

STATE OF IDAHO
DEPARTMENT OF WATER RESOURCES
PROOF OF BENEFICIAL USE

MAR 03 2005

Department of Water Resources

The Idaho Department of Water Resources considers this form a statement that the permit holder(s) has/have completed all development that will occur under this permit and that water has been applied according to the provisions of the permit for the beneficial use(s) described below. This form must be accompanied by a license examination fee, when necessary, or be accompanied by a completed field examination report prepared by a certified water right examiner.

1. Permit No. 22-7369 Telephone No. (208) 287-4800

2. Name of Permit Holder(s): Idaho Water Resource Board

3. Mailing Address: Statehouse Mail

City Boise State ID Zip 83720-0098

4. Source of Water: Teton River If **GROUNDWATER** (well), Date Drilled: mo. _____ / yr. _____

Well Driller: _____ Drilling Permit Number: _____

5. Use(s) (as authorized by the water right permit):

Domestic (No. of households): _____ Stockwater (No. and type of stock): _____

Irrigation (No. of acres): _____ Other: Minimum Stream Flow

6. Total rate of diversion and/or volume for which proof is submitted: 106 cfs OR _____ acre-feet

7. Measuring Device Requirement: (refer to the approval conditions on your permit and respond accordingly)

(This question is **not optional**. Please check either yes or no. Proofs returned not checked accordingly, will be considered incomplete)

Measuring Device: Is a measuring device required?

Yes _____ or No X

Has the measuring device been installed?

Yes _____ or No X

8. Fee Enclosed: \$ N/A (See Fee Schedule on back of the instructions for filing proof of beneficial use)

9. Person to contact to accompany the Department representative during field examination of the water system.

Name: Morgan Case Telephone Number: (208) 287-4800

Address: _____

10. **The information given on this form is my true statement of the extent to which the above numbered permit has been developed and water has been diverted. I agree to relinquish any undeveloped portion of the permit to the State of Idaho.**

Signature of permit holder: _____

(include your title, if on behalf of company or organization)

Date: 3-3-05

**PROOF OF USE DOCUMENTATION FOR INSTREAM
FLOW WATER PERMIT NO. 22-7369, TETON RIVER**

Submitted by:

Cindy Robertson, Idaho Department of Fish and Game

Morgan Case, Idaho Department of Water Resources

Liz Robbins, Idaho Department of Water Resources

Proof of Beneficial Use for Teton River (Permit No. 22-7369)

The Teton River originates on the west slope of the Teton Mountains and ultimately drains nearly 900 square miles to its confluence with the Henrys Fork near Rexburg. The primary game fish species found in the Teton River include Yellowstone cutthroat (*Oncorhynchus clarki bouvieri*) and rainbow trout (*O. mykiss*).

In 1981, Idaho Department of Fish and Game (IDFG) petitioned the Idaho Water Resource Board (IWRB) to file an application for a 106 cfs instream flow water right on a nine-mile reach of the Teton River to maintain important trout habitat. The instream flow reach extends from the confluence with Bitch Creek upstream through a canyon to the Highway 33 Bridge crossing. Data from a single study site, approximately one-mile downstream of the Highway 33 Bridge, were used to model habitat in the nine-mile reach. The study site was located in a broad, open valley, but while evidence presented at the hearing demonstrated 106 cfs met the minimum needs of the river in the valley setting, the stream channel in the canyon reach was not sufficiently similar to the channel in the valley to adequately model fish habitat in the canyon reach. The Memorandum Decision and Order (MDO), issued December 4, 1989, required an additional study to determine whether the requested flow of 106 cfs was indeed a minimum flow needed to protect fish habitat in the canyon reach.

In the early 1970s, researchers from the Idaho Cooperative Fishery Research Unit conducted a study of the impacts of potential irrigation water withdrawals on the canyon reach of the Teton River (White, 1976). One of the primary study objectives was to relate the changes in stream depth and velocity associated with variable flows to changes in fish habitat. Their study area overlaps the canyon reach of the instream flow permit and the results of their study are presented here to fulfill the requirements of the MDO.

White (1976) measured physical habitat parameters (velocity and depth) at known discharges on eight transects in the upper canyon area (Figure 1) and predicted physical habitat characteristics (cross sectional area, wetted perimeter, velocity, and depth) at

flows ranging from 50 cfs to approximately 400 cfs using the U. S. Forest Service R-2 Cross model (Table 1).

Velocity, depth, and instream cover have long been recognized as essential elements of fish habitat. Cover provides a means of predator avoidance and velocity shelters for resting habitat for fish. Cover can be provided by undercut banks, overhanging vegetation, submerged rocks or vegetation, water turbulence, and water depth. In the canyon reach of the Teton River, White observed only moderate amounts of overhanging stream side vegetation and essentially no undercut banks; large wood was also lacking. Bottom substrate was predominantly rubble and boulders. Since adult trout would normally seek out pool habitat (with corresponding lower velocities) where it was available, White did not believe velocity would be a limiting factor for trout in the study reach as flows declined. Rather, he suggested that trout populations would become limited by reductions in cover, which in the canyon reach of the Teton River is primarily in the form of water depth.

Based on a review of the literature, White suggested the carrying capacity of a stream, (defined as the maximum natural capability of habitats to produce and support aquatic organisms on a long-term, sustained basis) with sufficient over-wintering habitat and a relatively unaltered discharge regime, is set during the lowest flow period of the growing season. For the Teton River, this would be the month of September. He further postulated the trout population of the Teton River study area was likely adapted to a flow regime equal to the average daily flow for this low flow period and that habitat is at 100% (i.e., maximum available or “optimum”) at that flow. White reported the average daily flow for September during the time he conducted his study was approximately 350 cfs. Based on these assumptions, we related the White’s predicted habitat changes to known ecological requirements of rainbow and cutthroat trout (Table 2) to determine if the requested flow would be considered a minimum flow for the canyon reach.

From the values in Table 1, as flows decline from “optimum” flow levels (>350 cfs) to flows near the 106 cfs requested, the predicted velocities and depth decline as well.

Velocity, as suggested by White, does not appear to drop out of the “optimum” range for either rainbow or cutthroat trout adults or juveniles (Table 2) and would not be expected to limit trout habitat. Depth, however, is predicted to decline significantly as discharge decreases below the average daily flow quantity. The predicted depths are 45-50% less at flows near 100 cfs than at the “optimum” flow and are outside the range of “optimum” depths reported for rainbow and cutthroat trout (with the exception of rainbow trout juveniles).

The suggested flow of 106 cfs is capable of being maintained. While there are no long term gages are present within the reach modeled stream flows and a long term gage approximately 6.5 miles above the reach suggest that a flow of 106cfs will be exceeded 90% – 99% of the time (Figures 2 and 3).

Based on this analysis, we conclude the requested flow of 106 cfs for the entire nine-mile reach of the Teton River covered by permit no, 22-7369, is not an “optimum”, rather a minimum flow amount that meets the requirements under 42-1503(d) and the MDO.

LITERATURE CITED

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Cochnauer, Tim and Terry Elms-Cockrum. 1986. Probability-of-use curves for selected Idaho fish species. Project Performance Report, Project F-71-R-10. 50 pp. Idaho Department of Fish and Game. Boise, ID.

Raleigh, Robert F., Terry Hickman, R. Charles Solomon, and Patrick C. Nelson. 1984. Habitat suitability information: Rainbow trout. FWS/OBS-82/10.60. 64 pp. U.S. Fish and Wildlife Service. Washington, D.C.

White, Robert G. 1976. Predicted effects of water withdrawal on the fish population of the Teton River, Idaho. 46 pp. Idaho Cooperative Fishery Research Unit, College of Forestry, Wildlife, and Range Sciences, University of Idaho. Moscow, ID

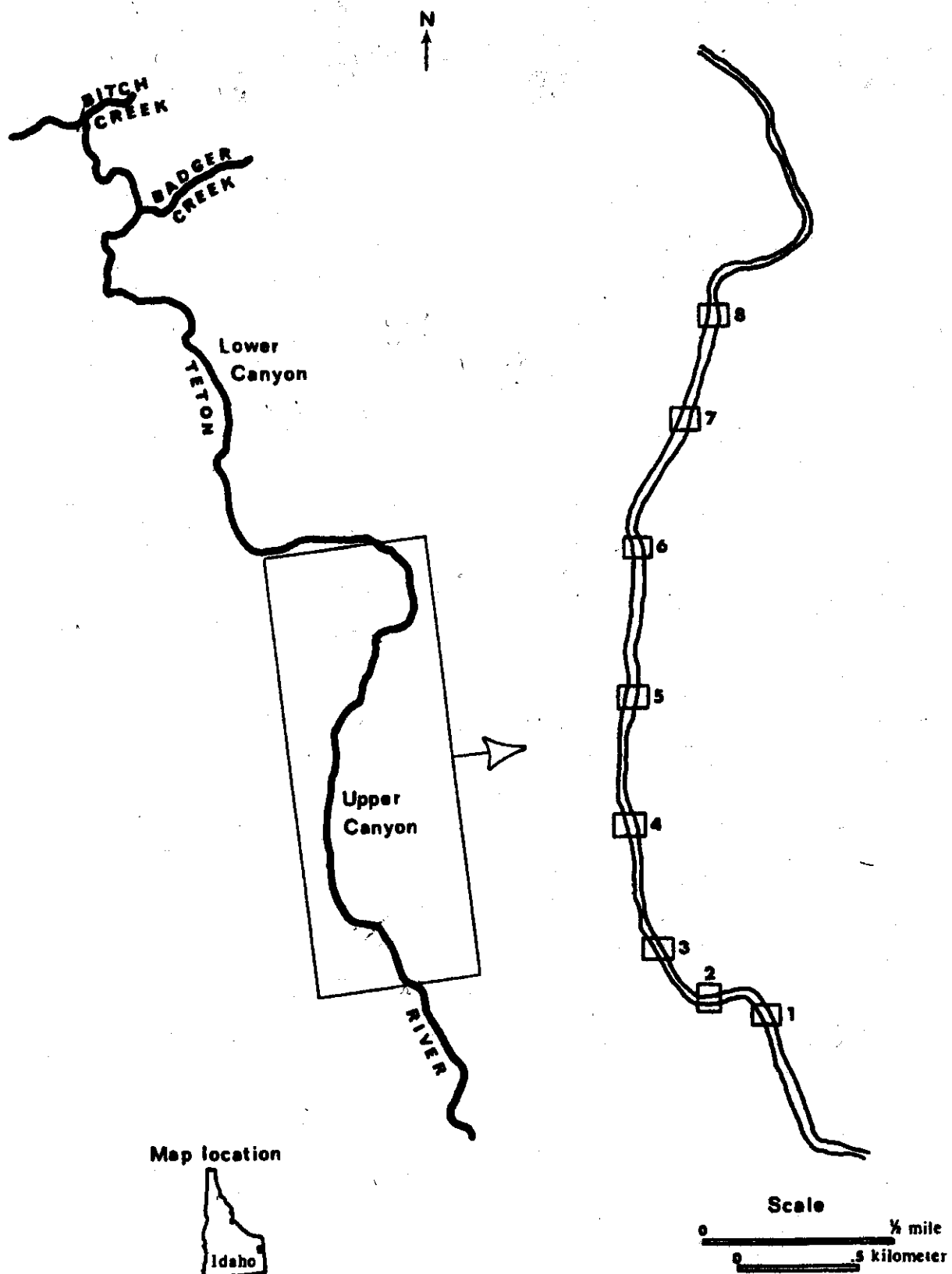


Figure 1. Map of the Teton River irrigation withdrawal study area and sampling sites.

Table 1. Comparison of predicted changes in selected physical parameters of representative transects at predicted flows within the study area, Teton River. (Adapted from White, 1976). Highlighted cells represent predicted physical parameters closest to requested instream amount of 106 cfs.

TRANSECT NUMBER	FLOW (CFS)	MEAN VELOCITY (FPS)	MEAN DEPTH (FT)
401	408	2.4	1.39
	198	1.6	1.02
	98	1.1	0.7
	50	0.7	0.55
501	395	2.2	1.56
	215	1.6	1.21
	97	1.0	0.85
	56	0.8	0.68
601	382	2.3	1.55
	211	1.7	1.18
	98	1.2	0.87
	61	0.9	0.68
705	367	2.3	1.68
	208	1.7	1.28
	96	1.2	0.91
	58	0.9	0.72
805	370	2.5	1.51
	208	1.9	1.18
	100	1.4	0.86
	60	1.1	0.70

Table 2. Literature values for “optimum” velocity and depth for rainbow trout (*Oncorhynchus mykiss*) and Yellowstone cutthroat trout (*O. clarki bouvieri*). Based on Bovee, 1978; Raleigh et al., 1984; and Cochnauer and Elms-Cockrum, 1986.

SPECIES	LIFE STAGE	VELOCITY (FPS)	DEPTH (FT)
Rainbow	Adult	0.7-2.0	1.5-2.0
	Juvenile	0.4-1.4	0.5-2.0
Cutthroat	Adult	0.75-1.75	>1.2
	Juvenile	0.6-1.8	>1.2

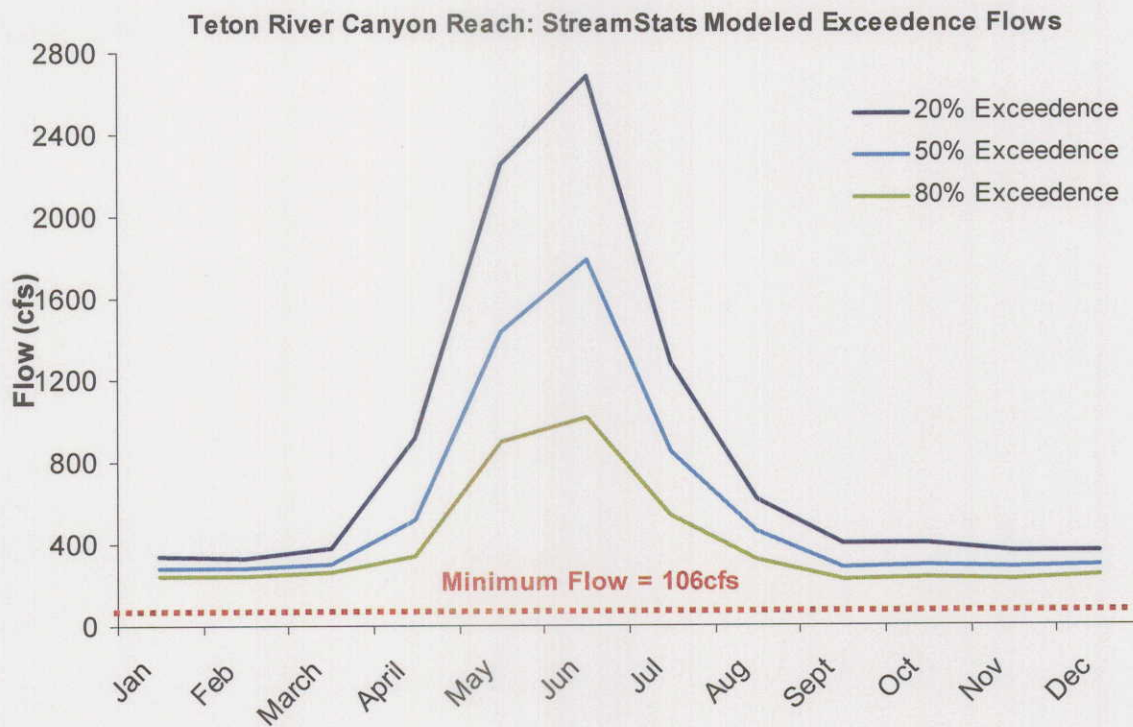


Figure 2: Teton River StreamStats modeled flows. Source: (<http://streamstats.usgs.gov/idstreamstats/>)

