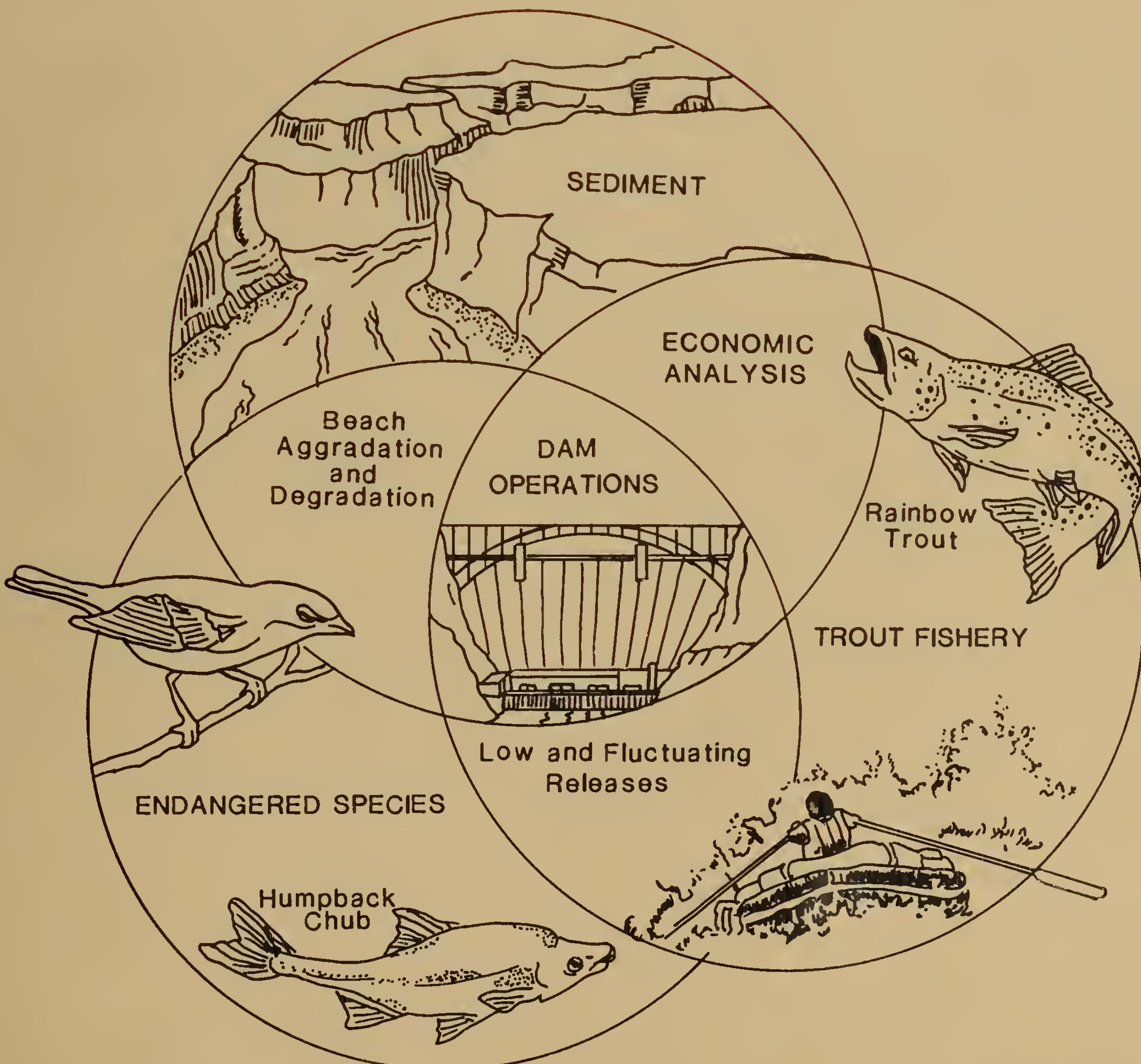
GLEN CANYON ENVIRONMENTAL STUDIES PHASE II

DRAFT INTEGRATED RESEARCH PLAN



Volume 1

AUGUST 1990

GLEN CANYON ENVIRONMENTAL STUDIES

PHASE II

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PREFACE

This document, in two Volumes, is the first compilation of the separate research plans for Phase II of the Glen Canyon Environmental Studies (GCES). It is issued as a DRAFT for information and review as an intermediate step in defining the research program. The Introduction explains that the INTEGRATED RESEARCH PROGRAM report is not intended to detail the final or the exact way in which every task is to be performed.

This DRAFT document is issued at this time because it is important for those with interests and responsibilities to be able to gain insight into the overall approach for Phase II GCES. The majority of the research studies have begun, related to prescribed research river flow patterns.

Several portions of the document are noted to be added later. Other portions will be revised as part of continuing discussions on research needs, costs, and schedules. Within the next several months, it is intended that the missing pieces will be added, necessary adjustments made to existing text, costs, and schedules, and the completed document will be reprinted for general use throughout the GCES Phase II time period.

Comments on this DRAFT document may be directed to: *Colorado River Studies Office, (Attention UC-119), P.O. Box 11568, Salt Lake City, Utah 84147. Questions on the specific research programs should be directed to the GCES Office in Flagstaff, Arizona, phone (602) 527-7363.

* author

INTRODUCTION

GLEN CANYON ENVIRONMENTAL STUDIES
PHASE II
INTEGRATED RESEARCH PLAN

This document represents the Glen Canyon Environmental Studies (GCES) Phase II Integrated Research Plan. This document is a compilation of the individual research programs that comprise the specific studies to be completed under the scientific umbrella for the GCES Phase II research effort.

The **objective** of this document is to provide to the researchers, the scientific community and the interested public, the background information on the research logic, integration process, and the report development procedure that the GCES Phase II scientific program will follow. The GCES Phase II Integrated Research Plan document is intended to meet several purposes:

1. Provide a roadmap, not a bible, for the completion of the GCES Phase II research program. This is a guide.

2. Provide documentation of the overall research direction and logic.

3. Provide for technical research information transfer to the GCES researchers, the scientific community and the interested public.

The **organization** of this document includes: a definition of the GCES Phase II integrated research approach; a discussion of the GCES Phase II Research Flows and research flow protocol; the individual study plans; the review process; data availability; team membership; and an overall estimated budget.

The **focus** of the GCES Phase II Integrated Research program is to ensure that a complete and scientifically rigorous research program results. This document is a compilation of the program process and has been prepared jointly by the GCES Flagstaff Office, the researchers, the Senior Scientist and others.

> "One learns a landscape finally not by knowing the name or identity of everything in it, but by perceiving the relationships in it"

WEGNER
August 1990

GLEN CANYON ENVIRONMENTAL STUDIES
PHASE II
TECHNICAL STUDY PLANS OUTLINE

SECTION X:
A. Survey design for Archeological Survey along the Colorado River, Grand Canyon National Park, AZ.
B. Native American Coordination. (to be added later)

SECTION XI: Economics.
A. Power Resource studies.
B. Recreation Economics.
C. Resource (non-use) Economics.

SECTION XII: Long-term Monitoring Program and Data Interpretation.
A. Long-term monitoring components.
B. Geographic Information System Program.

