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David L. Wegner

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Glen Canyon Environmental Studies
Bureau of Reclamation
P.O. Box 11568
Salt Lake City, UT 84147

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INSTREAM FLOW ANALYSIS OF THE GLEN CANYON DAM TAILWATER

Physical habitat modling of the Colorado River within the Glen Canyon Dam tailwater was conducted using the Physical Habitat Simulation modeling program to determine the relationship between operation of Glen Canyon Dam and the habitat for rainbow trout over a range of discharges from 2,000 to 26,000 cubic feet per second. Refined habitat suitability data collected in 1986 were utilized to enhance a 1980 analysis. An evaluation of the 1980 and 1986 study results showed minimal changes in the amount of usable habitat area for trout following high flows in 1983.

By David L. Wegner
Glen Canyon Environmental Studies
Bureau of Reclamation
Flagstaff, Arizona

INTRODUCTION

On March 13, 1963, the gates at Glen Canyon Dam were closed, initiating major changes in the Colorado River's aquatic ecosystem. With the closure of Glen Canyon Dam and the filling of Lake Powell, controlled releases, reservoir-modified water quality, and temperature altered the character of the Colorado River. The river changed from a seasonally warm, sediment-laden stream to one with clear and constant cold water flows. The impact of dams on the downstream aquatic resources has been well documented (Ward 1974; Cummins 1979; Holden and Stalnaker 1975; Hickman 1983; and Vanicek, Kramer, and Franklin 1970).

In 1964, the Arizona Game and Fish Department (AGF) began stocking rainbow trout (*Salmo gairdneri*) (Brancroft and Sylvester 1978) in the dam's tailwaters. The trout were not native to this stretch of the Colorado River; therefore, special care and management were required to establish a viable fishery resource. The present tailwaters have developed into a world-class trout fishery. However, this aquatic ecosystem is an artificial environment resulting from the regulated flows from Glen Canyon Dam.

During the peaking power investigations at Glen Canyon Dam in 1980 (Bureau of Reclamation 1982), an instream flow study identified relationships between the operations of the dam and the trout fishery. After the 1983 high releases from the dam, the U.S. Fish and Wildlife Service (FWS) requested a revaluation of these

relationships to determine if results of the 1980 studies were still applicable. The investigation reported here was conducted by the Bureau of Reclamation (BOR) in response to this request.

Objectives. This paper reports a reanalysis of the 1980 instream flow study using the Physical Habitat Simulation (PHABSIM) (Milhous, Wegner, and Waddle 1981) computer programs. The objectives of the reanalysis were to determine if the 1980 analysis was still usable after the impact of the 1983 high flow releases and to determine if refinement of the 1980 results could be made with the addition of more definitive trout habitat relationships.

METHODS

The information used in this study included: the 1980 instream flow hydrologic analysis developed under the Peaking Power Studies (Bureau of Reclamation 1982); the habitat suitability indices developed for the 1980 instream flow study (Bureau of Reclamation 1982); trout microhabitat studies conducted below Glen Canyon Dam (Gosse and Gosse 1985); and an analysis made of the aggradation/degradation that occurred in the Glen Canyon Dam tailwater as a result of the 1983 high flow releases (Bureau of Reclamation 1986). No new data was collected as part of this study.

The methods used were as follows: (1) an analysis of the stream bed of the Glen Canyon Dam tailwater made after 1983 was compared to data collected in 1980 to ascertain changes in aggradation and degradation; (2) an analysis was made of the 1980 instream flow study site hydrological analysis to allow for a complete listing of all the hydrologic and physical variables; (3) the 1980 instream flow hydrologic data were reanalyzed, (4) trout microhabitat data collected by Gosse and Gosse (1985) were used to develop Glen Canyon Dam tailwater-specific habitat suitability indices. These results were then compared to the 1980 habitat suitability indices; (5) using PHABSIM, the 1980 instream flow hydrologic data were re-run with the new habitat suitability data, and the results were compared to the original 1980 study results; and (6) an evaluation was made of the use of the original and the revised Glen Canyon Dam tailwater studies.

Study Site. In 1980, a representative reach of the Glen Canyon Dam tailwater was chosen for the instream flow study. The site was located approximately six

miles below Glen Canyon Dam, within the Glen Canyon National Recreation Area. Eleven transects were selected to represent instream hydraulics and the aquatic habitat.