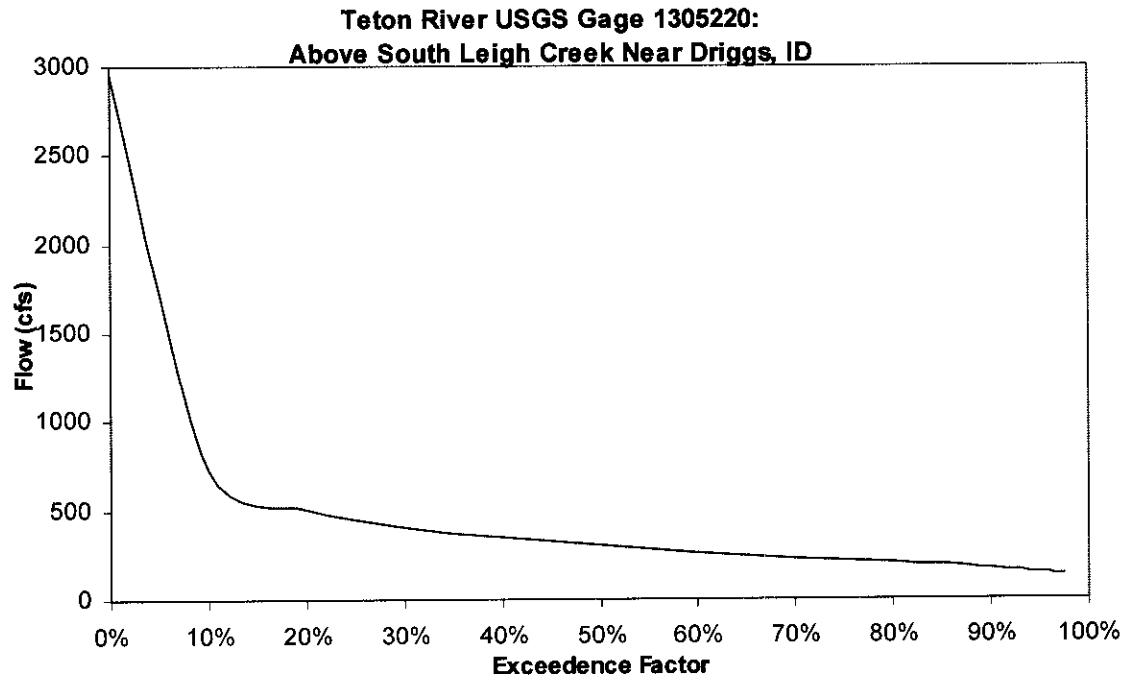


Figure 3: Gage data (1961-2003) from the Teton River above minimum instream flow reach (<http://waterdata.usgs.gov>) supports that a flow of 106cfs is capable of being maintained 95% to 99% of the time. Flows in the minimum flow reach would most likely be greater than the depicted flows due to inflows from tributaries between the gage and the minimum flow reach.

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College of Forestry, Wildlife
and Range Sciences

PREDICTED EFFECTS OF WATER WITHDRAWAL
ON THE
FISH POPULATIONS OF THE TETON RIVER, IDAHO

by
Robert G. White
Idaho Cooperative Fishery Research Unit

1976

Forest, Wildlife and Range
Experiment Station



University
of Idaho

Completion Report
to
U.S. Bureau of Reclamation
Boise, Idaho

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ABSTRACT

The primary objective of this study was to predict the effect on the fish population of proposed reductions in discharge which would result from irrigation withdrawal in a section of the Teton River, Idaho. Physical parameters were measured in representative habitats at known discharge and a predictive model was used to evaluate changes in habitat at reduced flows. Predicted changes in habitat were related to habitat requirements of aquatic insects and of rainbow trout.

The river channel in the study section was well defined, rectangular shaped and made up of riffle-run type habitat with essentially no pools and minimal overhanging streamside vegetation. The most abundant cover was the predominant rubble-boulder substrate in association with preferred depth.

With reduced discharge, predicted changes in depth and velocity over riffles were within the reported range of good aquatic insect habitat and wetted perimeter remained nearly constant. Therefore, aquatic insect production was not considered an important limiting factor for the rainbow trout population in the study area.

Predicted velocities in runs were found to be in the acceptable range for rainbow trout but as depth decreased with flow reduction, the amount of habitat with reported acceptable depth was reduced. It was hypothesized that the rainbow trout population in the study area would first be limited by decreases in cover, in the form of depth and that this decrease in cover could be related to decrease in the rainbow population. Based upon predicted changes in depth with reductions in discharge, a fish-cover-discharge relationship was developed for application to the study area. A general theoretical relationship between fish abundance and/or biomass in run-riffle and pool-riffle channels was discussed.

In evaluating effects of proposed irrigation withdrawal from the study section of the Teton River, it was concluded that in an average water year the effect of water withdrawal on the rainbow trout population would be minimal prior to early August, but that the fish population would theoretically be reduced by 16 to 54 percent during the remainder of the irrigation season. During low water years, when the fish population would theoretically decrease naturally, the effects of irrigation withdrawal would be more severe.

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INTRODUCTION

With man's ever increasing demand upon water resources for domestic, industrial, and irrigation uses, the problem of reduced discharge is becoming critical for many streams in northwestern United States. Biologists and managers are under increasing pressure to provide information on how much water is needed to meet the ecological requirements of fish species and what is lost in terms of fish numbers or biomass at various increments of reduced discharge.

Biological changes which result from alteration of in-stream flows are difficult to predict. This predictive difficulty arises from the many interactions which occur in the aquatic environment and the relationship of these interactions, both physical and biological, to a particular flow regime. However, when a water development project, such as an irrigation diversion, is proposed for a stream it is important to be able to predict its impact upon the fishery resource. Considerable interest in in-stream flow needs has been generated in the past few years but methodologies and information to determine stream resource maintenance flows are not well developed.

Methodologies span the range from those which are basically subjective, relying upon little or no field data, to ones based upon in-depth quantification of a number of variables which can be related to the ecological requirements of fish species. Most field oriented approaches are based upon field observations made at several increments of reduced discharge, occurring naturally or controlled by a dam or diversion. This approach is probably the most satisfactory if a realistic range of flows can be evaluated. However, in a situation like the Teton River, in which there was not opportunity to observe the river and fish populations at the smaller discharges that would result from water withdrawals for irrigation, we had to use other approaches to estimate the impacts of the reduced flows.

Recently, two predictive approaches have been proposed (Anonymous 1974; White 1975). The basic distinction between these methodologies and those previously used is the predictive component. From one set of field observations, channel morphology and hydraulic characteristics are predicted for various increments of reduced stage or discharge.

Prediction of the effects of a proposed flow regime on a fish population requires an understanding of habitat requirements of the species at each stage of its life history (spawning, incubation, and rearing). The most critical problem with making this prediction is that of relating the physical characteristics of the stream to the ecological requirements of the fish. Despite voluminous literature dealing with the life histories of fishes, comparatively little data is available on specific ecological requirements. Many studies have described food habits and the general habitat occupied by a particular species but few have ascertained the specific physical habitat requirements (such as depth and velocity) of the species or its food organisms. Knowledge of instream flow requirements of salmonid species is the most advanced, but even in this extensively studied group, information on rearing requirements is limited. Numerous studies have evaluated the changes in habitat associated with reductions in discharge, but to the author's knowledge only two have directly related habitat changes to the response of a fish population in terms of biomass and numbers (Kraft 1968, 1972; Nicholson 1976).

Recognizing the limitations but responding to the need for estimating the effects of water withdrawal on the fish population of the Teton River, this study was undertaken. The fishery resources of the Teton River drainage are valuable to a large number of recreationists. The recently completed Teton Dam will impound a 17-mile (27.4 km) stretch of the Teton River. In addition there are applications for irrigation withdrawal permits of more than 120 cfs (3.36 cu m/sec) from the free flowing river immediately above the impounded area. This study was an attempt to estimate the effects of various increments of reduced discharge on the fish population in this portion of the river. The objectives were:

1. To determine the morphometry of the channel of the Teton River from the point of water withdrawal downstream to the mouth of Bitch Creek.
2. To determine the velocity, depth, and area wetted along selected transect lines across the river at the range of flows present in 1974 and at projected flows with water withdrawal.
3. To assess the fish and insect populations present in section of river to be affected by water withdrawal.

4. To relate the changes in stream depth, velocity, and wetted area with reduced flows to changes in fish and insect populations and estimate the impact of projected flows on fish and insect abundance in the study section of the river.

STUDY AREA

The Teton River irrigation withdrawal study area begins about 1 mile (1.6 km) below highway 33 bridge at the mouth of Teton Canyon, (Section 15, Tetonia quadrangle) and extends downstream for ~~6.4~~^{8.8} miles (~~10.3~~^{14.2} km) to the confluence of the Teton River with Bitch Creek (Figure 1). Above the study area the river meanders through a broad flood plain, draining an area of about 335 square miles (868 sq km). The surrounding land is intensively developed for agriculture with irrigation diversion above the study area of about ~~42,000~~^{4,200} acres (1699.7 hectares) of which about 1,000 acres (404.7 hectares) are by withdrawals from ground water.

Throughout the study area, the river is confined within the Teton Canyon. Depth of the steep-walled canyon becomes progressively greater and the channel narrows as one moves downstream. The channel is relatively straight with a rectangular shape; bottom materials are predominantly rubble and boulder. There is only a moderate amount of overhanging stream side vegetation and essentially no undercut banks; riffles and runs are the predominant habitat types. The upper 3 miles (4.8 km) of the study section had widths ranging from 110 to 130 ft (33.5 to 39.6 m) at a discharge of approximately 520 cfs (14.7 cu m/sec). The flow system in this portion of the river has no man-made controls except for irrigation diversion from the tributaries.

Streamflow in the Teton River usually reaches a minimum in January and peaks in June (discharge records from United States Geological Survey (USGS) Gauge Station near Tetonia, Idaho, located a short distance above the study area and from USGS Gauge Station 1305220 on the Teton River upstream from South Leigh Creek, 4 miles above the study area). The maximum recorded daily discharge of 2,270 cfs (64.3 cu m/sec) occurred June 18, 19, 1974 and the minimum daily discharge of 62 cfs (1.7 cu m/sec) on January 16, 17, 1943.

The average daily flow for the period of record (32 years, 1930 to 1974, discontinuous) is 395 cfs (11.1 cu m/sec) as compared to 407 cfs (11.4 cu m/sec) for the most recent 13 years (1961-1974). For the irrigation season, June-September, the average daily flow for the period of record is 559 cfs (15.6 cu m/sec), a flow which is equaled or exceeded 37 percent of the time (Figure 2). During this same period the minimum flow was 100 cfs (2.8 cu m/sec) September 21, 1934 with a maximum of 2,270 cfs (64.3 cu m/sec) June 18, 19, 1974 (Appendix 1).

September flows are the lowest encountered by the fish population during the irrigation season. Mean flow for September for the period of record is 356 cfs (9.97 cu m/sec) while mean minimum flow for September is 317.5 cfs (8.9 cu m/sec) (Appendix 1).

METHODS

We approached the problem of predicting effects of irrigation withdrawal upon the fishery resource of the Teton River by: 1) measuring physical parameters in the field, 2) predicting physical habitat available at reduced flows, and 3) relating predicted habitat changes to known ecological requirements of fish and invertebrate populations and then estimating the response of fish populations to the reduced discharge.

Sample Sites:

After a reconnaissance of the study area we selected eight sites which we considered representative of the habitat present; four in the upper canyon and four in the lower canyon (Figure 1). Sampling sites in the lower canyon had velocities and/or depths which precluded making physical measurements. We therefore concentrated our efforts in the upper section by selecting four additional study sites. Because of channel configuration, it was assumed that fish populations in the narrow, deeper zone of the lower canyon would be less affected by flow reduction than fish in the more shallow and wider upper canyon area. Two sets of field observations were taken; one in August, 520 cfs (14.6 cu m/sec) and one in September, 380 cfs (10.6 cu m/sec), 1974, so we could compare actual measured habitat changes with predicted changes using a computer model.

Sample sites were 160 ft (48.8 m) in length and consisted of five transects at 40 ft (12.2 m) intervals. Transects were established perpendicular to the thalweg and were permanently marked with wooden stakes.

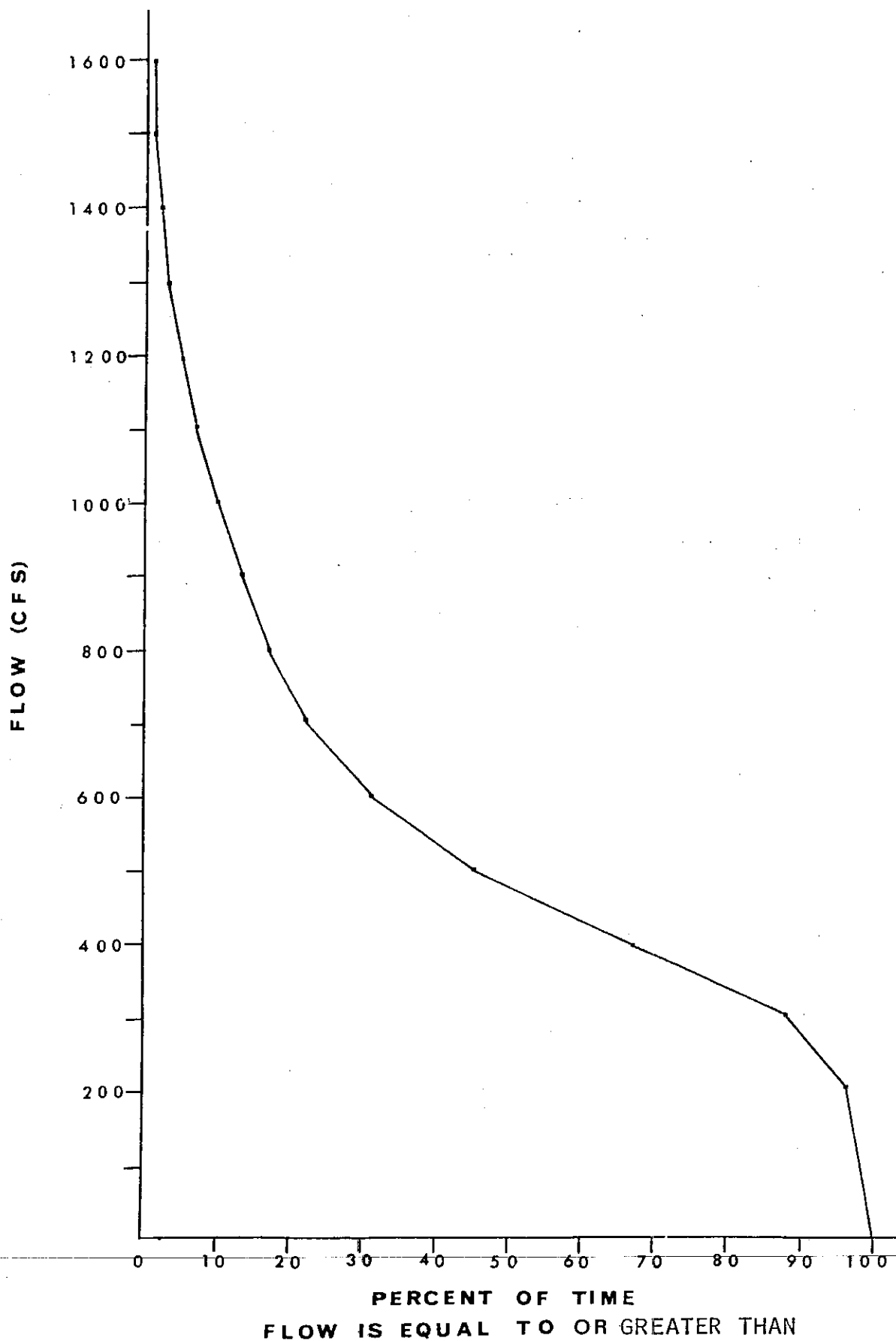


Figure 2. Flow duration curve for Teton River for the irrigation season, June-September, based upon 31 years of record.