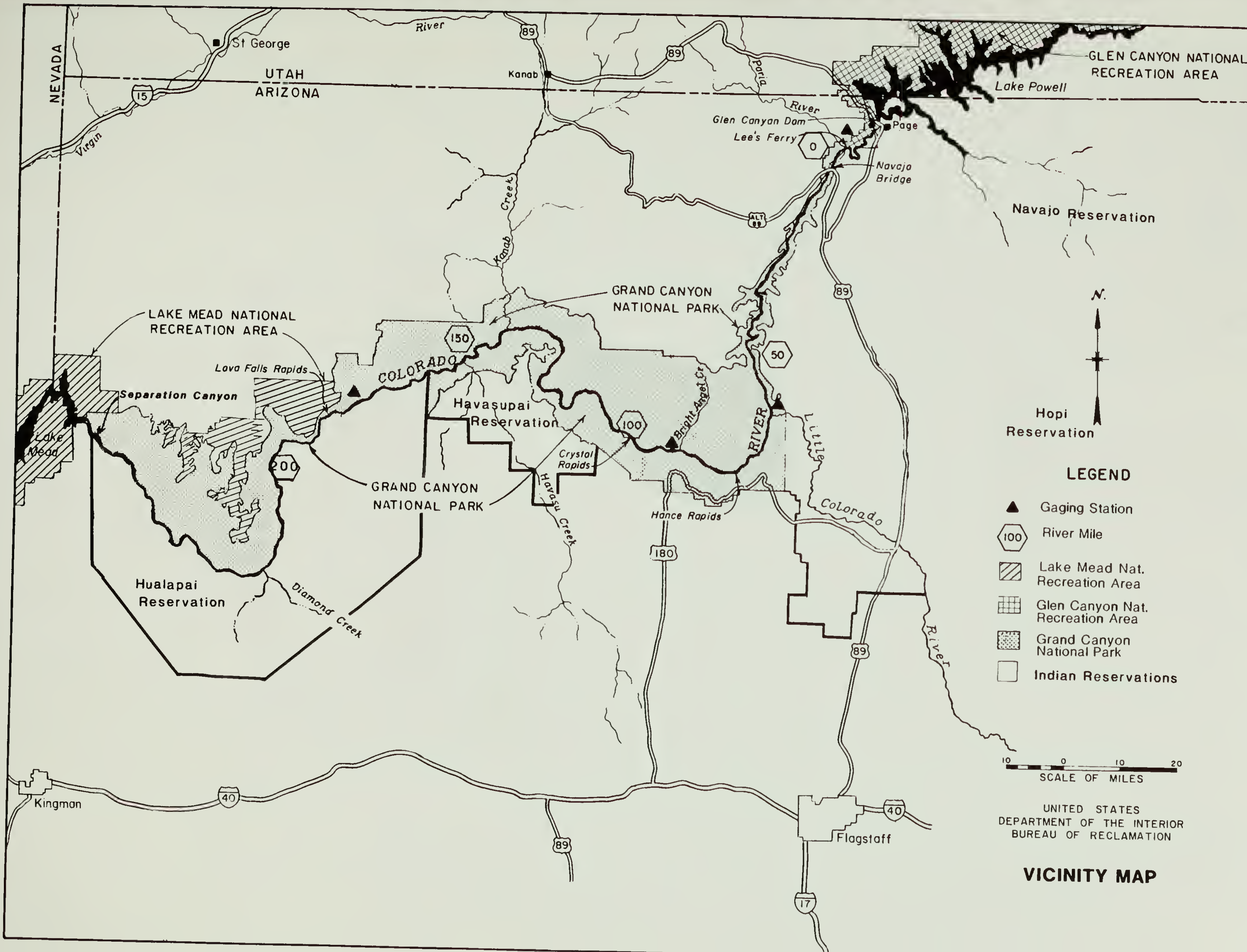
SECTION XIII: Glen Canyon Environmental Studies Report Integration Procedure.

SECTION XIV: Glen Canyon Environmental Studies Technical and Integrated Reports Protocol.

SECTION XV: Glen Canyon Environmental Studies Procedure for Handling Data Requests. (to be added later)

SECTION XVI: Estimated Phase II Budget. (to be added later)

SECTION XVII: Appendices.


GLEN CANYON NATIONAL RECREATION AREA
Lake Powell
St George
UTAH
ARIZONA
NEVADA
Kanab
Paria
River
Glen Canyon Dam
Lee's Ferry
Page
Navajo Bridge
Navajo Reservation
Virgin
Kanab Creek
GRAND CANYON NATIONAL PARK
LAKE MEAD NATIONAL RECREATION AREA
Lava Falls Rapids
Separation Canyon
COLORADO
RIVER
Havasupai Reservation
Crystal Rapids
Havasu Creek
Bright Angel Cr
Hance Rapids
Little Colorado River
Lake Mead
Hualapai Reservation
Diamond Creek
Hopi Reservation
Kingman
Flagstaff
N.
LEGEND
Gaging Station
River Mile
Lake Mead Nat. Recreation Area
Glen Canyon Nat. Recreation Area
Grand Canyon National Park
Indian Reservations
SCALE OF MILES
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
VICINITY MAP

RESEARCH LOGIC

GLEN CANYON ENVIRONMENTAL STUDIES

PHASE II

INTEGRATED RESEARCH PROGRAM

PHASE II RESEARCH PLAN DEVELOPMENT
OVERALL LOGIC AND HYPOTHESES DEVELOPMENT

I. Background

On June 19, 1988, the Department of the Interior, under the authority of the Assistant Secretary for Fish, Wildlife & Parks and the Assistant Secretary for Water and Science, directed the Bureau of Reclamation to continue the Glen Canyon Environmental Studies (GCES). The necessity for this continuance was a recognition that sufficient data had not been collected or analyzed under the initial GCES effort (Phase I) to make operational decisions at Glen Canyon Dam. The Assistant Secretaries directed that the GCES Phase II program be focused on: a better understanding the relationships of low and fluctuating flow on specific resources of the Grand Canyon, and studies to evaluate the potential economic impact of operational modification.

In addition, the Assistant Secretaries directed that, where possible, the National Academy of Sciences the recommendations should be integrated into the study process. Two key areas of National Academy of Sciences concern in their review of the GCES Phase I program was:

1. The need for a "senior" level scientist to guide the overall GCES research program, and

2. That the integrated approach to the GCES program should be developed "up front" and not attempted after all of the research is completed.

In April 1989, the GCES Executive Review Committee met to discuss the GCES Phase II program and agreed that a Senior Level Scientist should be brought on board. **Dr. Duncan Patten**, Director of the Center for Environmental Studies, Arizona State University, was selected for the GCES Senior Scientist position. Dr. Patten is currently on an Intergovernmental Personnel Action (IPA) appointment to the Bureau of Reclamation.

II. GCES Phase II Research Program Background

Duncan Patten and the GCES researchers began the development of the GCES Phase II research program with the understanding that the program would be four to five years long and be structured around the "Normal" operations at Glen Canyon Dam. With the intent that all research would be structured around the existing operation procedures for Glen Canyon Dam, the researchers began the process of developing an integrated approach designed around the scientific procedure of developing **hypotheses**. The development of **hypotheses** is central to a rigorous scientific approach.

In July 1989, the GCES Senior Scientists, a group of GCES researchers, interested constituent groups, and several members of the National Academy of Sciences traveled the course of the Colorado River through the Grand Canyon. The objective of this trip was to identify the key resources of concern and develop a "rough" outline of the hypotheses that would be tested under the GCES Phase II integrated research program. The objective of the program at the time of the trip was to support the Department of the Interior and the Bureau of Reclamation in their development of future operating considerations for Glen Canyon Dam.

On July 27, 1989, the Secretary of the Interior, Manual Lujan, directed that an **Environmental Impact Statement** (EIS) on the operations of Glen Canyon Dam be initiated. No specific timetable or boundaries of the EIS were defined. Of key importance though was the intent that the GCES program would support and supply the scientific information required for the EIS. The focus of the GCES Phase II Integrated Research Program shifted with the announcement of the Glen Canyon Dam - Environmental Impact Statement. The focus shifted to supporting the EIS process and developing the scientific background information necessary to evaluate the alternative of the EIS.

Since the announcement of the Glen Canyon Dam - Environmental Impact Statement in July 1989, the enddate for the EIS has shifted from five years to 24 months to 36 months and still is uncertain. This uncertainty in the enddates and the overall boundaries of the EIS has required that the GCES Phase II Integrated Research Plan remain flexible.

It is vitally important that the information utilized in the Glen Canyon Dam - Environmental Impact Statement be scientifically rigorous able to stand the test of review by the public, the bureaus, the agencies and the courts.

III. GCES Phase II Integrated Research Plan Development

Over the next several pages, the overall research logic for the GCES Phase II integrated research program is defined. The information presented has been developed by Dr. Duncan Patten, the GCES researchers and has been reviewed and discussed by the GCES Technical Team, the National Academy of Sciences and the GCES Executive Review Committee.

