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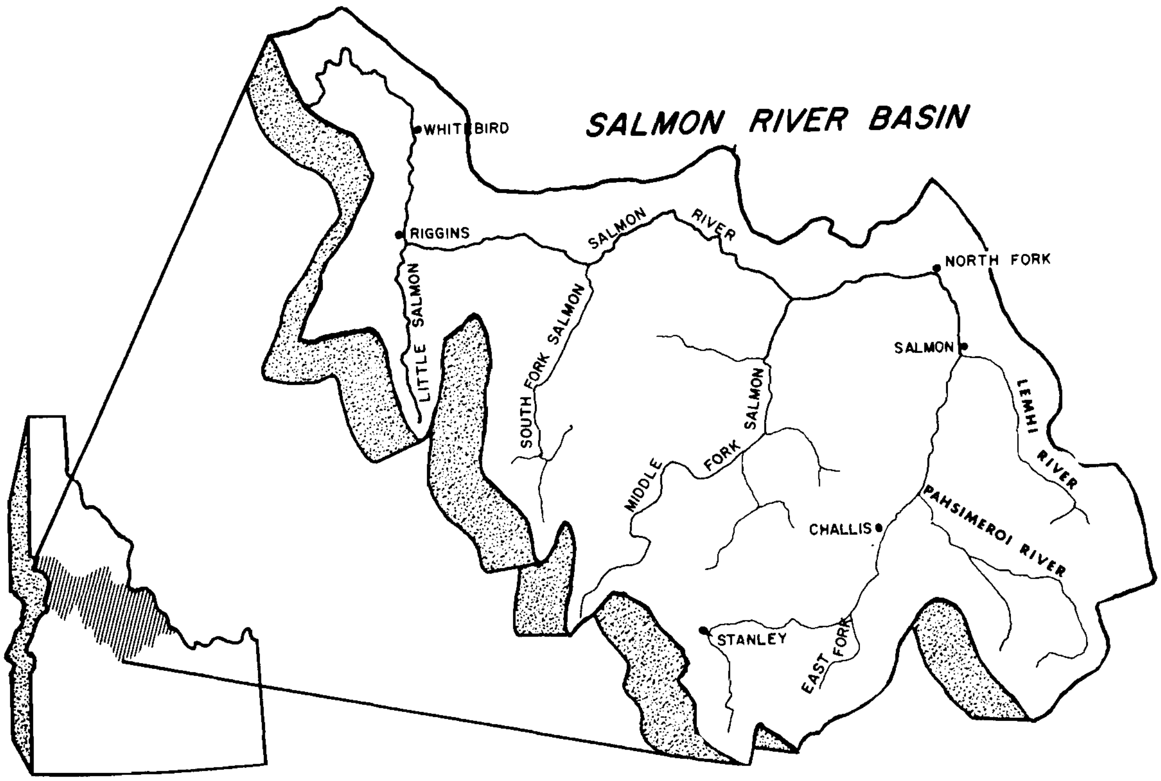
A Methodology Study To Develop Evaluation Criteria For Wild And Scenic Rivers



Report of

Water Quality Subproject

by

Fred J. Watts

Water Resources Research Institute
University of Idaho
Moscow, Idaho

November, 1971

A METHODOLOGY STUDY TO DEVELOP EVALUATION CRITERIA FOR WILD AND SCENIC RIVERS

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CONTENTS

ILLUSTRATIONS

ACKNOWLEDGMENTS

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INTRODUCTION

Public Law 90-542, signed into law, October 2, 1968, provides for a National Wild and Scenic Rivers System. The purpose of the law is to protect for the enjoyment and benefit of the people of the United States certain rivers which in conjunction with lands bordering the waters possess outstanding scenic, recreational, historical, fish and wildlife, geologic land forms, and other such desirable features.

Two categories of rivers, instant rivers and study rivers, are specified by the Act. "Instant Rivers" are authorized for immediate inclusion in the National Wild and Scenic Rivers System. The Middle Fork of the Salmon River and the Middle Fork of the Clearwater River are the two rivers located in Idaho included in this category. "Study Rivers" are rivers to be studied for possible inclusion in the Wild and Scenic Rivers System. The main stem of the Salmon, Bruneau, St. Joe, Priest, and Moyie Rivers are five Idaho rivers placed in the second category.

The Act specifies three classes of system rivers: wild, scenic, and recreational.[1] A "wild river" is a river free from impoundments, generally inaccessible except by trail, with non-polluted water and with essentially primitive watershed and shoreline. A "scenic river" is free from impoundments with shoreline and watershed still essentially primitive and undeveloped but it is accessible in places by roads. A "recreational river" is readily accessible by roads and railroads, it may have development along the shoreline and it may have undergone some impoundment or diversion in the past. Public Law 90-542 specifies a ten-year time limit on classification studies after which recommendations on the disposition of study rivers are to be made to the Congress.

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[1]Henceforth a system river will refer to any one of three classifications of wild rivers: wild, scenic or recreational.

There are few valid criteria available for evaluating rivers for wild or scenic classification. For this reason the Water Resources Research Institute of the University of Idaho has organized a Scenic Rivers Study Unit for the purpose of developing a methodology for evaluation of study rivers. The goal of this project is to establish criteria which can be used to identify and estimate economic, aesthetic, social, and other values associated with study rivers.

The Salmon River in Idaho has been selected as the study river for this project. A map of the Salmon River is shown in Figure 1. This river originates in central Idaho and flows about 425 miles generally through precipitous undeveloped canyon country and discharges into the Snake River 49 miles above Lewiston. The average annual discharge of the Salmon River at its mouth is about 8,000,000 acre feet.

The portion of the Salmon from its mouth to the town of North Fork has been designated as a "study river". However, for the methodology study the entire Salmon drainage basin is being studied. There are two reasons for this; first, any economic development--impoundments, diversions, mining, logging, or other major industry--would affect the main stem wild river section,and second, the study is more meaningful when the entire watershed is considered.

The purpose of the methodology study is to develop information pertinent to decision-making and planning as it pertains to the selection, management, and use of system rivers. The methodology study has four broad objectives:

1. Inventory the natural and human resources of the area and estimate future demands for and potentials of these resources.
2. Identify, describe and quantify, where possible, benefits from scenic beauty, personal enrichment and other aesthetic experiences derived from the river.

3. Develop a series of models to evaluate resource use patterns with and without the river classified in the National System.
4. Present alternatives for resource uses compatible with the possible river classifications and outline the economic and social ramifications for each alternative.

The plan for the methodology study is to divide the research work into a series of subprojects, each covering an important activity related to the river. These subprojects consist of fifteen resource and service functions:

1. Forest and range resources
2. Minerals
3. Outdoor recreation
4. Commercial fisheries
5. Irrigation
6. Water for municipal and industrial use
7. Water quality control
8. Hydroelectric power
9. Flood control
10. Navigation
11. Transportation and access
12. Anthropology
13. History
14. Agriculture
15. Hunting

Basically there are three steps which will be implemented for each of these subprojects. First, individual researchers will inventory the physical, biological, institutional, and human resources affecting each subproject. Second, the inventory data obtained will be used to make an economic evaluation of the current use of these resources, and the potential benefits available from them. Third, this data will be used as a basis for projecting future resource use and values under varying alternatives ranging from non-inclusion in the System to inclusion in the System under various classifications.

Data from the subprojects will be used in various models to evaluate alternative resource uses. Two types of models are presently planned for making these evaluations. The first model will be a small area input-output model which will be used to establish benchmark values for all economic activity in the area. The second model is a linear programming model which will be used to estimate the benefits for various areas of development.

Efforts will be made throughout the study to identify and quantify the aesthetic and personal enrichment values associated with a given river basin.

Estimates will be made for 1980, 2000, and 2020 consistent with the water resource planning done by the Pacific Northwest River Basins Commission under the Water Resources Planning Act of 1965.

The Methodology study, then, is concerned with the evaluation process. Upon completion in June 1972, it will provide input for the "joint" studies by the Federal and State agencies. These joint studies will result in recommendations to Congress.

The purpose of this subproject study is to examine the role of water quality in the selection and management of a system river. Part I of this study presents a brief review of significant water quality parameters and their importance to a system river and suggests water quality criteria suitable for a system river. The factors which control the quality of water in a system river and the constraints necessary to maintain water quality are discussed.

Part II of the report is an analysis of the Salmon River. A general appraisal of existing quality of water based on available data is presented. A method for simulating the temperature regime of a river was developed and applied to the Salmon River. Ramifications of utilizing Salmon River water for temperature control in the Snake are examined.

PART I

WATER QUALITY PARAMETERS

The water quality parameters that are most significant from a system river viewpoint are dissolved oxygen (DO), biochemical oxygen demand (BOD), coliform bacteria (MPN, most probably number), nutrients (phosphorous, nitrogen and carbon compounds), temperature, bed load transport, turbidity, color, odor, and floating man-caused debris. These parameters, not necessarily independent of each other, are all significant to the ecological environment of the stream and to the river oriented recreation experience.

In some instances concentrations of toxic materials such as cyanide, metals, ammonia, and phenols may be significant water quality parameters. Industrial and domestic effluents are the usual source of these pollutants. They are not a factor on Salmon at the present time. However, in some watersheds, these elements are significant to the freshwater ecology and should be considered in the evaluation process.

The following paragraphs describe significant parameters and the manner in which they are usually reported. Most of the material is obtained from chapters 11 and 19, reference (1), and from references (2) and (3). Accepted methodology for quantitative determination of the various parameters are available in reference (4).

Dissolved Oxygen (DO, mg/liter)

Dissolved oxygen is of particular importance in a fish supporting stream. Atmosphere contains about 20.9% of oxygen by volume whereas stream water exposed to an atmosphere containing 20.9% oxygen under standard pressure conditions at 30°C has a saturated DO value of about 7.6 mg/l or about 0.8% by volume. Thus it is apparent that oxygen demands of aquatic organisms must be obtained from a small fraction of the water volume and for this reason aquatic environment is critically sensitive to oxygen depletion.

Dissolved oxygen is usually near or at saturation in a turbulent free flowing stream. Problems can occur, however, under at least two common sets of circumstances. When heavy organic loads are received by a stream, the supply of oxygen present or taken into solution by contact with the atmosphere may be insufficient to keep pace with the biochemical oxygen demand of the organic load. Where the river is loaded at frequent intervals, it may not recover between loading points.

Another source of DO problems may be a deep upstream impoundment. The lower level of a deep reservoir may be completely devoid of dissolved oxygen. This results when organic decomposition uses up all available oxygen.

When this water is released into natural channels, it may require many miles to reaerate the stream, depending on the turbulence and depth of flow.

"Rules and Regulations for the Establishment of Standards of Water Quality and for Waste Water Treatment Requirements for Waters of the State of Idaho" (5) placed in effect September 4, 1968, specifies standards formulated by the Idaho State Board of Health. These standards require DO levels to be at least 75 percent of saturation at seasonal low and 100 percent saturation during spawning, hatching and fry stages along salmonid supporting streams.

Federal recommendations (6) for the levels of dissolved oxygen for the maintenance of fish and other aquatic life in streams are quoted below:

> For a diversified warm-water biota, including game fish, daily DO concentration should be above 5 mg/l, assuming that there are normal seasonal and daily variations above this concentration. Under extreme conditions, however, and with the same stipulation for seasonal and daily fluctuations, the DO may range between 5 mg/l and 4 mg/l for short periods of time, provided that the water quality is favorable in all other respects. . .

> These requirements should apply to all waters except administratively established mixing zones. . . In streams, there must be no blocks to migration and there must be adequate and safe passageways for migrating forms. These zones of passage must be extensive enough so that the majority of plankton and other drifting organisms are protected . . .
>
> For the cold water biota, it is desirable that DO concentrations be at or near saturation. This is especially important in spawning areas where DO levels must not be below 7 mg/l at any time. For good growth and the general well being of trout, salmon, and other species of the biota, DO concentrations should not be below 6 mg/l. Under extreme conditions they may range between 6 and 5 mg/l for short periods provided that the water quality is favorable and normal daily and seasonal fluctuations occur. In large streams that have some stratification or that serve principally as migratory routes, DO levels may be as low as 5 mg/l for periods up to 6 hours, but should never be below 4 mg/l at any time or place.

The Idaho criteria should be satisfactory for a system river that includes spawning and hatching areas. The Federal criteria should be adequate for all other system rivers. The Federal regulations are at the present time guide lines and for this reason a criteria would have to be specified when the river is classified as a system river.

Biochemical Oxygen Demand (BOD, mg/liter)

Biochemical oxygen demand (BOD) is a measure of the decomposability of organic matter and its potential nuisance level. BOD is determined by measuring the amount of dissolved oxygen consumed by biochemical stabilization of organic matter during the incubation of a sample of water for a specific length of time under standard conditions. Short term (5 to 10 days) tests indicate only the oxidation of the carbon of the organic matter. To obtain a more complete picture of biochemical oxygen demand including the nitrification stage, long term tests must be conducted.

Normal background levels of BOD on the order of one mg/liter result from decaying vegetation, contamination by animals, and other natural sources. BOD levels higher than this are an indication of organic loading due to either decomposition of algae or man caused waste loadings.

Limiting values of BOD are not usually specified for streams. High values of BOD indicate a potential for low dissolved oxygen and for this reason BOD should be monitored on a systems river.

Coliform Bacteria (MPN)

Coliform bacteria are indicator organisms whose presence in water warns that pathogenic bacteria which originate in the human intestine may be present.

"Rules and Regulations for the Establishment of Standards of Water Quality. . ." (5) prepared by the Idaho State Board of Health establishes the following standards for waters upstream of lakes and reservoirs used for recreation, drinking water supplies, fish and wildlife propogation and/or aesthetic purposes.

> No wastes shall be discharged and no activity shall be conducted which alone or in combination with other wastes will cause in these waters: average concentrations of coliform bacteria to exceed 240 per 100 milliliters with 20 percent of the samples not to exceed 1000 per 100 milliliters and fecal coliform not to exceed 50 per 100 milliliters with 20 percent of the samples not to exceed 200 per 100 milliliters.

The usual unit for reporting coliform organisms is the most probable number (MPN). This number is obtained by applying a probability technique to an ensemble of data and represents statistically the number of organisms which occurs most frequently in a series of random samples. The number of coliform growths is obtained by counting bacterial growth resulting from innoculation of a nutrients medium with a water sample. More recent work has centered around a process where a measured amount of water is filtered through a membrane which will retain the bacteria; the membrane is then placed over a differential medium, incubated, and appropriate groups counted. Data obtained using this method are not acceptable in courts of law but are useful for inventory and research where survey type of information is needed. The 24 hour agar plate count, with serial dilution where the number of developing colonies is large, is the accepted standard.

A standard similar to that quoted from Reference (5) above should be an adequate standard for a system river. The problem is to develop an adequate monitoring system for the drainages above or within the system river area and to adequately enforce the regulations.

Nutrients (mg/liter)

The presence of nutrients (nitrogen, phosphorous and carbon compounds) in free flowing water indicates a potential for algae growth. Phosphorous concentrations (expressed as phosphate) above 0.03 mg/liter may promote nuisance aquatic growth. The threshold value for nitrogen at which excessive algae production normally occurs is about 0.3 mg/liter. These percentages are not very definitive; certain combinations of temperature, light and chemicals are necessary for growth to occur.

The source of nutrients may be organic materials flushed or discharged into the river or ground water which has leached minerals from the aquifer. The former source is the usual source.

Algal growth and slimes interfere with swimming, boating and sport fishing, and are detrimental from an aesthetic viewpoint. Additionally, decomposition of algae ties up significant quantities of dissolved oxygen; the result may be serious oxygen depletion in the lower levels of reservoirs or deep streams. Residue from decaying organisms (colloidial size) when released from impoundments results in highly turbid water with significant oxygen demand.

