Pacific Gas and Electric Company

Technical and Ecological Services
3400 Crow Canyon Road
San Ramon, CA 94583
510/820-2000

August 24, 1995

RECEIVED
PLACER COUNTY WATER AGENCY
POWER SYSTEM

AUG 28 1995

Mr. Steve Jones
Placer County Water Agency
P.O. Box 667
Forestville, CA 95631

Dear Mr. Jones:

Enclosed is the executive summary from the baseline report on the Response of Fish Populations to Altered Flows Project. The project is evaluating the Instream Flow Incremental Methodology and its ability to predict the response of rainbow and brown trout populations under altered flow regimes. The report documents the baseline conditions and our predicted trout responses under the altered flows. Study sites are located on three streams on the west slope of California's Sierra Nevada. Baseline data were collected from 1985 to 1992, and new minimum instream flows were implemented in 1993. Data will be collected under the altered flow regimes through 1996, and a final report will be prepared in late 1997. This project is sponsored by Pacific Gas and Electric Company, the Electric Power Research Institute, Southern California Edison Company, California Department of Fish and Game, and the U.S. Forest Service.

If you have co-workers that are interested in this research, please feel free to provide them with copies of the executive summary. If you have any questions or would like to request a copy of the baseline report, you can call me at (510) 866-5834 or send me an e-mail at TKS3@PGE.COM. Thank you for your interest in the Altered Flows Project.

Sincerely,

Thomas K Studley

Thomas K. Studley
Project Manager

TKS(251-5834):nlg

Enclosure

Report Issued: June 20, 1995

PG&E

Research and Development

Response of Fish Populations to Altered Flows Project, Volume I: Predicting Trout Populations from Streamflow and Habitat Variables

Cost Reduction Projects
Report 009.4-94.3

Project Manager: Thomas K. Studley

Natural Resources Management

May 1995

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Several people donated their time by serving on the project's Technical Advisory Committee and provided numerous recommendations that improved the study design, sampling methods, data analysis techniques, and contents of project-related reports. They include Tom Lisle (U.S. Forest Service), Peter Moyle (University of California, Davis), Mike Sale (Oak Ridge National Laboratory), Clair Stalnaker (National Biological Survey), and Woody Trihey (Trihey and Associates), Jack Mattice, Bill Snider, and John Palmer. We are greatly indebted to these individuals for their contributions.

We would also like to thank the people who co-authored previous project-related reports, helped collect data discussed in this report, provided critical reviews of project components, and provided moral support or technical advice. We would especially like to recognize Tom Keegan, who authored or co-authored several earlier project reports and was responsible for the fish population and creel census programs during the earlier years of this project. Although we cannot name all of the other individuals who worked on the project, we would also like to thank Rob Aramayo, John Bartholow, Ken Bovee, Steve Canata, Jess Crane, Jack Erickson, Bob Franklin, Henry French, Gene Geary, Charlene Hall, Paul Hampton, Tom Hebrard, Joe Hill, Jim Holeman, Todd Hopkins, Tim Jennings, Sharon Keegan, Brent Kloppenburg, Paul Kubicek, Wayne Lifton, Hugh Lin, Dave Longanecker, John McKeon, Carl Page, Verrie Pearce, Greg Reub, Paul Riggs, Bob Richardson, Dennis Smith, Derek Stallard, Curtis Steitz, Brian Waters, Webb Van Winkle, and Yetta Jager. Terry Silver (Environmental Publication Consultants) edited the report, and Carole Petrini (California Consulting Association) did the word processing.

This report is dedicated to "Smiley," a 500-mm brown trout captured 13 times over a 7-year period at the Tule River Project. He was 11-13 years old when last seen in September 1992.

EXECUTIVE SUMMARY

OVERVIEW AND OBJECTIVES

Instream flows are required at hydropower projects to maintain or enhance fishery resources. Instream flow requirements are typically set as conditions in licenses issued by the Federal Energy Regulatory Commission (FERC). As licenses expire, or new projects are proposed, FERC has often based flow requirements on an Instream Flow Incremental Methodology (IFIM) analysis, which predicts how weighted usable area (WUA), an index of physical habitat, changes with flow. WUA, the habitat index derived from computer models of the Physical Habitat Simulation System (PHABSIM), is often assumed to represent the fisheries benefits of instream flows. However, relationships between WUA and fish populations are not well established. The IFIM is the most common instream flow method used in the United States and is usually required by resource agencies in California for evaluating impacts and determining instream flow requirements. FERC licenses will expire at 12 PG&E hydro projects in the next 15 years, and a substantial amount of water may be reallocated between power generation and fishery resources. The goal of the Response of Fish Populations to Altered Flows Project (Altered Flows Project) is to investigate the relationships between physical habitat indices (i.e., WUA and other indices) and trout populations under two different flow regimes and to improve methods used to allocate water between power generation and fishery resources.