The research logic begins with a definition of the General Issues Dealing with Operations and Management of Glen Canyon Dam. Following the definition of the issues, is an indepth evaluation of each issue including:

1. Statement of the specific **Question** of interest.

2. Development of a specific **Hypotheses** to be tested.

3. Definition of the **Justification** for the question and hypotheses.

4. Definition of the **Information Needs**, and

5. Definition of the **Secondary Hypotheses** to be tested under the aegis of the research effort.

The research hypotheses identified in this section represent the group of research items that the GCES researchers items and the Senior Scientist believed are the **minimum** amount of research needed to complete the overall objectives of the GCES integrated scientific program and ultimately the need of the Glen Canyon Dam - Environmental Impact Statement.

An area of concern that has plagued the GCES program, both during Phase I and II has been the moving target of the ending date and research boundaries. Without firm and articulated definition of both of these items, the development of the overall research plan will have to remain flexible.

The GCES Phase II research logic has presented to the GCES Technical Teams, the National Academy of Sciences and the GCES Executive Review Committee. The Executive Review Committee gave their approval to the overall GCES Phase II research plan on **May 2, 1990** in Phoenix, AZ.

GLEN CANYON ENVIRONMENTAL STUDIES

Research Program

GENERAL ISSUES DEALING WITH OPERATIONS AND MANAGEMENT

I. Effects of Dam Operations

A. Effects of the Magnitude of Daily Discharge Fluctuations, Minimum Discharges, and Rate of Change (Ramping) of Fluctuating Discharges

II. Effects of Recreation

A. Effects of Fishing Activities

B. Effects of Rafting and Camping Activities

III. Effects on Economic Balances

A. Power Economics

B. Recreational Economics

C. Non-use Economics

IV. Potential Future Mitigation Alternatives in Addition to Modification of Discharge Criteria

A. Effects of "No Change" Alternative

B. Effects of Variable Intake Structures

C. Effects of A Reregulation Dam

D. Effects of Beach Protection Devices

E. Effects of Sediment Augmentation

HYPOTHESIS TESTING

I. Effects of Dam Operations

A. Effects of the Magnitude of Daily Discharge Fluctuations, Minimum Discharges, and Rate of Change (Ramping) of Fluctuating Discharges

1. **Question:** How significant are discharge fluctuations, minimum discharges, and ramping in the degradation or aggradation of beaches?

H_0-1.1. There is no significant relationship between discharge fluctuations, minimum discharges and ramping, and the processes of beach degradation or aggradation.

Justification: The "normal" operations of Glen Canyon Dam during low and normal water years are for peak loading which creates discharge fluctuations. These discharge fluctuations vary daily, monthly and seasonally, producing different discharge volumes and having different minimums. The rate at which the daily discharges change (ramping), during increasing and decreasing discharges, are tied both to power demands and the difference between the maximum and minimum daily discharges. Based on aerial photo interpretation, camping beaches have increasingly diminished in size over the past twenty years, with the exception of some beach building during the 1983-86 high water years. Fluctuating discharges with daily high discharge volumes and steep ramping rates (especially the down ramp) have been related to beach degradation by most observers but the connections, if they exist, have not been quantified.

Information Needs: Short-term changes in beach surface topography will be measured, using representative beaches (or above new high water zone deposits) in different reaches of the Canyon. Relationship of these changes to: (a) discharge fluctuations (assuming they are within normal operating ranges), (b) minimum discharges, (c) discharge rate changes (d) seasonal differences (e.g., frozen surfaces), (e) wind, (f) wet vs dry surfaces, (g) beach face topography (e.g., steepness), (h) eddy sediment storage conditions, (i) hydrodynamics of eddies (current movements within eddies), (j) sediment composition, and (k) armoring will be determined.

This will require an initial survey of each beach and then the establishment of an intensive microtopographic measuring system on the beaches, as done during the October 1989 5000 cfs research discharge. Surface temperatures and wind patterns will have to be determined for each beach. Eddy sediment storage and hydrodynamics of eddies will be based on eddy models, if time permits, and channel topography, and channel and eddy sediment storage determined from aerial photographs taken during a very low constant discharge period (e.g., 1000 cfs) when the river is low in suspended sediment (e.g., April/May or October). Short-term changes in beach surface topography will need to be measured under normal operations discharges, as well as controlled fluctuating discharges and non-fluctuating discharges.

In order to create response curves, these research discharges will include both constant and fluctuating discharges. There will be five constant discharge regimes and seven fluctuating discharges. Fluctuating discharges will be both low/medium fluctuations and high fluctuations. The low/medium fluctuations will have low, medium and high minimum discharges, while the high fluctuations will have low and high minimum discharges. The high fluctuating discharges will also have high and low up ramp and down ramp rates. Following each research discharge episode (10-11 days), a 3-4 day period of relatively low constant discharge (ca. 3000 cfs) is needed to evaluate the effects on beaches, larval fish in backwaters, etc. Because of bank storage and time to equilibrium of the system, tests will not be made for a few days after starting a research flow, especially those with low minima. The effects of bank stored water discharge on beach erosion will be tested with multiple piezometers (wells) in several beaches as done during the October 1989 5000 cfs constant discharge study.

The following are secondary hypotheses to be tested under the research program for testing the above primary hypothesis. These are simplified hypotheses which do not recognize the potential interaction between the various discharge parameters.

H_0-1.1a. There is no relationship between the magnitude of daily discharge fluctuations and beach degradation or aggradation.

H_0-1.1b. Erosion of old high water deposits is not influenced by the magnitude of daily discharge fluctuations.

H_0-1.1c. There is no relationship between the magnitude of daily minimum discharges and beach degradation and aggradation.

H_0-1.1d. There is no relationship between the rate of increasing daily discharges (up ramp) and beach degradation or aggradation.

H_0-1.1e. There is no relationship between the rate of decreasing daily discharges (down ramp) and beach degradation or aggradation.

2. **Question:** Do discharge fluctuations, differences in minimum discharges, or different rates of change in daily discharges (ramping rates) interact with other uses and components of the Canyon to affect rates of sediment degradation?

H_0-2.1. The are no significant relationships between the effects of recreational use of beaches and the magnitude in daily discharge fluctuations, daily discharge minima, or rates of change of daily discharge fluctuations.

Justification: Recreational use of beaches for camping or daily picnicking causes a certain amount of disturbance of the beach surface. This surface may also be influenced by other factors such as wind and variances in discharges. These influencing factors may not be exclusive, as casual observations support the concept that human use of beach faces may exacerbate the erosional loss of beach sands by fluctuating discharges and possibly discharge rate changes. Human use of other parts of the beach surface may also compound the amount of sand and other sediment moved by wind.

Information Needs: The information generated to test hypothesis H_0-1.1 will be used, in part, to test this hypothesis. In addition, human use areas on the selected beaches will be limited and will be sampled for changes in microtopography during the period of a group camping experience. If possible, paired beaches will be selected with one kept off limits for camping. The change in beach face topography where there is human use will be measured periodically for erosional loss to discharge connected factors. Beach surfaces will be sampled for microtopographic changes as in H_0-1.1.

Research for testing hypothesis H_0-2.1 should be done under normal operating discharges, and controlled research discharges from constant to widely fluctuating (see H_0-1.1).

The following are secondary hypotheses that will be tested under the research program established to test the above H_0-2.1 hypothesis.

H_0-2.1a. There is no significant relationship between the effects of recreational use of beaches and the magnitude of daily discharge fluctuations.

H_0-2.1b. There is no significant relationship between the effects of recreational use of beaches and the magnitude of daily minimum discharges.

H_o-2.1c. There is no significant relationship between the effects of recreational use of beaches and the rate of change (ramping) of daily fluctuating discharges.

H_o-2.2. There is no significant relationship between the role of vegetation as a beach stabilizer and the magnitude of daily discharge fluctuations.

Justification: One of the factors appearing to stabilize the camping beaches is vegetation which has established on the beach faces as well as other beach surfaces. This vegetative cover is impacted by river discharges (especially on the beach face), human activity, and other environmental factors. Stability of the beach surfaces may vary depending on how the vegetation responds to the influencing factors; the beach face may be the most critical surface relative to persistence of riverside alluvial deposits. In addition, ecological feedback between dam operations, depositional processes and vegetation may influence both beach stability and riparian vegetation.