The presence of high nutrient levels is generally a function of the activity in the watershed-agricultural, municipal or industrial. If a certain allowable level of nutrients is established for a system river, it will be necessary to have a management plan for the entire watershed above and including the system river. In some instances this land will be primarily Federal land and the management of the land will be internal. In other instances (and probably the usual case) the land will be owned by private, corporate, and government entities and thus will require easements and use zoning to insure adequate management of the watershed.

Idaho regulations (5) forbid the addition to waterways of any measurable concentration of phosphorous or nitrogen compounds above those of natural origin.

Natural background levels are difficult to ascertain. Criteria will have to be developed and adhered to if the aesthetic quality of the river is to be maintained.

Various tests for nitrogen, phosphorous, and carbon compounds are prescribed in reference (1), (2), or (4). The unit reported for Idaho stations is mg/liter.

Temperature (°C)

Water temperature is an important parameter from the viewpoint of water contact sports and because temperature is a primary variable of biologic activity. Dissolved oxygen content, chemical and biological reactions, fish migration cycles and triggering mechanisms for various types of biotic activity are all a function of temperature. The reader is referred to chapter V, "Water Temperature Effects, Requirements and Problems" (7) for a more complete discussion of temperature effects. Though directed specifically at the Columbia River anadromous fishery, the reader can obtain some understanding of the importance of temperature on the aquatic environment.

The temperatures of a stream may be modified in many ways. Some of these include: dumping large quantities of warm water into the stream such as might occur at a thermal electric plant; changing shade conditions on upstream tributaries through timber harvest or fire; increasing the inflow of warm surface runoff waters (irrigation runoff); release from upstream impoundments; and reducing the discharge in the stream by upstream diversions. A method of modifying temperatures in downstream reaches by selective withdrawals from deep impoundments and a model for predicting temperature in a stream are discussed in a later section.

Locations of sampling sites in Idaho where temperatures are recorded can be found in "Water Resources Data for Idaho" (8). Referring to "Rules and Regulations --- State of Idaho" (5), for waters upstream of recreation areas, it is stated that "No . . . activities . . . will cause in these waters any measurable increase (in temperature) when stream temperatures are 66°F or above or more than 2°F increase when temperatures are 64°F or less. This regulation, if enforced, should be adequate for a system river.

Sediment (mg/liter or ppm)

> "Sediment is solid material that originates mostly from disintegrated rocks and is transported by, suspended or deposited from water; it includes chemical and biochemical precipitates and decomposed organic material such as humus. The quantity, characteristics, and causes of the occurrence of sediment in streams are influenced by environmental factors. Some major factors are degree of slope, length of slope, soil characteristics, land usage and quantity and intensity of precipitation." (8)

Quantities of sediment, both bed load and suspended are measured in mg/liter or parts per million (ppm). The quantity of suspended sediment passing a given cross section can be obtained by integrating over the cross section selective samples obtained with a depth-integrating sediment sampler.

Reliable bed load quantities are difficult to obtain. Estimates are obtained by collecting material in a bed load trap systematically across a section. Material moving along the bed is trapped for a specified interval of time, weighed, and then integrated across the width of the channel. Other methods of measuring bed load are to direct the entire flow of the stream over a turbulence sill and collect representative samples of temporarily suspended bed load material with a depth integrating sampler or to trap the entire bed load in a slot or trench constructed across the width of the stream. These methods are only applicable for small sand-bed streams. The reader is referred to reference (9) for a more complete treatment on the measurement of sediment loads in streams.

Bed load deposits may be detrimental from an aesthetic viewpoint though in some cases beaches resulting from exposure of these deposits at low water may enhance the recreational characteristics. In some instances the generation of large quantities of bed load has led to the burial of spawning bed gravels (South Fork Salmon River) and thus degrades the fishery.

If sediment input into a system river is to be controlled, a management plan for the watershed will have to be in effect. Certain development associated with logging, cropping etc., generates significant quantities of sediment above normal background levels. This activity will need to be regulated if water quality is to be maintained.

Turbidity (JTU)

Turbidity, which is the cloudiness in a liquid, results from the suspension in water of fine organic and inorganic matter and microscopic organisms. Turbidity is usually measured as the ratio of the intensity of light scattered by the particles in the liquid to the intensity of light transmitted through the liquid.

The standard instrument for measuring turbidity is the Jackson Turbidimeter. A tube with a transparent bottom and dark sides is placed over a lighted candle. The tube is filled until the depth of liquid is such that the outline of the candle flame is no longer discernable. Turbidity units can then be read directly from the calibration scale on the vertical tube.

Another type of turbidity measurement equipment consists of a pumping and recirculating system, sedimentation chamber, turbidity detector and recording systems. The instrument measures, indicates, and records the degree of turbidity in a flowing liquid by means of an electric cell and recorder (9).

The Jackson turbidity unit based on the scattering of light rays directed through a stream of water is the usual unit reported. Turbidity in water lowers the catchability of fish, can trigger abnormal insect drift, reduces productivity of aquatic life and is detrimental from an aesthetic viewpoint.

Idaho regulations, (5) specify that activity on the stream cannot result in turbidity other than of natural origin to exceed 5 Jackson Turbidity Units. This appears to be a reasonable specification for a system river.

<u>Color</u>

Extracts from leaves, peaty material or dissolved or colloidal substances impart color to natural water. Color is usually specified by the number of units (platinum-cobalt scale). The number is obtained by comparing the sample with a known concentration of platinum-cobalt. If other water quality regulations are complied with, it is unlikely that color will be a problem in a system river. During high water periods, contact of the water with leaves, needles of conifers etc., may result in a coloring of the water. Tannins, humic acid and humates are considered to be the principal coloring compounds. Natural seasonal discoloration of this type would not be detrimental to a system river.

Odor

Odors in water result from volatile substances associated with organic matter and from the release of gasses such as hydrogen sulfide from solution. Odor intensity is reported as a threshold odor number. This number is the reciprocal of the dilution ratio of the fluid with odor free water when the sample is diluted to the point that the odor is just noticeable. As an example, if 4 ml of sample diluted to 200 ml reduces the odor to a point where it is just noticeable, the threshold odor number would $\frac{200}{4} = 50$.

If other water quality criteria outlined in this report are adhered to, odor should not be a problem in a system river.

Floating Debris

This material usually originates from flooding of dumps and careless or thoughtless solid waste disposal practices. The corridor management concept of system rivers would preclude this type of pollution. Again, proper management of the watershed will be necessary to eliminate floating debris originating from tributaries and reaches above the system river.

PART II

WATER QUALITY - SALMON RIVER

Three rather limited sources of water quality data are available for the Salmon River. Starting with the water year of 1967 the U.S. Geological Survey has collected and reported water quality data for the White Bird gage site at river mile 53.7. The data is reported in the annual publication, "Water Resource Data for Idaho" (8). Additionally, several other sites in the upper Salmon drainage have been monitored in recent years on an intermittant basis. Sites for which data is available include: the Lemhi River near Salmon, Little Boulder Creek below Boulder Chain Lake Lookout, Little Boulder Creek above Baker Lake, Big Boulder Creek near Clayton, Jim Creek near Clayton, Salmon River at Salmon and Pahsimeroi River at Ellis. This data can be obtained from the U.S. Geological Society, Boise office. Data from these sources will henceforth be referred to as U.S.G.S. data.

From July 8 to August 10, 1971, an investigation of some chemical, physical and bacteriological aspects of the Salmon River from the confluence of the North Fork (river mile 237.1, Figure 1) to Salmon Falls (river mile 170) was conducted by members of Ricks College Biological Science Department. "Water Quality Study on the Salmon River Between North Fork and Salmon Falls" (10) was performed for the Intermountain Range and Forest Research Station, Ogden, Utah. Though the report specifically states that inadequate data was obtained to establish base line data, it presents reasonable data for the season the study took place. The data will be referred to as Ricks data.

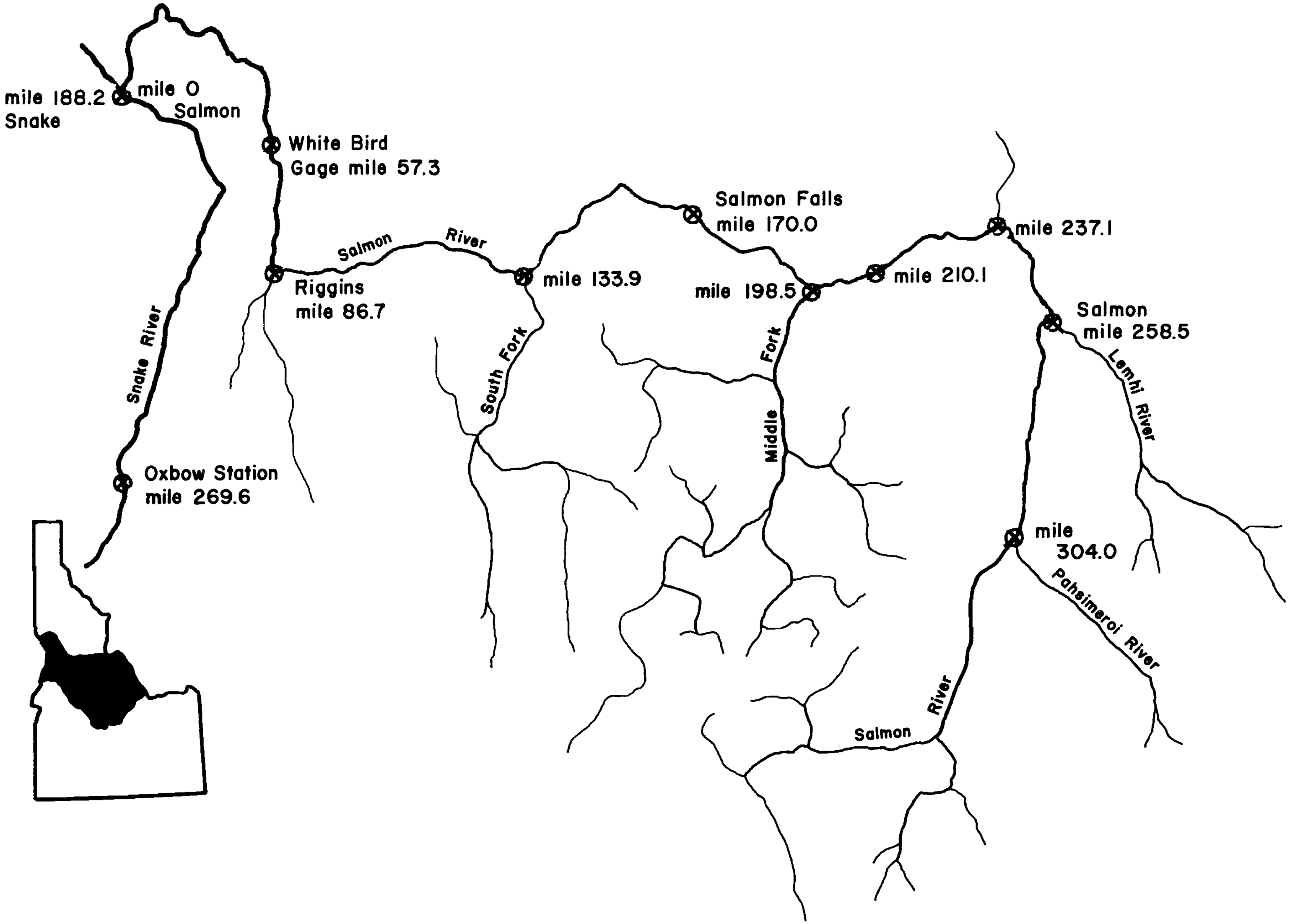


Figure 1. Plan of the Salmon River Drainage.

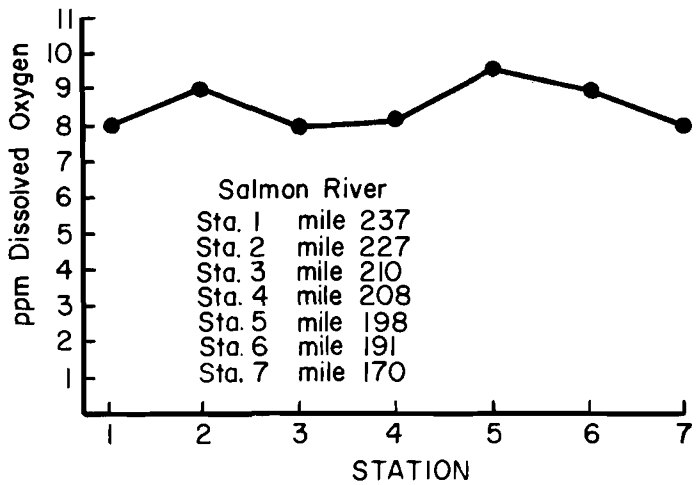


Figure 3. Dissolved oxygen plotted as a mean for all samples taken at each collecting station for the entire investigation.

(From Reference 10)

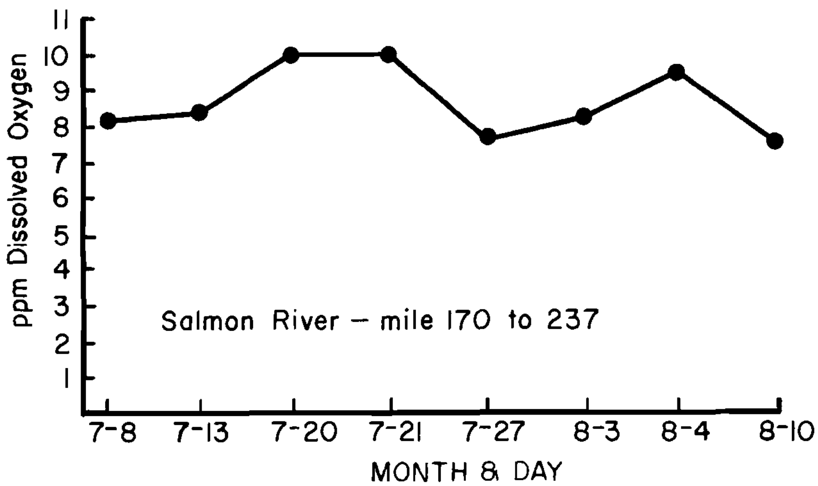


Figure 2. Dissolved oxygen plotted as a mean for all stations on each collecting day.

(From Reference 10)

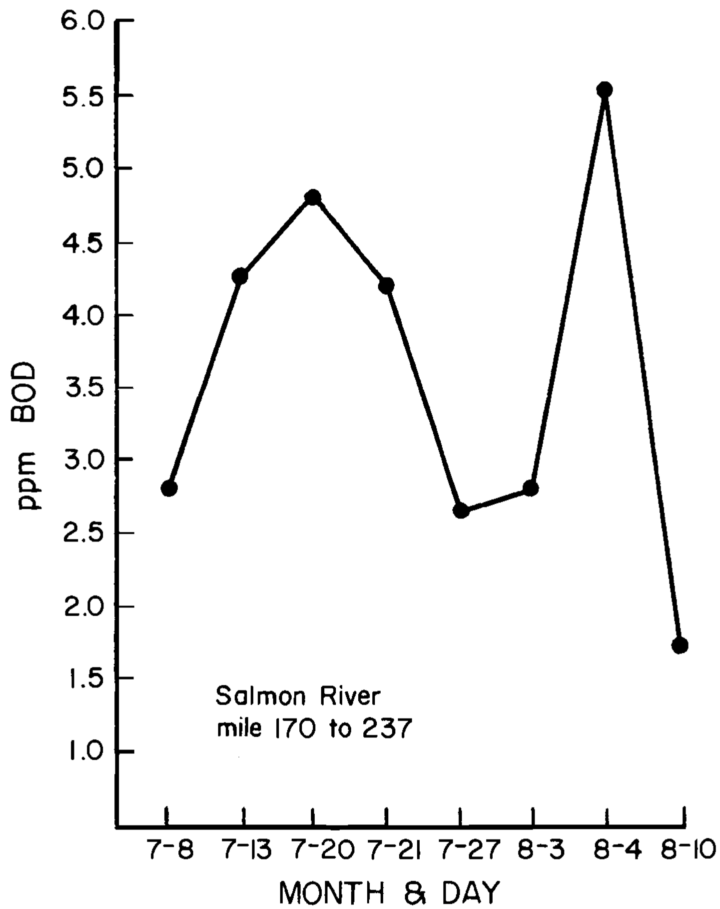


Figure 4. Biochemical Oxygen Demand (ppm) mean for all stations on each collecting date.