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Physical Data:

We made physical measurements at 3 ft (0.9 m) intervals along a marked rope stretched across the river at each transect location. We measured velocity along the transect with a current meter at 0.6 depth. In transects 2, 3, and 4, at each site, velocity measurements were made at 6 ft (1.8 m) intervals except near shore. Depth was measured to the nearest 0.01 ft (0.003 m) with a stadia rod at 3 ft (0.9 m) intervals in all transects. A plane table map was drawn of each study site. Photographs were also taken of each study section at the time of cross-sectional measurement.

Predominant substrate type and location of aquatic vegetation were recorded for each 3 ft (0.9 m) interval. Categorization of substrate was as follows:

Silt-sand	< 0.1 inch (0.25 cm)
Gravel	0.1-2.9 inches (0.25-7.4 cm)
Cobble	3.0-5.9 inches (7.6-15.0 cm)
Rubble	6.0-12 inches (15.2-30.5 cm)
Boulder	> 12 inches (30.5 cm)

Biological Data:

Distribution and relative abundance of aquatic invertebrates was determined from seven bottom samples (Hess Sampler) taken along transect 5 in each of sections 2, 4, 6, and 7. Bottom samples were taken on both sides of the channel immediately next to shore (4 samples) and at the point where the first major change in substrate was observed (2 samples). In addition, one sample was taken at the approximate mid point of the channel. Depth, velocity, and substrate composition were recorded at each sampling site. Aquatic insects were picked, classified to family, and enumerated in terms of numbers and volume.

Fish samples were collected by electrofishing and angling. Each specimen was identified and total length recorded. Creel-census information, collected in an on-going angler use and attitude study, was also utilized.

Historical Streamflow Data:

Historical streamflow data were obtained from USGS records (1930-32, 1934, 1941-56, 1962-1973) and used in flow duration and recurrence flow analysis.

Data Analysis:

Due to unavailability of techniques to predict point velocities with decreased flows, it was not possible to develop depth-velocity contour maps of each study area as originally planned. Since channel configuration and mean hydraulic characteristics of each transect within a study site were similar, one transect from each of five sites was selected for final analysis. We considered these transects representative of the habitat present in the entire upper canyon study area.

Transect data were analyzed by the Forest Service R-2 "Cross" computer program designed to calculate a series of hydrologic parameters from transect field data (collected by the sag-tape method) and Manning's formula for stream discharge. The program produces a computer plot of the measured cross section and computes stream discharge, average flow velocity, wetted perimeter, cross-sectional area, maximum water depth, and hydraulic radius for the actual streamflow at the time of measurement as well as for various selected water stages (Anonymous 1974).

Data input included tape weight, tape tension, distance from high water line to observed water line and to each depth reading, depths, width, slope, and roughness coefficient. Although we used survey techniques for collecting transect data, we were able to use the program by using minimum tape weight (.0001 lbs) and maximum tape tension (99.9 lbs). In addition to these data it is also necessary to have an accurate measurement of discharge, taken at the time of cross-section measurement. Discharge and transect data are used to refine the estimated Manning's "n" value. For a more detailed account of the use of the R-2 "Cross" program see Appendix 2.

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RESULTS

Predicted values for select physical parameters at each transect at each discharge level, expressed as percentage of the value obtained at the predicted flow nearest 100 percent of the average daily flow (ADF), are summarized in Table 1; predicted values of all physical parameters studied are summarized in Appendix 3. Predicted flows nearest the ADF were selected so we would have a common reference point for making comparisons. Although we planned to compare predicted with observed values at two flow regimes, we were unable to do so due to the method of analysis. However, Forest Service hydrologists have tested the model and it has proven to give reliable predictions in riffle-run type channels.

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Table 1. Comparison of predicted changes in physical parameters of five representative transects within the irrigation withdrawal study area, Teton River, expressed as percentage of the predicted flow nearest 407 cfs (average daily flow).

Transect number	Percentage average daily flow	Flow	Cross Sectional Area	Wetted Perimeter	Velocity	Mean depth
401	100	408	100 (0.54) ^{1/}	100 (0.02)	100 (0.65)	100 (0.52)
	49	198	72.3 (0.86)	99.2 (0.15)	66.7 (0.74)	73.4 (0.81)
	32	129	58.8 (0.91)	96.7 (0.00)	54.2 (1.11)	59.7 (1.22)
	24	98	50.9 (1.05)	96.7 (0.13)	45.8 (0.67)	50.4 (0.59)
	18	74	44.5 (1.21)	95.9 (0.00)	41.7 (2.19)	46.8 (1.26)
	12	50	37.6	95.9	29.2	39.6
	97	395	100 (0.53)	100 (0.02)	100 (0.60)	100 (0.49)
	53	215	75.7 (0.75)	99.1 (0.00)	72.7 (0.80)	77.6 (0.72)
	36	148	63.0 (0.94)	99.1 (0.20)	59.1 (1.05)	65.4 (0.84)
	24	97	50.8 (1.02)	96.5 (0.50)	45.5 (0.85)	54.5 (0.94)
	19	76	45.3 (1.22)	93.8 (0.18)	40.9 (0.80)	49.4 (1.16)
	14	56	39.2	92.9	36.4	43.6
601	94	382	100 (0.58)	100 (0.08)	100 (0.58)	100 (0.53)
	52	211	74.1 (0.68)	96.4 (0.00)	73.9 (0.95)	76.1 (0.66)
	35	141	61.7 (0.99)	96.4 (0.73)	56.5 (0.38)	64.5 (0.75)
	21	98	50.6 (1.27)	88.2 (0.57)	52.2 (1.35)	56.1 (1.25)
	15	61	38.2	82.7	39.1	43.9

Table 1. (Continued)

Transect number	Percentage average daily flow	Flow	Cross Sectional Area	Wetted Perimeter	Velocity	Mean depth
705	90	367	100	100	100	100
			(0.58)	(0.04)	(0.60)	(0.55)
	51	208	74.8	98.1	73.9	76.2
			(0.67)	(0.02)	(0.77)	(0.63)
	36	146	63.5	97.7	60.9	65.5
			(0.83)	(0.03)	(0.63)	(0.83)
805	24	96	52.2	97.3	52.2	54.2
			(1.09)	(0.00)	(1.26)	(1.09)
	14	58	40.9	97.3	39.1	42.9
	91	370	100	100	100	100
			(0.58)	(0.14)	(0.55)	(0.50)
	51	208	74.5	93.8	76.0	78.1
			(0.87)	(0.61)	(0.53)	(0.61)
	37	152	61.4	84.5	68.0	68.9
			(0.83)	(0.00)	(0.85)	(0.84)
	25	100	49.7	84.5	56.0	57.0
			(1.02)	(0.29)	(1.11)	(0.98)
	15	60	38.6	81.4	44.0	46.0

^{1/}Value in parenthesis is ratio of percentage parameter decrease to percentage flow decrease.

Predicted Hydrologic Parameters:

Predicted velocity and cross sectional area were the parameters most critically influenced by reduced discharge in each transect. These data agree with empirical findings of Kraft (1968), McClay (1968), Banks et al. (1973), and Wesche (1973, 1974). At the five transects analyzed, mean velocity and cross sectional area decreased 62.4 and 61.1 percent respectively from 94.4 percent {384 cfs (10.87 cu m/sec)} to 14 percent {57 cfs (1.61 cu m/sec)} average daily flow (ADF) (Table 2, Figure 3). At 14 percent ADF, mean transect depth was reduced 56.8 percent from the 94.4 mean percent ADF level. Least affected by dewatering was wetted perimeter with a mean reduction of only 10 percent at low flow (Table 2, Figure 3). Changes in physical morphology with reductions in discharge are best visualized by examining changes associated with flow reductions at one transect (Figure 4). Due to the rectangular shape of the channel, it is readily evident why changes in wetted perimeter and surface width are small with large reductions in discharge.

Hydraulic parameters did not decrease at a constant rate between discharge levels (Figure 3). The largest decrease in physical parameters for the means of all transects combined per unit flow reduction occurred between 23.6 percent and 14 percent ADF (Table 2). Although these results are similar to those reported by Wesche (1973, 1974), the change in rate of habitat loss below 23.6 percent ADF was not as large.

Although the R 2 "Cross" model does not predict point changes in depth, calculations of hydrologic parameters are based upon a particular water stage, thus making it possible to evaluate point changes in depth by manipulating observed depth values. Mean depth at each transect at all predicted flows differed a maximum of only 0.35 ft (0.11 m) (Figure 5). The percentage of surface area with depth ≥ 1.5 ft (0.46 m) decreased from 64 percent of the area at 94 percent ADF to 2.4 percent at 23 percent ADF and no area ≥ 1.5 (0.46 m) in depth was present at 14 percent ADF. Percent of depth < 0.5 ft (0.15 m) and 0.5-0.99 ft (0.15-0.30 m) increased in a similar pattern to the decrease in depth of water ≥ 1.5 ft (0.46 m); the percentage of the surface area 1.0-1.49 feet in depth (0.30-0.45 m) first increased and then decreased (Figure 6).

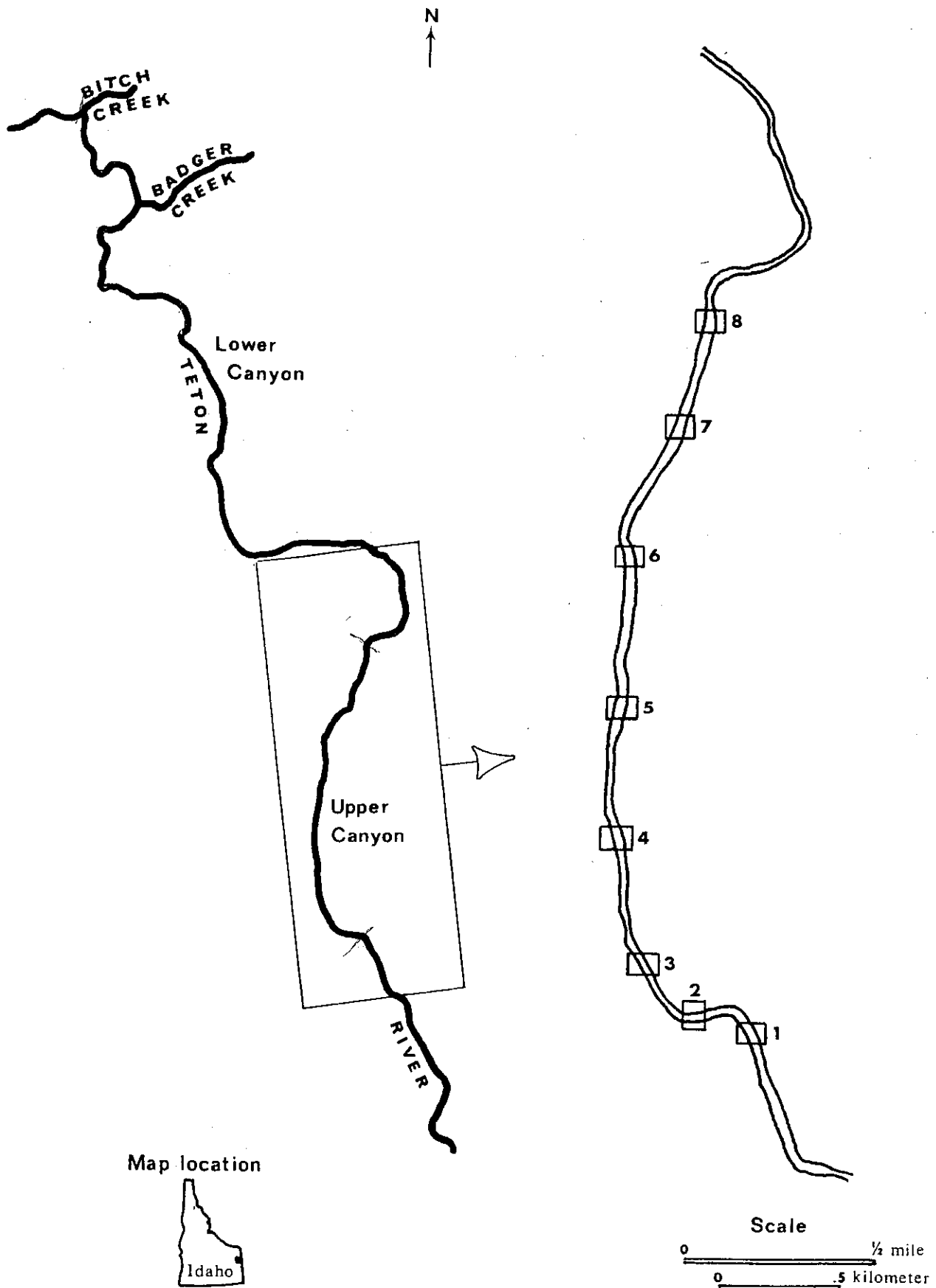


Figure 1. Map of the Teton River irrigation withdrawal study area and sampling sites.

Table 2. Comparison of mean predicted changes in physical parameters of five representative transects within the irrigation withdrawal study area, Teton River, expressed as percentage of the value obtained at the predicted flow nearest 407 cfs (average daily flow).