Information Needs: Information developed to test hypotheses H_o-1.1 and H_o-2.1 will be used, in part, to test this hypothesis. In addition, on the study beaches, locations of vegetation, on the beach face and other surfaces, will be selected to measure their resistance to erosional loss as well as the erosional loss of sand and other sediments they stabilize. Resistance to erosion will be related to vegetation composition, cover and density. Paired locations with no vegetation will be used for comparison.

The following are secondary hypotheses that will be tested under the research program that will test H_o-2.2.

H_o-2.2a. There is no significant relationship between the role of vegetation as a beach stabilizer and the magnitude of daily discharge fluctuations.

H_o-2.2b. There is no significant relationship between the continuing invasion of exotic <u>Tamarix ramosissima</u> and <u>Alhagi camelorum</u> and flows resulting from variations in dam discharges.

3. **Question:** How do discharge fluctuations, minimum discharges and rates of change of fluctuating discharges influence the transport of sediment through the Canyon?

H_o-3.1. There is no significant relationship between the magnitude of daily discharge fluctuations, minimum discharges or rate changes in discharge fluctuations and the amount of sediment stored in or transported in the Canyon system.

Justification: The total sediment budget of the canyon is dependent, not only on how much is stored in various forms (e.g., pre-dam terraces, beaches, channel, eddies), but on how much is moving into the system from tributaries, in relationship to tributary flood frequency and stability of pre- and post-dam deposits, and within and through the system. Factors that might cause an increase in sediment transport will probably delay or prevent future development of an equilibrium in the canyon sediment dynamics. If an operation scheme could be identified that reduced to a minimum the transport of sediment through and out of the system, then net storage of sand may be increased.

Information Needs: A discharge (flood) routing model needs to be developed. This will require river channel topography (bathymetry) and a series of periodic measurements of discharges stages (in actuality mini-flood stages) at the gages through the canyon. The bathymetry can be developed from aerial photographs taken during a low constant discharge (see H_o-1.1). Sediment deposit stability, tributary and mainstream flood frequency can be determined from analyses of pre-dam alluvial terrace stage/discharge relationships. Suspended sediment will be sampled during constant, controlled fluctuating and normal operations discharges at the six gaging stations in the Canyon (Glen Canyon Dam, Lee's Ferry, Little Colorado, Grand Canyon, National Canyon and Diamond Creek). Bed load transport will be sampled at the same time as suspended sediment sampling but at few gages (e.g., Lee's Ferry, Grand Canyon and National Canyon).

The following secondary hypotheses can be tested under the research program established to test H_o-3.1, especially using a series of different research discharge groupings.

H_o-3.1a. There is no significant relationship between the magnitude of daily discharge fluctuations and the amount of sediment stored in or transported through the Canyon system.

H_o-3.1b. There is no significant relationship between the magnitude of the daily minimum discharge and the amount of sediment stored in or transported through the Canyon system.

H_o-3.1c. There is no significant relationship between the rate of change of fluctuating discharges and the amount of sediment stored in or transported through the Canyon system.

H_o-3.1d. There is no significant relationship between the variations in discharge due to dam operations, flooding frequency and equilibration of sediment storage in the Canyon system.

4. **Question:** How do discharge fluctuations, minimum discharges and rates of change of fluctuating discharges affect trout?

H_0-4.1. There is no significant relationship between the rate of stranding of trout and the magnitude of discharge fluctuations, and minimum discharges, or the rate of change of fluctuating discharges.

Justification: The tailwater reach below Glen Canyon Dam is considered a blue ribbon trout fishery. The fishing public utilizing this resource has expressed a desire for the opportunity to catch both large and naturally reproduced trout. Regulatory changes are being instituted to increase the probability of catching larger fish, but the degree of successful natural reproduction is believed to be limited by dam operations. Spawning trout often develop their redds in gravels that are inundated and then subsequently exposed during each fluctuating flow cycle. Spawning trout which attempt to remain with their redds can become stranded at low water and suffer mortality. In addition, the redds may be desiccated and emergent alevins suffer high mortality as was shown experimentally during GCES Phase I. In downstream areas, flows from discharge fluctuations having low minima may also limit trout access to tributaries which serve as important sites of natural reproduction (see also H_0-5.1).

Information Needs: Data will be collected on the amount of stranding under various discharge regimes (see H_q-1.1) between Lee's Ferry and Glen Canyon Dam. This will be primarily during the spawning season. Length, weight, sex, reproductive stage and fecundity will be determined for a representative sample of the fish. Stranding will be determined relative to location, area, time, and number of fish. Stranding areas will also be sampled for exposed redds in order to develop a relationship between standing and spawning. Limnological variables, including water temperature, dissolved oxygen, pH, and conductivity will be measured to determine correlations with observed mortalities.

The following secondary hypotheses will be tested using the research program established for H_0-4.1.

H_0-4.1a. There is no significant relationship between the rate of stranding of trout and the magnitude of daily discharge fluctuations.

H_0-4.1b. There is no significant relationship between the rate of stranding of trout and the magnitude of daily minimum discharges.

H_0-4.1c. There is no significant relationship between the rate of stranding of trout and the rate of change in daily fluctuating discharges.

H_0-4.1d. There is no significant relationship between stranding of trout and their spawning activities.

H_0-4.2. There is no significant relationship between behavioral activity of rainbow trout and the magnitude of daily discharge fluctuations, daily minimum discharges and rate of change of fluctuating discharges.

Justification: The behavior patterns of trout determine where they will be at any point in time. This includes feeding, spawning, or moving within their territory. If the environment in which they live is constantly changing, they must set up some behavior pattern to adjust to it. If they don't, they could be unsuccessful in any of their activities, thus reducing potential success for the overall population The present operations of Glen Canyon Dam create a highly variable environment. Trout adjustment to this fluctuating environment has not been quantified. Results of GCES Phase I suggested that some fluctuations in flow might benefit trout by increasing food availability under different flow levels resulting from steady and fluctuating discharges.

Information Needs: Some data to test hypothesis H_0-4.1 will be used to test this hypothesis. Also data will be collected on the degree and timing of movement of trout (e.g., with radio tracking), and reproductive (see H_0-4.1) and feeding activities. These data will be augmented with those collected under H_0-7.2, H_0-7.3 and H_0-7.4 as they are related to the availability of food resources. Additional controlled experiments will be conducted in the Glen Canyon sluiceways on the effects of different discharge regimes on food resources of trout , and trout feeding, growth and survivorship.

The secondary hypotheses to be tested under this research program are:

H_0-4.2a. There is no significant relationship between the behavioral activities of trout and the magnitude in daily discharge fluctuations.

H_0-4.2b. There is no significant relationship between the behavioral activities of trout and the magnitude of daily minimum discharges.

H_o-4.2c. There is no significant relationship between the behavioral activities of trout and the rate of change (ramping) of daily fluctuating discharges.

5. **Question:** How do discharge fluctuations, minimum discharges and rates of change of fluctuating discharges affect foraging success of wintering bald eagles?

H_o-5.1. There is no significant relationship between trout availability, trout access, bald eagle presence, bald eagle abundance or bald eagle foraging success in the mainstream or Nankoweap Creek and the magnitude of daily discharges.

> **Justification:** The trout population in the mainstream Colorado River near Nankoweap Creek uses Nankoweap Creek for spawning. Results of GCES Phase I showed that there is little downstream migration of stocked trout from the Lee's Ferry reach. Therefore, maintenance of the trout population in Grand Canyon is dependent largely upon natural reproduction. These trout use Nankoweap Creek and other tributaries extensively for reproduction. This trout population is a primary foraging resource for the overwintering bald eagle population near Nankoweap. Flows resulting from low discharges in the mainstem may be of insufficient magnitude during the spawning season (late fall and winter) to prevent movement of trout up Nankoweap Creek to spawn and to cause trout to be a readily accessible food source for the eagles. Discharges and the associated flows that reduce the spawning potential of trout may be tied to fluctuations or minima.
>
> **Information Needs:** The necessary period for continuity of a sufficient mainstream level at the mouth of Nankoweap Creek needs to be established and compared to the periods created by normal operational discharges as well as controlled research discharges. Success of trout movement up Nankoweap Creek under various discharge and flow regimes during the spawning season also needs to be determined and compared with other factors affecting trout reproductive success in the tributary. Estimates on success of bald eagle foraging for trout in the mainstream and Nankoweap Creek during the season they are at Nankoweap need to be made and related to trout access to Nankoweap Creek.