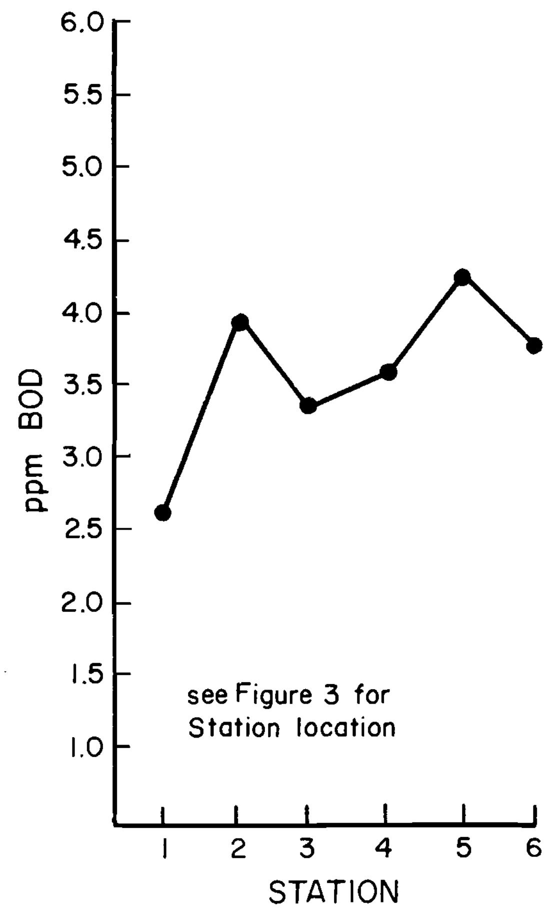


Figure 5. Biochemical Oxygen Demand (ppm) mean for all samples taken at each collecting station for the entire investigation.

(From Reference 10)

The third source of information was furnished by the Water Pollution Control Administration of the Idaho Department of Health (11).

A series of dissolved oxygen and Biochemical Oxygen Demand samples were taken at selected sites along the Salmon in October, 1970. Also, total coliform counts were obtained for the Salmon above and below Riggins.

Dissolved Oxygen and Biochemical Oxygen Demand

Results reported by the Idaho Department of Health for samples taken from the Salmon River and its tributaries in October, 1970 are as follows:

	DO ppm	BOD ppm	River Mile
East Fork Salmon at mouth	11.4	1.6	343.0
Salmon River at Clayton	13.9	1.3	347.2
Salmon River at Challis	13.8	2.2	317.4
Salmon River at North Fork	13.5	2.4	237.1
Salmon River at Salmon	13.6	2.7	254.9
Salmon River at White Bird	11.5		53.6
Yankee Fork at mouth	12.1	3.3	367.1

Dissolved oxygen reported are at or near saturation and BOD values are in a satisfactory range.

The Ricks study covered a reach from North Fork to Salmon Falls. Values obtained by averaging results from six stations show DO ranging from 7.5 to 10.0 ppm (July - August) and BOD ranging from 1.6 to 5.5 (July - August). Significant plots from this study are shown as Figures 2 thru 5.

The Ricks study took place during the critical low water season. Even during this adverse period dissolved oxygen was at or near saturation and Biochemical Oxygen Demand were reasonable though somewhat higher than one would expect. This probably indicates significant organic loading, however, the nature of the river (shallow and turbulent) is such that the river has the capability of assimilating the organic load.

Fecal Coliform

The Idaho Department of Health reported total coliform counts of 100/100 ml above Riggins and 400/100 ml below Riggins for the Salmon

River in October 1970. The 100/100 ml is well within the generally accepted limit of 240/100 ml for water contact sports reaches. The 400/100 ml though not considered excessively high illustrates that even a small community such as Riggins can have an impact on a relatively large river.

Results from the Ricks study are shown in Figures (6) thru (9). Though mean values of Fecal Coliform for all stations and mean values of Fecal Coliform for all samples are acceptable, coliform counts are somewhat high. This high count is a result of raw sewage dumped into the Salmon River by the community of Salmon. The Ricks study emphasized that their number of samples was too small to make more than general conclusions, but it is evident that if the reach immediately below the Salmon is to be used for contact sport, additional treatment of sewage (which is in the planning stage) is needed.

<u>Chemical analysis</u>

Chemical analysis are available from all three sources mentioned at the start of this chapter. Phosphate and nitrates contribute to algal growth, a potential problem on the Salmon, and for this reason will be discussed.

The Ricks study (Figure 10 and 11) reports mean values of phosphate for the reach below North Fork ranging from 1.40 PPM to 0.04. High values of phosphate were measured from early July to mid or late July followed by low values through August. Nitrates ranged from 7.6 PPM to 1.7 PPM with a temporal variation similar to that reported for phosphate.

The large quantities of nutrients apparently result from high spring runoff from agricultural lands above the North Fork. As runoff subsides leaving primarily ground water supplying the river, the nutrient levels drop drastically. The high concentrations of nutrients are sufficient for triggering algal bloom if temperature and other factors are favorable. Algal bloom have been reported in this reach of the water.

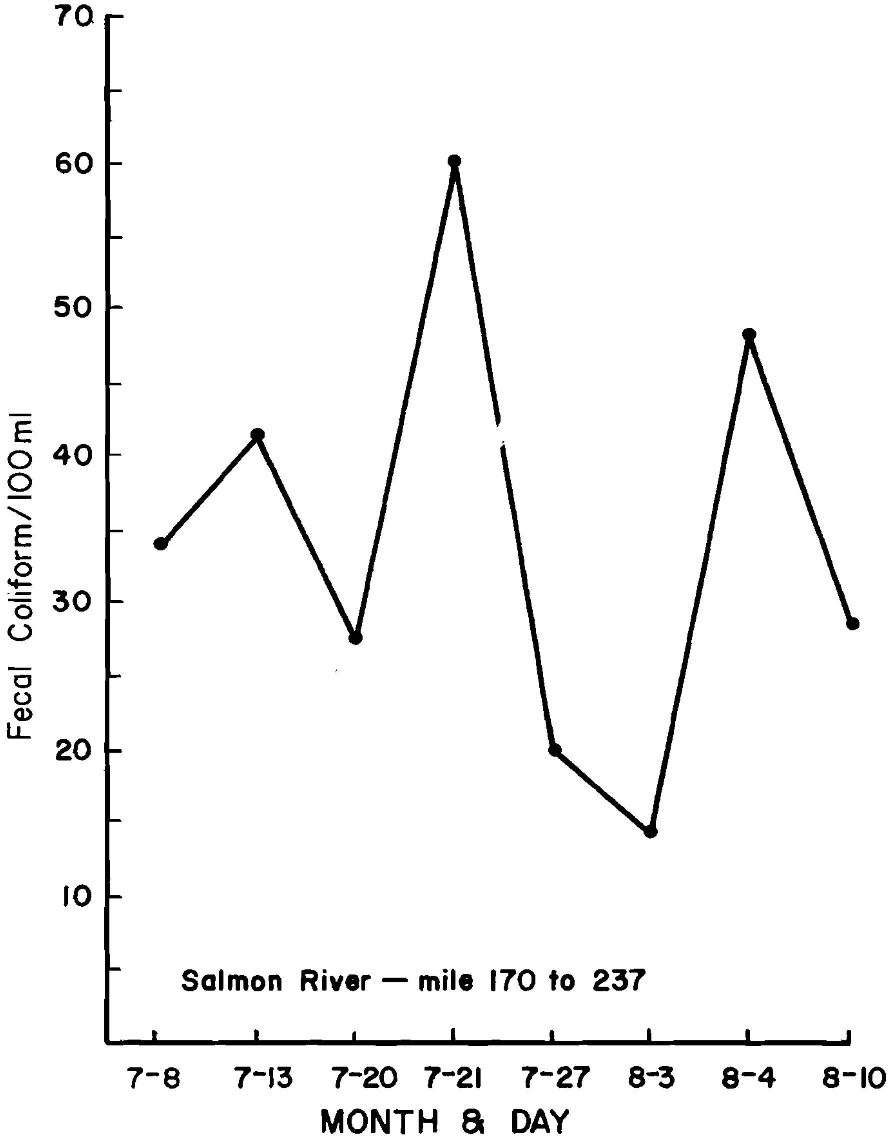


Figure 6. Fecal Coliform plotted as a mean for all stations on each collecting date.

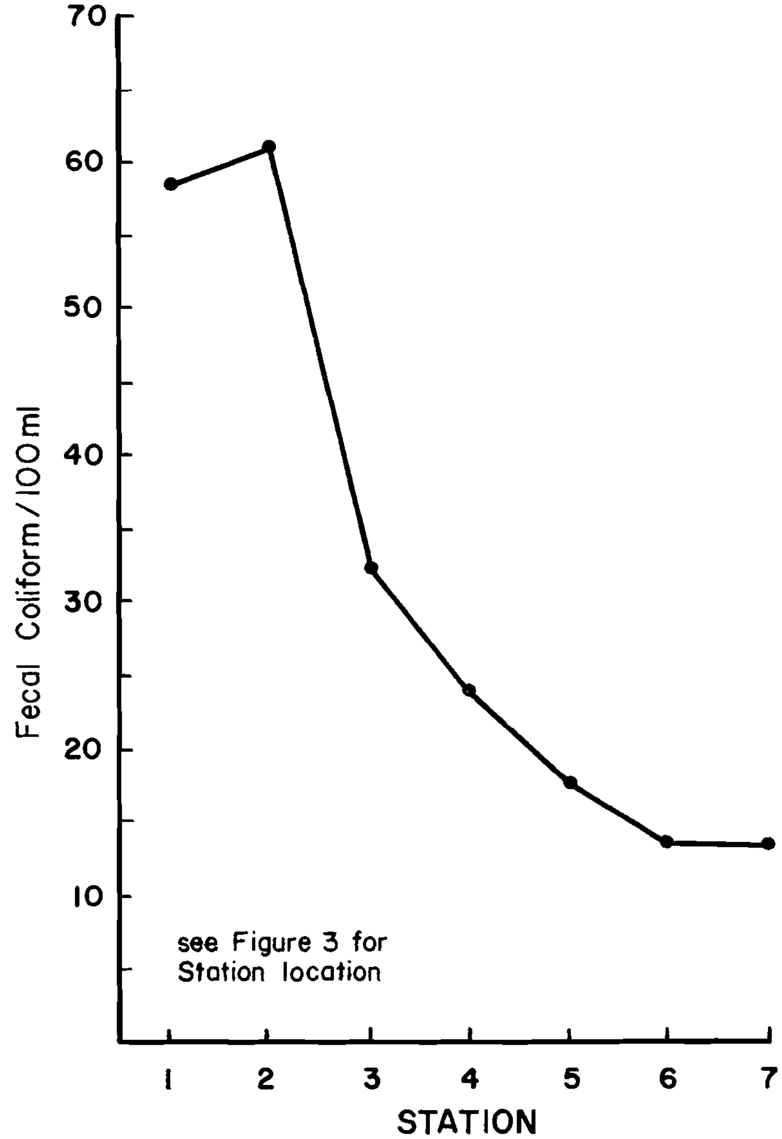


Figure 7. Fecal Coliform plotted as a mean for all samples taken at each collecting station for the entire investigation.

(From Reference 10)

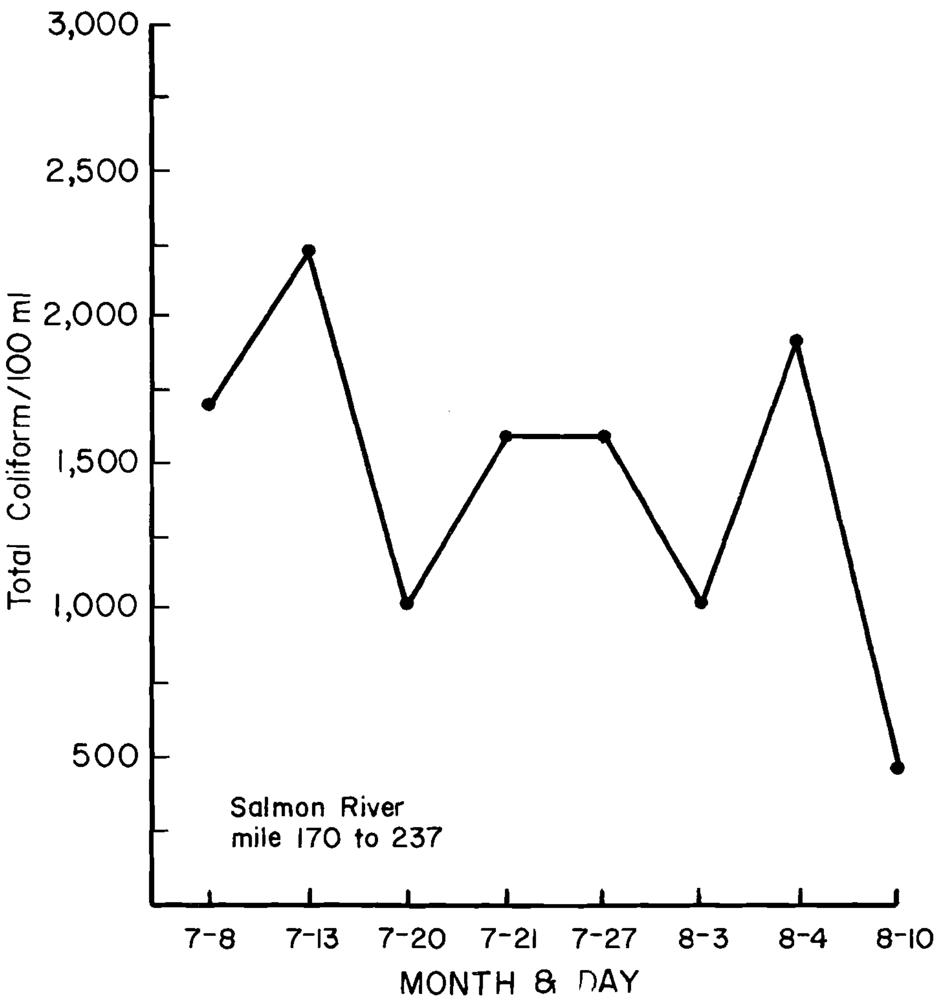


Figure 8. Total Coliform plotted as a mean for all stations on each collecting date.