The primary study objective is to test the ability of habitat-based instream flow methods such as the IFIM to predict how rainbow and brown trout populations respond to a change in minimum instream flow. To achieve this objective, the study addresses the following questions:

1. Can we detect a response of fish populations to changes in streamflow and streamflow-dependent habitat variables?
2. If so, can these population responses be predicted reliably by habitat simulation models?

Secondary objectives of this study are to (1) determine what and when factors other than minimum flows and WUA limit trout populations, and (2) compare the ability of complex habitat simulation models versus simple streamflow-dependent variables to predict the response of fish populations to minimum flow alterations. Meeting these objectives should improve our understanding of the strengths and weaknesses of existing instream flow methods, lead to improvements in instream flow methods, and enable more efficient allocation of water among competing uses.

Our preliminary findings from the baseline monitoring period indicate that relationships between trout populations and WUA depend on the presence or absence of other major limiting factors (i.e., factors that cause mortality and emigration or reduced growth and condition). In our study sites, high water temperatures, lack of spawning habitat, competitive interactions with other species, and competitive interactions with other trout age groups (i.e., age 1 trout) affected relationships between adult trout populations and WUA. If major limiting factors (other than WUA) are influencing fish populations, then increased WUA may not provide expected benefits. In the final report, we will evaluate whether increases in flow and WUA benefit fish populations at the study sites.

The Altered Flows Project is an ongoing cooperative effort among industry and regulatory agencies. PG&E, Southern California Edison Company (SCE), and the Electric Power Research Institute (EPRI) provide most of the funding. Other financial contributors include the California Department of Fish and Game (CDFG) and the U.S. Forest Service (USFS). A Technical Advisory Committee, which usually meets annually, was established in 1986 and includes Tom Lisle (USFS), Jack Mattice (EPRI), Peter Moyle (University of California, Davis), John Palmer (SCE), Mike Sale (U.S. Department of Energy), Bill Snider (CDFG), Clair Stalnaker (National Biological Survey; formerly part of the USFWS), and Woody Trihey (Trihey and Associates).

Study Approach

The Altered Flows Project was designed to (1) monitor fish populations, instream flows, and other physical and biological variables under one level of minimum instream flows (i.e., the baseline period: 1985-1992); (2) use the baseline data to predict trout population responses to higher minimum instream flows (i.e., altered flows) using three prediction methods; (3) monitor the response of fish populations and other physical and biological variables under the altered flows (1993-1996); and (4) evaluate the accuracy of the predictions and identify ways to improve instream flow assessment methods (1997).

The research project maintains 18 fish population study sites in eight stream segments at Pacific Gas and Electric Company's (PG&E) Tule River and Crane Valley hydroelectric projects, on the west slope of California's Sierra Nevada. PHABSIM models were developed for 13 of the study sites. Five study sites are in two stream segments upstream of diversion dams where flows are not regulated (North Fork Middle Fork Tule River [NFMFTR] above Tule River Diversion and South Fork Willow Creek [SFWC] above Browns Diversion). Eleven study sites are in five stream segments below diversion dams without storage capacity (NFMFTR below Tule River Diversion, NFMFTR below Doyle Springs Diversion, NFMFTR below Meadow Creek, SFWC below Browns Diversion, and SFWC below Forest Service Road). Two study sites are in one stream segment where flows are almost fully regulated (North Fork Willow Creek [NFWC] below Bass Lake). Capacities of the two main diversions without storage are 66-100 cfs. Fish species composition within study sites includes (1) rainbow trout only, (2) rainbow and brown trout, (3) rainbow trout, brown trout, and a native minnow, and (4) several warm-water species and rainbow trout. Site elevations range between 2800 and 4200 ft. Median summer flows in the baseline period ranged from 0.2 to 1.1 cubic feet per second (cfs) in controlled sites and from 0.9 to 7.7 cfs in uncontrolled sites.

Report Objectives

This report documents the baseline period of the Altered Flows Project. The primary objective of the report is to describe the three levels of analysis used to predict trout population responses under altered flows and to document the predicted responses. Secondary objectives of the report are to describe the study areas, document the physical and biological conditions during the baseline period, identify factors that limit fish populations other than flow and WUA, and present preliminary conclusions on the relationships between trout populations and WUA (or simpler measures of physical habitat).