The study site was selected to represent the primary types of aquatic habitats of the Colorado River within the Glen Canyon Dam tailwater. It does not represent the entire range of aquatic habitats through the Grand Canyon. The study site is characterized by a slope of three feet per mile and contains no rapids. Several riffles do appear at lower water levels as cobble bars are exposed. Due to its close proximity to Glen Canyon Dam, the influences of hydroelectric generation releases are quickly manifest.

The water quality of the study site reflects the hypolimnion (deep water) releases from Lake Powell. Variation of the water quality parameters result from the seasonal flows and limnological characteristics of Lake Powell. The seasonal short-term variation is relatively minor; however, long-term variation in conductivity, productivity, and temperature were observed (Miller, Wegner, and Bruemmer 1983).

The three physical habitat variables used to define the aquatic habitat in the Glen Canyon Dam tailwater instream flow study were mean column velocity, depth, and substrate. Measurements of these variables were made at intervals along the transects in the study site at discharge levels of 2,000, 16,000 and 26,000 cubic feet per second (cfs) during the months of February, April, and June 1980.

Color aerial photographs were taken of the study site at a flow of 5,000 cfs. The 11 study transects were identified on the photos at a scale of 1:4800, where 1 inch equals 400 feet. Cross-sectional plots of the 11 transects were developed and used to identify habitat locations at the measured and modeled flow levels.

<u>The 1985 Reanalysis.</u> To determine if the hydraulic conditions below Glen Canyon Dam, as measured in 1980, had changed as a result of the 1983 flood releases from Glen Canyon Dam, and if the 1980 hydrology data were used accurately to represent the Glen Canyon Dam tailwater study site, a cross-sectional analysis of the river channel between Glen Canyon Dam and Lees Ferry (a distance of 16 miles) was made.

The analysis was based on surveys of 12 previously defined evaluation sites established from the dam down

to Lees Ferry by BOR after the closure of Glen Canyon Dam in 1963. The purpose of establishing these transects (range lines) was to provide consistent and long-term locations where channel-change characteristics could be monitored. Two of the 12 range lines are located within this study's research site: Range Lines 19 and 11A. In October 1983, BOR surveyed the 12 sites (Bureau of Reclamation 1986). A comparison was made of the 1983 surveyed profile and cross sections to the pre-1983 high flow range line measurements to quantify what change may have occurred.

Model Calculation. The physical aquatic habitat variables of the study site were modeled using the Physical Habitat Simulation (PHABSIM) computer model developed by the Instream Flow and Aquatic Systems Group (IFG-4) of the FWS (Milhous, Wegner, and Waddle 1981; Bouvee 1982). The PHABSIM system consists of computer programs used to related changes in water discharge to changes in physical habitat availability. The underlying principles of PHABSIM are: (1) each species exhibits preferences within a range of habitat conditions that it can tolerate, (2) the ranges can be defined for each species, and (3) the area of stream providing these conditions can be quantified as a function of discharge and channel structure (Bovee 1982).

A natural stream is a complex mosaic of physical features. As flow levels (discharges) change, the combinations of available habitat are altered. For example, in a given stretch of the river, lowering the discharge will reduce the water depth. This in turn affects light penetration, water temperature, pressure, availability of space, etc., all factors pertinent to use of that location by fish. Any given location will become more or less usable as a result of the change in discharge.

PHABSIM describes the mosaic of aquatic habitat on the basis of defined transect lines which are used to show the distribution of the different hydrological and habitat conditions within the study site. Field measurements of water depth, velocity, and bottom substrate type are made at points long the transect line. The resulting information is a quantification of the study site as a series of transects and "cells" of physical habitat area. Cells are measured intervals on the transects that delineate areas of habitat extending in two-dimension: along the transect and from the water surface down to the riverbed.

The usability of each cell for an aquatic species is then evaluated by applying the known habitat criteria for that species. In this way, the hydrologic relationships are "weighted" by the habitat's suitability for use by the fish in question. The end result of the PHABSIM's analysis is an evaluation of the habitat potential of the individual cells and a composite estimate of habitat potential within the study site. This index, labeled the "Weighted Usable Area," varies by flow level, aquatic species, and life stage.