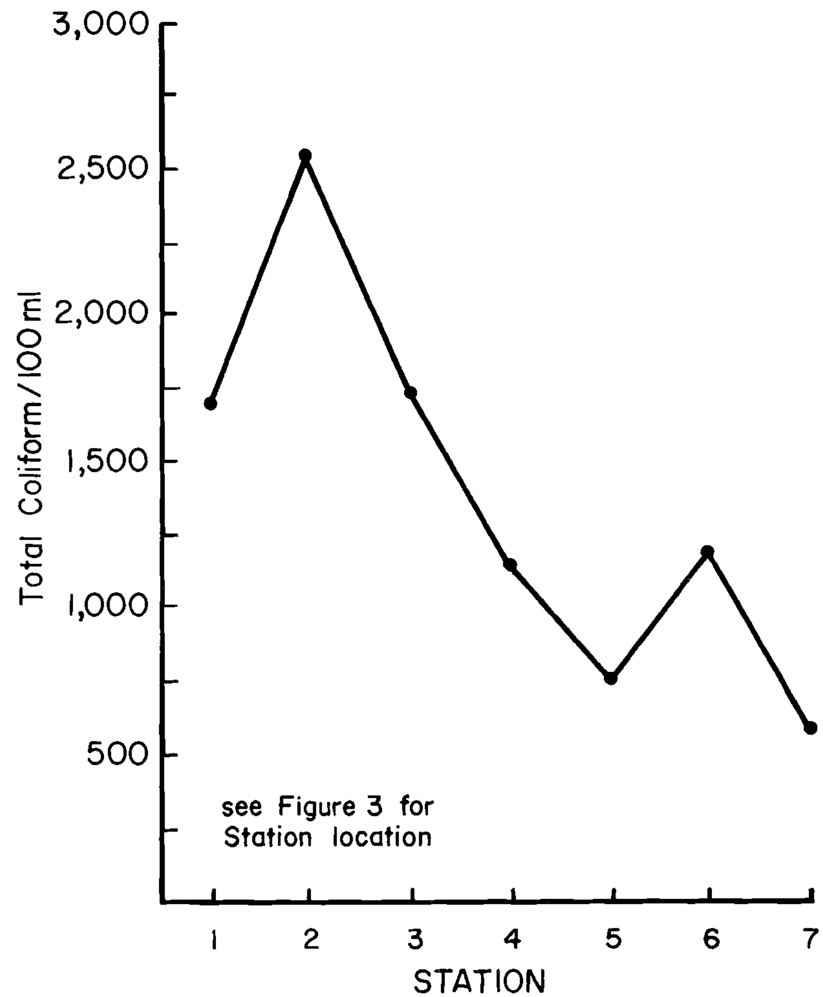


Figure 9. Total Coliform plotted as a mean for all samples taken at each collecting station for the entire investigation.

From Reference 10)

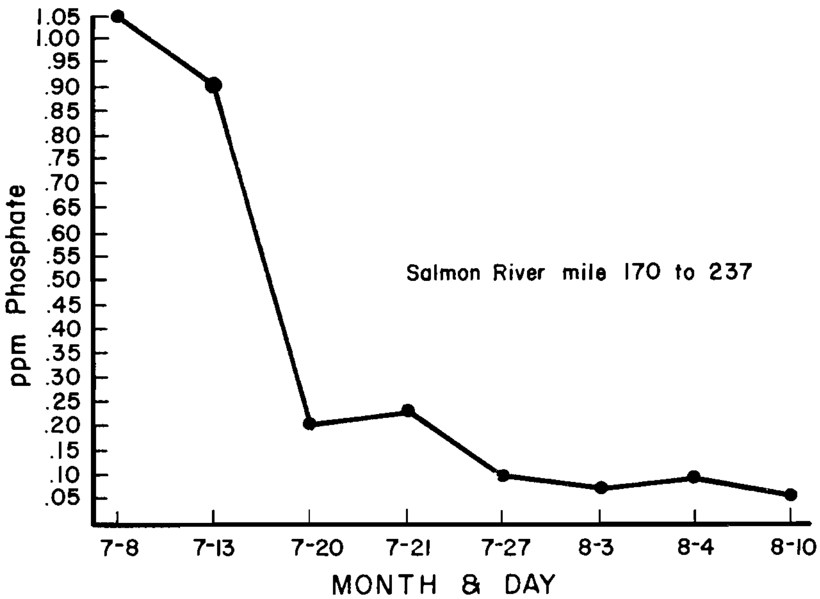


Figure 10. Phosphate plotted as a mean for all stations on each collecting day.

(From Reference 10)

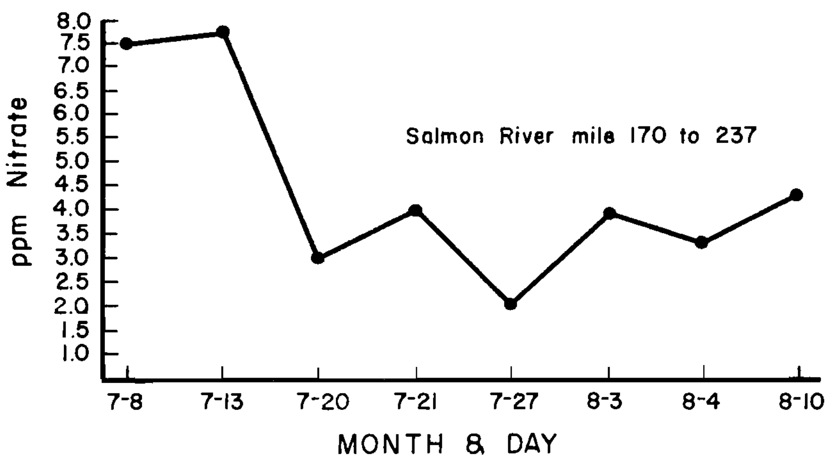


Figure 11. Nitrate plotted as a mean for all stations on each collecting day.

(From Reference 10)

A review of water quality reports for the White Bird reach prepared by the Idaho Department of Health and the U.S.G.S. show a range of phosphate from 0 to 0.11 PPM for the year 1961 to 1970, with a slight trend upward. Nitrate levels range from 0 to 1.92 PPM. These levels are significantly lower than those reported for the upper reaches of the Salmon and reflect the dilution of main stream Salmon water by the relatively nutrient free Middle Fork and South Fork; a reduction of organic material by natural processes; and the undeveloped primitive shoreline of the main stem and tributaries of the Salmon below Middle Fork.

Parts per million of other chemical elements are reported by the U.S.G.S. and can be found in standard U.S. Geological Survey publications. Hardness, metalic ions, pH values, and alkalinity (all well within acceptable range) are not significant to the Salmon River from a system river viewpoint and therefore are not discussed.

Bed Load Transport

There is no known bed load transport data on the main stem of the Salmon. Large sand bars which appear during the low water season attest to the presence of significant bed load deposits, however, this cannot be quantified.

Physical Tests

Jackson turbidity units reported in the Ricks study for the upper reach of the Salmon varied from 13 to 2, for July thru August, with high values occurring during the latter phases of runoff. During unusually high runoff in the spring of 1971 it was obvious (personal observation) that the level of turbidity was significantly higher in the Riggins area of the Salmon than those reported above; however, there is no data to support this.

The Ricks study also recorded "visibility in inches" at the point where water samples were taken. In general, visibility ranged from 11" to 60" with low visibility in early July with maximum visibility in mid-August. This unit is a little more sensitive to low levels of turbidity and is not usually reported.

The report states that,

> there were no offensive odors coming from the Salmon at any of the sampling stations during the entire study. In addition, there were few aquatic plants along the shoreline and no slime, scum, algae or froth that was apparent.

The section of the Salmon from North Fork to Salmon Falls was described as "definitely aesthetic to the senses of sight and smell."

Similar information is not available for other reaches of the Salmon, but based on available water quality data and personal observation and conversations with persons who have traversed the main stem of the Salmon, most of the Salmon system below the community of Salmon would fall in the category described above. The exception to this would be during spring runoff when the river is very turbid and carries significant quantities of timber debris. In addition, levels of nutrients are such that algal blooms are possible during warm water periods. Where the pristine Middle Fork enters the main stem of the Salmon, significant water quality disparity is visually apparent. However, by any comparison, the Salmon is a high quality river.

PART III

USE OF SALMON STORAGE FOR WATER TEMPERATURE CONTROL

One possible use of Salmon River water is for modification of the temperature regime of the Snake. In late August and September, water released from Brownlee storage results in a significant increase (up to 6°F) in the water temperatures of the Snake at Hells Canyon. By releasing cold water stored in a reservoir on the Salmon, the temperature of the Snake below the confluence with the Salmon could be reduced significantly. To determine the net effect of the cold water releases on water temperatures of the Snake at Lewiston, a river temperature simulation model was developed. This model is discussed in a later section and in the appendix.

Temperature

The temperatures of the Salmon in its free flowing state at White Bird as measured by the U.S.G.S. for the year 1967 and 1968 are shown in Figure 12.

The impact of Salmon River waters on the temperature regime of the Snake is illustrated in Figures 13 through 27. Data for these plots was obtained from reference (12). The Salmon currently has very little effect on the Snake River temperatures except it tends to cool the Snake 2° to 4°F during June.

The Ricks study reports maximum water temperatures for the upper Salmon for August 8 ranging from 81°F at Indianola (mile 226.7) to 63°F at Corn Creek (mile 190.8). The cooling influence of the Middle Fork (mile 198.5) of the Salmon is evident. Minimum temperature for July 1970 was 59°F at mile 207.8.

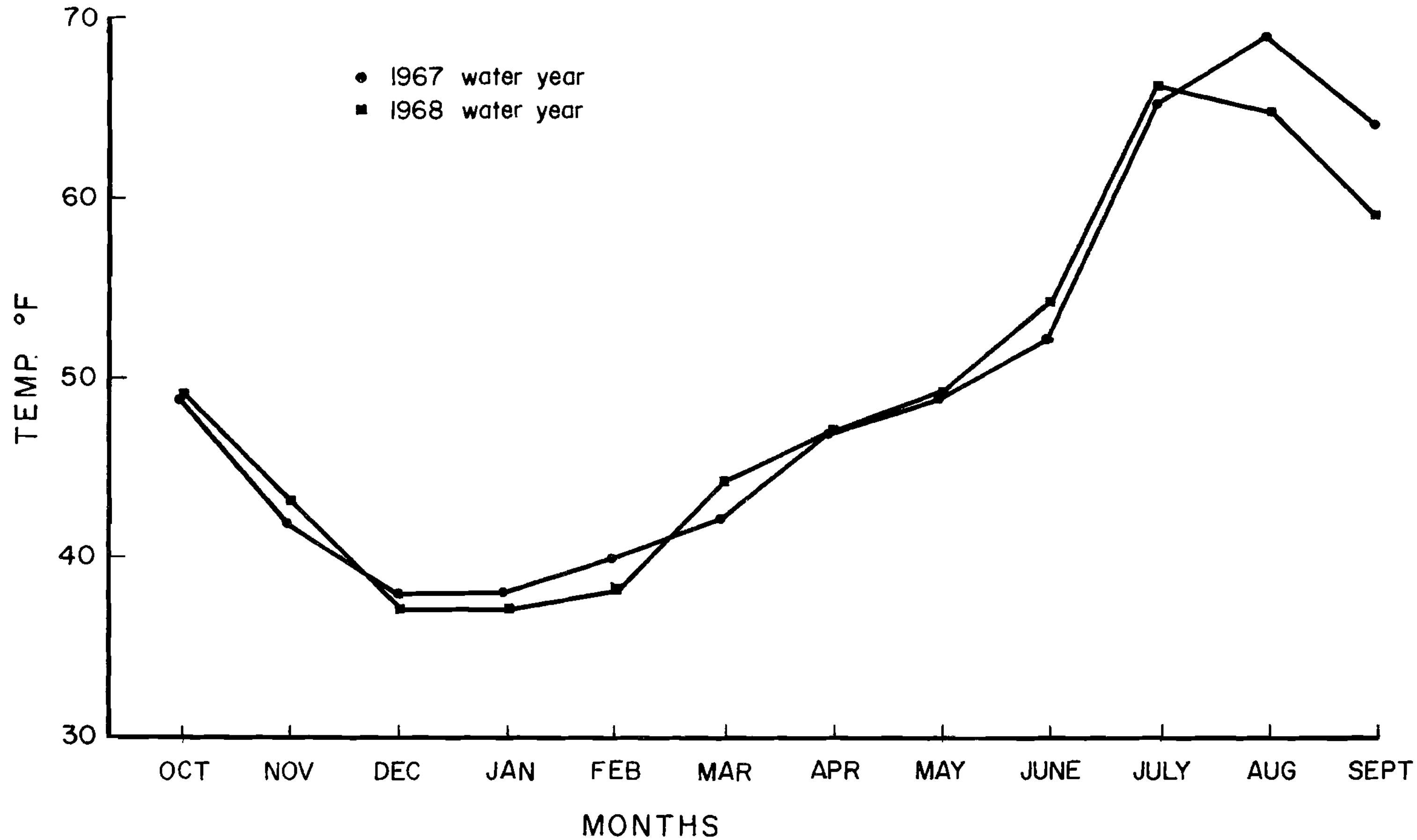
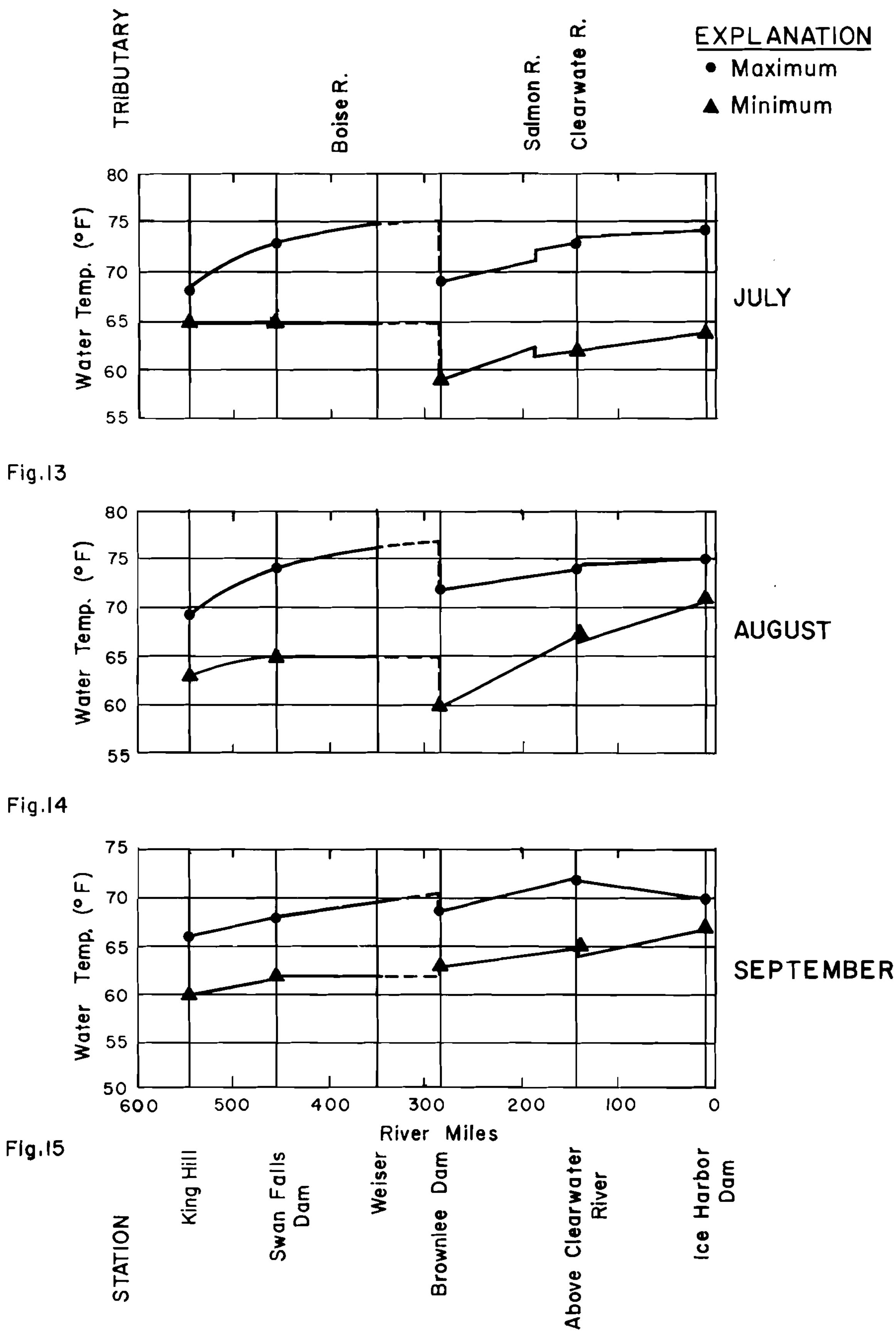
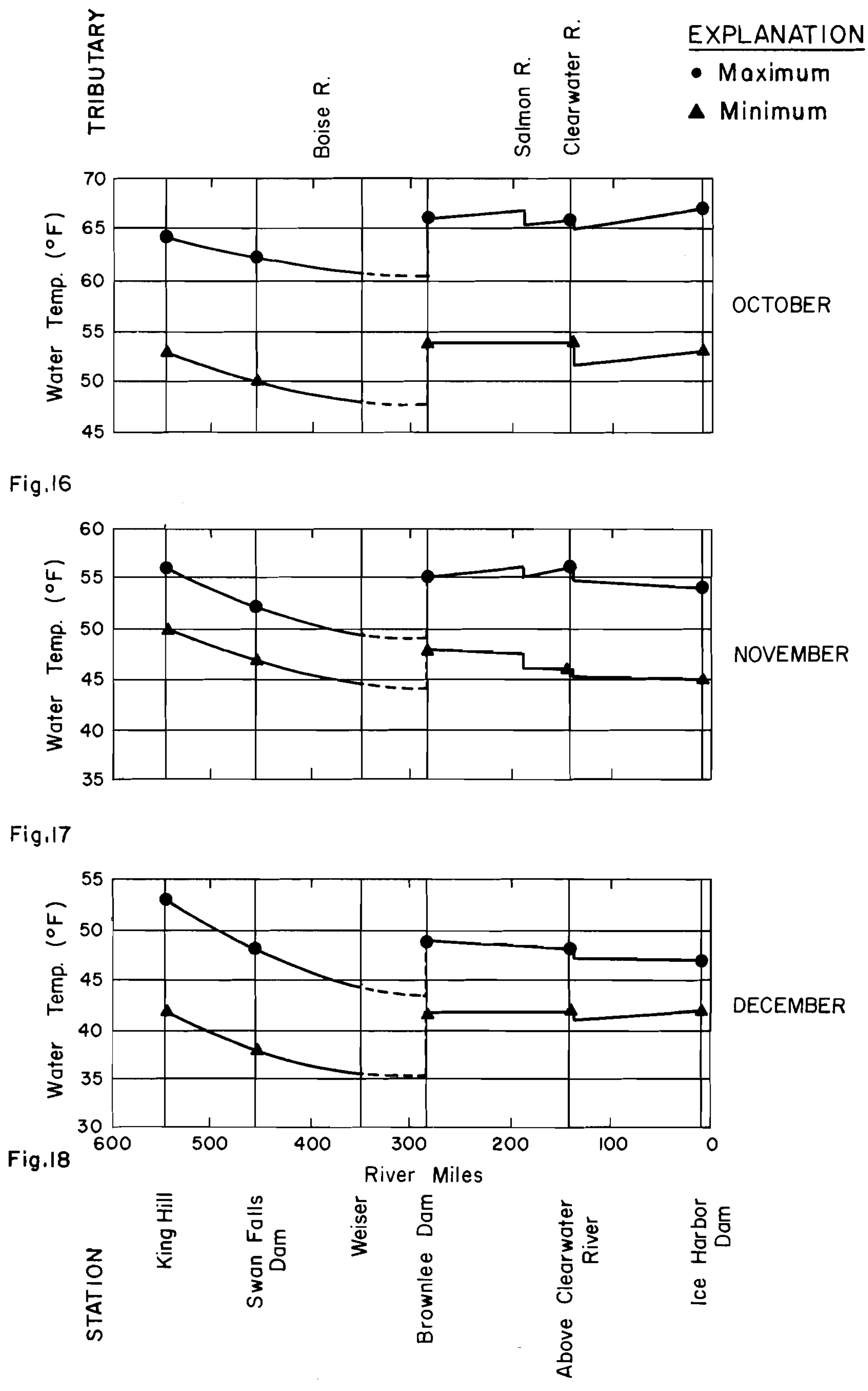


