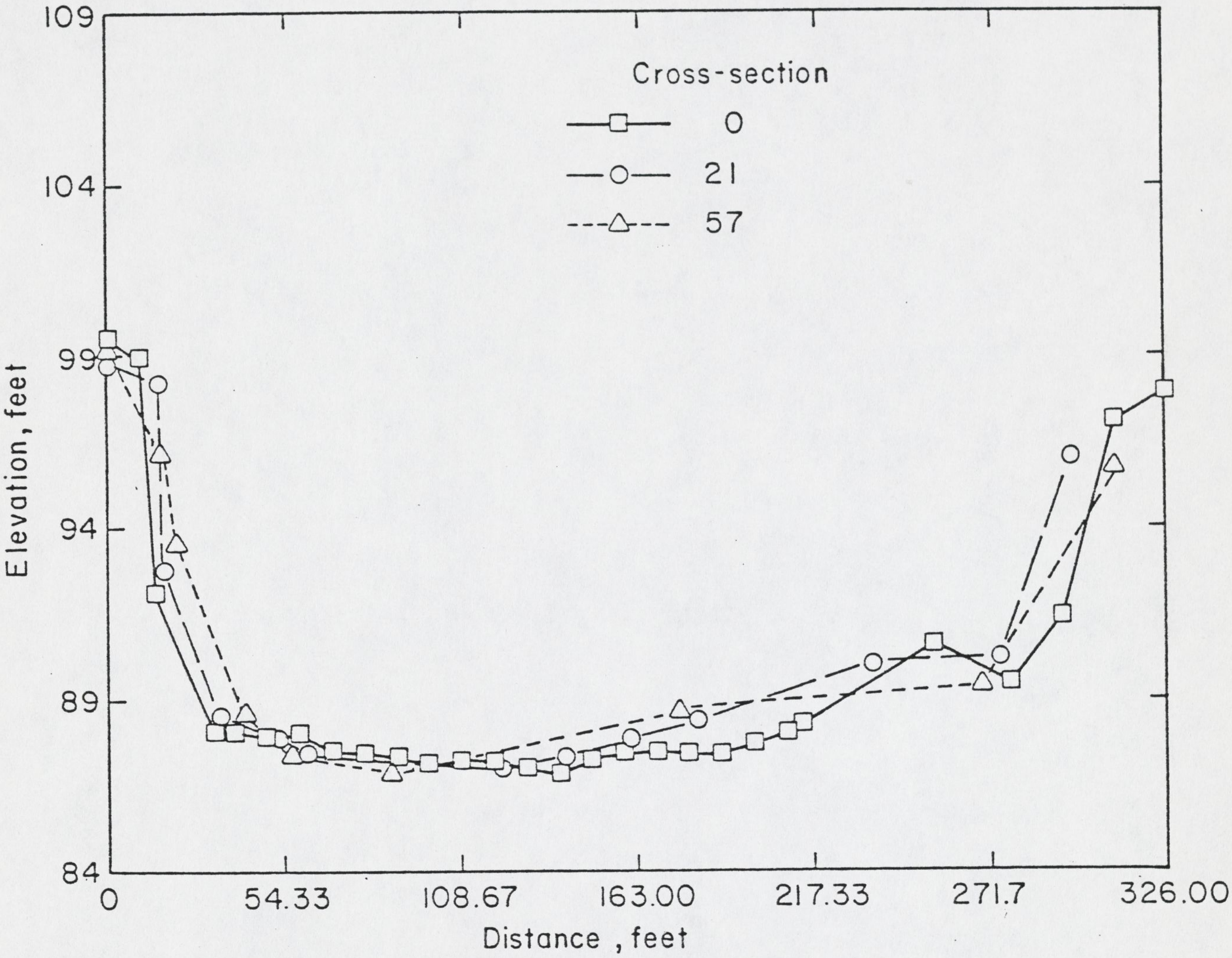


Figure 3. Channel cross sections of the Maybell Reach.