The following secondary hypotheses will be tested using the research program established to test H_o-4.3.

H_o-5.1a. There is no significant relationship between trout availability, trout access, bald eagle presence, bald eagle abundance or bald eagle foraging success in the mainstream or

Nankoweap Creek and the magnitude of daily discharge fluctuations.

H_o-5.1b. There is no significant relationship between trout availability, trout access, bald eagle presence and abundance, or bald eagle foraging success in the mainstream or Nankoweap Creek and the magnitude of minimum discharges.

6. **Question:** How do discharge fluctuations and rates of change in fluctuating discharges affect other fish, especially native fish species? Do the USFWS Conservation Measures adequately address this question?

H_o-6.1. There is no significant relationship between the population dynamics (including short-term abundance of early life stages and potential predation relationships) of native (especially the humpback chub) and introduced fish species in the mainstem Colorado, including mainstem backwaters and the confluence of the Little Colorado, and the magnitude of fluctuations, minimum discharges and rates of change of fluctuating discharges.

Justification: Native fish species, especially the humpback chub, are found in the mainstem Colorado River, but their potential for reproduction and survival is thought to be dependent on tributaries and backwaters. The availability of appropriate habitats for reproduction and food sources in the tributaries and backwaters may be directly related to influences from the various discharge levels and volumes in the mainstem. Also, availability of appropriate and sufficient food sources in the mainstem may be influenced by discharge variables. Therefore, potential success of the native fish species in the mainstem Colorado may be directly related to their ability to (1) accommodate the transition between tributary/backwater and mainstem and (2) successfully feed in the mainstem. Survival of the native fish species may also depend on their interrelationships with other fish species, especially introduced species that have been introduced into the Colorado River system.

Information Needs: Resource and food availability in the tributaries, backwaters and mainstem need to be determined. The ability of larval stages to survive both tributary /backwater habitats and transition to the cold water mainstem needs to be determined (e.g., the latter through laboratory studies). Adult maintenance in the mainstem should be measured through periodic sampling, and reproductive success in appropriate habitats needs to be measured. Representative tributaries (especially LCR, Kanab, Havasu and Paria) and backwaters will be selected for study of food and changing habitat conditions, and fish reproduction under various discharge regimes. Interrelationships between native and introduced fish species will be suggested based upon the population and reproduction dynamics of each species.

The following secondary hypotheses will be tested using the research program established to test H_0-5.1.

H_0-6.1a. There is no significant relationship between population dynamics of native and introduced fish species in the mainstem Colorado, including backwaters and tributaries, and the magnitude of discharge fluctuations.

H_0-6.1b. There is no significant relationship between population dynamics of native and introduced fish species in the mainstem Colorado, including backwaters and tributaries, and the magnitude of minimum discharges.

7. **Question:** How are water quality (nutrients and other characteristics) and stream productivity (algae and invertebrates) affected by discharge fluctuations, and the rate of change in fluctuating discharges.

H_0-7.1. There is no significant relationship between nutrient availability, productivity (of algae and macroinvertebrates) and import-export rates of organic matter to and from the Lee's Ferry reach, and the magnitude of discharge fluctuations, and the rate of change of fluctuating discharges.

Justification: Lake Powell serves as an effective nutrient and sediment trap, removing more than 90% of the sediments and associated phosphorus entering the reservoir. Phosphorus has been implicated as the potential "limiting nutrient" for primary productivity in Colorado River reservoirs and downstream tailwaters. Deep, hypolimnetic releases from the dam may contain higher concentrations of phosphorus than waters drawn from higher levels in the reservoir, but they are also considerably colder during much of the year and higher in salinity.

Nutrient availability in the Colorado River below Glen Canyon Dam is determined by input concentrations and volumes delivered from the dam and downstream tributaries (loading), and by production and regeneration (recycling) processes which occur in the river. Flows from fluctuating discharges appear to increase the amount of organic drift in the river through detachment and through stranding and desiccation which contribute to the mortality of algae, invertebrates and fish. Daily fluctuations, in conjunction with the volume of discharge, also have the capacity to set limits on primary and secondary production by determining the area and volume available for effective benthic and planktonic production, respectively. The extent to which fluctuating flows affect the organic load, nutrient regeneration processes, and the resulting provisioning of dissolved nutrients necessary for downstream production is presently unknown.

Information Needs: Seasonal data will be collected on the distribution of water temperature, salinity, nutrients, and organic matter in Lake Powell above Glen Canyon Dam (see also H_0-17.1). These same parameters and sediment load will be measured in discharge waters from the dam at selected downstream sites, and from selected tributaries during research discharge periods. System-level production will be assessed through a combination of primary production/respiration and organic matter import/export ratios during these same periods. Site-specific estimates of nutrient levels, nutrient uptake and regeneration processes, and primary productivity will also be made in zones of fluctuations with controls below the level of minimum flows.

The following secondary hypotheses will be tested using information generated in the research program to test hypothesis H_0-7.1.

H_0-7.1a. There is no significant relationship between nutrient availability in the stream system and the magnitude of discharge fluctuation and rate of change of fluctuating discharges.

H_0-7.1b. There is no significant change in the short-term (within seasons) relationship between the import and export rates of organic matter and nutrients to and from the Lee's Ferry reach and the magnitude of discharge fluctuations, discharge volume (a function of discharge rate) and the rate of change of discharge fluctuations.

H_0-7.1c. There is no significant relationship between the distribution of primary (and associated secondary productivity) throughout the Canyon system and the magnitude of discharge fluctuations, discharge volumes and the rate of change of fluctuating discharges.

H_0-7.1d. There is no significant relationship between the short-term (within seasons) availability of important food resources (algal and invertebrate) for trout and the magnitude of discharge fluctuations, discharge volume, and the rate of change of discharge fluctuations.

8. **Question:** How are recreational values influenced by characteristics of discharge from Glen Canyon Dam, such as discharge fluctuations, minimum discharges and rates of change of fluctuating discharges.

H_o-8.1. There is no significant relationship between recreational response variables (angler safety and rafting safety, satisfaction, experiential quality and economics) and the magnitude of seasonal or daily discharge fluctuations, minimum discharges or the rate of change of fluctuating discharges.

Justification: Use of the Canyon for recreation is of primary concern for those who manage the system. The response variables indicated in H_o-8.1 are used as measurements to determine how recreation is functioning within the environment created by nature and humans in the Canyon. If a response variable indicates a significant negative response to some factor managed by humans, then serious consideration must be given to decisions made relative to that factor.

Information Needs: All variations in discharge parameters need to be tested against recreational satisfaction, experiential quality and economics. Mean and minimum discharges need to be tested against safety, angler access and satisfaction. Rates of change in fluctuations need to be tested against angler safety.

Secondary hypotheses can be developed from primary hypothesis H_o-8.1 that will relate each recreational response variable individually to each discharge variable. This is an extensive list and is not presented here.

9. **Question:** Are there sufficient camping beaches, in location, numbers, and surface area, during high discharge periods (i.e., 31,500 cfs or possibly 33,200 cfs) to satisfy the needs of the recreational rafting community based on the NPS acceptable carrying capacity of the Grand Canyon system?

H_o-9.1. There is no significant relationship between availability of camping beaches and maximum normal operations discharges from Glen Canyon Dam (i.e., 31,500 cfs or 33,200 cfs).

Justification: Fluctuating discharges from Glen Canyon Dam create waves of fluctuating high flow stages through the Canyon system. These high flows may inundate portions of camping beaches at times when they are occupied. Assuming the high flow stages may occur at any time, availability of camping beaches may be limited, possibly requiring readjustments in recreational use during high discharge periods.

Information Needs: The number, surface area, and location of camping beaches at discharges of 31,500 cfs and 33,200 cfs need to be determined. A detailed (0.5 m contour) topographic/ bathymetric map of the Canyon can be developed from the aerial photographs taken during the 1000 cfs constant discharge period in April 1990. Beaches (location, number and area) above high discharge stages can be determined from the map and stage recordings taken through the Canyon during research discharge periods.