Figure 12. Salmon River water temperature at Whitebird.



Water temperature profiles for 1966
(from reference 12)



Water temperature profiles for 1966
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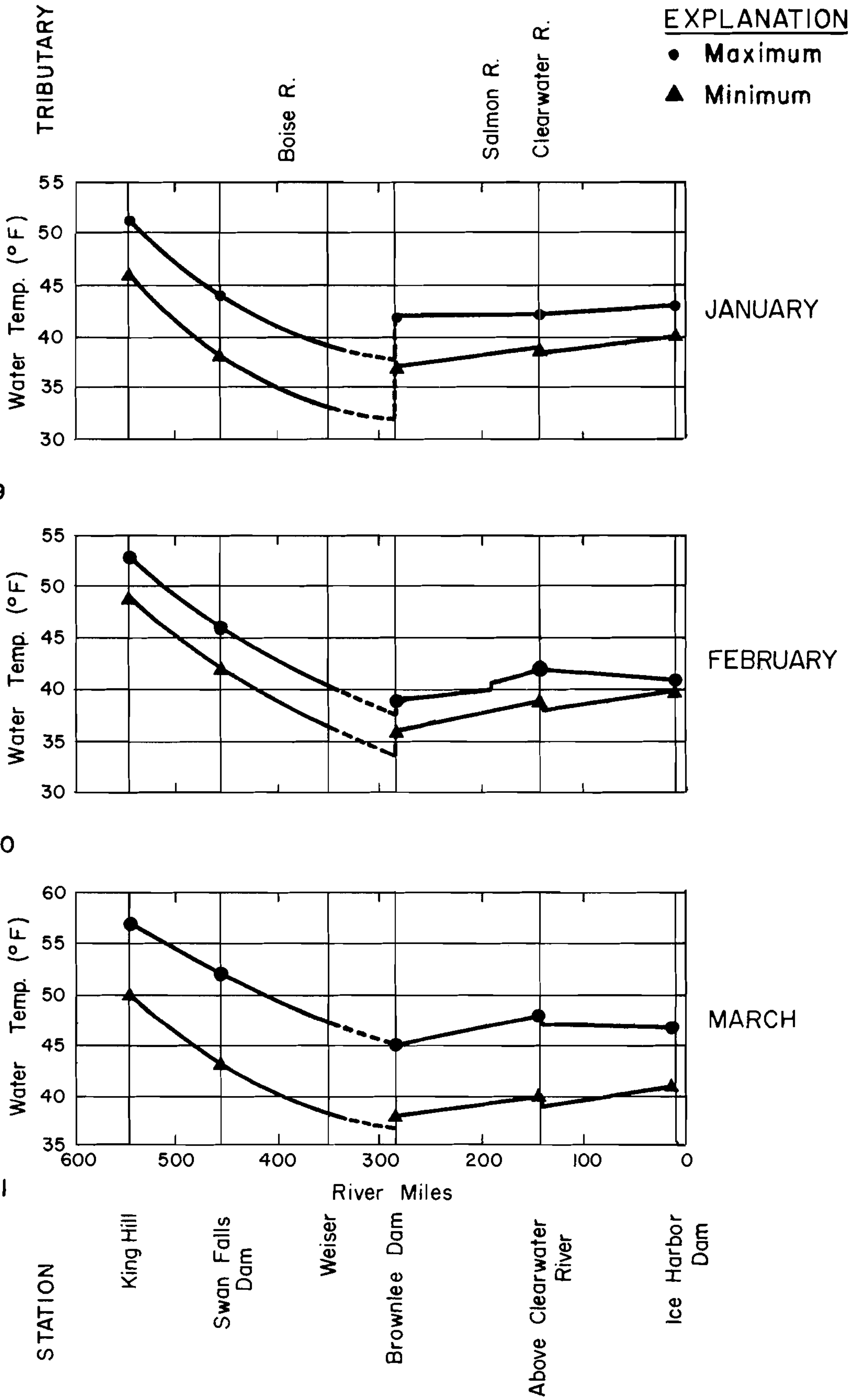


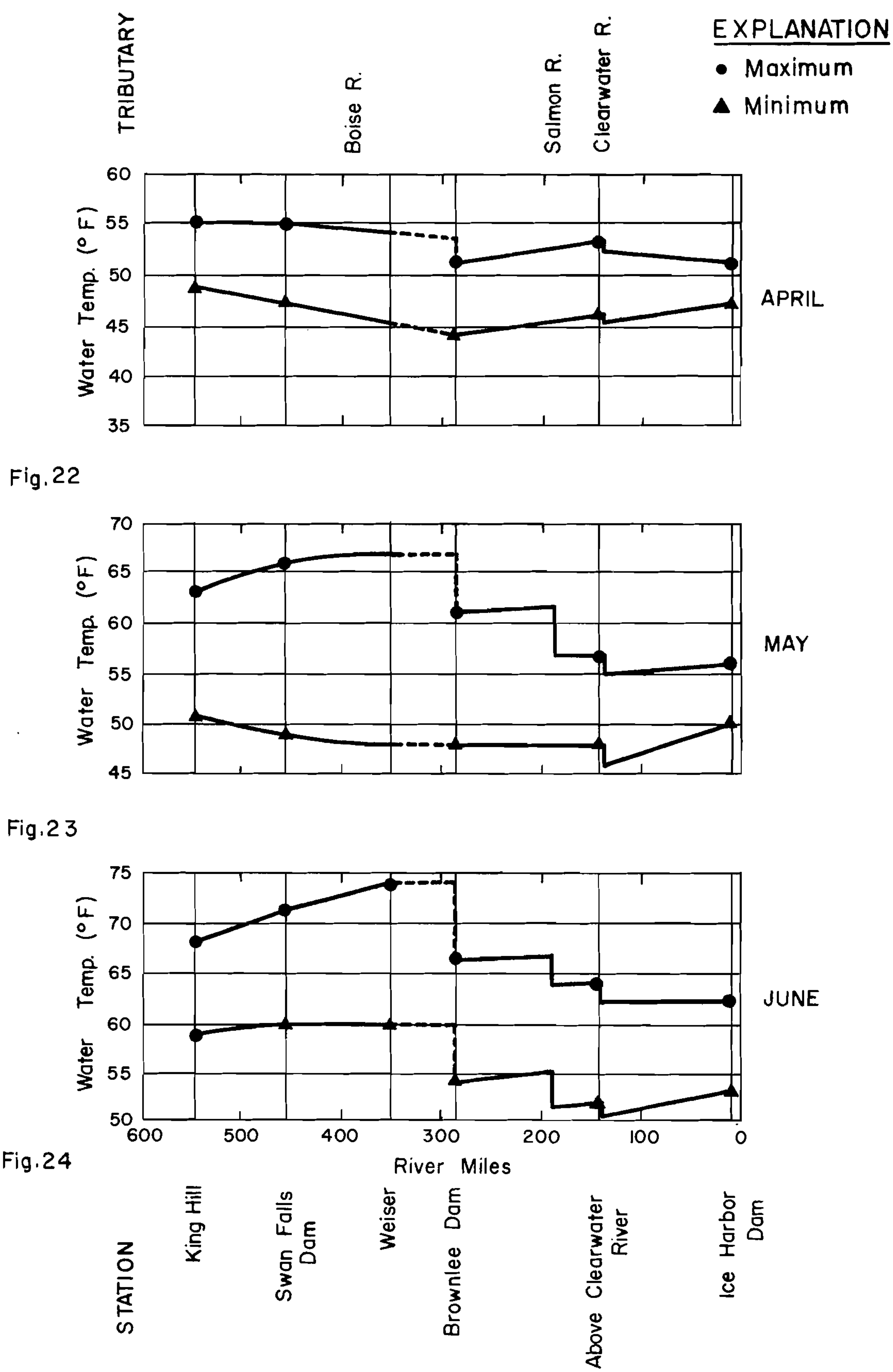
Fig.19

Fig.20

Fig.21

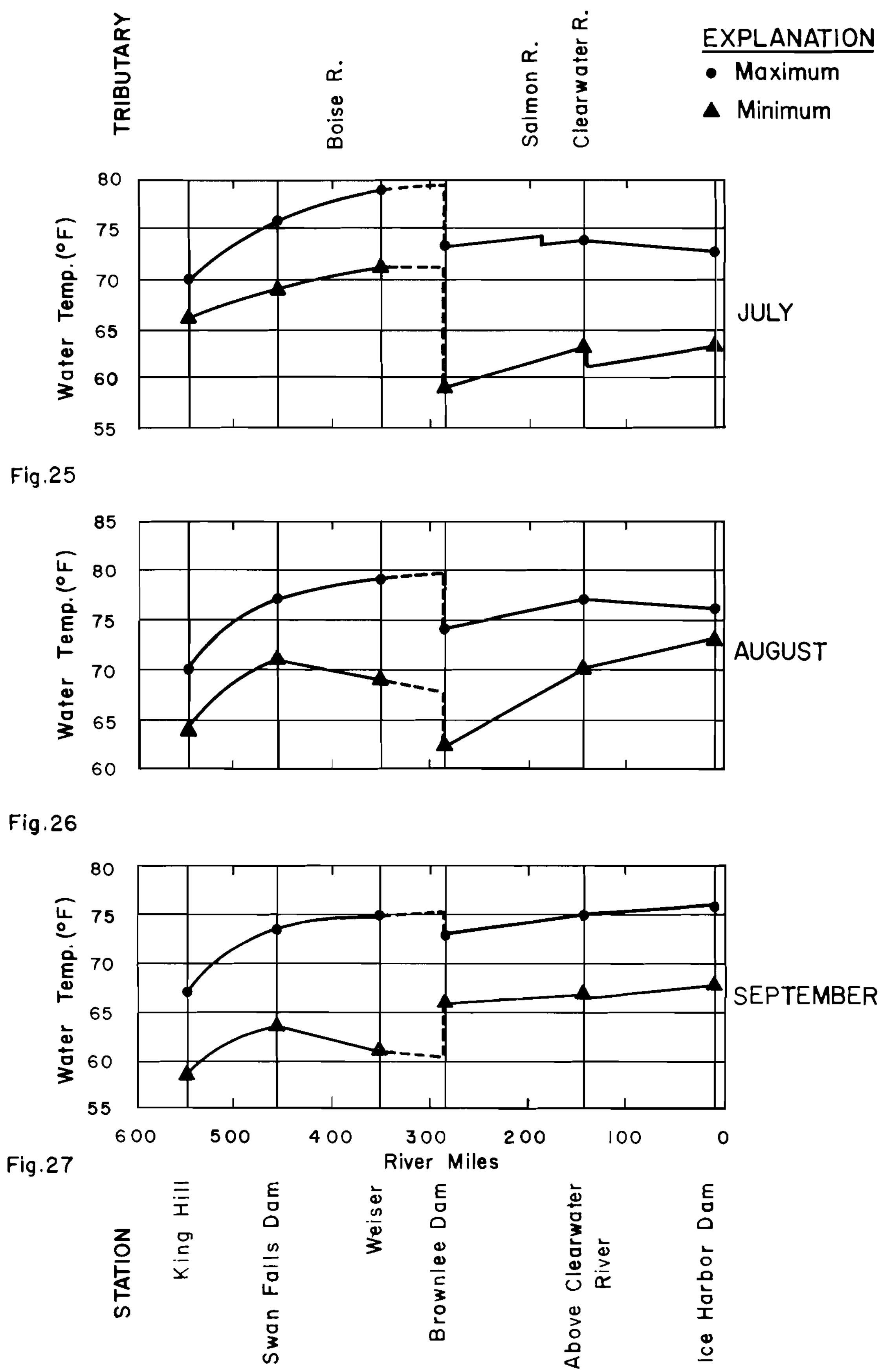
Water temperature profiles for 1967

(from reference 12)



Water temperature profiles for 1967

(from reference 12)



Water temperature profiles for 1967

(from reference 12)

This wide range of temperatures in the upper reach of the Salmon probably results from the location of sample collection sites adjacent to tributary streams where incomplete mixing occurs.