The field survey data on channel cross sections and thalweg elevation of the Lily Park reach of the Yampa River indicates that the cross-sectional shapes change from highly skewed toward one side to symmetrical and then skewed toward the other side and the cross sections have the distinct pool-riffle-pool sequence characteristics. Comparisons of thalweg profiles surveyed at discharges of 810 cfs and 4900 cfs as shown in Figure 4 indicate that there is no appreciable change of channel cross section due to changing flow conditions. This is an indication that the channel in this reach is very well stabilized by armor layer. Figure 5 shows similar results found near Mantle Ranch.

The result shown in Figure 6 is very interesting. It shows that there is no appreciable change of thalweg profile at low and median flows. However, at a high flow of 2810 cfs, the profile is higher than those measured at lower discharges. This is an indication that sediments from the Little Snake River which were deposited near the confluence of the Little Snake and the Yampa can be transported to the Box Elder reach and cause channel aggradation during high flows.

MORPHOLOGICAL CHANGES

Based on the longitudinal bed profile shown in Figure 2, morphological changes may occur in three reaches. These are the Lily Park reach, the reach near the confluence of the Little Snake and the Yampa, and the reach near Box Elder. The reach between Box Elder and the Little Snake River is very steep and the bed is either covered by armor layers or bedrock. Any sediment entering this reach will be flushed out, and no change is anticipated in the future. The only possible change of the Box Elder reach is the elimination of periodic channel aggradation during high flows since the high flows will be eliminated or reduced after the construction of the reservoirs.

The reach near the confluence of the Little Snake and the Yampa may be sensitive to the construction of the reservoirs. Future changes depend on the operation of the reservoir with respect to the hydrologic conditions of the Little Snake. Currently available data are inadequate to make a meaningful analysis and prediction.

The Lily Park reach is located immediately downstream of the Cross Mountain Reservoir and certain morphological changes are likely to occur after the completion of the reservoir. Quantitative analyses can not be made here due to the lack of detailed hydraulic and hydrologic as well as reservoir operation data.

Qualitative predictions of morphological changes are made based on generalized background information stated in the previous section. The predicted changes emphasize the long-term effects of the reservoirs and are more applicable to the Lily Park reach which is located immediately downstream of the reservoirs. These changes include meander pattern, channel configuration, substrate material, and pool and riffle sequences.