10. **Question:** Do dam operations (e.g., magnitude of stage, magnitude of fluctuations and/or ramping rate) affect the stability of cultural resource sites along the Colorado River in Grand Canyon?

H_0-10.1. There is no significant relationship between the magnitude of stage, magnitude of discharge fluctuations and/or ramping rates and the stability of cultural resource sites along the river in the Grand Canyon.

Justification: Recent evidence indicates that spillover flooding in 1983-1986 may have initiated erosion of cultural resource sites along the river. Progressive erosion of these sites may warrant protective mitigation or excavation.

Information Needs: The extent of erosion of pre-dam sediment deposits is not yet known. Determination of whether the erosion is short term and of young sediments, or whether impoundment and sediment starvation has initiated erosion of ancient sediment beds will require aging of the sediments.

II. Effects of Recreation

A. Effects of Fishing Activities

11. **Question:** How does fishing activities affect other canyon resources, especially in the Lee's Ferry reach (Glen Canyon Dam to CR mile 14)?

H_0-11.1. There is no significant relationship between beach stability and fishing activity, including boating, in the Lee's Ferry reach.

Justification: Recent studies indicate that riverside sediments are reworked by the wakes of motorized boats in the tailwaters reach above Lee's Ferry. Also, angler use of riverside habitats from Lee's Ferry to CR Mile 8 may affect populations of the newly discovered Euphorbia species that occupies the new high water zone (Holmgren, pers. comm.).

Information Needs: Response curve of motor boat wake effects on beaches under different dam operation scenarios need to be developed, and the distribution, density and risk status of the new Euphorbia needs to be determined.

H_0-11.2. There is no significant relationship between the trout population of the Lee's Ferry reach and fishing activities, especially catch and release or keep relationships.

Justification: The trout population in the Lee's Ferry reach is intensively managed. The population is a result of stocking and natural regeneration, minus those lost to stranding, angler damage and keep, and migration downstream. Few apparently migrate downstream and thus stranding and angler influence are the primary loss factors.

Information Needs: Stranding losses will be determined under H_0-4.1. The effects of anglers on the population should be determined through evaluation of Arizona Game and Fish records.

B. Effects of Rafting and Camping Activities

12. **Question:** How does rafting/camping affect other canyon resources?

H_0-12.1. There is no significant relationship between the sediment volume of beaches and recreation (also see H_0-2.1).

Justification: Human impacts on the beaches during docking, loading and camping activities may move sediment into position to be removed by wind and/or water action. The amounts of sediment disturbed and actually lost has not been accurately determined. It is possible that human impacts may play a significant role in what appears to be a continuing degradation of camping beaches. The justification for this study is also addressed in H_0-2.1

Information Needs: Beach surface microtopography will be measured under the research program established for H_0-2.1. By using paired beaches that receive different intensities of camping use, and by experimentally manipulating beaches, it should be possible to separate beach surface changes tied to human activity and those tied to natural physical processes.

III. Effects on Economic Balances

Economic balances in this section not only relate the economics of recreational and non-use values of the Canyon to power economics, but to the actual and potential operations of the dam. The effects of changes in dam operations on power economics is being studied by the Power Economics Team. Use benefits of downstream recreation was studied in GCES Phase I but should be reestimated.

A. Power Economics

13. **Question:** If creating a more stable environment in the Canyon below Glen Canyon Dam requires changes in power operations, what is the economic impact of these changes?

H_0-13.1. Changes in operations will not result in significant economic losses associated with power production.

> **Justification:** The amount of energy available from a hydro project is largely a function of the hydrology in the basin. Changes in operations are very unlikely to have an impact on the amount of energy available. Changes in operations may, however, have a substantial impact on the temporal pattern (both daily and seasonal) of power production. The changes in temporal production patterns may result in changes in the value of the energy produced.

> **Information Needs:** A method to estimate the change in the value of power caused by a change in the operations at the dam is needed. This method must be consistent with the Principles and Guidelines and current economic practice, and must be able to address a wide variety of operational changes. The GCES Power Economics Team is currently preparing a report containing recommendations as to which method or methods should be used.

B. Recreational Economics

14. **Question:** Are the economic benefits of downstream recreational activities affected by dam operations?

H_0-14.1. The economic benefits of downstream recreational activities as well as associated tourism services (e.g., lodging, airlines, restaurants, etc.) are not affected by operations of Glen Canyon dam.

> **Justification:** During GCES Phase I, extensive surveys of downstream recreationists were conducted. These surveys demonstrated a relationship between economic benefits and

discharge and associated flows and fluctuations. By the completion of the Glen Canyon EIS, these values will be eight years old. In addition, these studies were conducted during periods of relatively high and steady flows. Finally, there has been the observation that the nature of commercial white water trips have changed in terms of average trip length. For the purpose of comparisons with impacts to power production discussed above, it would be useful to reestimate these relationships. Associated services toed to rafting trips also need to be determined.

Information Needs: Contingent valuation surveys will be designed to determine the relation between the economic benefits of recreation, its associated services, and flow characteristics.

C. Non-use Economics

15. **Question:** Are there any non-use benefits that are attributable to the maintenance of a stable environment in the canyon below Glen Canyon Dam and if so would these values be affected by changes in dam operations?

H_0-15.1. There are no significant non-use values associated with existence and condition of Grand Canyon resources unless individuals intend to directly utilize them for their own recreational activities.

Justification: Various surveys have shown that individuals have non-zero values for maintenance of the environment. These non-use values could be motivated by a sense of environmental responsibility, the desire to preserve the resource for personal use, or the desire to preserve the resource for future generations. The question is whether these attitudes and associated economic benefits are present with respect to any portion of the Grand Canyon that are affected by dam operations.

Information Needs: Surveys will be designed to determine the attitude of the public toward supporting preservation and maintenance of the Grand Canyon environment. The appropriate sample to be surveyed is yet to be determined. Possibilities include a sample of resident western states, a sample of U.S. residents, or a sample of households served by utilities-that have a firm power contract for CRSP power.

IV. Potential Future Mitigation Alternatives in Addition to Modification of Discharge Criteria

A. Effects of "No Change" Alternative

16. **Question:** What are the economic and environmental costs (loss, mitigation, legal, etc.) of the "No Change" alternative?

Comments: The null hypothesis for this question would state that there are no significant economic or environmental costs to the "No Change" alternative. The research program presented here is designed to address the various downstream discharge components to determine their significance in the dynamics of the Canyon system. The "No Change" alternative will be addressed after the research program is complete.

B. Effects of Variable Intake Structures

17. **Question:** If a variable intake structure is used on Glen Canyon Dam, what will be the effects of intake at various levels on the downstream ecosystem?

H_o-17.1. There will be no significant relationship between potential different levels of intake of water for the penstocks from Lake Powell and the quality of water discharged below Glen Canyon Dam and downstream biological productivity.

Justification: The present operation of Glen Canyon Dam has the penstock intake below the thermocline in the hypolimnion in Lake Powell. This produces water that is colder than the predam river. The nutrient and sediment levels of this water is also quite different than predam river water. The temperature and levels of nutrients in the water discharged below Glen Canyon Dam may be directly affecting the primary productivity of the system which supports other aquatic organisms. The trout fishery, for example, has apparently been successful because a sufficient food source has been established and the river temperature is near optimum for trout. Other changes in river biota may also be a response to the quality of dam discharges. One mitigation technology that might be used to address the need to discharge warmer water is to retrofit a variable intake structure on Glen Canyon Dam, similar to that at Flaming Gorge Dam. The alteration of the quality of the discharge water through use of a variable intake structure may cause other changes to occur in the ecosystem below the dam.

Information Needs: Profiles of Lake Powell water quality (e.g., nutrients, sediment, temperature) need to be taken on a regular basis to determine what the potential water quality would be throughout the year, should a variable intake be used. Nutrient dynamic and temperature models need to be developed for the river from the dam down to at least Grand Canyon, that is, past the primary trout and humpback chub fishery areas. Nutrient-productivity relationships need to be refined. Predictions of downstream changes might then be made if quality of discharge water is tied to the variable levels in the Lake Powell profiles (see H_0-7.1).