PREDICTED RESPONSES OF FISH POPULATIONS

Predictions were developed for each study site using expected changes in streamflows and WUA, and other information collected during baseline conditions. Three levels of analysis were used, and all shared the basic premise that trout abundance is related to WUA (a premise generally supported by the baseline data). The three levels of analysis ranged from simplistic, but commonly used, PHABSIM-based analyses to more elaborate analyses using all physical and biological data collected from 1985 to 1992. Altered flows were implemented in 1993 and include year-round increases in some stream segments and seasonal increases (October-June) in others. The altered flows were selected to facilitate testing of specific predictions under all three levels of analysis at each study site. We considered the following factors before the altered flows were selected: (1) improving habitat for limiting trout lifestages (i.e., lifestages that showed high mortality or were present in relatively low numbers); (2) changing WUA to levels expected to significantly increase fish populations (i.e., a change of at least 100%); (3) limitations of natural flows; and (4) flows needed for each level of analysis. Although flows were altered in 1993, the predictions in this report were documented before data from the altered flows period were analyzed to ensure that development of the prediction methods and the predicted responses of fish populations were not biased by such data.

Methods

Three levels of analysis were used to make predictions of trout population responses. Input to the analyses included fish population characteristics observed under baseline conditions, projected increases in WUA, and other baseline information depending on the level of analysis. Predicted abundances of trout were based on Studley-Spina (1992), Bovee (1978), and Raleigh et al. (1984b, 1986) habitat suitability criteria. Studley-Spina criteria are California-based habitat utilization criteria that were modified by professional judgment, whereas Bovee and Raleigh criteria are generic criteria developed primarily from literature reviews of habitat requirements. Predictions based on Studley-Spina criteria (without cover) are considered the primary predictions.

For all levels of analysis, the average 10-day low flow (i.e., the highest flow during the lowest consecutive 10-day low-flow period) was used in determining increases in WUA between baseline conditions and altered flow conditions. Although we found more statistically significant regressions between trout populations and WUA based on median flows than between trout populations and WUA based on 10-day low flows, the average 10-day low flow was used because the change in 10-day low flows can be more accurately predicted. In the final project report, WUA will be calculated using actual median and 10-day low flows occurring during altered flow conditions, and predictions will be revised using the methods defined in this report. Development of site-specific criteria is scheduled to be completed in 1996. Site-specific criteria will be treated as a new set of criteria, and predictions for those criteria will be made for the final report in the same manner that they were made for other criteria sets in this report.

Level I: Adult Rainbow Trout Habitat. The Level I analysis is the least sophisticated analysis and focuses on increasing adult rainbow trout abundance by increasing WUA on a year-round basis. State and federal agencies usually recommend flows derived from WUA for adult rainbow trout. Under our Level I analysis, we assume there is a direct relationship between WUA and adult rainbow trout abundance and an increase in WUA would result in a corresponding increase in the number of adult rainbow trout. The assumption inherent in this level of analysis is that adult rainbow trout habitat (i.e., WUA) is the primary limiting factor.

The Level I analysis disregards the presence of other fish species and the influence of limiting factors other than physical habitat as defined by PHABSIM (i.e., WUA). Fish population and hydrology data from 1986 through 1992 were used in computing average baseline conditions without regard to the different types of water years. Level I predictions were computed by multiplying the average fall abundance of adult (i.e., age 2 and older) rainbow trout during baseline conditions by the factor by which WUA is increased under altered flows.

Level II: Effective Habitat Time Series. Level II analysis uses the effective habitat time-series method described by Bovee (1982). The National Biological Survey (formerly the National Ecology Research Center) provided the computer programs, habitat ratios, and instruction. Like the Level I analysis, the Level II analysis disregards the presence of other species, the influence of limiting factors other than WUA, and assumes a proportional increase in trout abundance to increases in WUA. Unlike Level I, the Level II analysis considers linkages between lifestages.

The effective habitat time-series analysis looks at a historic WUA time series and identifies periods when habitat for one lifestage may limit the number of fish in later lifestages. The "effective habitat" represents the portion of available physical habitat actually required by a lifestage considering mortality of previous lifestages. We used (1) historic flow records converted to WUA records using the flow-WUA relationships for each lifestage from PHABSIM; (2) literature values of survival ratios for each lifestage; (3) literature values of habitat requirements for each lifestage (square feet of WUA needed per individual); (4) a single PHABSIM model for each stream segment (Levels I and III used PHABSIM models configured for each study site); and (5) trout abundance developed from our first year of field data.