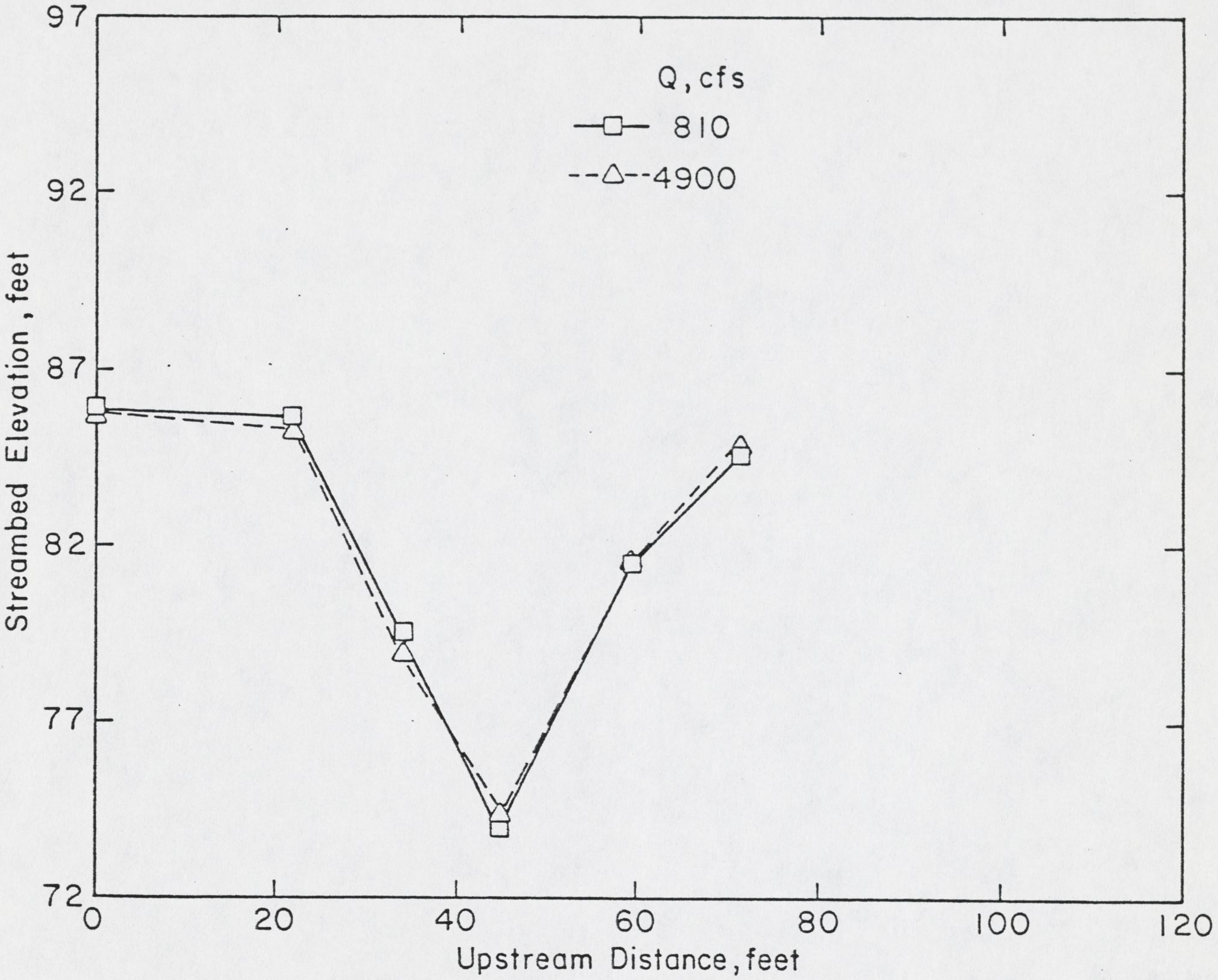


Figure 4. Variation of thalweg in the Lily Park Reach.