Mean percent average daily flow	Mean flow	Cross sectional area	Wetted perimeter	Velocity	Mean depth
94.4	384.2	100	100	100	100
		(0.59) ^{1/}	(0.06)	(0.63)	(0.55)
51.2	208.4	74.3	97.3	72.6	76.3
		(0.74)	(0.14)	(0.76)	(0.68)
35.2	143.3	61.7	94.9	59.7	64.8
		(0.94)	(0.20)	(0.81)	(0.90)
23.6	96.0	50.8	92.6	50.3	54.4
		(1.24)	(0.27)	(1.32)	(1.17)
14.0	57.0	38.9	90.0	37.6	43.2

^{1/}Value in parenthesis is ratio of percentage parameter decrease to percentage flow decrease.

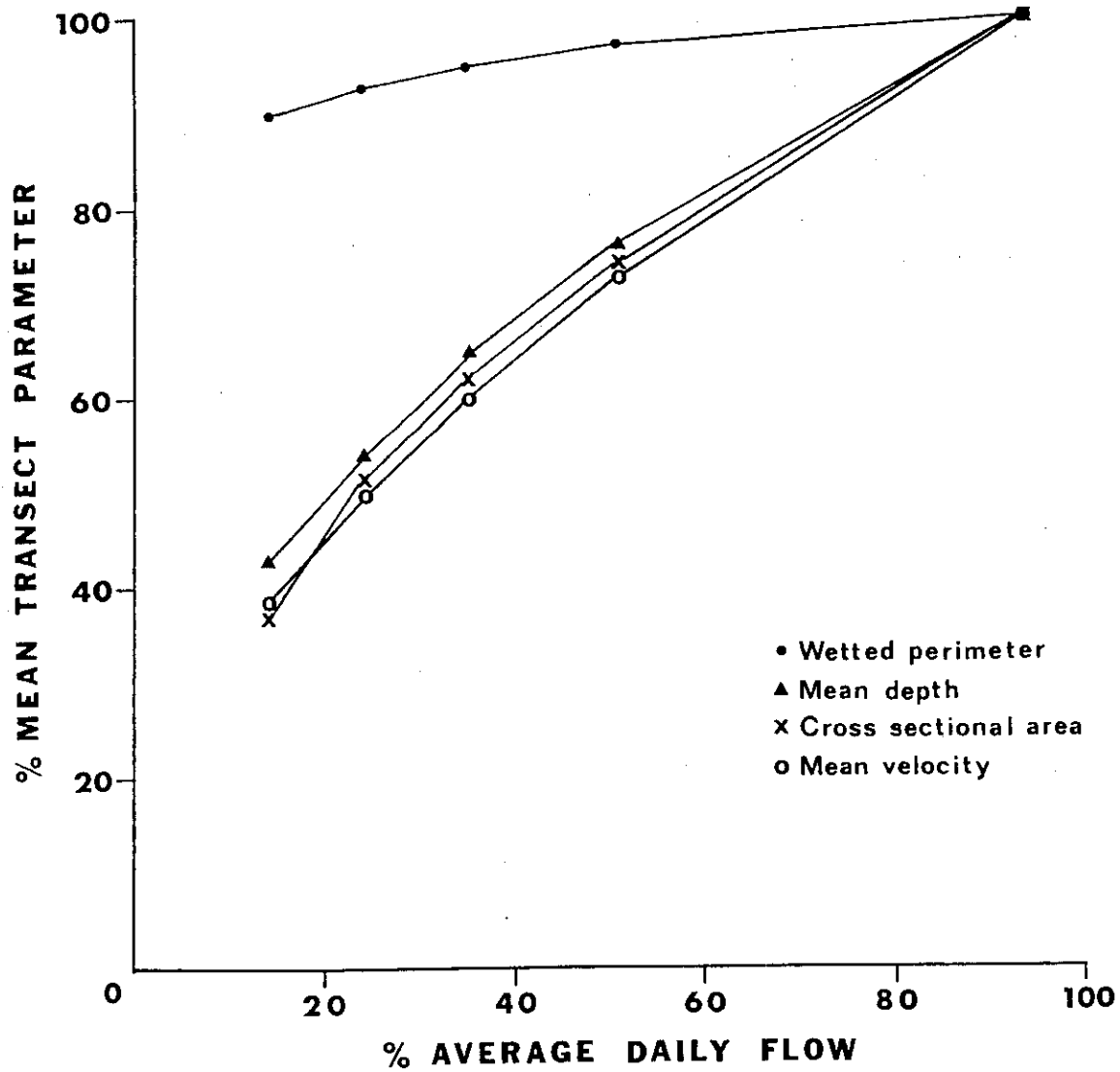
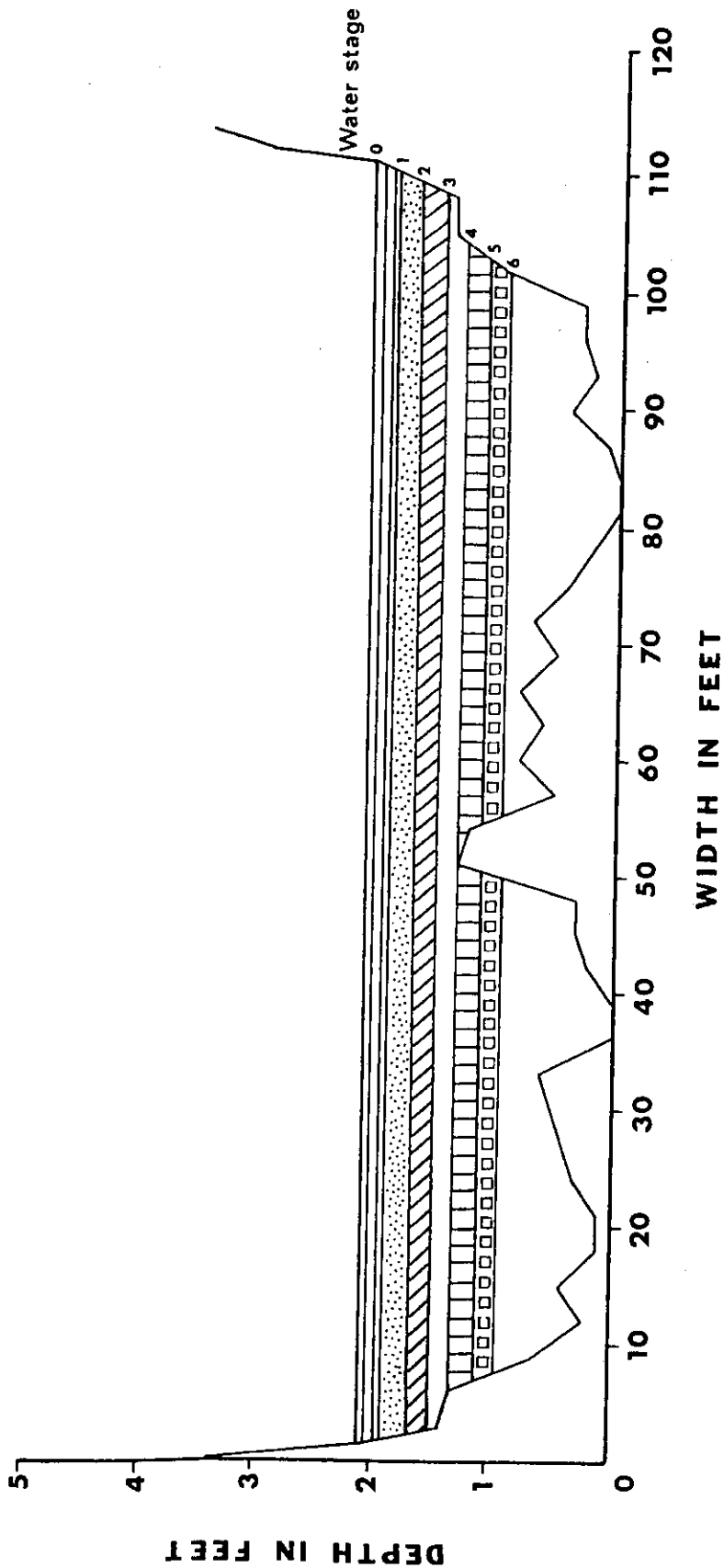


Figure 3. Comparison of predicted changes in mean transect parameters with reduced discharge.



Flow (cfs)	Percent average daily flow	Cross Sectional area (sq ft)	Wetted perimeter (ft)	Mean velocity (fps)	Mean depth (ft)	Maximum depth (ft)	Hydraulic radius (ft)
382	94	170	110	2.3	1.6	2.1	1.5
291	71	147	107	2.0	1.4	1.9	1.4
211	52	126	106	1.7	1.2	1.7	1.2
141	35	105	106	1.3	1.0	1.5	1.0
98	21	86	97	1.2	0.9	1.3	0.9
61	15	65	91	0.9	0.7	1.1	0.7

Figure 4. Comparison of predicted changes in hydrologic parameters with stages of reduced discharge, study section 600, Teton River, 1974.

Figure 4. Comparison of predicted changes in hydrologic parameters with stages of reduced

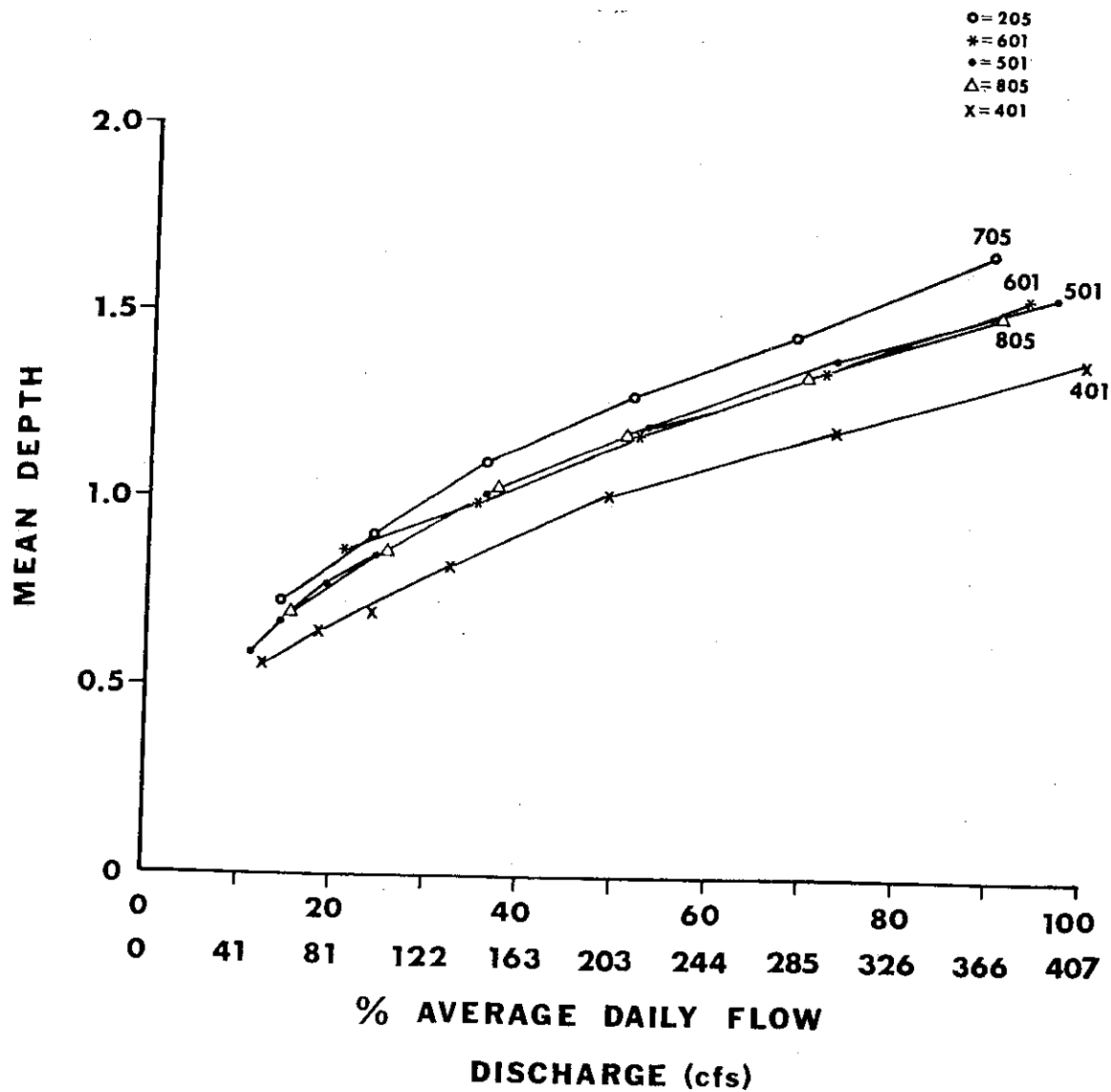


Figure 5. Comparison of changes in mean depth of five representative transects with decreases in discharge.

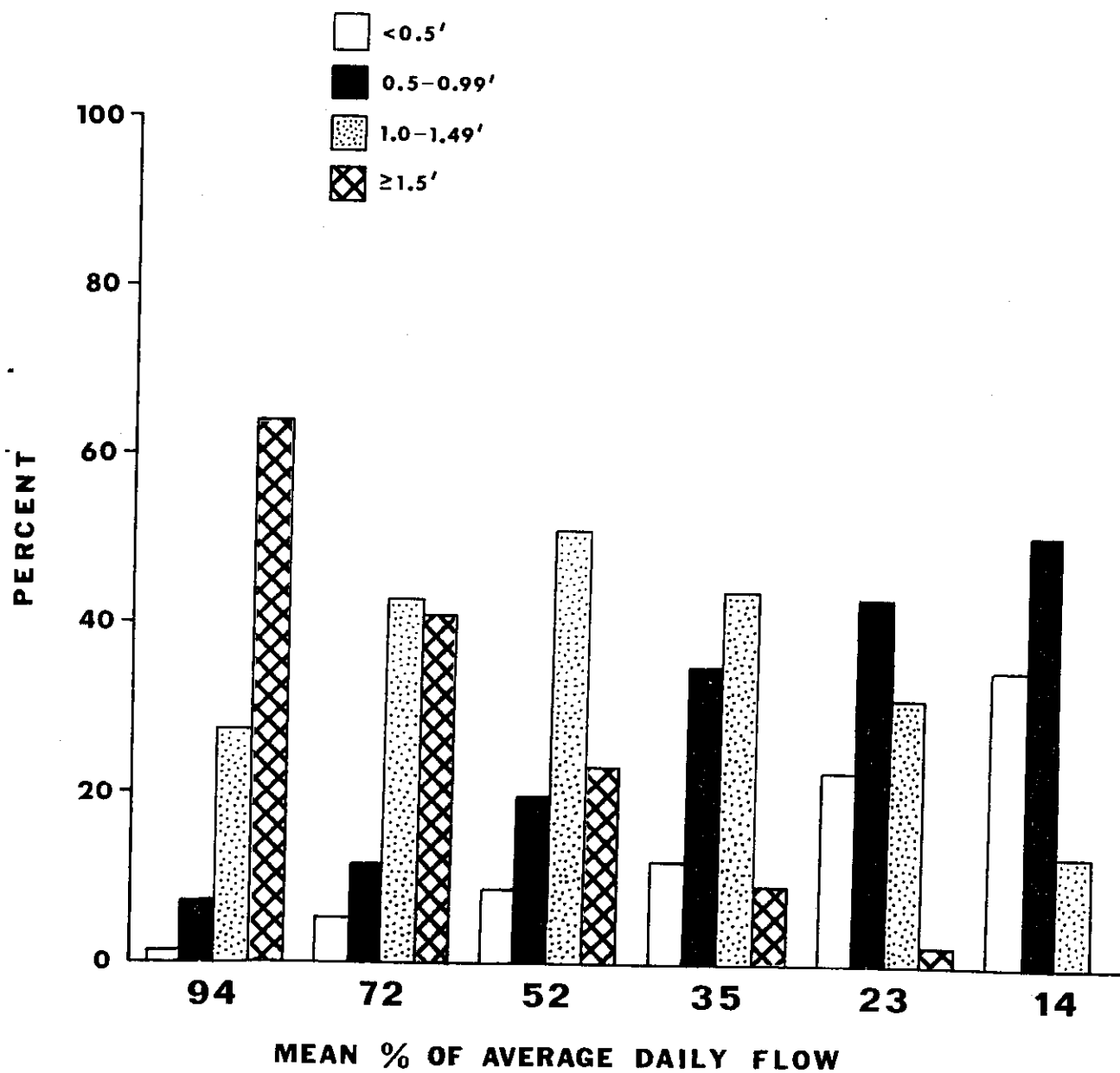


Figure 6. Comparison of mean percentage changes in depth distribution as affected by reduced discharge.