Level II predictions were computed by multiplying the average trout abundances of limiting lifestages (e.g., fall age 0 or fall age 1) during baseline conditions by the factor by which the baseline WUA was to be increased under altered flows. The assumption inherent in the Level II analysis is that WUA for a limiting lifestage identified in the effective habitat time-series analysis is the primary limiting factor. Although Studley-Spina and Bovee criteria were the only criteria used in the effective habitat analysis, predictions were made using all three sets of criteria for the limiting lifestages identified by the effective habitat analyses. Fish population and hydrology data from 1986 through 1992 were used in computing average baseline conditions.

Level III: Limiting Factor Analysis. The Level III analysis used all information collected during baseline conditions and represented the most complex level of analysis. We conducted limiting factor analyses, cohort analyses, food availability studies, harvest estimates, regression analyses between trout populations and habitat indices, and considered inter- and intra-specific competition and habitat overlaps among species. The initial prediction for the Level III analysis involved identifying a limiting lifestage or age group (e.g., age 1 and older), determining the average baseline abundance and increase in WUA under altered flows, and multiplying the baseline abundance by the factor by which WUA was expected to increase.

Although the Level III analysis assumed that there is a relationship between WUA and trout abundance, the Level III analysis did not necessarily assume increases in trout abundance were proportional to increases in WUA. For example, if WUA:fish abundance ratios were expected to decrease due to the elimination of a major limiting factor under altered flows (e.g., reduced summer stream temperatures), increases in fish abundance proportional to increases in WUA were not expected. Accordingly, expected WUA:fish ratios were used to adjust the initial prediction upward or downward.

The Level III analysis focused on identifying the lifestages that limit trout populations and factors that limit populations other than WUA. Methods to identify limiting lifestages in the baseline period included regression analysis to determine if the population of one lifestage appeared controlled by the population of an earlier lifestage (instead of by habitat) and examining survival rates of individual year classes to determine what lifestages suffered high mortality.

Numerous factors other than flow and WUA were examined to determine if they limited baseline trout populations and therefore needed to be considered in predicting the response of populations to the altered flows. The effects of recruitment success (the number of new fish produced each year) on adult populations were investigated by determining if adult populations were correlated to spawning habitat availability and juvenile populations; such correlations indicated that population predictions should consider expected changes in recruitment. A temperature model and literature on temperature effects were used to predict whether water temperatures will limit populations under altered flows. The biomass of benthic invertebrates was monitored during the baseline period and used as an indicator of food availability; correlations of populations versus benthic biomass were used to identify sites where food availability might limit populations and to predict whether this limit would increase or decrease under altered flows. Low fish growth rates or condition factors were also used to identify sites with food limitations. Competition within and among species was examined by comparing growth rates with population sizes to determine if higher populations resulted in lower growth. In addition, competition between brown and rainbow trout for the additional habitat created by higher flows was considered, and many of the predictions were total trout predictions based on increases in total trout WUA (i.e., WUA derived from suitability curves that encompassed habitat for rainbow and brown trout) instead of on each species separately. Creel census data were used to evaluate the effects of angler harvest on adult trout populations at the Tule River sites where fishing is common and to determine the effects of angling on predicted populations.

In contrast to the Level I and II analyses, fish population and flow data from 1986, which had unusually high flows, were not used in computing baseline conditions for Level III. The 1987-1992 data were more uniform and had less overall variation than data for 1986-1992.

Predictions

A summary of the primary predictions of trout population responses for the Tule River and Crane Valley study sites is given in Tables ES-1 and ES-2, respectively. At first glance, it may appear that conflicting instream flows occur at several study sites; however, the discrepancies are explained in the footnotes or, in some cases, the appropriate text in the report. For example, the altered flows under the Level III predictions for NFMFTR below Tule River Diversion (Table ES-1) indicate that there are different altered flows for the same stream segment (i.e., 1.8 and 5 cfs). As explained in footnote 3, the altered flow may differ from Level I and II altered flows as a result of seasonal releases for the Level III test. In other

Table ES-1

Primary Predictions of Trout Population Responses under Altered Flows for Tule River Study Sites