C. Effects of a Reregulation Dam

18. **Question:** If a reregulation dam were constructed in the Canyon some where between Glen Canyon Dam and Lee's Ferry, what would be the effects of the discharges, and variations in both water quantity and quality, on the downstream ecosystem? What also would be the effects on the system in the location of the impoundment behind the reregulation dam?

H_0-18.1. There will be no significant differences between the response of the downstream Canyon ecosystem to discharges from a reregulation dam and the discharges from Glen Canyon Dam.

Justification: The purpose for constructing a reregulation dam is to create a more natural downstream flow, in both quantity and quality. How possible it would be to create such a natural discharge and how different that discharge would be from the existing discharges need to be known.

Information Needs: A hypothetical model will need to be developed to test various parameters of the dam, water discharge system and impoundment to determine how these will affect the water quality and quantity discharged down stream. Information on quality and quantity of input from discharges below Glen Canyon Dam will need to be known (H_0-13.1 will answer some of this).

H_0-18.2. The will be no significant impact on the Lee's Ferry reach of the Canyon if a reregulation dam is constructed in the reach.

Justification: Construction of a reregulation dam will inundate a yet-to be determined length of the Lee's Ferry reach. The magnitude of the effects of this inundation needs to be determined.

Information Needs: Once the length of the Lee's Ferry reach that will be inundated is determined, basic biological, physical and ecological information can be used to determine potential impacts. This basic information has been gathered, in part, in

GCES I, and will continue to be gathered in the testing of the hypotheses in this GCES II Research Plan.

D. Effects of Beach Protection Devices

19. **Questions:** If the beaches in the Canyon are degrading as many observers say they are, is it possible to mitigate this loss with devices designed to protect or stabilize sediment degradation? If so, what would the impacts be of building and maintaining such structures? What would be the effects on the recreational experience in the Canyon?

Comments: In order to state hypotheses and establish a research program to address the above questions on beach protection devices, the type of protection devices as well as sediment augmentation would have to be determined and the methods of constructing and maintaining them developed. If the techniques are natural in nature, such as establishing vegetation, then the hypotheses testing the relationships between vegetation and stability of the beaches (e.g., H_0-2.2) will help address this potential success of these techniques. One hypothesis that might be tested under this study is:

H_0-19.1 There is no relationship between the potential success of rehabilitating deteriorated camping beaches and dam opertions.

E. Effects of Sediment Augmentation

20. **Questions:** If sediment is being lost out of the Canyon system (shown by testing H_0-1.1 and H_0-3.1) and natural processes for reestablishing beaches have been determined (see GCES I), is it possible to help establish a sediment equilibrium in the Canyon and build beaches by augmenting sediment input and creating appropriate discharges? If sediment is to be augmented, what methods would be most successful and have the least environmental impact?

Comments: Until it is determined, more accurately than presently known, how much augmented sediment would be needed to mitigate for sediment loss in the Canyon (this might be answered through testing H_0-3.1 along with more long-term studies of sediment dynamics); and the technology is worked out for the augmentation process, the above questions must remain speculative.

RESEARCH FLOWS

GLEN CANYON ENVIRONMENTAL STUDIES

PHASE II

INTEGRATED RESEARCH PROGRAM

DRAFT #6
5-30-90

OPERATING GUIDELINES
SYSTEM OPERATIONS FOR GCES RESEARCH RELEASES

The following operational procedures have been jointly prepared by Western Area Power Administration (Western) and the Bureau of Reclamation (Reclamation) for use during the Glen Canyon Environmental Studies (GCES) Research Release period. For informational purposes, attached is a copy of the GCES special release schedule.

Western and Reclamation have agreed that the completion of scheduled research releases within the time frame specified by the release schedule is the ultimate goal. Western and Reclamation will not violate special release criteria based solely on economics. If a violation of any discharge criteria becomes necessary, the decision will be based on the need to maintain system integrity, reliability and/or the possibility that firm load cannot be served under the then-present discharge scenario. However if the cost of replacement energy becomes unreasonable due to a system shortage, Western/Reclamation supervisors will discuss the possibility of delaying special releases until replacement energy prices become acceptable. Human safety will not be compromised in-order to preserve special release requirements. The Page SCADA will be the official measure of all special release flows from Glen Canyon.

High Flow Conditions:

During each eleven day release period, Reclamation will water-up two by-pass jets and place them on operational standby. These by-pass jets will be opened under the following specific conditions, to maintain discharge levels if an unplanned unit dropping condition occurs at the Glen Canyon powerplant.

If less than 200 MW of generation is dropped, the by-pass jets will be opened only after it has been determined that generation cannot be restored within an one-hour time frame. If more than 200 MW of generation is lost, by-pass jets will be opened as soon as possible to the extent necessary in order to reduce the impact on research flows. Plant generation will be restored as quickly as possible after the outage to the necessary research release levels. Western/Reclamation supervisors (in order of the attached calling tree) will then decide if special releases have been compromised enough to cancel/postpone releases or continue as planned. If a particular research release is abandoned, then Western and Reclamation will revert to a non-research operating mode until the next scheduled research release.

All high research release flows will ultimately be scheduled to follow Glen Canyon plant release capability through the turbines. It has been determined that during these high special release flows, Glen Canyon units will not be loaded to a level more than 90% gate unless an emergency arises. Once a specified release level has been set, releases from Glen Canyon will reach the high flow level at least 2 hours each day. If a release period should begin at a specified level and a unit is lost, a by-pass jet will be opened after supervisory approval following the same above criteria to maintain flows for the remainder of the special release period or until the unit is restored.

Low Flows - 5,000 c.f.s/constant release:

During low flow/constant release situations, the availability of supplemental resources to serve firm load will determine how CRSP resources are operated and/or if low flow/constant releases can be maintained.

If a supplemental resource is lost by Western, it is agreed that Glen Canyon generation will be available to support the lost resource until a another source of energy can be found. This increase in generation at Glen Canyon will be called upon only as a last resort and will be increased only if all other CRSP generation has been utilized to maximum allowable levels. In all situations, Glen Canyon generation will be the last CRSP resource increased and the first decreased. Under a lost resource scenario, Western will call for replacement resources from other interconnected utilities and/or generation from other Western Area offices. While additional resources are being located, Flaming Gorge and Curecanti generation will be brought on line as needed or to the maximum extent possible, as defined in the monthly guidelines, to cover load. If additional generation is needed, Glen Canyon generation will then be increased up to the level needed. If it is anticipated that Glen canyon will be needed to support a lost resource for more than one hour, supervisors will be contacted and they will determine how to proceed with the special release.

If there is a major system disturbance and/or additional resources cannot be found within a "one hour" time period to replace what was lost, dispatchers/plant operators will automatically begin calling assigned supervisors to advise them of the situation. Western/Reclamation supervisors will determine how system generation will be maintained and/or if the special release is to be continued.

Reclamation has agreed to motor Glen Canyon units at levels necessary to maintain operating reserves and cover the difference between firm load and supplemental imports for Inland Power Pool reporting purposes.

PHASE II RESEARCH FLOWS
LOGIC AND SCHEDULING

I. Background

Upon the initiation of the GCES Phase II Integrated Research program a need existed to be able to study specific fluctuating and constant flow release patterns in the Grand Canyon. A serious flaw in the initial GCES efforts, and one recognized by the National Academy of Sciences, was that limited conclusions could be drawn about the effects of any one flow level without having sufficient data collected at that flow level. The NAS recommended that the GCES effort focus on studying specific flow levels.

The GCES researchers and Senor Scientist began evaluating the specific flow patterns that would be required for study and the amount of time needed for each flow. From the initial discussions it was apparent that limited sound scientific data could be collected under a "normal" flow regime. The need for a specific Glen Canyon Dam research flow schedule was further defined as necessary when the timing of the GCES Phase II research program was slipped "forward" from five years to 24 months.

In October 1989 negotiations with the GCES Office, the Senior Scientist, the Bureau of Reclamation, and Western Area Power Administration over the types, extent and duration of the required research flows were initiated. In April 1990, the approval for the research flows was given by the Upper Colorado Regional Director. The GCES researchers were directed to begin the field data collection program upon approval of the overall GCES Integrated Study Plan.