Fish and Aquatic Insect Populations:

By angling and electrofishing in the irrigation withdrawal study area we found the relative abundance of trout species to be as follows:

Species	Total number	Relative abundance
Rainbow trout (<u>Salmo gairdneri</u>)	220	76.2%
Brook trout (<u>Salvelinus fontinalis</u>)	45	15.5%
Cutthroat trout (<u>Salmo clarki</u>)	24	8.3%

All trout collected were larger than 6 inches (15.2 mm) total length. Mountain whitefish (Prosopium williamsoni) were not present in the angler catch but made up 68.3 percent of the electrofishing catch. Irving, Elle and Bjornn (1975) found mountain whitefish to be the most abundant species in all sections of the Teton River sampled, including the irrigation withdrawal study area. Small numbers of redbside shiner (Richardsonius balteatus) and suckers (Catostomus sp.) were also collected.

Aquatic insect abundance varied considerably between transects, but sample size was too small to determine if variation was real or an artifact of sampling procedure. Numbers and volume of aquatic insects collected typically were small next to shore; maximum in samples taken at the point of first major change in the physical character of the channel and intermediate in mid-channel samples. Needham (1934) and Needham and Usinger (1956) report similar distribution in large streams. *In general, maximum number of aquatic insects was associated with water deeper than 1.5 ft (0.46 m) and velocities faster than 1.0 ft/sec (0.6 m/sec). However, other variables were interacting as evidenced by physical conditions at mid-channel (where insect abundance was intermediate) being similar to those of the maximum abundance area. Total abundance of aquatic insects showed a progressive decrease between transects sampled from the upstream to downstream sites.

Aquatic insect families found in the study area in order of relative abundance were Trichoptera (70.5%), Coleoptera (8.9%), Ephemeroptera (7.7%), Diptera (7.5%), Plecoptera (4.9%), and Hemiptera (0.5%).

Historical Flow Analysis:

Recurrence intervals based on mean flows for (a) the entire irrigation season, June-September, (b) each month of the irrigation season and (c) 14-day mean flows through the irrigation season, were determined from historical flow data for the 31 year period of record. Evaluation of these data provide some insight into how often a particular flow condition may reoccur. It is important to point out, however, that "recurrence interval" is a statistical term and is not analogous to a timetable; a recurrence interval of 20 years does not mean that every 20 years a mean flow of a particular magnitude will occur. It simply means that on an average interval of 20 years over a long period of time, a flow equal to or less than the one specified will occur (Kazmann, 1972).

The probabilities that at least one flow will occur, which equals or is less than a particular recurrence interval flow, were calculated for the period of record by the method described by Linsley and Franzini (1964) (Table 3). These show, for example, that there are four chances in 10 that a 20-year mean flow (or less) will occur in any 10 year period and even a 26 percent chance that a 30 year mean flow will occur in the 10 years. On the other hand, there are 29 chances in 100 that the 30-year mean flow will not occur in any 25-year period.

Taking all months of the irrigation season collectively, flows of 370 cfs (10.47 cu m/sec) (91% ADF), 200 cfs (5.66 cu m/sec) (49% ADF), and 140 cfs (3.96 cu m/sec) (34% ADF) have recurrence intervals of 1, 6, and 11 years respectively (Figure 7). Effects of various increments of reduced discharge on the recurrence interval are depicted. Since low flows normally do not occur in June or July, recurrence interval plots were also constructed for each month of the irrigation season. These data provide information, by month, on recurrence of a particular mean discharge. For example, the recurrence interval for a mean flow of 300 cfs (8.4 cu m/sec) or less is approximately 11, 11, 9.5, and 4.5 years for June, July, August and September, respectively (Figures 8-11).

Although fish populations may not be adversely affected by low flows of short duration (less than one week), extended exposure to low flow conditions may result in population reduction. The question is, how long can a fish population be subjected to a low flow without being affected? Although we

Table 3. Probability that a flow of given recurrence interval will be less than or equaled during periods of various lengths.

Return period (years)	Period (Years)									
	1	5	10	20	30	40	50	75	100	200
1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2	0.5	0.97	0.999	*	*	*	*	*	*	*
5	0.2	0.67	0.89	0.99	0.999	*	*	*	*	*
10	0.1	0.41	0.65	0.88	0.97	0.98	0.995	0.999	*	*
15	0.07	0.29	0.50	0.75	0.88	0.94	0.97	0.994	0.999	*
20	0.05	0.23	0.40	0.64	0.78	0.87	0.92	0.98	0.995	0.999
25	0.04	0.18	0.33	0.56	0.71	0.80	0.87	0.95	0.98	0.999
30	0.03	0.14	0.26	0.46	0.60	0.70	0.78	0.90	0.95	0.998

* In these cases the probability can never be exactly 1, but for all practical purposes its value may be taken as unity.

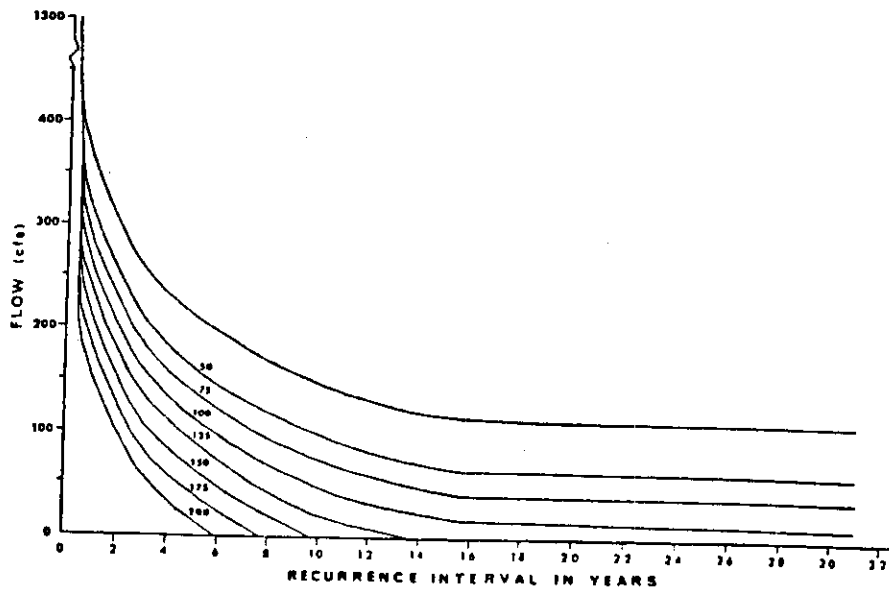


Figure 7. Recurrence intervals of mean monthly flows, June-September for the 31 year period of record, 1930-1973 (incomplete), and how these intervals would be affected by reductions in discharge.

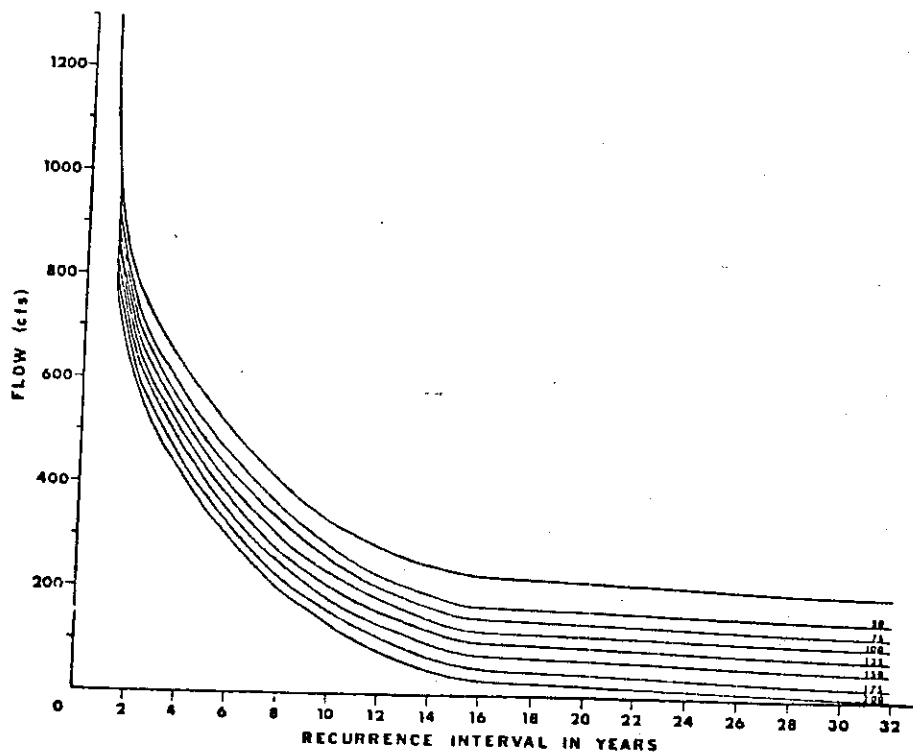


Figure 8. Recurrence intervals of mean monthly flows for June, for the 31 year period of record 1930-1973 (incomplete), and how these intervals would be affected by reductions in discharge.

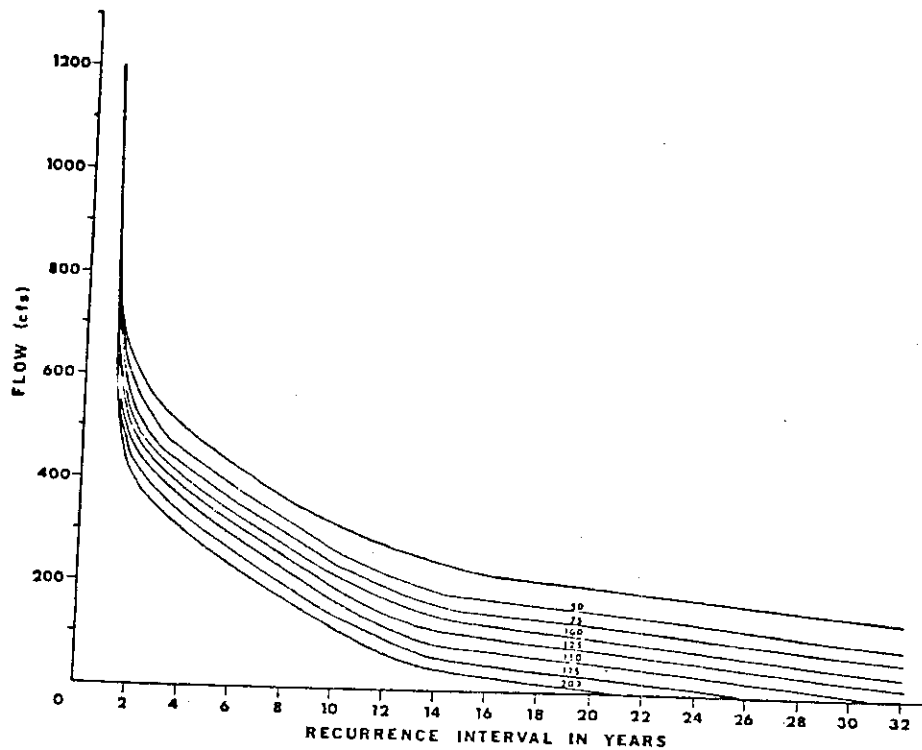


Figure 9. Recurrence intervals of mean monthly flows for July, for the 31 year period of record 1930-1973 (incomplete), and how these intervals would be affected by reductions in discharge.

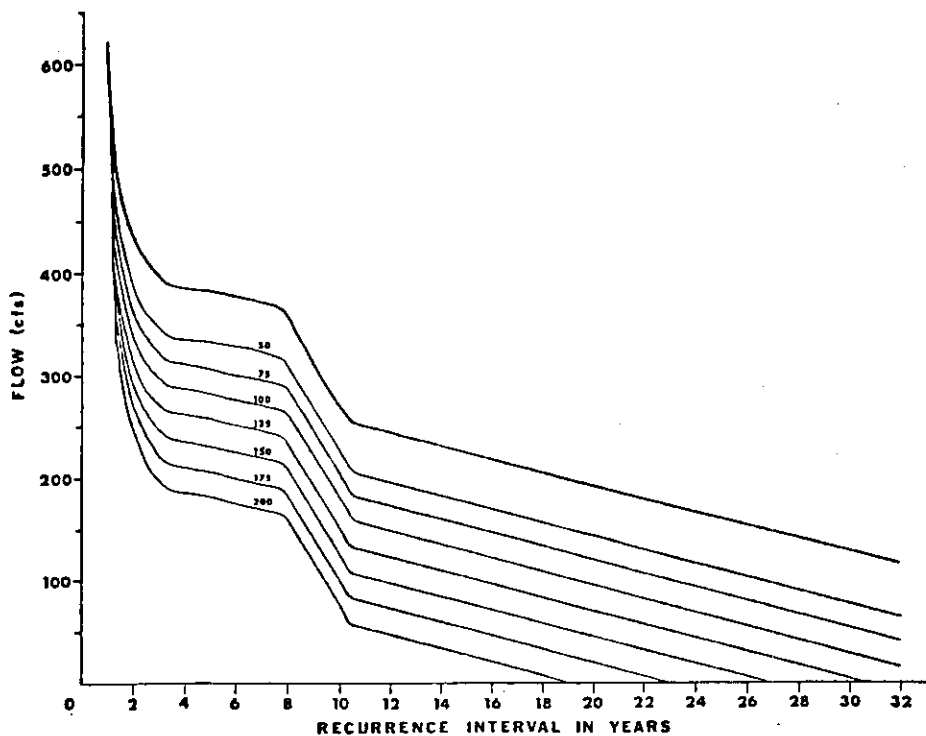


Figure 10. Recurrence intervals of mean monthly flows, for August, for the 31 year period of record, 1930-1973 (incomplete), and how these intervals would be affected by reductions in discharge.