Stream Segment/ Study Site	Prediction Level	Population Prediction Variable[1]	Baseline Low Flow (cfs) and (WUA)[2]	Altered Low Flow (cfs) and (WUA)[2]	Average Baseline Population (fish/100 m)	Predicted Abundance with Altered Flows (fish/100 m)
NFMFTR above Tule River Diversion						
NfT 7.7	I	Fall adult RT	7.7 (4077)	7.7 (4077)	8.0	8
	II	--	--	--	--	--
	III[3]	Fall adult TT	7.1 (4352)	7.1 (4352)	48.2	48
NFMFTR below Tule River Diversion						
NfT 6.1	I	Fall adult RT	1.1 (1529)	1.8 (1949)	7.4	10
	II	Fall juvenile RT	1.1 (204)*	1.8 (463)*	36.6	84
	III	Fall adult TT	1.1 (2225)	1.8 (2612)	15.7	19
	III	Summer adult TT	1.1 (2225)	5.0 (3882)	27.2	46
NfT 6.0	I	Fall adult RT	1.1 (1142)	1.8 (1452)	6.6	9
	II	Fall juvenile RT	1.1 (219)*	1.8 (480)*	56.0	123
	III	Fall adult TT	1.1 (1654)	1.8 (1933)	12.3	15
	III	Summer adult TT	1.1 (1654)	5.0 (2849)	21.0	36
NFMFTR below Doyle Springs Diversion						
NfT 5.1	I	Fall adult RT	0.4 (774)	4.0 (3952)	9.3	47
	II	Fall juvenile RT	0.4 (1129)	4.0 (7459)	25.1	166
	III	Fall base TT	0.2 (964)	4.0 (4436)	29.0	92-133
	III	Fall adult TT	0.2 (964)	4.0 (4436)	11.8	30-54
NfT 5.0	I	Fall adult RT	0.4 (1409)	4.0 (4994)	16.9	59
	II	Fall juvenile RT	0.4 (1656)	4.0 (7418)	44.1	198
	III	Fall base TT	0.2 (1917)	4.0 (5994)	58.3	121-181
	III	Fall adult TT	0.2 (1917)	4.0 (5994)	26.4	44-82
NFMFTR below Meadow Creek						
NfT 4.0	I	Fall adult RT	1.0 (1678)	4.5 (3629)	6.1	13
	II	Fall YOY RT	1.0 (210)*	4.5 (342)*	69.8	112
	III	Fall base TT	0.7 (2328)	4.5 (4578)	31.4	63-167
	III	Fall adult TT	0.7 (2328)	4.5 (4578)	6.4	13-36
NfT 2.4	I	Fall adult RT	1.0 (1797)	4.5 (3916)	4.4	10
	II	Fall YOY RT	1.0 (227)*	4.5 (366)*	64.0	102
	III	Fall base TT	0.7 (2477)	4.5 (4924)	36.5	73-180
	III	Fall adult TT	0.7 (2477)	4.5 (4924)	5.6	11-38

[1] YOY, RT, TT, base = young-of-the-year, rainbow trout, total trout, and age 1 and older trout, respectively.

[2] WUA is based on Studley-Spina habitat suitability criteria without cover; those designated with (*) are based on Bovee criteria without cover. Baseline flows are 10-day low flows. WUA is in units/1,000 ft of stream.

[3] Level III baseline flows are based on 1987-1992 hydrology data; Level I and II baseline flows are based on 1986-1992 hydrology data. The Level III altered low flow may also differ from the Level I and II altered flows as a result of seasonal releases for the Level III test.

Table ES-2

Primary Predictions of Trout Population Responses under Altered Flows for Crane Valley Study Sites

Stream Segment/ Study Site	Prediction Level	Population Prediction Variable[1]	Baseline Low Flow (cfs) and (WUA)[2]	Altered Low Flow (cfs) and (WUA)[2]	Average Baseline Population (fish/100 m)	Predicted Abundance with Altered Flows (fish/100 m)
SFWC above Browns Diversion[3]						
SaN 1.3	III[4]	Fall base TT	0.5 (--)	0.5 (--)	46.7	47
SfW 11.1	III	Fall base TT	0.5 (--)	0.5 (--)	38.5	39
SfW 10.9	III	Fall base TT	0.5 (--)	0.5 (--)	42.0	42
SFWC below Browns Diversion[3]						
SfW 10.0	III	Summer base TT	0.5 (--)	4.0 (--)	23.3	53
SfW 8.4	III	Summer base TT	0.5 (--)	4.0 (--)	32.3	53
SFWC below Forest Service Road						
SfW 7.9	I	Fall adult RT	0.5 (387)	1.5 (752)	6.6	13
	II	Fall adult RT	0.5 (387)	1.5 (752)	6.6	13
	III	Summer base TT	0.5 (667)	4.0 (1876)	50.9	76
	III	Summer adult TT	0.5 (667)	4.0 (1876)	10.1	28
SfW 7.7	I	Fall adult RT	0.5 (326)	1.5 (671)	4.1	9
	II	Fall adult RT	0.5 (326)	1.5 (671)	4.1	9
	III	Summer base TT	0.5 (545)	4.0 (1623)	22.8	34
	III	Summer adult TT	0.5 (545)	4.0 (1623)	6.0	18
SfW 5.8	I	Fall adult RT	0.5 (291)	1.5 (613)	5.7	12
	II	Fall adult RT	0.5 (291)	1.5 (613)	5.7	12
	III	Summer base TT	0.5 (493)	4.0 (1540)	67.0	100
	III	Summer adult TT	0.5 (493)	4.0 (1540)	11.5	36
NFWC below Bass Lake						
NfW 11.2	I	Fall adult RT	0.2 (348)	4.0 (1307)	0.2	1
	II	Fall juvenile RT	0.2 (446)	4.0 (1817)	1.8	7
	III	Fall YOY RT	0.2 (6646)	4.0 (6397)	21.0	86
	III	Summer base RT	0.2 (348)	4.0 (1307)	2.9	61
NfW 11.0	I	Fall adult RT	0.2 (443)	4.0 (1612)	0.1	0.4
	II	Fall juvenile RT	0.2 (552)	4.0 (2135)	0.7	3
	III	Fall YOY RT	0.2 (8197)	4.0 (7433)	6.5	86
	III	Summer base RT	0.2 (443)	4.0 (1612)	2.0	76