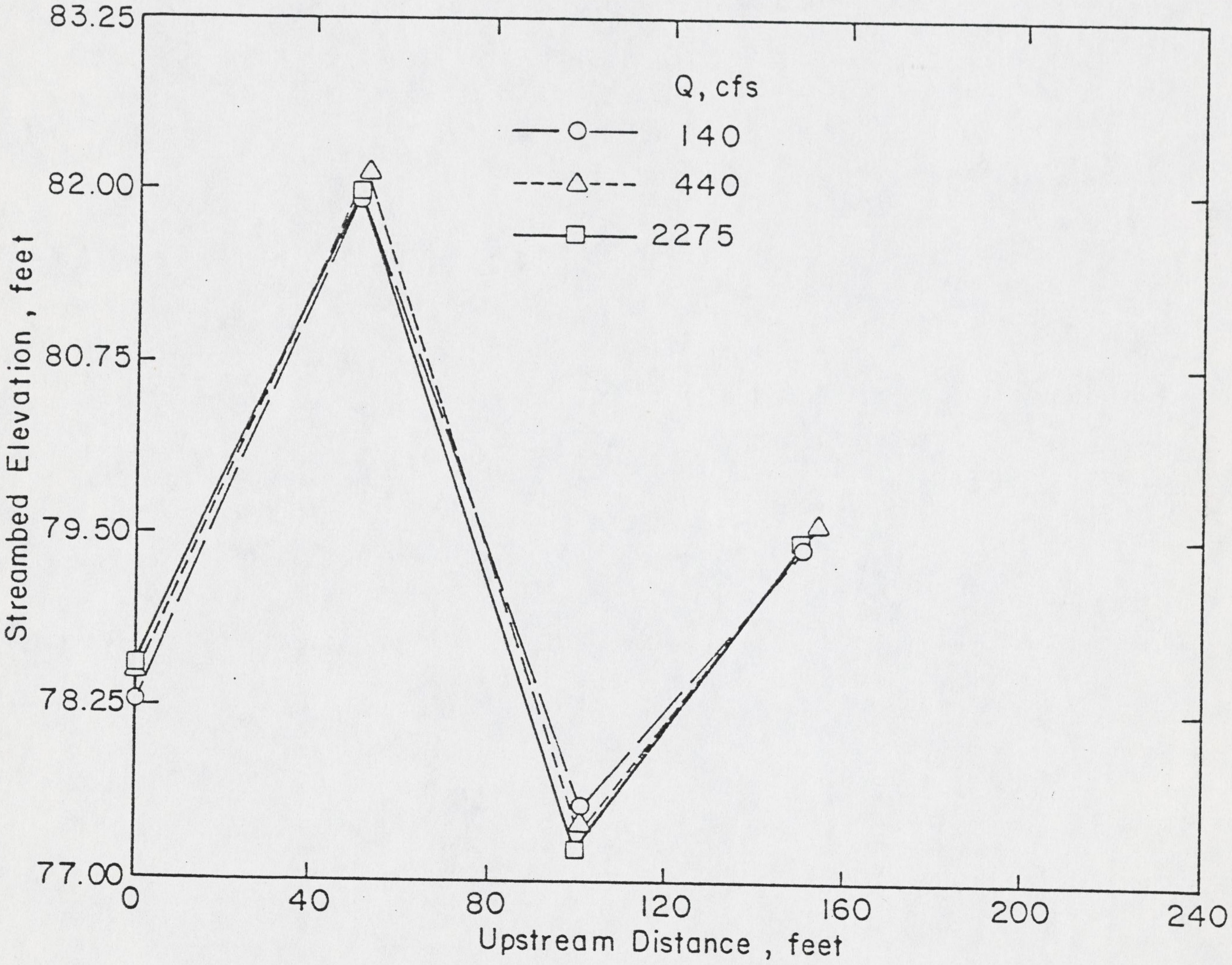


Figure 5. Variation of thalweg in the Mantel Ranch Reach.