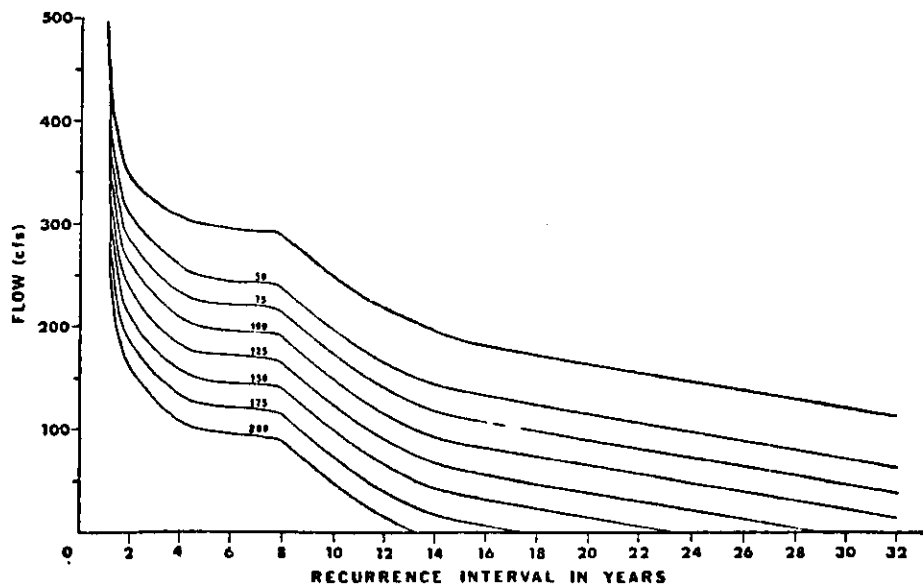


Figure 11. Recurrence intervals of mean monthly flows for September, for the 31 year period of record 1930-1973 (incomplete), and how these intervals would be affected by reductions in discharge.

have little data to support it, a 14-day flow period is suspected to be a sufficient length of time to bring about a population response. Kraft (1968, 1972) found that by reducing flows 90 percent of a base flow level, movement of fish out of the study area reached a peak 10 days after dewatering was completed. Therefore, the effects of low flows on fish populations may be realized in a shorter period of time than 14 days. Examination of the recurrence intervals based upon 14-day mean flows for the period of record reveal that a mean flow of 120 cfs (3.4 cu m/sec) has a recurrence interval of 8.5 years (Figure 12). Therefore, over a long period of time, with irrigation withdrawals of 120 cfs (3.4 cu m/sec), the river would be dried up on the average of once every 8.5 years.

The 14-day recurrence interval curve is influenced by the extreme low flows of 1931 and 1934. If these years are omitted, the recurrence intervals are changed (Figure 12), with the recurrence interval of a 120 cfs (3.4 cu m/sec) flow being longer than 34 years. It would be convenient to drop extremely low flow years but since we do not have a long enough period of record, there is no evidence to support doing so. That is, we do not know if the 1931 and 1934 low flows were 30 year, 50 year, 100 year or longer low flow events.

DISCUSSION

The primary objective of this study was to predict the response of fish populations in a section of the Teton River to proposed reductions in discharge which would result from irrigation withdrawal. Physical parameters were measured in the field at known discharge and a predictive model was used to evaluate changes in habitat at reduced flows. The next step, and the most difficult, is to relate predicted changes in habitat to probable response of the fish populations. To do this one must consider the habitat requirements of important fish species at each life history stage (spawning, incubation, and rearing) affected by discharge reduction.

During the irrigation season, June-September, the major biological activity of rainbow trout, the dominant trout species in the study section of the Teton River, is rearing. Rearing refers to all requirements for successfully completing the life history stages of fish species from hatching to spawning age. For most stream fishes this includes several size and age classes. Assuming good water quality, other important habitat requirements for rearing include

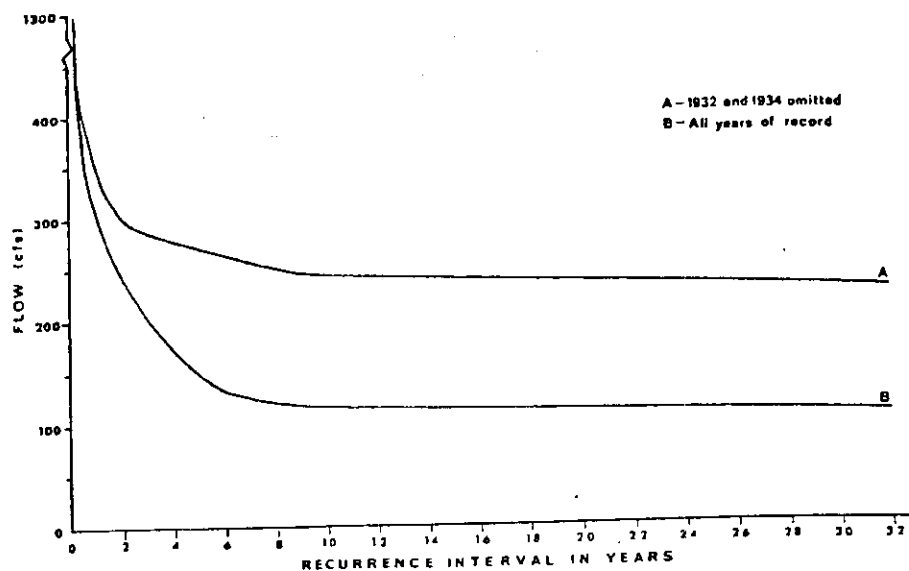


Figure 12. Recurrence interval of mean 14 day flows, June-September, for the 31 year period of record, 1930-1973 (incomplete), and how recurrence intervals would be affected if extreme low flow years (1932 and 1934) were omitted.

adequate food supply and suitable cover, both of which are influenced by discharge. The complexity and significance of the organism-cover-discharge relationship, although recognized, is not well understood. However, it is not difficult to visualize reductions in flows affecting the quantity and quality of instream and riparian cover and the production of fish food organisms.

Cover has long been recognized as one of the essential elements of fish habitat. Cover serves as a means of predator avoidance and provides areas of moderate velocity utilized by fish as resting microhabitat (Giger 1973). Cover for fish in streams is provided by undercut banks, overhanging vegetation, submerged objects, submerged vegetation, water depth, and water turbulence.

Many studies have indicated a relationship between cover and trout populations. For example, Gunderson (1966) found that brown trout occupying a stream section with a higher percentage of deeper water and more cover were 27 percent more numerous and 44 percent larger, by weight, than those occupying a section of the same stream having less cover and shallower water. Lewis (1969) reported that 66 percent of the variation in trout numbers between pools in Little Prickly Pear Creek, Montana, was accounted for by cover and current velocity and Boussu (1954) found that the removal of undercut banks and brush in a stream section was followed by a decrease in trout numbers and weight.

Cover requirements of salmonids are not easily determined. Cover needs may vary diurnally, seasonally, by fish species, and by fish size. In addition, definitions of what constitutes cover and how it is measured are neither clear nor consistent (Giger 1973)

Types of cover available differ from stream to stream, depending upon stream size and channel configuration. In the upper canyon area of the Teton River, the channel is well defined, rectangular shaped, and made up of riffle-run type habitat with essentially no pools; overhanging streamside vegetation is minimal. The most abundant and probably the most important cover is provided by the predominant rubble-boulder substrate.

In examining the probable relationship between rainbow trout populations and discharge in the study section of the Teton River, the fundamental question is, what will become limiting as flows are reduced? Biological criteria of

rainbow trout for rearing are not well documented. Some data are available on microhabitat preference in terms of depth and velocity (Table 4). Preferred microhabitat velocities of age I, II, and III rainbow trout were usually less than 1 fps (0.3 mps) and depths occupied ranged from less than 0.5 foot (0.15 m) to a maximum of 2.6 feet (0.79 m).

Lewis (1969) and Platts (1974) reported that rainbow trout prefer fast water pools. Lewis found that cover was the most important factor in accounting for the variation in brown trout numbers, while velocity was most important for rainbow trout. Stewart (1970) found cover to be highly correlated with density of brook trout but not rainbow. Stewart reported that mean depth was the single most important variable in predicting abundance of both rainbow and brook trout. Criteria of Banks et al. (1973) for trout microhabitat requires water ≥ 1.5 feet (0.46 m) deep with velocities of 0-0.99 fps (0-0.30 mps). Wesche (1974), working with brown, brook and rainbow trout, defined trout cover as instream rubble-boulder areas having a substrate diameter of at least 0.5 foot (0.15 m), and undercut banks with a width of at least 0.3 foot (0.09 m) in association with water at least 0.5 foot (0.15 m) deep. Trout 6 inches (152 mm) or larger were shown to exhibit a stronger preference for undercut banks than did smaller fish. Of 27 rainbow trout sampled < 6 inches (152 mm) in length, 13 (48%) were collected in water ≥ 1.5 feet (0.46 m) while 5 (19%), 6 (22%), and 3 (11%) were collected at depths of < 0.5 foot (0.15 m), 0.5-0.99 foot (0.15-0.30 m) and 1.0-1.49 feet (0.30-0.45 m), respectively; 24 (89%) rainbow were collected at point velocities of < 0.5 fps (0.15 mps). No rainbow trout ≥ 6 inches (152 mm) in length were collected in water < 0.5 foot (0.15 m) while 100 percent of the 14 fish in this size group were collected at point velocities < 0.5 fps (0.15 mps); 5 (36%), 4 (29%), and 5 (36%) fish were collected in the depth intervals of 0.5-0.99 foot (0.15-0.30 m), 1.0-1.49 feet (0.30-0.45 m) and ≥ 1.5 feet (0.46 m) respectively.

Although we have no predictions of point velocity, it appears reasonable to assume that depth will become limiting to rainbow trout in the upper canyon area of the Teton River before velocity. Data available in the literature suggest that rainbow trout age I and older usually occupy water depths > 1.0 foot (0.30 m) with a preference for depths > 1.5 feet (0.46 m).

Table 4. Depth and velocity characteristics of rainbow trout microhabitats.

Age	Length		Depth		Velocity		Reference
	(cm)	(in)	(m)	(ft)	(m/sec)	(f/sec)	
0	3.2	1.26	<.15	<.49	<.15	<.5	Everest and Chapman (1972)
1	9.5	3.74	.60-.75	2.0-2.5	.15-.30	0.5-1.0	Everest and Chapman (1972)
0, 1	varied		.18-.67	-2.2	.06-.49	.20-1.6	Thompson (1972)
1	11.3	4.4	.48-.63	1.3-2.1	.10-.69	.33-2.3	Hanson, 1975, personal communication
2	15.8	6.2	.50-.72	1.6-2.4	.12-.16	.39-.52	Hanson, 1975, personal communication
3	19.8	7.8	.39-.80	1.3-2.6	.09-.21	.30-.69	Hanson, 1975, personal communication

Food supply is the other major habitat requirement of fish that may become limiting as a result of reduced discharge but the food production-discharge relationship is unknown. Several studies have reported depth and velocity criteria for aquatic insect production. Preferred velocities range from 0.5-4.0 fps (0.15-1.22 mps) and depth from 0.25-3.0 feet (0.08-0.91 m) Table 5).

Table 5. Reported aquatic insect depth velocity criteria (from Stalnaker, et al. 1976).

Preferred Velocity (fps)		Depth	Reference
Mean or Median	Range		
2.0	0.5-3.5		Surber (1951)
	2.0-3.5		Needham and Usinger (1956)
2.0	0.5-4.0		Pearson et al. (1970)
1.2	0.5-3.0	0.25-0.5	Kennedy (1967)
	1.5-3.5	0.5 -3.0	Hooper (1973)

Another important parameter affecting aquatic insect production is substrate. Under natural conditions rubble is usually considered the most productive substrate type. Since rubble makes up about 50 percent of the substrate in the study section of the Teton River, insect habitat is good. Predicted depths and velocities at reduced discharges fall within the range for good insect production (Appendix 3). Based upon these data, aquatic insect production is not considered as an important limiting factor for rainbow trout in the study section of the Teton River at any predicted discharge level studied.

Most studies that have been conducted in relation to the effects of reduced discharge on fish populations have focused upon the influence of decreasing cover. Kraft (1968, 1972) related changes in stream flow to cover and to fish populations in runs and pools in Blacktail Creek, Montana. He found that at 75 percent reduction in discharge (from a base flow level) abundance of brook trout in a run was reduced by 20 percent. No fish left the study area during the 75 percent reduced flow period, indicating a shift from inhabiting runs to inhabiting pools. At 90 percent reduction in discharge,

abundance of brook trout in two runs decreased 76 and 71 percent and there was upstream movement out of the study area. Although Kraft did not specifically relate changes in trout abundance to changes in fish cover in the runs, his data indicate a reasonably good relationship between the two (Figure 13).

In an effort to quantify the biological significance of instream dewatering in regard to trout populations, Wesche (1974) developed a cover rating system and is attempting to verify the rating as an indicator of standing crop of trout. He found that cover rating decreased with decreased discharge and that the maximum rate of decrease occurred between 25 and 11 percent ADF. Wesche made biomass estimates and cover ratings at 11 study sites and found a good relationship between the two. He did not, however, relate changes in cover to changes in biomass over a range of flows within one stream. Converting Wesche's cover data for three streams into percent reduction in cover related to percent reduction in ADF (Figure 14), one gets a slightly convex curve which is very similar to that drawn from Kraft's (1968) data. Whether or not reduction in cover can be related directly to reduction in fish populations is not known. However, based upon the findings of these studies and on our general knowledge of the aquatic ecosystem as it relates to discharge, one can theorize on the relationship between discharge and fish biomass or numbers.

Because of the diversity of lotic ecosystems, no one discharge - fish biomass relationship would be expected to apply to all streams. However, I would hypothesize that all fish-discharge curves are sigmoid in shape (assuming they are not affected by water quality), with the major difference being in the slope of the linear segment of the curves. This slope is expected to be dependent upon the influence of discharge on important habitat parameters including food, cover, and microhabitat.

In a basically run-riffle, rectangular shaped channel, it is hypothesized that conditions for production of food organisms would not become limiting until after the fish populations have been reduced by decreases in cover and microhabitat, primarily related to reductions in depth. The linear segment of the fish-discharge curve would theoretically have a gradual slope (Figure 15).

In a pool-riffle channel, the discharge-fish relationship is thought to be more complex. As discharge is reduced, overhanging cover and undercut bank cover is decreased along with the decreases in food producing areas. The fish become crowded into pools and social interactions become more intense.