Modeling for the study consisted of four phases: (1) preparation of the data input files for PHABSIM; (2) hydraulic simulation modeling, using the program IFG-4, of the depth, velocity, and substrate characteristics as a function of discharge; (3) development of the biological suitability relationships (probability for trout use as related to dam discharge); and (4) calculation of the habitat responses over the range of discharges.

Hydraulic Simulation. The hydraulic simulation for the study site was based on the field data collected in 1980. The IFG-4 hydraulic simulation model (Milhous, Wegner, and Waddle 1981) was used to develop a series of linear regression equations for (1) river level (depth) versus dam discharge for each transect in the study site and (2) river velocity versus dam discharge for each cell measured along the transect. To verify the validity of using the simulated data to interpolate flows, the calculated dam discharges, river levels (depth), and internal velocities were compared to the measured values from the study site.

Upon completion of the hydraulic simulation of the study reach, the estimated depth and velocity relationships, measured discharges, substrate data, and distance between transects were combined with a numerical measure of the habitat requirements (called habitat suitability indices) for adult, juvenile, and fry life stages of rainbow trout. This was done to evaluate the biological usefulness of the study site to trout.

Habitat Suitability Indices. Habitat suitability indices are a dimensionless index bounded by 0.0 and 1.0, where 0.0 represents no usable habitat and 1.0 represents optimal habitat. Habitat suitability curves have been developed for trout (Bouvee 1978), but their application to large western rivers has been limited.

The premise for development of the habitat suitability indices for the study site assumed that individual trout will select the most preferred habitat in the river when given a choice, and that the individual life stages will require different habitats. Poor habitat is less likely to be used by trout. It was assumed that this range of use could numerically be defined on a scale of 1.0 to 0.0. It was further assumed that individuals would leave an area when it becomes totally unsuitable for their needs.

The habitat suitability indices used in the 1980 instream flow analysis were composites of empirical, hypothesized, and existing information from small streams and rivers. Consequently, the results were biased. To avoid a similar bias, the indices developed for the 1985 habitat reanalysis were based on actual measurements made in the Glen Canyon Dam tailwater.

These measurements resulted from studies conducted by Gosse and Gosse (1985) in the Colorado River below Glen Canyon Dam during the summer of 1984 and the winters of 1984 and 1985. The Gosses surveyed trout habitat to determine if there were seasonal (winter versus summer) differences in trout habitat requirements. The habitat surveys analyzed the aquatic environment variables that would or could change with small changes in the trout's location. Seven aquatic habitat variables were measured for each trout observation: fish velocity, mean column velocity, fish depth, water depth, distance to cover, overhead light, and substrate type. In addition, an analysis was made to determine if the trout exhibited different activity responses during the seasons. Gosse (1982) categorized the life stages of trout as follows: fry were 12 centimeters (cm) or smaller, juveniles were 12 to 27 cm, and adults were fish longer than 27 cm.

Using these data, new habitat suitability indices were developed for water depth and mean column velocities for adult, juvenile, and fry life stages of rainbow trout in the study site. The suitability indices were further expanded by evaluating seasonal, activity, and life stage differences. The indices were calculated using frequency analysis, curve fitting, and tolerance intervals as outlined by Bovee and Cochnauer (1977) and Bovee (1982). The 1980 and 1985 habitat suitability indices were then compared to determine if significant differences occurred between years, seasons, and activity levels.

Weighted Usable Area. To complete the simulation, the 1985 habitat suitability indices were combined with the hydraulic characteristics of the IFG-4 analysis to calculate an index of potential use: the Weighted Usable Area. An expanded flow regime of 1,000 to 60,000 cfs was modeled to predict the overall habitat response over a wide range of Glen Canyon Dam releases. Analysis was by season, life stage, and flow regimes. "Available habitat" was computed and the results were organized into tables defining the habitat availability by life stage versus discharge level. Summer and winter seasonal trends were combined to develop annual relationships. The 1980 and 1985 results were then compared.