1 YOY, RT, TT, base = young-of-the-year, rainbow trout, total trout, and age 1 and older trout, respectively.
2 WUA is based on Studley-Spina habitat suitability criteria without cover; those designated with (*) are based on Bovee criteria without cover. Baseline flows are 10-day low flows. WUA is in units/1,000 ft of stream.
3 PHABSIM analyses were not conducted in these stream segments; therefore, Level I and Level II predictions could not be made.
4 Level III baseline flows are based on 1987-1992 hydrology data; Level I and II baseline flows are based on 1986-1992 hydrology data. The Level III altered low flow may also differ from the Level I and II altered flows as a result of seasonal releases for the Level III test.

situations, the predicted fish abundances may consist of a range for the predicted response. These generally relate to uncertainties associated with recruitment levels or other limiting factors. Unless noted otherwise, the primary predictions are based on Studley-Spina criteria without cover. These predictions will be revised using actual instream flows in the final project report in 1997.

In the final report, we will test the accuracy of our predictions and examine why populations respond as they did to the altered flows. Three orders of statistical analysis will be used, and statistical methods are being developed. The first order test will determine if a significant change in fish abundance occurred between the baseline and altered flows periods. If no significant change is found, then any predicted increase in abundance is assumed to be incorrect. The second order test will determine if the observed abundance under altered flows is significantly different from the predicted abundance. The simplest way to conduct this order test is to determine whether the prediction (with or without the variability in the prediction that results from variability in the baseline data used to make the prediction) falls within the confidence limits of the abundances measured in the altered flows period. However, variability in observed abundances is expected to result in wide confidence intervals, so there will be a wide range of possible predictions that could not be rejected as inaccurate; this method is expected to have little power for testing predictions. "Before-after, control-impact" methods will also be applied to test whether the relationship between fish abundance and predictor variables (e.g., WUA for Level I predictions) remained the same between baseline and altered flow periods; if so, then the predictions can be assumed accurate. In addition, predicted vs. observed fish abundances will be examined across all sites in a watershed (e.g., by regressing observed vs. predicted abundance and seeing how close the slope is to 1) to determine whether the prediction methods were successful at a watershed scale. The third order of analysis will be to explore relationships between fish populations and habitat variables. This analysis will focus on identifying factors that limit populations other than WUA. Special attention will be given to explain population responses at sites where Level I and II predictions were inaccurate.

INTERIM FINDINGS AND FUTURE RESEARCH CONSIDERATIONS

The baseline data were analyzed to explore relationships between trout populations and physical and biological variables. The following conclusions were based on observed responses of trout populations to variation in the physical and biological variables over time at individual study sites and across all study sites. These analyses were limited by the low variability in hydraulic conditions among the baseline years and will be re-examined using data from the altered flows period in the final report.

Physical and Biological Characteristics during Baseline Conditions

We monitored regulating variables (streamflow, temperature, water quality, and habitat indices), response variables (fish abundance, biomass, recruitment, growth, and mortality), and restraining variables (angler harvest, trout stocking, feeding habits of trout, and benthic macroinvertebrates). The following are some of the important baseline conditions that provided direction to the predictions of fish populations presented in this report.

- Of the 8 baseline years of data collection, there were 6 dry years (1987-1992) and 1 wet year (1986). High scouring flows occurred in the winter or spring in 1986 and 1991.

- Mean daily stream temperatures were usually less than 20°C in all stream segments during the summer, except NFMFTR below Meadow Creek at the Tule River Project. Stream temperatures during the winter fell to 1-5°C in most stream segments, but freezing generally did not occur. Winter stream temperatures in NFMFTR below Doyle Springs Diversion were warmer than other stream segments (due to spring water) and usually did not fall below 10°C. Other water quality parameters were generally within acceptable ranges for trout.