Modification of Snake River Temperatures

The thermal regime of a river may be altered significantly by selective withdrawal and release from deep upstream stratified reservoirs. The water flowing into a reservoir has a slight seasonal variation in density which is a function of its temperature. Heavier cold water from early spring runoffs accumulates in the lower level of the reservoir, the lighter (warmer) carry-over water from the previous season remains in the upper level.

If multilevel outlets are available at the dam, water can be selectively withdrawn from an appropriate temperature region and released into the river. By releasing low temperature water the temperature of the river can be lowered during hot summer months. When the supply of cold water is exhausted, the warm surface water and warm summer inflows must be released. This may result in a stream temperature higher than pre-impoundment temperatures.

An example of this phenomena is the temperature regime in the Snake River below Brownlee Reservoir where low level outlets are used, temperatures run about 10°F below pre-impoundment temperatures during July. Fall temperatures run about 6°F higher than pre-impoundment temperatures; thus maximum river temperatures were reduced during the summer months but were increased during early fall. This is graphically illustrated in Figures 13 thru 27. Overall, the average annual temperature of the river was reduced slightly by the impoundment.

To take full advantage of temperature regulation by selective withdrawal from stratified reservoirs it is necessary to have a predictive model of the river below the reservoir. The simulation model is useful for selecting quantities and temperature of release water for an optimum or desirable downstream temperature.

Temperature models

There are two basic temperature simulation models. The simplest expression for describing temperature change is: $T_2 = T_1 \text{ EXP } (\frac{-KLx}{Q})$ where T_1 and T_2 are the equilibrium temperature in two sections of a channel a distance x apart, L is the average width of water surface and Q is the rate of flow. The constant K is a function of meteorological variables such as wind velocity, relative humidity, air temperature, and cloud cover.

The constant K must be determined by correlating meteorological data with appropriate stream temperature data. Once this calibration is complete the equation is simple to use requiring only meteorological data from an adjacent weather bureau station. The equation is not as readily useable when large diversions or additions of water occur.

Because of these limitations a model was developed based on maintaining an energy budget on a specific volume of water as it progresses down a stream. The model is primarily a digital adaption of a scheme presented by Raphael (13). A discussion of the method can be found in the Appendix.

Results

Inadequate channel cross section data and time and money limitations put definite restraints on the rigor of the analysis. The only portion of the system that was modeled was from the confluence of the Salmon and the Snake to Lewiston, a distance of 49.3 miles.

Temperature records were available for the years 1967 and 1968 at mile 269.6 on the Snake (3.3 miles downstream from Oxbow Dam) and at White Bird on the Salmon at mile 53.7 of the Salmon. The confluence of the

Salmon and the Snake is at mile 188.2, 53.7 miles downstream from the Whitebird Station, and 81.4 miles down river from the Oxbow Station.

To obtain information on the temperature regime of a stratified reservoir on the Salmon it was assumed that such a reservoir would have essentially the same characteristics as Dworshak reservoir on the North Fork of the Clearwater. Streamflow temperatures of the North Fork at Ahsahka were compared (for the years 1967 and 1968) with streamflow temperatures at White Bird. The Salmon was about 2° warmer than the Clearwater during the months when the reservoir would fill, therefore, the isotherms for the conjectural Salmon reservoir were adjusted upwards 2°. After examining the temperature regime of Dworshak Reservoir (14) and comparing temperatures at Ahsahka and White Bird, Salmon water reservoir releases were assumed to be 46°, 46°, and 47°F for July, August, and September, respectively.

After evaluating results from numerous computer runs for the 49.3 miles reach and careful comparison with temperature gradients in the Snake, shown in Figures 13 thru 27, results from the temperature model were extrapolated in a very general way for the unmodeled reaches between stations of known temperature and the Salmon-Snake confluence.

The results of these simulated runs are shown in Table 1. Because of necessary extrapolations and lack of field data for verification of the model, these numbers are at best crude estimates. However, on the basis of mass balance and known records of temperature changes per mile of river downstream of Brownlee reservoir, the estimates appear to be conservative.

The numbers quoted are based on average meteorological data for each respective month and are for constant discharges. No allowance was made for fluctuating releases resulting from peaking operations; the flow is assumed constant as shown in the table. Brief periods of clear warm weather in conjunction with low releases on the Snake could result in significant deviations from the predicted data.

A benefit-cost analysis does not appear reasonable for temperature control feasibility. The main resource that is affected by temperature control is the fishery. The construction of a high dam for the enhancement of downstream fish habitat which would eliminate 50% of the Idaho anadromous fishery does not appear to be a reasonable alternative. Some future series of events might make this alternative a possibility.

Table 1. Effect of Salmon Water Releases on the temperature of the Snake River at Lewiston.

	Snake River above Confluence	Salmon Storage	Snake River at Lewiston
	Discharge CFS	Discharge CFS	Net Effect Decreases in Temperatures (nearest degree)
July	10,000	5,000	2
	10,000	7,500	4
	10,000	10,000	5
	12,000	5,000	2
	12,000	7,500	4
	12,000	10,000	5
August	10,000	5,000	5
	10,000	7,500	7
	10,000	10,000	8
	12,000	5,000	5
	12,000	7,500	6
	12,000	10,000	7
September	10,000	5,000	3
	10,000	7,500	4
	10,000	10,000	6
	12,000	5,000	2
	12,000	7,500	4
	12,000	10,000	6

CONCLUSIONS

The Salmon River in its present condition is a high quality river by any standard. With adequate sewage treatment at the community of Salmon the coliform levels should become quite acceptable in the entire stretch of the river.

"Idaho Water Quality Rules and Regulations . . ." (5) are sufficient to maintain water quality adequate for any of the three designated classes of river if enforced. For this reason a "System river" designation is of little consequence economically as far as water quality is concerned, i.e. state regulations will control, and as long as these standards are met, the water will be of adequate quality for any of the three types of system rivers. The major problem that remains is the establishment of "background levels" of the various pollutants which the state laws refer to but do not quantify. Reasonable limits will have to be determined based on a rather thorough monitoring systems. If the state water quality requirements are to be met and if the main stem of the Salmon is to be designated a system river, then a management plan for the drainage area and river will have to be developed to ensure that water quality will remain at least at the present level. In particular, logging areas will have to be developed in such a way that no appreciable increase in sedimentation above normal background levels will occur. This will probably be a difficult criteria to develop and enforce.

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APPENDIX

APPENDIX

TEMPERATURE SIMULATION MODEL

The Energy Budget

The energy budget is expressed as

$$Qx = Qs - Qr - Qb - Qh - Qe + Qv \quad BTU/Ft^2Hr.$$

in which

Qx is the net heat exchange of the body of water.

Qs is the net shortwave radiation from the sun and the atmosphere. (400 to 2800 BTU $Ft^{-2}Day^{-1}$)

Qr is the amount of shortwave radiation reflected from the water surface. (40-200 BTU $Ft^{-2}Day^{-1}$)

Qb is the net longwave radiation exchanged between the water surface and the atmosphere. ($\pm$2400 to $\pm$3600 BTU $Ft^{-2}Day^{-1}$)

Qh is the energy exchange due to conduction between the water surface and the air. (-300 $\pm$400 BTU $Ft^{-2}Day^{-1}$)

Qe is the energy loss due to evaporation. (2000-8000 BTU $Ft^{-2}Day^{-1}$)

Qv is the energy gained from additional water entering the original body of water.

The temperature change of the water is calculated by the net increase or decrease in the amount of energy Qx, contained in the water, therefore the key to predicting the water temperature lies in approximating the various terms of the energy budget.

Solar radiation

The value of Qs is mainly a function of the altitude of the sun, but it is subject to many other variables and can only be approximated.

Raphael (13) has tabulated values of shortwave radiation for every five degrees of altitude of the sun, from standard radiation curves developed by Moon (15). A polynomial regression was used to fit these values to a sixth degree equation, for use in the program.

Reflectivity

The reflectivity of the water surface is a function of the solar altitude, wind velocity, and type and amount of atmospheric turbidity. The reflected radiation was studied by E. R. Anderson (16) at Lake Hefner. His studies showed the solar altitude to be the main factor in the value of reflectivity, with the turbidity having a smaller effect that was of importance only at low solar altitudes. Because the solar radiation was not large at low altitudes, the effects of turbidity on reflectivity was relatively unimportant, and therefore an average value was used. The values of reflectivity given by Raphael, were in the form of a graph which was approximated by a polynomial equation, for use in the program.

Cloud effects

The effect of cloud cover on solar radiation was studied by H. Mosby (17), and later by S. Fritz (18). Combining the results of the two studies, Raphael proposed the expression

$$Qi = (1 - 0.0071\ C^2)\ (Qs - Qr)$$

in which

Qi is the net incoming solar radiation including the effects of cloud cover.

C is the amount of cloud cover, in tenths of sky covered.

Back radiation

The back radiation is the sum of the longwave radiation from the surface of the water and the atmosphere. The net longwave radiation is calculated from the expression

$$Qb = 0.97\ \sigma(Ts^4 - \beta Ta^4)$$

where

Qb is the net longwave radiation.

Ts is the temperature of the water surface. (°R)

Ta is the temperature of the air. (°R)

σ is the Boltzman constant.

and the constant 0.97 is both the emmisivity of the water surface and, one minus the reflectivity (0.03) of the water surface. For use with the units in the program, this equation reduces to

$$Qb = 1.66 \times 10^{-9}(Ts^4 - \beta Ta^4).$$

The constant is an empirical value proposed by Anderson (16), to correct for cloud height, cloud cover, and vapor pressure of the atmosphere. The value of β is given by

$$\beta = 0.74 + 0.25\ C\ EXP(-0.0584\ h) + Ea(0.0049 - 0.00054\ C\ EXP(-0.06h))$$

in which

C is the cloud cover in tenths.

h is the elevation of the clouds, in thousands of feet.

Ea is the vapor pressure of the atmosphere. (in. Hg)

Evaporation and Conduction

The equation for heat exchange due to evaporation is an empirical relationship developed at the Lake Hefner study. The value for the evaporated heat is given by the expression

$$Qe = 12\ U\ (Ew - Ea)$$

in which

Qe is the evaporated heat in BTU/Ft^2-Hr.

U is the wind velocity in knots.

Ea is the vapor pressure of the air above the surface of the water. (in. Hg)

Ew is the saturated vapor pressure of the water (in. Hg)

The conduction heat term is evaluated by the use of the Bowen Ratio (19), which is a relation between the heat lost by conduction to the heat lost by evaporation. The Bowen Ratio is expressed as

$$\frac{Qh}{Qe} = \frac{0.61(Ts - Ta)\ P}{1000(Ew - Ea)}$$

in which

P is the atmospheric pressure (in. Hg).

The expression for conduction reduces to

$$Qh = 0.00407\ U\ P(Ta - Ts)$$

in which

Qh is the heat exchange due to conduction in BTU/Ft^2Hr.

The possible heat loss due to conduction through the river bed was ignored, and no attempt was made to take into account the shortwave radiation that is reflected from the canyon walls.

The Model

A flow chart for the model is shown in figure 1. The program consists of four basic elements; determination of the position of the sun, calculation of the width and velocity of the river, determination of the heat exchange terms, and calculation of the incremental temperature change of the river.

The Sun

The position of the sun was determined using spherical trigonometry and several simplifying assumptions. It was assumed that the sun travels

N = Number of stations along the river.

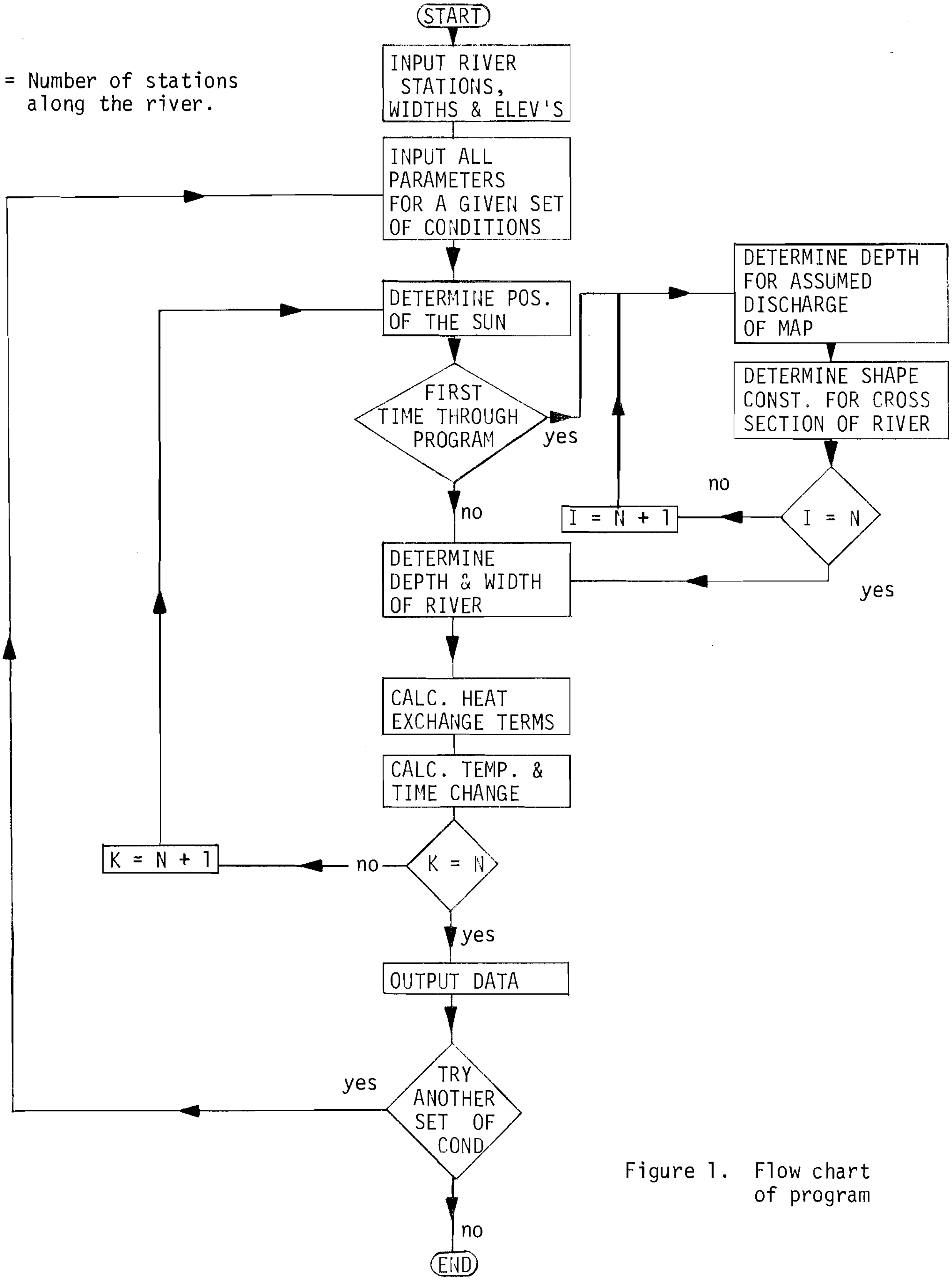

Figure 1. Flow chart of program

around the earth in a circular path, that is inclined to the axis of the earth at 23.45 degrees. Another assumption was that the zenith of the sun coincided with noon of the day of the run. The largest error in declination resulting from the assumed circular path was never more than one and a half degrees, which was considered good enough for the purpose of the program. Because the change in declination of the sun never exceeds more than one minute per hour, it was only calculated at the start of the run, and that value was used for the entire run.