Model Assumptions. The following assumptions were used in the application of the PHABSIM (Orth and Maughan 1982; Bovee 1982): (1) depth, velocity, and substrate are the most important habitat variables affecting fish distribution and abundance when changes in flow regime are considered; (2) the river channel is stable and not altered by changes in the discharge levels; (3) depth, velocity, and substrate independently influence habitat selection by the target species; (4) the habitat/discharge relationship can be modeled on the basis of a representative reach for the stream segment in question; and (5) a positive and linear relationship exists between the weighted usable area and habitat use.

RESULTS AND DISCUSSION

To complete the objectives of this study, it was necessary to (1) determine how valid the results of the modeling were and (2) determine how the results could and should be used. A review of the 1980 analysis indicated that several inherent errors were made in the development of the original hydrologic and biological data bases and in the use of the results in making impact assessments. The information presented in this section will identify the major problem areas in the 1980 analysis as compared to the work completed under this study. The intent is to identify how the information generated under the 1980 and this study should be used.

Profile Analysis. Based on the evaluation of the surveyed BOR range lines, it was concluded that a large scale change in the integrity of the river channel had not occurred, and that the channel geometry data collected in 1980 are still representative of the 1985

river channel. A cumulative gain in area of 1,272 square feet occurred at the Range Line 10 site and a net loss of 780 square feet occurred at Range Line 11A. This represents only a three percent change in the actual volume of material at these two sites.

Hydraulic Simulation. The IFG-4 calculated values of discharge, water surface elevations, and velocity were compared to the 1980 measured hydraulic values with the following results. The calculated water surface elevations compared to within ten percent of the measured values. The calculated mean column velocities of the main channel compared to within ten percent of the measured values; however, the calculated mean column velocities for the nearshore areas showed a great deal of variability, with a range from 10 to 30 percent.

A measure of the match of the IFG-4 calculated versus actual interval velocity values (Table 1) is the "Velocity Adjustment Factor" (VAF). A VAF value within the range of 0.90 to 1.10 indicates a good fit to the data set and consequently provides a verification for the calculation of interpolated flows (Milhous, Wegner, and Waddle 1981). A VAF value of 1.0 represents a perfect fit to the data set for the study site.

All transects except numbers 8 and 9 at 2,000 cfs and 26,000 cfs indicate an acceptable fit of calculated velocity values. Low velocity adjustment factors for transects 8 and 9 indicated the hydraulic relationships were unstable. Therefore the results of the analysis should be used with caution.

Habitat Suitability Indices. The 1985 refinement of the 1980 habitat suitability indices resulted in improved modeling and prediction of the habitat relationships of the rainbow trout below Glen Canyon Dam. Refinement of the results was in the quantification of the available and preferred habitat.

The 1980 habitat suitability indices of depth relationships for the adult, juvenile, and fry life stages of the rainbow trout indicated differences when compared to the 1985 habitat suitability indices based on actual field measurements. A comparison of the optimum levels of depth and range of depth most preferred for the three rainbow trout life stages is shown by Table 2.

Table 1. The Velocity Adjustment Factors for the Glen Canyon Dam tailwater study site in relation to the three measured discharges. ("*" indicates an unacceptable fit.)

Transect	2,000 cfs	16,000 cfs	26,000 cfs
1	0.95	0.99	0.95
2	1.01	0.99	0.96
3	1.01	1.0	0.96
4	0.99	1.0	0.98
5	0.95	1.03	0.94
6	0.98	1.0	0.94
7	0.91	0.96	0.97
8	0.74*	0.99	0.80*
9	0.79*	0.99	0.77*
10	0.96	1.02	0.98
11	0.95	0.99	0.94

Table 2. Comparison of 1980 and 1985 Habitat Suitability Indices (HSI) by Optimum Depth Preferences for three life stages of rainbow trout.

Life Stage	1980 Depth HSI (feet)	1985 Depth HSI (feet)
Fry	0.6 to 1.0	2.5 to 6.0
Juvenile	0.7 to 1.1	12.3 to 16.0
Adult	1.6 to 50.0	15.0 to 20.0

The 1985 habitat suitability indices reflect a preference for deeper water than was reflected in the 1980 analysis. The utilization and location of the most preferred aquatic habitat are restricted to specific depths with fry utilizing the nearshore, shallow habitat areas, and the adults and juveniles utilizing deeper water habitats along the channel margins. The 1985 depth data reflect a more close approximation or refinement of the trout habitat use and are consistent with existing knowledge of Glen Canyon Dam tailwater trout physiology, dynamics, and behavior (Brancroft and Sylvester 1978.)