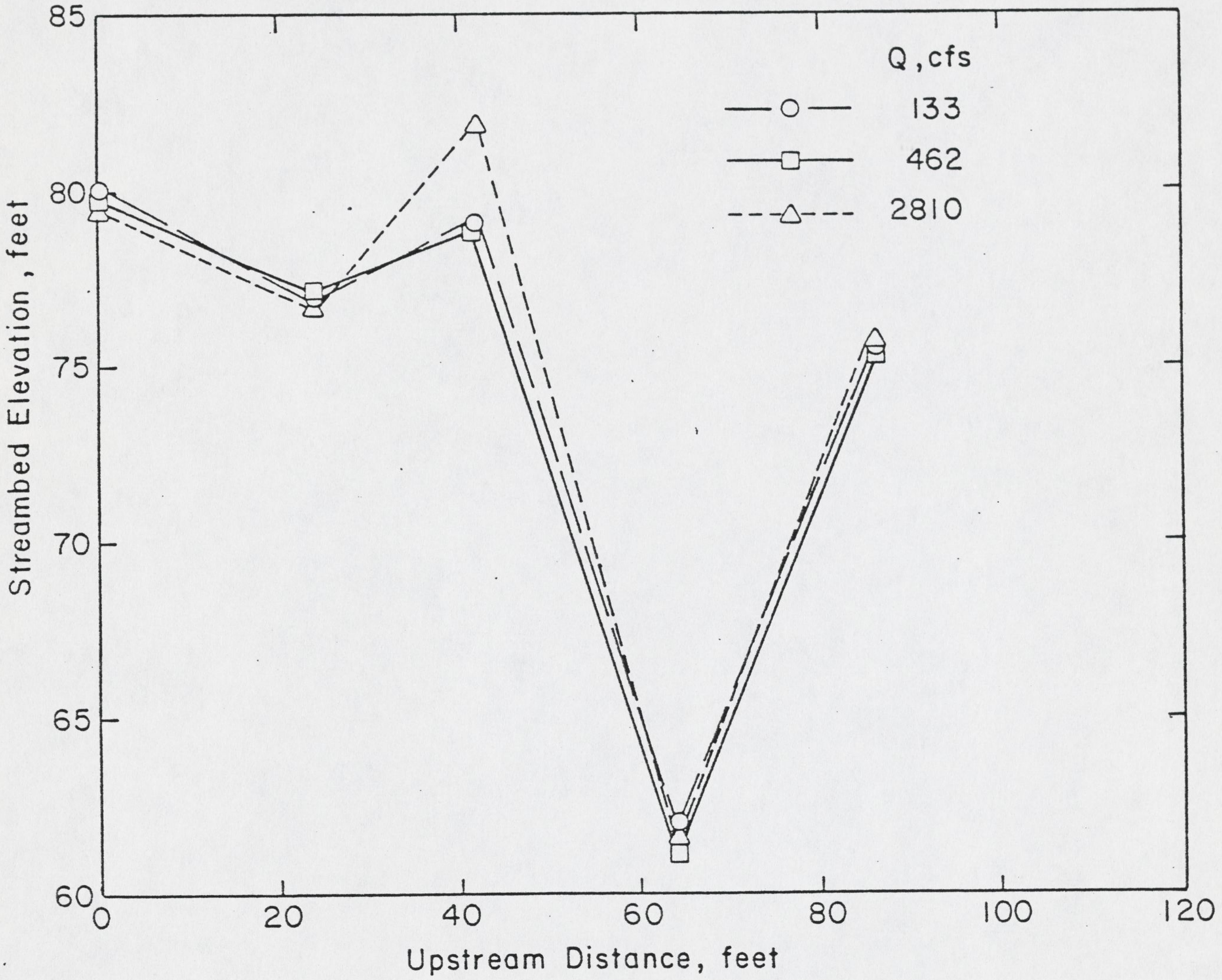


Figure 6. Variation of thalweg in the Box Elder Reach.

1. Meander Pattern. The thalweg of a river usually increases the amplitude of its meanders with decreasing water discharge. During high flow, the thalweg may cut through the point bar and reduce its amplitude of meanders. Yang (1971a, 1980) considered river meandering as a means available to a river to reduce its rate of energy dissipation. Higher discharge and slope are associated with a high rate of energy dissipation and should have smaller amplitude of meanders. After the construction of the two reservoirs, the discharge from the reservoir will be more evenly distributed over the year than the natural flow and the chance of having very high discharge from the reservoirs is very low. Because most sediment will be trapped in the reservoirs, the water released from reservoirs has the ability to erode the river bed and reduce river slope below the dams. The lack of high flows and the reduction of channel slope below a dam after construction of a reservoir should enhance the development of a more sinuous river. This is especially true for the reach immediately downstream of the proposed reservoirs because the valley width is relatively wide and bed materials are relatively erodible. However, it should be pointed out that due to the existence of coarse materials in the river bed the existing armor layer or the formation of a new armor layer should slow down the degradation process and eventually stop it. In the long run, a more symmetrical and sinuous river course may be formed.

2. Channel Configuration. Variation of channel configuration is closely related to the locations of pools at the meandering bends and crossings at the riffles. With more evenly distributed discharges from the reservoirs and a more fully developed meander pattern after the construction of reservoirs, it can be anticipated that the cross sections at the river bends would become more skewed and those at the crossing or riffles become more symmetrical.

Leopold and Maddock (1953) developed the hydraulic geometry relationships from U.S. Geological Survey gaging station records. Their relationships of channel geometry can be expressed by

$$W = aQ^b \tag{1}$$

$$D = cQ^f \tag{2}$$

in which W = channel width, D = average depth, Q = water discharge, and a, b, c, f = coefficients. Their at-a-station values for 20 gaging stations vary from 0.03 to 0.59 with a mean of 0.26, and from 0.06 to 0.63 with a mean of 0.40 for b and f, respectively. Their average downstream values are 0.5

and 0.4 for b and f, respectively. Under the assumption that a river is free to adjust its width and depth to reach an equilibrium condition, Yang et al., (1981) applied the theory of minimum rate of energy dissipation (Yang and Song 1979; Song and Yang 1980) to determine the values of b and f. The theoretical values of b and f thus determined have the same value of 0.409. This general agreement between the theoretical and observed values suggests that the theory of minimum rate of energy dissipation can be applied to predict the long term effects or the new equilibrium channel geometry under the new constraints imposed to the river after the construction of the reservoirs. Chang (1980a,b) also used the theory of minimum stream power to determine stable channel geometry and the results agreed fairly well with regime channels and natural rivers.