The Snake River lies in a deep canyon through most of the path from the Salmon River to Lewiston. To allow for the rays of the sun being blocked by the canyon walls, the heat energy from solar radiation was excluded from the calculations, whenever the altitude of the sun fell below fifteen degrees.

The River

The width and profile of the Snake River were obtained from a U.S. Geological Survey map. The river was assumed to be turbulent so that the velocity and temperature did not vary across any cross section.

A typical assumed section of the river is shown in figure 2. The cross section was assumed to be a parabola in which the dimensions were related by the expression, Depth = Constant x Width^2.

The Manning equation, $V = \frac{1.486}{N} R^{2/3} S^{1/2}$

in which

V is the velocity of the river (fps)

R is the hydraulic radius

S is the slope of the river channel

N is the manning coefficient,

was used to solve for the depth by using the following procedure. First,

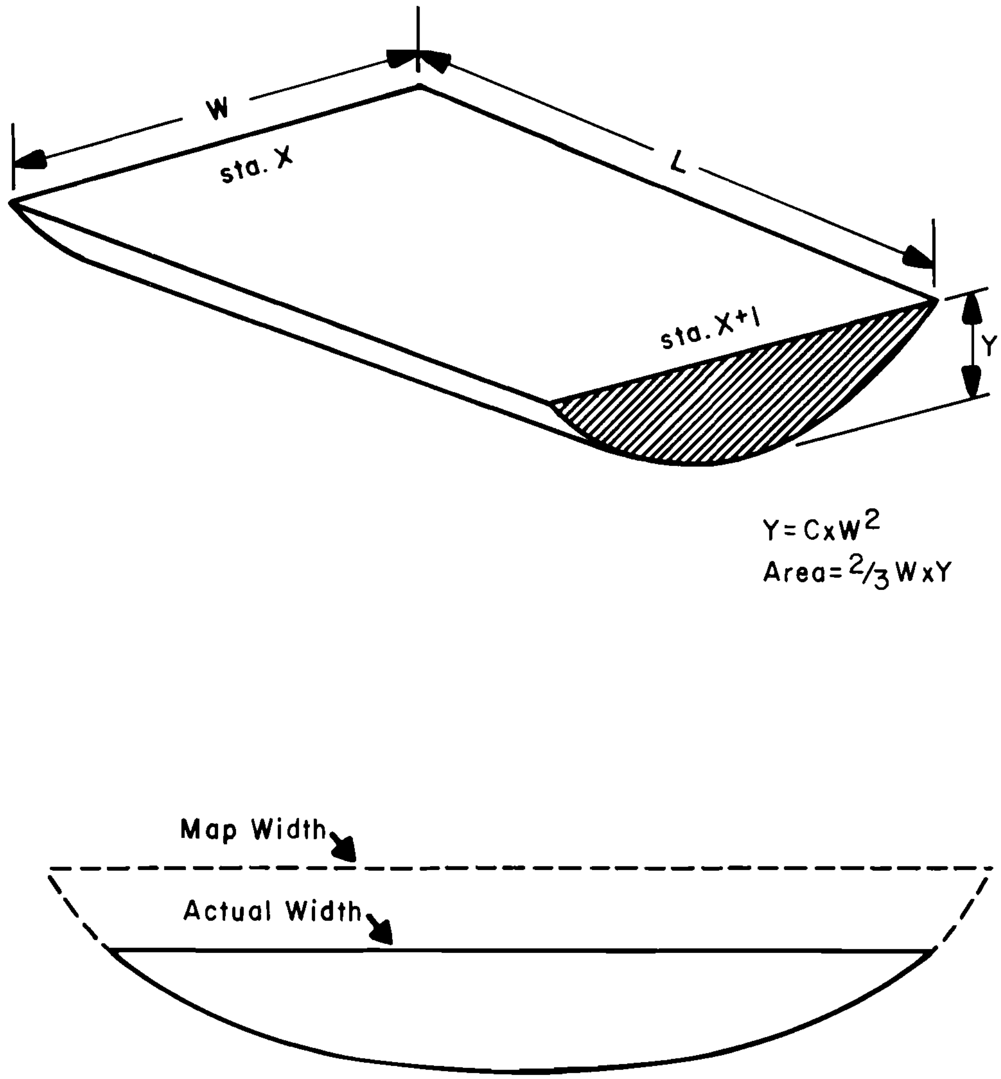

Figure 2
Assumed parabolic shape of the river

using the measured width, and an assumed discharge, a trial and error solution was found by varying the depth of the river until the depth, width, and slope of the river was such that the solution of the Manning equation gave a value of discharge that matched the assumed discharge. Next, with the depth and width known, the constant for the shape of the river of that section was determined and stored in memory. The variation of width and depth for different values of discharge were obtained by using a similar procedure, but in this case the discharge, slope and shape constant were known, and the trial and error solution gave the width and the depth.

Climatic parameters

All of the parameters, with the exception of cloud elevation, are commonly recorded by the weather bureau, and most airports. The values used in the program were average values, given by Burt (20) in a study of the same area of the river.

The temperature change

The temperature of the river is given by the expression

$$\Delta T = (Qx)\ A\ /[62.4\ Q\ (3600)]$$

in which

ΔT is the temperature change (°F)

Qx is the net heat exchange ($BTU/Ft^2 Hr.$)

A is the surface area between stations of the river

Q is the discharge rate of the river (cfs)

The time increment from station to station along the river was calculated using the velocity of the river at the upstream station.

Using the results of the temperature and time changes, the temperature of the river is adjusted and a new position of the sun is determined.

The foregoing process is repeated station by station down the river until the final destination is reached.

Some results from the study

A graph of the heat terms for a typical day are shown in figure 3. The graph shows the dominant role the sun plays in determining the temperature of a river. In order to check the validity of the procedure used in the program to determine the solar radiation, the values derived were averaged over a one day period and compared with average daily values given by Burt (20). Although the calculated values ran about ten percent high, the variation from month to month was very close, and it would be a simple matter to correct the radiation expression in the program if actual measurements were available for an exact comparison.

The three remaining terms in the analysis usually amounted to less than ten percent of the shortwave radiation, and for the conditions of this study were of opposite sign, so that the net effect was very close to zero.

In order to gauge the relative effects of the various parameters of the program, a run made under one set of conditions was chosen as a base and then repeated runs were made, each time changing one of the variables. Table 1 shows the original values of the terms at noon of the base day, and then the change in the values after a change in one of the parameters.

Because all of the terms except the shortwave radiation were small, the effect of climate was smaller than would be the case under more extreme conditions as would exist for example, during the winter months. The most important parameter for the conditions of this study was the

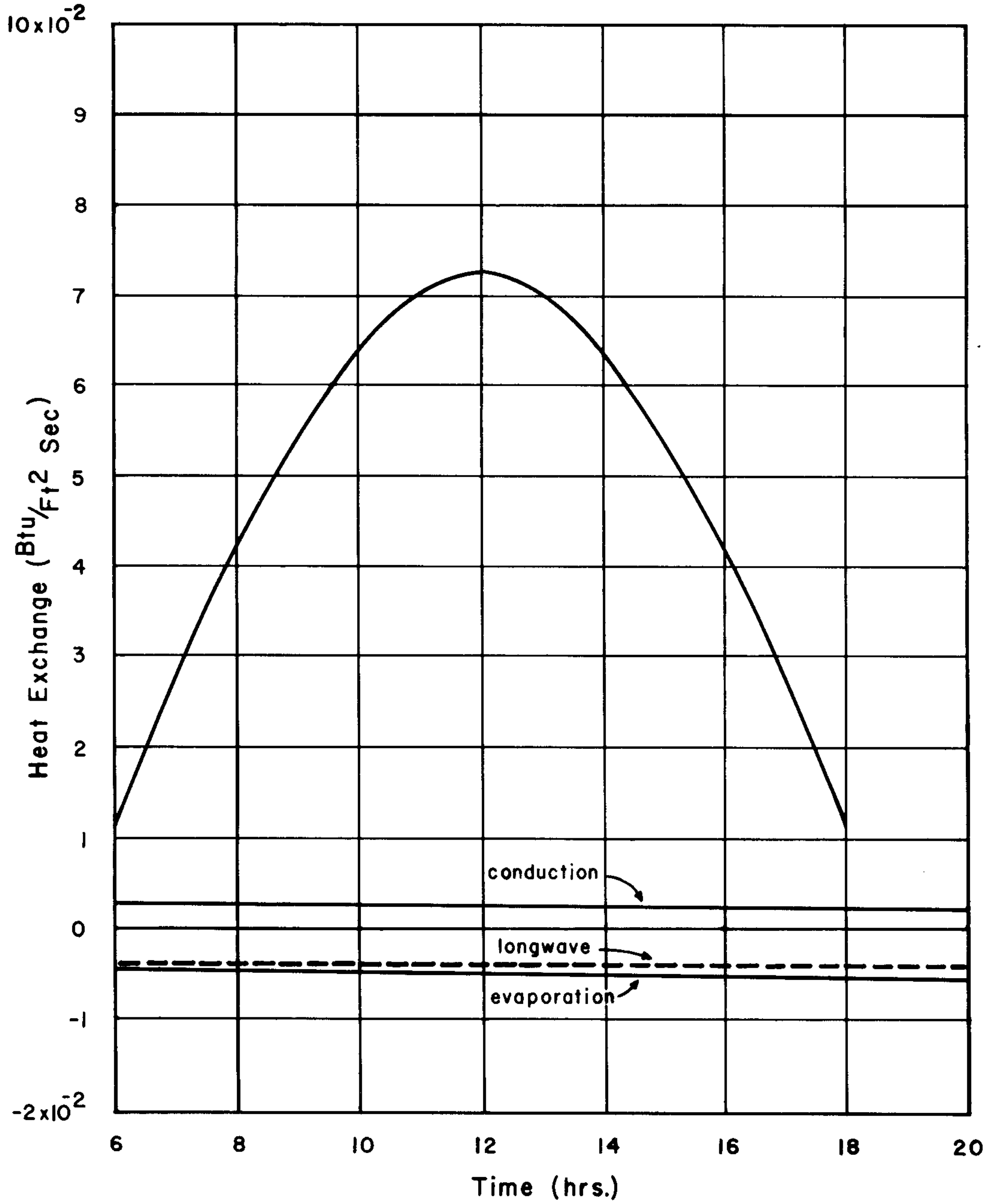

Figure 3
Heat exchange value for a typical day

PARAMETER	OLD VALUE	NEW VALUE	Q-sr	Q-lw	Q-evap	Q-cond
ORIGINAL VALUES			0.0731	-0.0017	-0.0029	0.0043
EVAPORATION COEFFICIENT	12.0	14.5			-0.0035	0.0052
CLOUD HEIGHT	10	30		-0.0024		
CLOUD COVER	2.7	10.0	0.0223	0.0015	-0.0023	0.0047
HUMIDITY	40.5	80.0		0.0000	0.0055	
WIND VELOCITY	8.5	20.0			-0.0069	0.0101
ATMOSPHERIC PRESSURE	29.05	28.0				0.0042
AIR TEMPERATURE	75.2	55.0		-0.0069	-0.0071	-0.0004
WATER TEMPERATURE	55.5	75.0		-0.0063	-0.0122	0.0002

Table 1. Change in heat exchange terms for a variation of a parameter, at noon of a typical day. ($BTU/Ft^2 Sec$)

amount of cloud cover, and since this value is mostly an estimation by an observer, it could result in a considerable error.