- Habitat mapping surveys indicated that spawning habitat was scarce in most stream segments. The greatest amount of spawning habitat (and young-of-the-year abundances) was found in NFMFTR above and below Tule River Diversion. Pool habitat was common, and dominant substrates usually consisted of boulder and cobble.

- Hydraulic variables were estimated using PHABSIM models and included different measures of depth, velocity, and cross-sectional area. Hydraulic parameters during spring varied among years by factors of 3 or more within sites, but there was little variation in summer.

- Age 1 rainbow and brown trout abundances were found to be recruitment limited at most stream segments. However, fall age 2 rainbow and brown trout abundances did not always respond to increased abundances of fall age 0 or yearling trout. This indicates that factors other than recruitment were also affecting adult trout populations. Analysis of WUA:fish ratios for total trout (i.e., rainbow and brown trout combined) at all study sites revealed that adult trout can be at relative habitat saturation levels even when earlier age groups appear to be recruitment limited. This indicates that several limiting factors can be operating at a time.

- We estimated an index of mortality that did not distinguish between actual fish deaths, immigration, and emigration from study sites. In general, mean monthly mortality indices for fall age 0 (i.e., fall age 0 to summer age 1) trout were the lowest and were the least variable for age 0 and age 1 trout. The lowest average mortality indices were usually found for age 0 and age 1 rainbow trout in stream segments where recruitment was limiting. Mortality indices for age 2 and older trout varied considerably between stream segments and between years. Brown trout mortality indices were generally lower than those for rainbow trout. Rainbow trout usually lived no longer than 2-3 years, whereas brown trout (when present) were relatively common up to 3 years old.

- The average lengths and weights of brown trout were always greater than that for rainbow trout of the same age. Growth rates for age 0 trout were relatively constant within study sites, even in years when growth rates declined in older age groups of trout as a result of density-dependent factors. This suggests that habitat for age 0 trout was generally not limiting. The highest growth rates were found at NFMFTR below Doyle Springs, which may be due to the influence of spring water that cools the water in the summer and warms the water in winter. Condition factors for rainbow and brown trout usually decreased from summer to fall (except at NFMFTR below Doyle Springs Diversion), and condition factors usually decreased as fish age increased.

- Fishing pressure was relatively light at the Tule River Project, with most of the fishing occurring in the two upper stream segments (NFMFTR above and below Tule River Diversion). Most of the fish harvested were hatchery rainbow trout with lower numbers of wild rainbow trout and few brown trout (virtually all hatchery trout planted near our study sites were in NFMFTR below Tule River Diversion). Baseline creel census data did not appear to explain the large decreases in wild trout abundance between summer and fall. In our study sites, harvest may be a function of trout abundance rather than a limiting factor for abundance. Although creel censuses were not conducted at the Crane Valley Project, harvest is believed to be very light. Consequently, harvest is not expected to interfere with the response of fish populations under altered flows at either project.

- Most trout fed on benthic macroinvertebrates (including benthic organisms on the stream bottom and those that entered the drift); less than 20% of the diet came from terrestrial insects or terrestrial forms of aquatic insects, with the exception of October. In October, terrestrial insects were 40-50% of the diet for older rainbow trout and 30% of the diet for older brown trout. Only 0.05% of rainbow trout (1 of 1,867 samples) and 1.6% of brown trout (12 of 761 samples) were found to have consumed other fish.

- Food availability may be a limiting factor for trout populations in NFMFTR above and below Tule River Diversion, SFWC below Forest Service Road, and NFWC below Bass Lake. If an increase in flow improves food supplies, food limitations may not be a major factor preventing the expansion of trout populations. However, food availability may regulate trout abundance at a new, higher level.

Streamflow, WUA, and Other Flow-dependent Variables as Predictors of Population Variations

Within study sites, the flow rates, WUA, and various hydraulic variables (measures of velocity, depth, area, etc.) were associated linearly over the range of flows observed in the baseline period (these variables would be nonlinear over wider ranges of flows beyond the range of new study flows). Therefore, flow rates and WUA were of equal usefulness for predicting variations in fish population due to small variations in base flows observed at each site.

At the Crane Valley Project study sites, annual variation in trout populations was generally not explained by variation in flow or WUA, most likely because there was little variation in flow among years. At the Tule River sites, variation in populations among years generally was related to base flows, especially median summer flow. Brown trout populations were less related to flow than rainbow trout, largely because brown trout year classes were virtually eliminated by high winter and spring flows in 1986 and 1991. The within-site analyses led to the following conclusions that were considered in developing predictions:

- Regression analysis indicated more significant relationships ($p < 0.1$) and more highly significant relationships ($p < 0.01$) between fall age 1 and older total trout populations and summer adult WUA than between either rainbow or brown trout and WUA. This indicates that relationships between individual species and WUA may not be apparent if a larger unit of biological measure (e.g., total trout) is responding to flow variation.