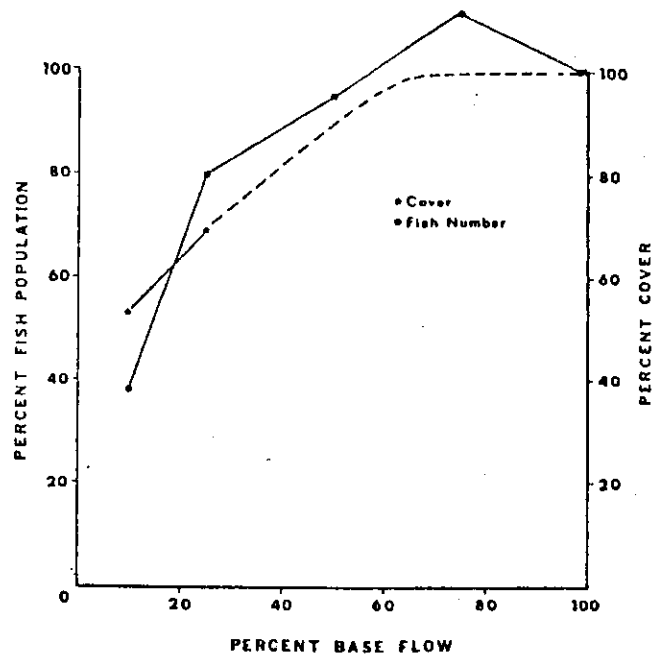


Figure 13. Comparison of percentage reductions of fish number and cover in three runs in Blacktail Creek, Montana. (Data from Kraft, 1968).

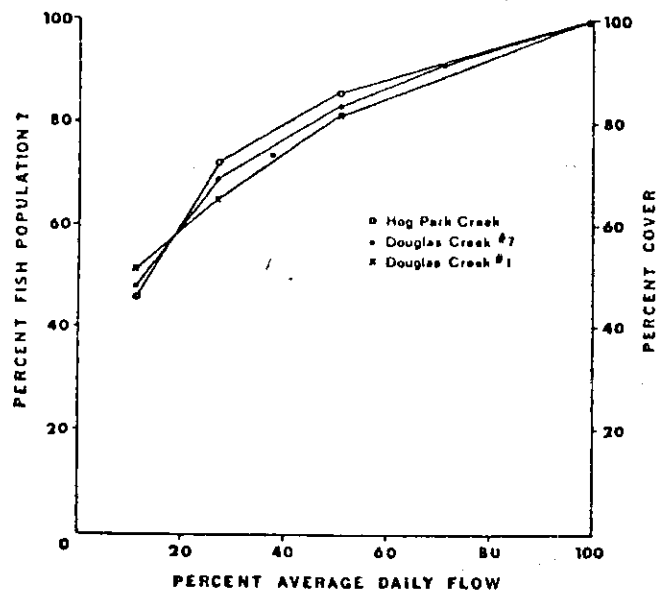


Figure 14. Comparison of percentage of habitat reduction with percentage decrease in average daily flow. (Data from Wesche, 1974).

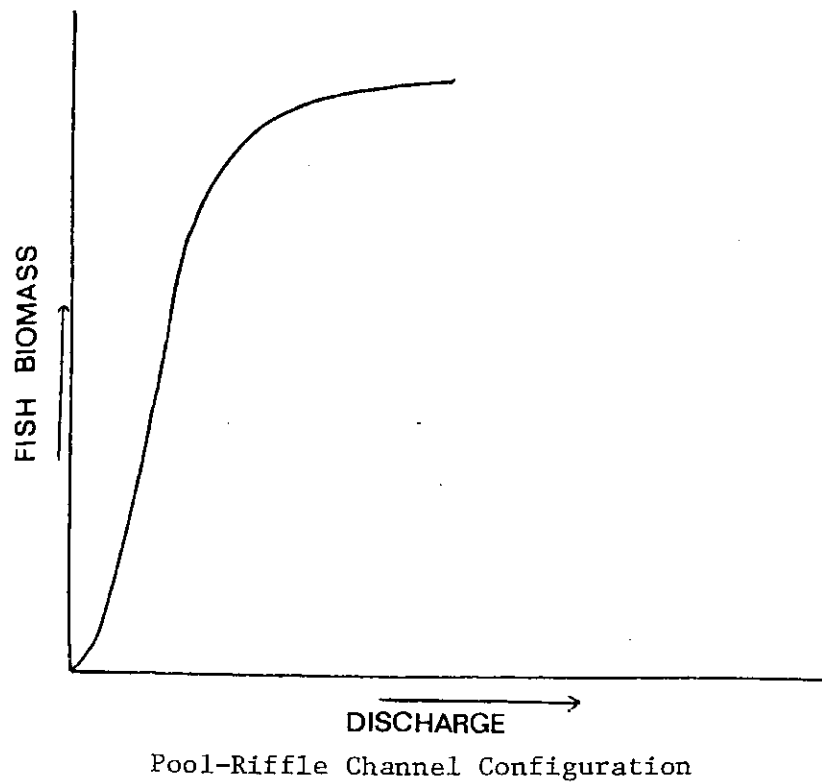
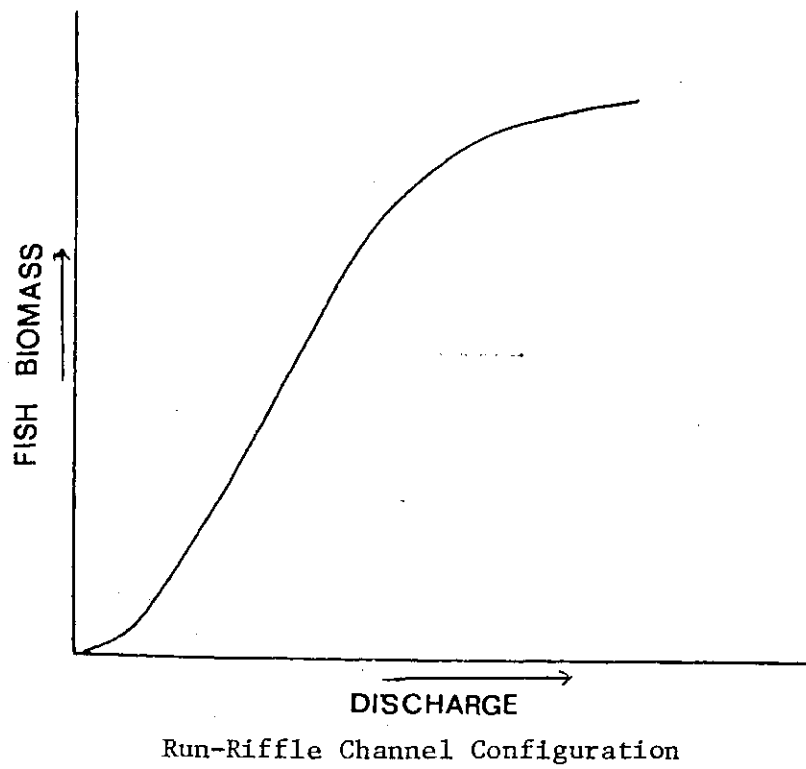


Figure 15. Comparison of theoretical relationship between stream discharge and fish biomass as influenced by channel configuration.

If the assumption that carrying capacity of streams is related to discharge is correct (and there is evidence that it is), then carrying capacity in streams with unaltered discharge and adequate overwintering habitat is probably set during the lowest flow period of the growing season. Since natural pool-riffle type streams typically are at a relatively low discharge during this period, it is hypothesized that fish biomass (numbers) will not be reduced dramatically until flows are reduced below this point. Thus the sigmoid fish biomass-discharge curve in a channel with a pool-riffle ratio of 50:50 is hypothesized to have a much steeper slope in the linear segment (Figure 15). Between the extreme of the run-riffle channel configuration and the 50:50 pool-riffle configuration, there is probably a family of fish-discharge curves.

Based upon findings of reported research and of this study, and upon the hypotheses discussed above, I would suggest that the rainbow trout population in the upper canyon area of the Teton River would first become limited by reductions in cover, primarily in the form of depth. I would also hypothesize that flows adequate to maintain the rainbow trout population in the riffle-run channel of the upper canyon area would also be adequate to maintain the population in the pool-riffle structured lower canyon area where physical conditions preempted making hydraulic measurements.

With a 30:70 riffle-run ratio in the upper canyon study area, reduced flows would probably reduce the trout population by forcing fish to move out rather than rearranging their distribution. If we assume that cover in the form of depth will be the factor limiting trout abundance or biomass at reduced discharge and that loss in cover can be related to the reduction in rainbow trout number or biomass, then we can predict the impact of various increments of water withdrawal upon the fish population.

Using the depth criteria for rainbow trout of greater than 1.0 foot (0.30 m) and greater than 1.5 feet (0.46 m), comparison of percentage loss of preferred habitat in terms of depth can be made (Figure 16). In evaluating these data it was assumed that the rainbow trout population of the Teton River study area is adapted to a flow regime equal to the mean daily flow for the lowest flow month of the growing season, September. Mean September flow for the period of record is 356 cfs (9.97 cu m/sec) and it is assumed that habitat is at 100 percent at this discharge. Percentage of instream habitat having a depth

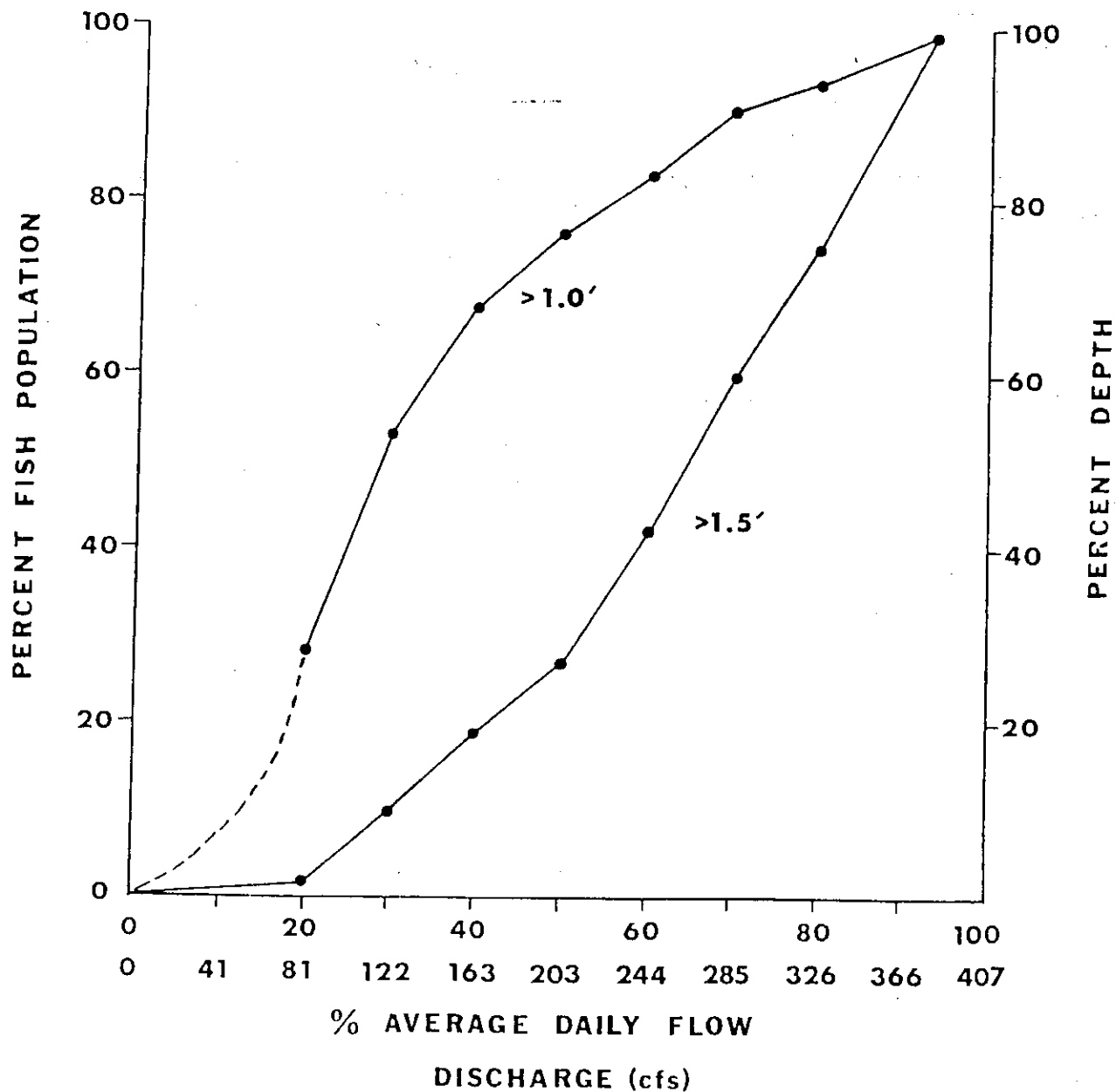


Figure 16. Comparison of mean percentage decrease in the amount of water greater than 1.0 foot (0.30m) and greater than 1.5 feet (0.46m) resulting from predicted reductions in discharge at all study sites and its relation to the theoretical response of the fish population.

greater than 1.0 foot (0.30 m) and greater than 1.5 feet (0.46 m) at the predicted flow nearest 356 cfs (9.97 cu m/sec) was considered to be the 100 percent cover value.

Based upon the best information available, the rainbow trout population in the study area of the Teton River will respond to decreased discharge within the bounds of the habitat (depth) curves (Figure 16). For example, at a flow of 244 cfs (6.83 cu m/sec) there would theoretically be a 16 to 58 percent reduction in fish numbers or biomass from the 100 percent value.

With this estimate of the response of the rainbow trout population in the study section of the Teton River, the next step is to relate this response to proposed irrigation withdrawals of about 17,000 acre feet annually. The estimated monthly diversion requirement during the irrigation season, June 1 - September 10, is as follows (Lauren Hampton, BOR, personal communication):

Month	<u>June</u>	<u>July</u>	<u>Aug.</u>	<u>Sept.</u>
Percent	19%	39%	33%	9%
Ac. ft./mo.	3230	6330	5610	1530
Assumed number of days pumping	20	25	25	8
Pumping rate cubic feet/sec	81	133	112	114

With the proposed rate of withdrawal, the impact on the rainbow trout population in the study area would be minimal before about August 10, in an average water year (Figure 17). The maximum theoretical reduction in trout abundance and/or biomass brought about by irrigation withdrawal would be between 16 and 54 percent (Figure 16) after August 10, based upon a flow of 251 cfs (7.03 cu m/sec).