FORTRAN IV PROGRAM FOR TEMPERATURE MODEL

```
C  A = THE SURFACE AREA OF A REACH OF THE RIVER
C  AL(I)=ALF = ALTITUDE OF THE SUN MEASURED FROM THE HORIZON
C  ALT = ANGLE OF ELEVATION OF THE CANYON WALLS
C  AR = AREA = CROSS SECTIONAL AREA OF THE RIVER
C  AX= A FACTOR USED IN COMPUTING CLOUD COVER EFFECTS ON BACKRADIATION
C  B = WETTED PERIMETER OF THE RIVER CROSS SECTION
C BET= THE FACTORS AX AND BX COMBINED
C  BX = A FACTOR USED IN COMPUTING CLOUD COVER EFFECTS ON BACKRADIATION
C  C= THE HOUR OF THE DAY
C  CC= AMOUNT OF CLOUD COVER IN TENTHS OF SKY
C  CEV= EVAPORATION COEFFICIENT
C  CONST(I)=A SHAPE CONSTANT FOR THE CROSS SECTION OF THE RIVER
C  D= THE MINUTE OF THE TIME AT THE START OF THE RUN
C  DA-  APPROXIMATE CHANGE IN CROSS SECTION AREA FOR CHANGE IN DISCHARGE
C  DEC= DECLINATION OF THE SUN, MEASURED FROM THE POLE
C =DELT CHANGE IN THE WATER TEMP
C  DP(I)=YX - DEPTH OF THE RIVER
C  DQ= AN INCREMENTAL CHANGE IN DISCHARGE
C  DY= AN INCREMENT OF DEPTH CHANGE IN THE RIVER
C  EA -VAPOR PRESSURE OF THE AIR
C  EW-SATURATED VAPOR PRESSURE OF THE WATER
C  H-ELEVATION OF THE CLOUDS IN 1000'S OF FEET
C  HA- HOUR ANGLE OF THE SUN FOR THE PARTICULAR DAY
C  HM- HUMIDITY IN PRECENT
C HO -HOUR ANGLE OF THE VERNAL EQUINOX
C  I- A COUNTER
C  K - A COUNTER
C  L- THE LENGTH OF A REACH OF THE RIVER
C M- A COUNTER
C MH- TIME, MEASURED IN HOURS
C MM TIME MEASURED IN MINUTES
C  MS- TIME MEASURED IN SECONDS
C MX- HOUR ANGLE OF THE SUN IN SECONDS
C  N- A COUNTER
C NA-NB-NC-ND  FACTORS USED IN THE SUBROUTINE FACTOR TO CONVERT DATES INTO
            SINGLE UNITS
C  NALT-ANGLE OF ELEVATION OF THE CANYON WALLS
C  NDAY- DATE OF THE TEMPERATURE STUDY
C  NLAT - LATITUDE OF THE RIVER
C  NTME- TIME OF DAY FOR THE START OF THE RUN
C  NVEQ - DATE OF THE VERNAL EQUINOX
C  P - ATMOSPHERIC PRESSURE IN INCHES OF MERCURY
C  PI - 3.14159
C  Q- DISCHARGE OF THE RIVER
C QAVE- AVERAGE DAILY RADIATION
C  QB- LONGWAVE RADIATION
C  QH- HEAT EXCHANGE DUE TO CONDUCTION
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C  QI- TOTAL SHORTWAVE RADIATION
C QINT=QSR
C  QLAST- INITIAL FLOW ASSUMED FOR THE GRANDE RONDE RIVER
C  QO- DISCHARGE ASSUMED TO COINCIDE WITH THE WIDTH OF THE RIVER MEASURED
C      FROM THE MAP
C  QQ-A TEMPORARY VALUE OF DISCHARGE USED IN CALCULATING THE DEPTH AND
C      WIDTH OF THE RIVER
C  QR- DISCHARGE OF THE GRANDE RONDE RIVER
C QSR- SOLAR RADIATION
C QT- HEAT LOST DUE TO EVAPORATION
C  QX - SUM OF THE HEAT EXCHANGE TERMS
C  QZ(I,J)  -STORAGE ARRAY FOR THE HEAT EXCHANGE TERMS
C  R- HYDRAULIC RADIUS
C  REF-REFLECTED RADIATION
C  S -  SUM OF THE SIDES OF THE SPHERICAL TRIANGLE
C  SR(I)- SQUARE ROOT OF THE SLOPE OF THE RIVER
C  SUM- ACCUMULATED VALUES OF SHORTWAVE RADIATION
C  SUP - DECLINATION OF THE SUN MEASURED FROM THE EQUATOR
C  T(I)=TS-  TEMPERATURE OF THE RIVER
C  TA- AIR TEMPERATURE
C  TG- TEMPERATURE GRADIENT OF THE RIVER
C  THETA - ANGLE AT WHICH THE SUNS RAYS WILL BE BLOCKED BY THE CANYON WALLS
C  TK- INCREMENT OF TEMPERATURE CHANGE AT THE INTERSECTING RIVERS
C  TMA- HOUR ANGLE OF THE SUN AT THE STARTING TIME
C  TMX- SUPPLEMENT OF TMA
C  TP- TIME INCREMENT BETWEEN STATIONS ON THE RIVER
C  TR- TEMPERATURE OF THE GRANDE RONDE RIVER
C  TT(I)-  STORAGE ARRAY FOR TIME
C  TY- TIME INCREMENT IN RADIANS
C  U - WIND VELOCITY IN KNOTS
C  UV- WIND VELOCITY IN MPH
C  V- VELOCITY OF FLOW
C  VSTR(I)-  STORAGE ARRAY FOR VELOCITY TERMS
C  XK- COEFFICIENT FOR TURBULENCE, USED IN THE CONDUCTION HEAT TERM
C  XLT - COMPLIMENT OF THE LATITUDE OF THE RIVER
C  XMM- STARTING TIME
C  XMH- ENDING TIME
C  XN - MANNING COEFFICIENT
C  XTA- RANKINE TEMPERATURE OF THE AIR
C  XTW - RANKINE TEMPERATURE OF THE WATER
C  YX- DEPTH OF THE RIVER
C  Z(I)- WIDTH OF THE RIVER
C
C
C
C
C
C
C
C
      DIMENSION X(200),Y(200),T(200),Z(200),EL(200),TT(200),DP(200),AL(2
     100),CONST(200),TPA(150),QZ(150,5),VSTR(150)
      DIMENSION SR(200)
      REAL L
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```
    1 FORMAT(10F7.2/3F7.2)
    2 FORMAT(4F5.2)
    3 FORMAT(1X,'STATION  WIDTH  DEPTH  TEMP  SOLAR ALT    TIME      Q-S
     1R   Q-LW     Q-EVAP    Q-COND     QNET     VELOCITY'/)
    4 FORMAT(2X,F5.2,F8.1,F6.1,F8.2,F8.2,2X,I2,':',I2,':',I2,F8.4,4F10.4
     1,F10.3)
    7 FORMAT(I3)
    8 FORMAT(5(2XI8))
  305 FORMAT('1',40X,'MONTH=',I2,1X'DAY=',I2)
  306 FORMAT('+'T15,'_____________________'T46,'_____________________'/)
  307 FORMAT(T15,'DISCHARGE(CFS) =',F6.0,T45,'TEMP GRD.(DEG/MI)= 'F5.4,/
     1       T15,'STARTING TEMP  =',F5.2,T45,'FINAL TEMP       = 'F5.2,/
     1       T15,'AIR TEMP       =',F5.2,T45,'AVE. RADIATION   = 'F4.0)
  308 FORMAT(T15,'ATM PRESS      =',F5.2,T45,'RIVER WIDTH @22  = 'F6.1,/
     1       T15,'HUMIDITY       =',F4.1,T45,'RIVER DEPTH @ 22 = 'F6.1,/
     1       T15,'CLOUD COVER    =',F4.1,T45,'FINAL RIVER VEL. = 'F5.2)
  309 FORMAT(T15,'CLD.HT.*1000   =',F4.1,T45,'ENDING TIME      = 'F5.2,/
     1       T15,'WIND VELOCITY  =',F4.1,/T15,'STARTING TIME  = 'F5.2/
     1       T15,'EVAP COEFF.    =',F4.1,/T15,'DECLINATION    = 'F7.2/
     1       T15,'LATITUDE       =',I8,///)
  310 FORMAT(T15,'MANNING COEFF.  =',F4.3,/T15,'COND. COEFF.  = 'F4.1)
  311 FORMAT(T20,'INPUT DATA'T50,'OUTPUT DATA')
  312 FORMAT('+'5X,'SET NUMBER  ',I2)
      K=0
      Q0=30000.
      QLAST=3000.
      PI=3.14159
      READ(1,7)N
      DO 10 I=1,N
C
C    READ IN RIVER STATIONS AND WIDTHS
C
C
      READ(1,2)X(I),Y(I),Z(I),EL(I)
      X(I)=5280.*X(I)+2640.*Y(I)
      Z(I)=2640.*Z(I)*.9
   10 CONTINUE
C
C   READ IN CLIMATIC PARAMETERS
C
C
   14 READ(1,1)TS,TA,Q,TR,QR,XK,P,UV,XN,HM,CC,H,CEV
      TA=TA+10.
      KCHART=K+1
      IF(Q.EQ.0)GO TO 53
      U=(5280.*UV)/6080.
      EA=6413260.*EXP(-7482.6/(TA+398.36))*HM/100.
      T(1)=TS
      M=N-1
C
C
C  READ IN TIME LATITUDE AND STARTING POSITION OF THE SUN
C
      READ(1,8)NVEQ,NDAY,NLAT,NTME,NALT
```

```
C
C
      DO 75 I=1,N
      Y(I)=X(I)/5280.
      IF(Y(I).GT.29.3.AND.Y(I).LT.29.8)QO=QO+QLAST
      IF(I.EQ.1)GO TO 63
      L=X(I-1)-X(I)
      SR(I)=((EL(I-1)-EL(I))/L)**.5
      GO TO 65
   63 L=X(I)-X(I+1)
      SR(I)=((EL(I)-EL(I+1))/L)**.5
   65 YX=15.
   32 AR=2./3.*YX*Z(I)
      B=Z(I)+8./3.*YX*YX/Z(I)
      R=((AR**5)/(B**2))**(1./3.)
      QQ=1.486/XN*SR(I)*R
      DQ=QO-QQ
      DA=DQ*AR/QQ
      DY=DA/Z(I)
      YX=YX+DY
      IF(ABS(DY).GT..01)GO TO 32
      CONST(I)=YX/Z(I)**2
   75 DP(I)=YX
C
C
C    DETERMINE NEW DEPTH AND WIDTH FOR GIVEN DISCHARGE
C
C
  101 DO 70 I=1,N
      IF(Y(I).GT.29.3.AND.Y(I).LT.29.8)Q=Q+QR
      YX=DP(I)
   33 Z(I)=SQRT(YX/CONST(I))
      AR=2./3.*YX*Z(I)
      B=Z(I)+8./3.*YX*YX/Z(I)
      R=((AR**5)/(B**2))**(1./3.)
      QQ=1.486/XN*SR(I)*R
      DQ=Q-QQ
      DA=DQ*AR/QQ
      DY=DA/Z(I)
      YX=YX+DY
      IF(ABS(DY).GT..01)GO TO 33
      DP(I)=YX
   70 Z(I)=SQRT(YX/CONST(I))
      Q=Q-QR
      SUM=0
      QINT=0
C
C
C    START OF TEMPERATURE CHANGE CALCULATION
C
C
      DO 20 I=1,M
      TMX=PI-TMA
      ALF=0
```

```
      I=0
C
C    DETERMINE DECLINATION OF THE SUN
C
C
      CALL FACTOR(NVEQ,NA,NB,NC,ND)
   41 C=NC
      D=ND
      IF(NA.EQ.01)HA=NB+C/24.+D/1440.+0
      IF(NA.EQ.02)HA=NB+C/24.+D/1440.+31.
      IF(NA.EQ.03)HA=NB+C/24.+D/1440.+59.
      IF(NA.EQ.04)HA=NB+C/24.+D/1440.+90.
      IF(NA.EQ.05)HA=NB+C/24.+D/1440.+120.
      IF(NA.EQ.06)HA=NB+C/24.+D/1440.+151.
      IF(NA.EQ.07)HA=NB+C/24.+D/1440.+181.
      IF(NA.EQ.08)HA=NB+C/24.+D/1440.+212.
      IF(NA.EQ.09)HA=NB+C/24.+D/1440.+243.
      IF(NA.EQ.10)HA=NB+C/24.+D/1440.+273.
      IF(NA.EQ.11)HA=NB+C/24.+D/1440.+304.
      IF(NA.EQ.12)HA=NB+C/24.+D/1440.+334.
      I=I+1
      IF(I.EQ.2)GO TO 42
      HO=HA
      CALL FACTOR(NDAY,NA,NB,NC,ND)
      GO TO 41
   42 IF(HO.GT.HA)HA=HA+365.
      WRITE(3,305)NA,NB
      WRITE(3,312)KCHART
      HA=(HA-HO)*2.*PI/366.
      DEC=PI/2.-ARSIN(SIN(23.445*PI/180.)*SIN(HA))
      SUP=(PI/2.-DEC)*57.296
C
      CALL FACTOR(NLAT,NA,NB,NC,ND)
      XLT=PI/2.-.01745329*NB+.00029089*NC+.00000485*ND
C
C DETERMINE THE HOUR ANGLE OF THE SUN WHEN FIRST RAYS HIT THE RIVER
C
C
      CALL FACTOR(NALT,NA,NB,NC,ND)
      ALT=PI/2.-.01745329*NB+.00029089*NC+.00000485*ND
      S=(ALT+XLT+DEC)/2.
      SK=((SIN(S-ALT)*SIN(S-DEC)*SIN(S-XLT))/SIN(S))**.5
      THETA=2.*ATAN(SK/SIN(S-ALT))
C
C  TIME OF DAY AT WHICH RUN STARTS
C
C     CALL FACTOR(NTME,NA,NB,NC,ND)
      TMA=(NB*3600.+NC*60.+ND)/(24.*3600.)*2.*PI
      TT(1)=TMA
      TPA(1)=TMA*12./PI
      IF(K.GT.0) GO TO 101
C
C  DETERMINE DEPTH OF RIVER FOR ASSUMED Q OF MAP
```

```
      QI=0
      QSR=0
C
C
C   DETERMINE IF SUNS ALTITUDE IS ABOVE CANYON WALLS
C
C
      IF(ABS(TMX).GT.THETA)GO TO 44
      ALT=ARCOS(COS(DEC)*COS(XLT)+SIN(DEC)*SIN(XLT)*COS(TMX))
      ALF=90.-57.2958*ALT
      W=ALF
C
C  POLYNOMIAL TO EXPRESS REFLECTED RADIATION
      REF=.3611-.021*W+.0005574*W**2-.00000672*W**3+.0000000301*W**4
C
C  POLYNOMIAL TO EXPRESS NET RADIATION
      QSR=-1.433+1.757*W+.26158*W**2-.00825*W**3+.000130*W**4-.000001078
     1*W**5+.0000000035477*W**6
C
C TOTAL INCOMING SHORTWAVE RADIATION WITH CLOUD COVER EFFECTS
C
      QI=(1.-.0071*CC*CC)*QSR*(1.-REF)/3600.
C
C  CALCULATION OF BACK RADIATION INCLUDING EFFECTS OF CLOUD ALTITUDE
   44 AX=.74+.025*CC*EXP(-.0584*H)
      BX=.0049-.00054*CC*EXP(-.06*H)
      BET=AX+BX*EA/.02953
      AL(I)=ALF
      XTW=TS+460.
      XTA=TA+460.
      QB=-1.66E-9*(XTW**4-BET*XTA**4)/3600.
C
      W=(Z(I)+Z(I+1))/2.
      L=X(I)-X(I+1)
      A=L*W
      D=TS
C
C VAPOR PRESSURE OF RIVER WATER
      EW=6413260.*EXP(-7482.6/(TS+398.36))
C
C HEAT EXCHANGE DUE TO EVAPORATION
      QT=-CEV*U*(EW-EA)/3600.
C
C HEAT EXCHANGE DUE TO CONDUCTION
      QH=-.000339*CEV*XK*U*P*(TS-TA)/3600.
C
C NET HEAT EXCHANGE
      QX=QI+QB+QT+QH
C
      QZ(I,1)=QX
      QZ(I,2)=QI
      QZ(I,3)=QB
      QZ(I,4)=QT
      QZ(I,5)=QH
```

```
      DELT=+QX*A/(62.4*Q)
      TS=TS+DELT
      T(I+1)=TS
C
C    DETERMINE TIME INCREMENT FROM LENGTH OF REACH & VELOCITY OF FLOW
C
C
      AREA=2./3.*DP(I)*Z(I)
      V=Q/AREA
      VSTR(I)=V
      TP=L/V
      IF(QSR.GT..1)SUM=TP*(QINT+QSR)+SUM
      QINT=QSR
C
C
C    ADJUST HOUR ANGLE OF THE SUN FOR THE TIME CHANGE
C
C
      TY=TP/(24.*3600.)*2.*PI
      TMA=TMA+TY
      IF(TMA.GT.(2.*PI))TMA=TMA-2.*PI
      TT(I+1)=TMA
      TPA(I+1)=TMA*12./PI
C
C   CHANGE TEMPERATURE OF RIVER FROM INTERSECTING RIVER
C
      IF(Y(I).GT.29.3.AND.Y(I).LT.29.8)GO TO 11
      GO TO 20
   11 TK=TS
      TS=(Q*TS+QR*TR)/(Q+QR)
      Q=Q+QR
      TK=TK-TS
C
   20 CONTINUE
C
C
C
      QAVE=SUM/(48.*3600.)
      QZ(N,1)=QZ(N-1,1)
      AL(N)=AL(N-1)
      Y(N)=X(N)/5280.
      WRITE(3,3)
      DO 40 I=1,N,5
      MX=TT(I)/2./PI*24.*3600.
      MH=MX/3600
      MM=(MX-MH*3600)/60
      MS=MX-MH*3600-MM*60
      IF(MH.GT.23)MH=MH-24
      WRITE(3,4)Y(I),Z(I),DP(I),T(I),AL(I),MH,MM,MS,QZ(I,2),QZ(I,3),QZ(I
     1,4),QZ(I,5),QZ(I,1),VSTR(I)
   40 CONTINUE
      TG=(T(N)-T(1)+TK)/Y(1)
      XMH=TT(1)/2./PI*24.
      XMM=TT(N)/2./PI*24.
```

```
      WRITE(3,311)
      WRITE(3,306)
      WRITE(3,307)Q,TG,T(1),T(N),TA,QAVE
      WRITE(3,308)P,Z(22),HM,DP(22),CC,V
      WRITE(3,310)XN,XK
      WRITE(3,309)H,XMM,UV,XMH,CEV,SUP,NLAT
      QLAST=QR
      QO=Q-QR
      K=K+1
      GO TO 14
   53 CALL EXIT
      END


      SUBROUTINE FACTOR(NDAT,NA,NB,NC,ND)
      NA=NDAT/1000000
      NB=(NDAT-NA*1000000)/10000
      NC=(NDAT-NA*1000000-NB*10000)/100
      ND=NDAT-NA*1000000-NB*10000-NC*100
      RETURN
      END
```