- There were more significant regressions between fall rainbow, brown, and total trout populations and summer WUA than between summer trout populations and spring WUA. This indicates that summer base flows may be a major factor affecting fall trout populations.

- There were more significant regressions between adult WUA in summer and fall age 1 and older rainbow, brown, and total trout populations than with age 2 and older trout. This finding is most likely due to habitat overlap between age 1 trout and age 2 and older trout.

- There were more highly significant regressions between adult WUA in summer and fall age 1 and older rainbow, brown, and total trout populations using Studley-Spina criteria than with Bovee or Raleigh criteria. This finding indicates that the Studley-Spina criteria should be more appropriate than the Bovee or Raleigh criteria for the streams under study.

Linear regression between WUA and trout populations across all study sites provided a greater range of conditions than were found within study sites (i.e., flow rates, WUA, and other hydraulic parameters are not linearly related to each other across all study sites) and provided an evaluation of relationships between WUA and trout populations in a regional perspective. The across-site analysis included using average baseline values for each site or yearly data for all sites. The across-site analysis led to the following conclusions:

- Different sets of habitat suitability criteria produced substantially different WUA values, but none of the three criteria sets used was distinctly better at predicting rainbow, brown, and total trout populations. However, the Studley-Spina criteria explained more of the variation in fall age 1 and older and fall age 2 and older total trout than either Bovee or Raleigh criteria. Including cover in WUA reduced its ability to predict brown trout populations.

- Fall trout populations were more closely related to summer median flows and the corresponding WUA than to summer minimum flows and corresponding WUA.

- Trout populations were significantly correlated to WUA and flow. WUA explained more variation in total trout populations than did flow or wetted perimeter. Wetted perimeter was a better predictor of rainbow, brown, and total trout populations than was the flow rate.

Factors That Limit Trout Populations Other Than Minimum Flow and WUA

In water allocation decisions, WUA is often used as a surrogate for all factors influencing a population. However, if other factors are influencing fish populations, then a change in WUA may not result in expected changes in fish populations. Other limiting factors, which are not often considered in instream flow studies, include stream temperature, scouring flows, spawning habitat, harvest, competition for habitat with other species, competition for habitat between lifestages of the same species, predation, or food availability. In conducting instream flow studies, it is important to understand how physical habitat (as defined by PHABSIM) ranks with other limiting factors affecting the fish populations. We made the following observations concerning limiting factors.

- There are strong indications that spawning habitat availability and recruitment success may be a major limiting factor for trout in our study sites. The percent of stream area suitable for spawning (data collected during habitat mapping surveys) was the variable that explained the most variation in age 1 and older trout populations among study sites. In addition, at most study sites, numbers of age 0 trout in the fall were predictive of age 1 fish the following summer, indicating that increased recruitment would result in increased numbers of age 1

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trout. This suggests that spawning habitat should not be ignored and may be more important than simply increasing instream flow for older age groups of trout. Although a PHABSIM analysis of spawning habitat is not easily conducted in many west-slope Sierra Nevada streams because of the patchy nature of spawning gravels, more reliable estimates of spawning habitat can be obtained during habitat mapping surveys. In addition, percent embeddedness was negatively correlated with age 1 and older trout populations.

- High, uncontrolled winter or spring flows affected trout populations by virtually eliminating brown trout year classes in 1986 and 1991. Brown trout spawn in early winter, and their eggs and larval stages are susceptible to being scoured and destroyed by flood flows (rainbow trout, which spawn in the spring and thereby avoid many scouring events that brown trout are subject to, had relatively successful year classes in all baseline years). The elimination of brown trout year classes may have masked relationships between fall trout populations and summer WUA in some cases.

- Stream temperature appears to have an important, non-linear effect on trout populations. The study sites have summer temperatures ranging from optimal to marginally high for trout (median summer temperatures ranged from 14 to 20°C). Rainbow trout populations showed a general decrease with increasing temperature; brown trout populations, however, were very low or zero at sites with summer temperatures above 17°C and appeared unrelated to temperatures less than 17°C.

- When not limited by spawning failure or temperature, brown trout appear to outcompete rainbow trout, displacing them from habitat that would otherwise be suitable. In such cases, increases in rainbow trout WUA may result in increased brown trout populations rather than increased rainbow trout populations. Therefore, total trout population responses to instream flows are more likely to be predictable than predictions based on individual species.

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