During some years, however, the rainbow trout population in the study area would be reduced by natural low flow conditions. Additional flow reductions for irrigation during low flow years would further reduce the amount of available fish habitat and consequently the rainbow trout population. For example, in water years like 1966, the third lowest flow year on record, the estimated effects of irrigation withdrawal would be pronounced throughout the irrigation season. Based upon the mean flow for the months of June (314 cfs, 8.79 cu m/sec), July (309 cfs, 8.65 cu m/sec), August (256 cfs, 7.17 cu m/sec), and the mean flow for the first 10 days of September (228 cfs, 6.38 cu m/sec), the estimated percentage reduction in the rainbow trout population resulting from proposed irrigation withdrawal would be 18 to 62 percent in June, 27 to

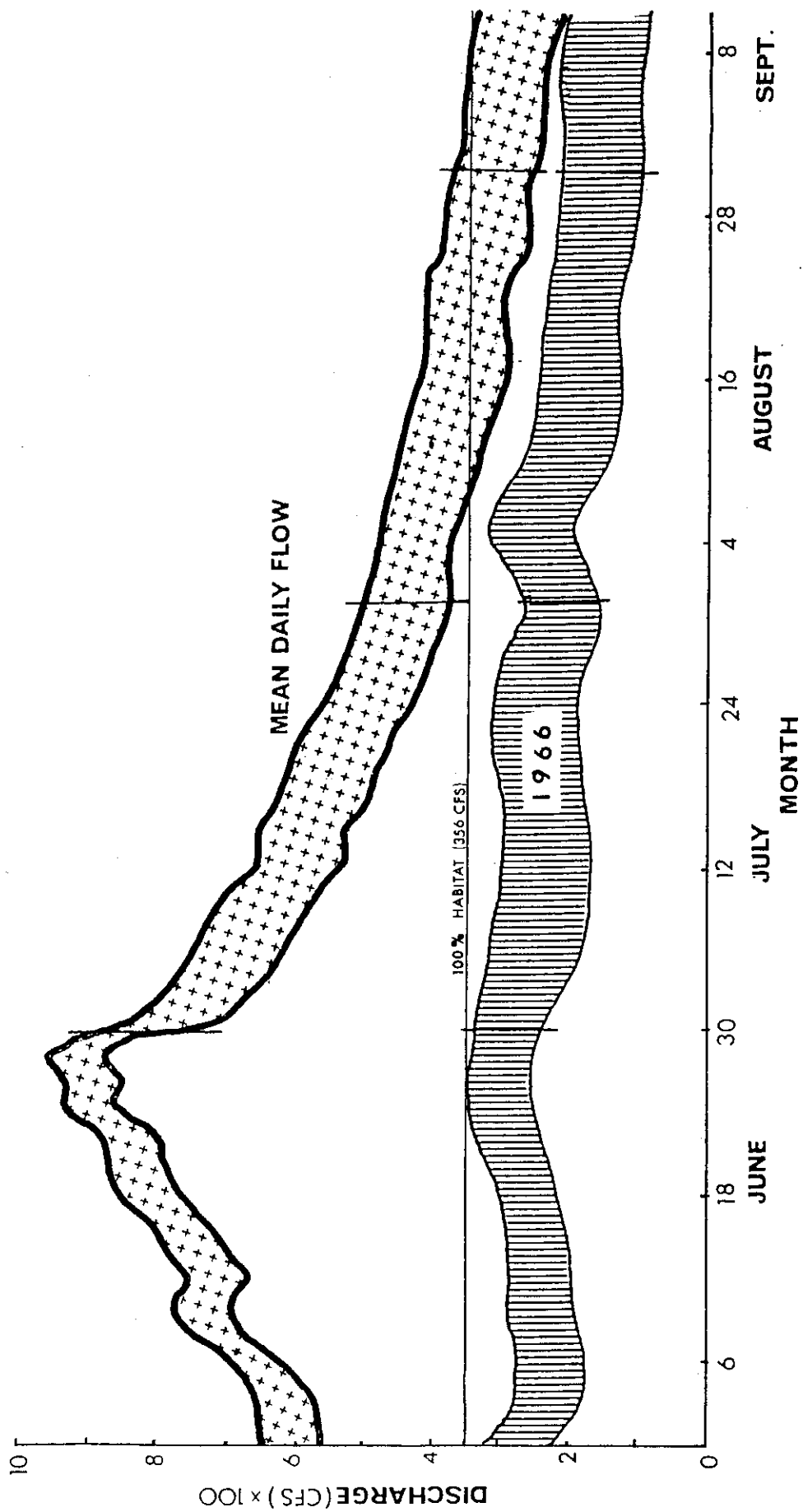


Figure 17. Comparison of the hydrograph of mean daily flows for the 31 year period of record and the hydrograph of 1966 daily flows illustrating the discharge which would remain in the Teton River after proposed irrigation withdrawal.

78 percent in July, 40 to 87 percent in August, and 51 to 93 percent in September (Figure 16). The recurrence interval for 1966 mean flow for June, July, August, and the first 10 days of September is 10.3 years (Figures 8-11). That is, on the average, over a long period of time, we would expect to have monthly mean flows during the irrigation season every 10.3 years equal to or less than those observed in 1966; the probability that similar mean flows to those in 1966 will recur in any 10 year period is 65 percent (Table 3). Similar comparisons of discharge and the estimated effects on the fish population can be made for any discharge level desired by utilizing historical data and the estimated fish-discharge relationship (Figures 8-11 and 16).

During low flow years, other possible adverse effects upon the fish population include increased vulnerability to angling and changes in water quality.

The predicted effects of water withdrawal on the fish population in the study area of the Teton River are based upon the best information available. Although the theoretical range of the impact of reduced discharge upon the fish population is broad at some discharge levels, there is evidence that the impact will be within the predicted ranges. This information should be useful for interim water resource planning but as better methodologies become available, they should be applied to the Teton River to refine estimates of impact of water withdrawal.

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APPENDICES

Appendix 1. Teton River mean and minimum flows, June-September, for the period of record.

Year	June		July		August		September		June-September	
	Mean	Minimum	Mean	Minimum	Mean	Minimum	Mean	Minimum	Mean	Minimum
1930	382	267	398	354	437	359	340	301	389	320
1931	227	183	233	223	219	174	182	158	215	184
1932	890	359	655	510	440	386	351	319	584	394
1934	197	150	144	123	117	110	113	100	143	121
1942	908	535	540	448	377	319	304	266	532	392
1943	1091	622	963	693	582	478	438	402	768	549
1944	855	472	635	472	398	334	325	301	553	395
1945	1209	792	1097	636	619	522	495	437	855	597
1946	698	516	521	448	394	354	357	314	492	408
1947	847	629	608	478	446	359	374	344	569	452
1948	973	664	569	460	371	292	302	270	554	422
1949	956	664	529	419	382	339	329	305	549	432
1950	866	503	942	629	532	431	446	392	696	489
1951	766	502	610	515	749	539	452	375	644	483
1952	933	689	582	466	428	344	338	305	570	451
1953	756	324	519	448	395	324	291	270	490	342
1954	551	364	549	466	426	354	325	292	463	369
1955	464	288	424	386	362	324	293	270	386	317
1956	1027	808	666	539	462	408	372	344	632	525

Appendix 1. (Continued)

Year	June		July		August		September		June-September	
	Mean	Minimum	Mean	Minimum	Mean	Minimum	Mean	Minimum	Mean	Minimum
1962	628	408	671	560	448	376	328	294	519	410
1963	756	447	484	389	367	302	335	289	486	357
1964	1104	497	900	613	514	442	380	335	724	472
1965	739	554	839	724	539	418	496	413	653	527
1966	314	263	309	266	256	214	240	214	280	239
1967	871	369	940	624	474	377	359	328	661	424
1968	833	316	770	618	610	478	438	390	663	450
1969	629	443	536	452	388	330	300	279	463	376
1970	935	475	836	594	490	420	445	380	676	467
1971	1298	735	1201	670	578	511	484	435	890	588
1972	1306	925	780	585	502	445	446	407	758	590
1973	633	366	534	425	373	324	357	315	474	358
Mean	795	477.7	644	491.4	441	367.3	356	317.5	559.1	416.1

Appendix 2: Use of the Forest Service R-2 CROSS Program

This program is designed to calculate a series of hydraulic parameters from transect field data (presently used with sag tape data) and Manning's discharge formula. The description of the program steps was written assuming the use of sag tape data (Anonymous, 1974).

Field Data Requirements

1. Distance in feet from 0-point to each depth measurement and to 0-point at the opposite stake.
2. Total length (feet) of tape spanning the cross section (may be same as 1).
3. Manning's n value, roughness coefficient (use of 0.55 or another selected value).
4. Slope (gradient) of the stream.
5. Accurate measurement of discharge at time of field data collection.

The program is divided into three operating steps.

Program Steps and Output

Step 1. The basic computer plot of the measured cross-section - Step 1 produced a channel cross-section print-out, and if desired, a "plot" (from a Cal comp Plotter) of the measured cross-section. The print-out will also provide cross-section area in sq. ft., maximum depth in ft. from the water level to channel bottom, wetted perimeter in ft., hydraulic radius (area/wetted perimeter) in ft., measured slope or gradient of the stream reach in percent, selected or calculated Manning's "n" (roughness coefficient), water flow in c.f.s., and average velocity in feet/second.

The "maximum depth" value given on the Step 1 print-out is used to establish the reference datum line on the graph paper "plot" of the cross-section print-out. Maximum depth is measured, with a scale, vertically up from the deepest point shown on the cross-section. A line drawn perpendicular to this vertical is the "reference datum" line and represents the computer corrected tape line. For those hydraulic data listed on the Step 1 print-out, the computer has assumed a water level equal to the reference datum line. Measurements from the reference datum line to the actual water level, or selected water levels are used in the program, steps 2 and 3.

Step 2. Developing information from which to calculate Manning's "n" value - In order to complete the CROSS program analysis it is necessary to have obtained accurate field measurements of the stream discharge or flow. It is also important to have noted on the field form the distance from the 0-point or stake at which both the first and furthest waterlines in the cross-section are encountered. The waterline or level, as interpreted from the field notes, is drawn directly on the graph paper "plot"; or in the event a Calcomp plotter is not available, the cross-section print-out can be used. The necessary data to run Step 2 includes: a depth value, identified in the program writeup as "depth to water," which is the difference between the maximum depth from the "reference datum" to the channel bottom and the actual water depth at that point. In effect, this value is the distance to the nearest tenth-foot from the computer corrected tape level to the waterline. two distance values, the distance in feet from the 0-point to the first streambank - waterline intersect, and the distance in feet from the 0-point to the furthest streambank - waterline intersect. These data are obtained from the cross-section "plot" on which the waterline has been drawn. total length of tape spanning the cross-section, in feet, from stake to stake, or 0-point to the end point. a selected or theoretical Manning's "n" (roughness coefficient) value. A value developed from field observations may be used, or if unknown use .055 for Step 2. the slope or gradient in percent of the stream reach immediately up and down stream from the cross-section.

The purpose of Step 2 is to provide a list of the above described hydraulic parameters for the cross-section as it existed at the time of measurement, along with a second cross-section print-out. Once the data from Step 2 is obtained it is used to refine the estimated Manning's "n" value (used in Steps 1 & 2) for use in the final Step 3. Manning's formula (see below) is solved for "n" using the area, hydraulic radius, and slope data from the Step 2 print-out; and the field measurement of stream discharge for the Q value in Manning's equation.

$$Q = \frac{1.49}{n} (A) (R^{2/3}) (S^{1/2})$$

Where: Q = discharge in cfs
 n = roughness coefficient
 A = area
 R = hydraulic radius
 S = slope in percent
 V = average velocity in ft/sec

Since roughness changes with reduced discharge it is possible to estimate this change by the following equations:

$$N_B = \frac{n_f}{\sqrt{\frac{D}{R}}} \quad n_a = N_B \sqrt{\frac{D}{R}}$$

Where N_B = constant
 n_f = field calculated n
 n_a = adjusted n for substrate diameter
 R = hydraulic radius

Adjusted roughness coefficients or a constant roughness coefficient equal to that calculated in Step 2 is used in Step 3. If adjusted roughness values are to be used, Step 3 is first completed holding the calculated "n" constant for all desired water stages, thus providing predictions of hydraulic radius to be used in the above equations.

Step 3. Stream discharge and hydraulic parameters at various or selected Water Stages, above or below the waterline existing at the time of field measurement - The purpose of Step 3 is to provide a range of hydraulic parameter values related to changes in the water stage of the cross-section.

To run Step 3, simply change the depth to water value (the distance from the "reference datum" to the new or selected water line) and determine the corresponding changes in waterline-streambank intercept distances using the "plot" from Step 1 (or the cross-section print-out). Also enter the calculated value or values for Manning's "n" developed in Step 2. The remaining information necessary for running Step 3, includes the same total length of tape and slope data as used in Step 2. Step 3 will produce a cross-section and print-out with the above described hydraulic parameters for each new or selected water stage.

The program produces a computer plot of the measured cross-section; and with completion of the three program steps, computes 1) stream discharge, 2) average flow velocity, 3) wetted perimeter, 4) cross-sectional area, 5) maximum water depth, and 6) hydraulic radius for the actual streamflow at the time of measurement as well as for various selected water stages.

Much of the above description was furnished by Dr. Clair Stalnaker, Federal Aid Coordinator, Region 6, USFWS, Denver, Colorado

Appendix 3. Summary of predicted changes in physical parameters for five representative transects within the irrigation withdrawal study area, Teton River.

Transect number	Flow (cfs)	Cross Sectional Area (sq. ft)	Wetted Perimeter (ft)	Mean velocity (fps)	Mean depth (ft)	Maximum depth (ft)	Hydraulic radius (ft)
401	408	173	123	2.4	1.39	1.9	1.4
	295	149	122	2.0	1.21	1.7	1.2
	198	125	122	1.6	1.02	1.5	1.0
	129	100	119	1.3	0.83	1.3	0.8
	98	88	119	1.1	0.70	1.2	0.7
	74	77	118	1.0	0.65	1.1	0.7
	50	65	118	0.7	0.55	1.0	0.5
501	395	181	113	2.2	1.56	2.4	1.6
	296	159	113	1.9	1.39	2.2	1.4
	215	137	112	1.6	1.21	2.0	1.2
	148	114	112	1.3	1.02	1.8	1.0
	97	92	109	1.0	0.85	1.6	0.9
	76	82	106	0.9	0.77	1.5	0.8
	56	71	105	0.8	0.68	1.4	0.7
601	382	170	110	2.3	1.55	2.1	1.5
	291	147	107	2.0	1.36	1.9	1.4
	211	126	106	1.7	1.18	1.7	1.2
	141	105	106	1.3	1.00	1.5	1.0
	98	86	97	1.2	0.87	1.3	0.9
	61	65	91	0.9	0.68	1.1	0.7
705	367	159	95	2.3	1.68	2.5	1.6
	281	137	93	2.1	1.45	2.3	1.5
	208	119	93	1.7	1.28	2.1	1.3
	146	101	92	1.4	1.10	1.9	1.1
	96	83	92	1.2	0.91	1.7	0.9
	58	65	92	0.9	0.72	1.5	0.7

Appendix 3. (continued)

Transect number	Flow (cfs)	Cross Sectional Area (sq. ft)	Wetted Perimeter (ft)	Mean velocity (fps)	Mean depth (ft)	Maximum depth (ft)	Hydraulic radius (ft)
805	370	145	97	2.5	1.51	2.4	1.5
	288	126	91	2.3	1.35	2.2	1.4
	208	108	91	1.9	1.18	2.0	1.2
	152	89	82	1.7	1.04	1.8	1.1
	100	72	82	1.4	0.86	1.6	0.9
	60	56	79	1.1	0.70	1.4	0.7