3. Substrate Material. As the channel degradation process continues below the proposed reservoirs, the bed materials will become courser. Eventually, an armor layer will develop and the degradation process will stop. Because the existing bed materials abound with gravel and boulders, it should not take too long for the river bed to form an armor layer of coarser materials.

4. Pool and Riffle Sequence. River meandering and the formation of pool and riffle sequences often coexist. A river can adjust its rate of energy dissipation through meandering in the lateral direction. The formation of riffle and pool sequence was considered by Yang (1971b, 1980) as a river's self-adjustment in the vertical direction to minimize its rate of energy dissipation. This is especially true during low flows with low rates of energy dissipation and at those places where coarse materials are available to resist higher velocities at riffles. Field measurements by Stall and Yang (1972) along the Middle Fork Vermilion River near Oakwood, Illinois, during low flow showed that the rate of energy dissipation per unit weight of water flowing through two complete pool and riffle sequences was 26% less than that of an equivalent reach without any pool and riffle sequence. After the construction of reservoirs, the chance of having high discharges through the reservoirs should be significantly reduced. The low flow below reservoirs and the existence of coarse materials in the river bed should enhance the formation of more pronounced pool and riffle sequences downstream of the reservoirs. Eventually, new equilibrium pool and riffle sequences will be established.

SUMMARY AND CONCLUSIONS

A preliminary qualitative assessment of morphological changes of the Yampa River below the proposed Cross Mountain Reservoir and Juniper Reservoir was made. Because the Yampa River above the confluence of the Little Snake River has relatively low sediment load, sedimentation in the proposed reservoirs should not be a serious problem. By contrast, the sediment load in the Little Snake River is rather high. The amount of sediment which could be trapped in the reservoirs should be relatively insignificant compared with that carried by the Little Snake River. Thus, no major morphological changes of the Yampa River below the confluence of the Little Snake River should be anticipated due to the construction of the reservoirs. The predicted long-term morphological changes downstream of the proposed reservoirs are summarized as follows.

1. The average amplitude of meanders should increase slightly until a new equilibrium condition is reached.

2. Along with the development of meanders, the channel cross sections will become more skewed near the bends and more symmetrical near riffles.

3. A limited amount of channel degradation below the proposed reservoirs should be anticipated until a new equilibrium profile is established. Bed materials near the bed surface will become coarser and an armor layer will be formed to stabilize the new bed profile.

4. The existing pool and riffle sequence should become more pronounced in the future.

5. Because the existing bed materials abound with gravels and boulders which can be used by the river to form an armor layer, if it has not formed already, no drastic river morphological changes downstream of the proposed reservoirs should be anticipated.

6. Because of the relatively low sediment load carried by the Yampa River above the confluence of the Little Snake River, construction of the proposed reservoirs should not have significant impact on the Yampa River morphology below the confluence of the Little Snake River.

7. The proposed reservoirs may have significant impacts on the morphological changes near the confluence of the Yampa and the Little Snake River. Available hydraulics and hydrologic data of the two rivers and the reservoir operation data are inadequate to make a meaningful prediction of future changes in this reach.

REFERENCES

Andrews, E. D. 1978. Present and Potential Sediment Yield in the Yampa River Basin, Colorado and Wyoming. U.S. Geological Survey Water-Resources Investigations, 78-105, December.

Chang, H. H. 1980a. Stable Alluvial Canal Design. Journal of the Hydraulics Division, ASCE, Vol. 106, No. HY5, May.

Chang, H. H. 1980b. Geometry of Gravel Streams. Journal of the Hydraulics Division, ASCE, Vol. 106, No. HY9, September.