The 1985 indices also reflect a refinement of trout activity levels. Two distinct types of activity levels have been identified for trout in rivers: **random swimming activity** exhibiting little or no orientation to current velocity; and **stationary swimming activity**, with a decided orientation to the current of the river. Random swimming activities have been hypothesized to reflect an energy conservation measure, while a stationary swimming activity level reflects an active response to feeding and habitat utilization (Gosse and Gosse 1985). Fish showing random swimming actions are not focussed on specific habitat niche while stationary swimming fish are. Analysis of the Gosse and Gosse (1985) data for the Glen Canyon Dam tailwater indicates that the trout exhibit variability in activity levels between the juvenile and adult life stages. The majority of observations of adult and juvenile rainbow trout exhibited a stationary swimming activity with an orientation to the current.

In studies conducted on trout in the Flaming Gorge tailwater of the Green River in Utah (Wegner and Williams 1985; and Gosse 1982), a change in the physical activity level was correlated with a seasonal shift in habitat requirements. The adult and juvenile rainbow trout exhibited a predominant stationary swimming activity from May through September and a random swimming activity from November to March. The Glen Canyon Dam tailwater trout do not appear to exhibit the same seasonal shift in habitat requirements. We ran a chi-square statistical analysis test on the differences between the activity levels (Random versus Stationary) and seasons (Summer versus Winter), at a probability level of 0.05. From the analysis, it was determined that no seasonal difference in trout habitat preferences exist in the Glen Canyon Dam tailwater. However, the trout do exhibit periodic, short-term shifts in activity levels as a compensation for the physiological stress of habitat shifting as the releases from Glen Canyon Dam fluctuate.

An area of concern is how much of the river channel is used "actively" by trout for food gathering and shelter, and how much of the river channel is used secondarily for movement. Gosse and Gosse (1985) identified that the trout primarily used the nearshore areas around cobble bars, and the reduced velocity zone near the bottom of the river channel. Limited use was made of the main channel as the velocities are unsuitable and cover unavailable.

In small trout streams the fish can typically use a large percentage of the available physical habitat. In larger streams and rivers, trout use a relatively smaller percentage of the total aquatic habitat because velocity and depth relationships are unsuitable. This is true of the Glen Canyon Dam tailwater, where trout can actively utilize only a small percentage of the total amount of aquatic habitat available. The remainder of the aquatic habitat is used primarily for movement from one location to another.

Weighted Usable Area Relationships. The WUA values reflect the changing relationships of usable aquatic habitat and discharge levels. Weighted usable area for the Glen Canyon Dam tailwater study site was calculated for rainbow trout adult, juvenile, and fry life stages. The maximum WUA occurred at 18,000 cfs for adult, 12,000 to 18,000 cfs for juvenile, and 9,000 cfs for fry life stages respectively.

The analysis of the changes in cross-sectional habitat location at the 11 transects reflects a shifting of the amount and location of usable trout habitat as the discharge level fluctuates from low to high and back to low.

It has been noted (Bureau of Reclamation 1982) that numerous trout do become stranded in isolated pools and on spawning bars as dam releases fluctuate. The maximum flows, minimum flows, and rate of change of the releases are important components of stranding.

The Weighted Usable Area calculation for the study reach and short-term relationships reflect only the relationship between the trout and the parameters of depth, velocity, and substrate. In an ecological reality, a more complex and dynamic relationship exists among these parameters, as well as food resources, habitat quality, and the total life history requirements.

SUMMARY AND CONCLUSIONS

This study presents a synopsis of a hydrologic and biologic simulation of the flow-habitat relationships in the Glen Canyon Dam tailwaters. The actual amount of usable area in 1985 was calculated and compared to the 1980 results, and differences were minimal. Only general trends of habitat utilization were shown. The trout habitat requirements used in the 1980 analysis

were modified to reflect conditions specific to the Glen Canyon tailwater area.

Results of this study should only be used to identify trends in habitat utilization by rainbow trout. These data should not be used to address more specific relationships such as areas of movement and actual amount of fry, juvenile, and adult habitat. Additional field data are necessary to expand application of the data to other areas of interest.

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