Leopold, L. B. and T. Maddock, Jr. 1953. The Hydraulic Geometry of Stream Channels and Some Physiographic Implications. U.S. Geological Survey Professional Paper 252.

Song, C. C. S., and C. T. Yang. 1980. On the Theory of Minimum Stream Power. Journal of the Hydraulics Division, ASCE, Vol. 106, No. HY9, September.

Stall, J. B., and C. T. Yang. 1972. Hydraulic Geometry and Low Streamflow Regimen. University of Illinois Water Resources Center Research Report No. 54, July, pp. 11-16.

Yang, C. T. 1971a. On River Meanders. J. Hydrology 13:231-253.

Yang, C. T. 1971b. Formation of Riffles and Pools. Water Resour. Res. 7, (6):1567-1574.

Yang, C. T. 1980. Theory of Minimum Rate of Energy Dissipation and Its Applications. Post symposium lecture notes, International Symposium on River Sedimentation, Beijing, China, March.

Yang, C. T., and C. C. S. Song. 1979. Theory of Minimum Rate of Energy Dissipation. Journal of the Hydarulics Division, ASCE, Vol. 105, N. HY7, July, pp. 769-784.

Yang, C. T., C. C. S. Song, and M. J. Woldenberg. 1981. Hydraulic Geometry and Minimum Rate of Energy Dissipation. Paper to be published by the Water Resources Research.

SUMMARY OF POPLAR CREEK DISCUSSION

Stanley A. Schumm
Professor, Earth Resources, Colorado State University,
Fort Collins, Colorado, U.S.A.

Poplar Creek is a sand and gravel bed stream located in northern California. It is a tributary to Sacramento River. Precipitation ranges from 70 inches in the headwaters to between 25 and 30 inches in the reach of interest below the proposed Dutch Gulch dam site. For purposes of the discussion the reach of concern was divided into two reaches as follows: Reach 1 between the dam and the junction of a major tributary, Dry Creek, Reach 2 below the junction of Dry Creek.

It became apparent early in the discussion that the participants were totally in agreement that the information that was provided was inadequate and that even with additional data, field work was essential to the development of an understanding of the present condition of Poplar Creek. Without this the ability to predict future changes is severely limited.

Discussion centered on the immediate response of Poplar Creek, although it was recognized that the long-term adjustment would be complex with degradation followed by aggradation and vice versa, depending on the reach under consideration. Main channel scour will rejuvenate the Dry Creek tributary. The influx of sediment from this source will cause deposition below the Dry Creek confluence, and as this sediment accumulates, renewed scour is likely.

The complexity of channel response and the group's inability to predict the course of events with assurance led to the suggestion that experimental and field studies be carried out on the effect of dam construction on a range of channel types. It was also suggested that available information on this topic be assembled in a volume of case studies.

The possible effects of bedrock controls and of variations of the erosional resistance of the valley alluvium was considered to be of sufficient importance that there should be borings to obtain representative samples of the alluvium.

The evaluation of the reach by each expert relied heavily on his past experience, and at first a qualitative approach was followed, although standard sediment-transport and hydraulic equations were used to support conclusions.

The considerable experience of the participants resulted in a healthy degree of caution concerning channel response. All recognized that each river is sufficiently different from others that generalizations about channel response are hazardous. Only after field inspection and collection and analysis of additional sedimentologic, hydraulic,

POPLAR CREEK

PAPERS AND PARTICIPANTS

Reporter: STANELY A. SCHUMM
Geomorphologist
Department of Earth Resources
Colorado State University
Fort Collins, Colorado 80523

Monitor: ROBERT T. MILHOUS
Hydraulic Engineer
Instream Flow Group
U.S. Fish and Wildlife Service
Fort Collins, Colorado

Participants: EDMUND D. ANDREWS
Hydrologist
U.S. Geological Survey
Water Resources Division
P.O. Box 25046, Mail Stop 415
Federal Center
Lakewood, Colorado 80225

WILLIAM W. EMMETT
Hydrologist
U.S. Geologist Survey
P.O. Box 25046, Mail Stop 413
Federal Center
Lakewood, Colorado 80225

RICHARD D. HEY
Hydrologist
School of Environmental Sciences
University of East Angler
Norwich, England, U.K.

GARY PARKER
River Engineer
St. Anthony Falls Hydraulic Lab.
Minneapolis, Minnesota

VITO A. VANONI
Civil Engineer
California Institute of Technology
1201 East California Street
Pasadena, California 91109

BRIEN R. WINKLEY
Hydraulic Research Engineer
U.S. Army Corps of Engineers
P.O. Box 60
Vicksburg, Mississippi 39180

geologic, hydrologic and geomorphic data can predictions of channel response be made with any degree of confidence. However, even with these data, the river reach must be considered as a component of a larger fluvial system. Historical studies of channel behavior through time also should be made if old maps and photographs can be located.

Because of the limited information available each participant used several approaches to evaluate the channel and its likely response. For this reason the approaches were relatively straight forward and simple in concept. For example, sediment transport equations were used to estimate depths of scour and the potential for armor development. Hydraulic geometry equations were used to estimate changes of channel dimensions. Histories of gravel-bed channel response elsewhere were used to suggest the changes of channel morphology and sediment character that could be anticipated.

All participants relied heavily on their past experience, and each stressed the need for careful map, aerial photograph, and field studies. Because of the complexity of the long term response of the channel, the use of existing equations alone is inadequate, because they only provide information on the short-term response of the channel. For example, tributary response to main channel adjustment is critical. Influx of sediment from both Dry and Little Dry Creeks will greatly complicate the response of Poplar Creek. Future changes of Sacramento River position, laterally or vertically, can also significantly affect Poplar Creek in unanticipated ways.

A further complication is the operating schedule of the dam. Large water releases could exacerbate the downstream problems, but greatly reduced flows could permit the tributaries and the Sacramento River to become dominant factors in determining reach characteristics.

In spite of the desire for further information, the group was in general agreement that at least initially Reach 1 would degrade and armor, whereas Reach 2 would aggrade, as a result of initial degradation and rejuvenation of Dry Creek. During the discussion the reporter attempted to summarize the conclusions of each participant concerning changes of channel morphology (width, depth, shape, sinuosity, and pool and riffle spacing) channel behavior (meander shift, cutoffs, bed elevation change) as well as the potential for vegetation encroachment into the channel and changes of sediment characteristics (size and potential for armoring). The majority of the participants agreed that channel width, depth, and width-depth ratio would decrease. Sinuosity would probably increase slightly. Opinion was divided concerning changes of pool and riffle spacing, meander shift, and cutoffs. Streambed elevation will generally decrease in Reach 1 and increase in Reach 2. Vegetation is expected to encroach on the channel, and bed material will increase in size and an armor will develop in Reach 1. Bed material size should decrease in Reach 2 as aggradation occurs. The evaluations of the participants are summarized in Table 1.

Table 1. Poplar Creek participants evaluations

Channel Change	Andrews	Emmett	Hey	Parker	Vanoni	Winkley
Depth	-15%	- slight	cyclic change + and -	R1 -	?	cyclic change + and -
Width	-20%	0	R1 - R2 +	-	-	cyclic but mainly -
Shape (w/d)	-	R1 - R2 +	?	- slight	?	?
Sinuosity	+	0	+	0	+	+
Pool and riffle spacing	+	0	R1 - R2 +	0		
Meander shift	+	0	+	0	+	+
Cutoffs	+	0	?	0		+
Bed elevation	R1 - R2 0	R1 - R2 +	R1 - R2 +	R1 - LT - R2 +	+	cyclic + and -
Vegetation encroachment	+	?	+	+	+	+
Bed material size	+20%	R1 + R2 - no	R1 + R2 -	R1 + R2 0	+	cyclic + and -
Armor	+	0	R1 + R2 -	R1 + R2 0	+	0

Explanation
R1 = reach 1
R2 = reach 2
LT = long term response
\+ = increase
\- = decrease