II. Logic and Objectives of the GCES Research Flow Program

The operations of Glen Canyon Dam and the resultant release of water can be separated into distinct discharge variables. These variables are:

1. The <u>magnitude</u> of fluctuation
2. The <u>minimum/maximum</u> discharges
3. The <u>rate of change</u> in fluctuating discharges for both increasing and decreasing releases, and
4. The <u>seasonal</u> aspects

The variables of flow are the key parameters to be tested under the dam impact hypotheses, numbers HO-1 through HO-7.

In a perfect scientific endeavor, each flow variable would be separately tested while all other variables are held constant. In addition, each ecosystem component would be evaluated over a large range of discharges. This would require an extensive number of research flows. A compromise in the number of variables and research flows to be evaluated led to the development of the use of <u>response curves</u> for the GCES Phase II program. The concept of response curves is not new. It requires selecting specific and critical components of flow release parameters and evaluating specific ecosystem component responses to the varying flow levels. Of critical importance is that a <u>minimum</u> number of flows and ecosystem parameters have been selected for evaluation.

The resulting GCES Research Flow package allows for the development of the basic response curves for selected ecosystem components. Inherent in each single response curve will be a nested set of additional response curves for other related and linking ecological variables, be they driving or response.

The discharges required to produce scientifically adequate response curves are defined in the Dendogram, Figure 1. The dendogram depicts a separation between the constant and fluctuating discharge patterns. The fluctuating discharges are further divided between discharges with low and high fluctuations. Several different levels of minimum discharges have been set. The fluctuating discharges meet the same volume of release as do the comparable constant discharges.

The GCES Research Flow discharge sequencing ties together the controlled fluctuating discharges with similar (by volume) constant discharges and are preceded or followed by "Normal" seasonal operation discharges with similar volumes and patterns. The use of the term "Normal" is defined as how Glen Canyon Dam has been operated in the past during the specific season of interest.

Each research flow discharge is followed by a three day period of 5,000 cfs, the <u>Research Evaluation Flow</u>. This Research Evaluation Flow creates a low downstream flow that enables the researchers to measure the effects of each particular research flow on the ecosystem components.

The discharge\sequencing for 1990 and 1991 are depicted in Figures 2 and 3. The research flows have been sequenced to allow for evaluation of seasonal relationships and the timing of ecological responses, such as spawning, larval dispersal, Lake Powell limnology, and other ecological requirements. The GCES Research Flows have been coordinated with the Colorado River Basin Annual Operating Plan and will meet all downstream release requirements.

III. Emergency Glen Canyon Dam Release Protocol

A separate group of representatives from Western Reclamation and the GCES office has established a protocol for the handling of power and dam emergencies at Glen Canyon Dam. The protocol follows.

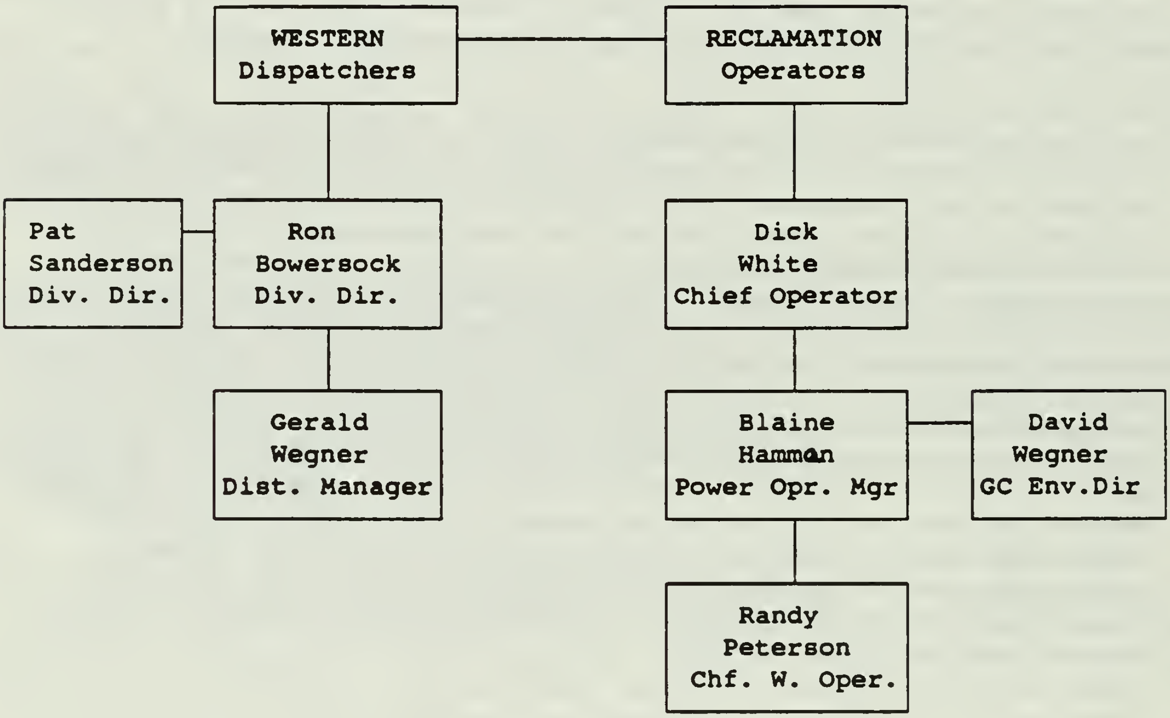
Regulation:

It is agreed that during all scheduled special release periods, either the Curecanti or Flaming Gorge units will be placed on supervisory control for system regulation purposes. During these special release periods, Glen Canyon generation will be available for base assist across the hour up to 10% deviation from scheduled release levels. Any deviation above 10% from the scheduled research flows will be allowed only in emergency situations and only by supervisory approval.

During the summer irrigation season and/or as conditions permit, the Curecanti units will be used as first priority for all regulation needs. Reclamation will determine when regulation control will be switched from Curecanti to Flaming Gorge, taking into consideration sufficient water and associated generation must be made available to maintain control area needs on an hourly basis. When Curecanti is used for regulation, it will be necessary to operate Crystal reservoir in the Dry Season Mode to give Western the flexibility needed to generate from the Morrow Point and Blue Mesa units as needed. The Dry Season Mode is defined as a 10-foot-per-day fluctuation limit with a maximum 3-day draw down of 15 feet. The reservoir cannot fluctuate more than one-half foot per day if below elevation 6,733 feet. Crystal reservoir will be drawn down over weekend periods and fluctuated as needed during weekdays within dry season operating limits. If a spill situation at Crystal becomes likely, Western/Reclamation supervisors will be asked for approval. A by-pass/spill from any reservoir to maintain special releases will be allowed only as a last resort.

CALLING TREE

This calling list is to be used when system conditions exist which may affect the ability to maintain scheduled special release flows under the above mentioned situations.



Concur:

By: ______________________________
Gerald C. Wegner, District Manager
WESTERN AREA POWER ADMINISTRATION

By: ______________________________
Blaine Hammon, Power Operations Manager
BUREAU OF RECLAMATION

SUMMARY OF SCHEDULED RESEARCH DISCHARGES AT GLEN CANYON

Year	Release Date	Release Rate	Number of Days	Starting 1/		Ending 1/		Release Range		Ramp Rate	
				Day	Hour Ending	Day	Hour Ending	Minimum	Maximum	UP	DOWN
1990	June 1-4	5000 cfs	4	Friday	100	Monday	2400				
	June 29-July 1	5000 cfs	3	Friday	100	Sunday	2400				
	July 2-12	Discharge G	11	Monday	100	Thursday	2400	8,000	28,000 2/	High	Low
	July 13-15	5000 cfs	3	Friday	100	Sunday	2400				
	July 16-26	Discharge F	11	Monday	100	Thursday	2400	8,000	28,000 2/	Low	Low
	July 27-29	5000 cfs	3	Friday	100	Sunday	2400				
	Sept. 14-16	5000 cfs	3	Friday	100	Sunday	2400				
	Sept. 17-27	Discharge E	11	Monday	100	Thursday	2400	3,000	26,200	High	High
	Sept. 28-30	5000 cfs	3	Friday	100	Sunday	2400				
	Oct. 1-11	Discharge A	11	Monday	100	Thursday	2400	3,000	13,000	Low	Low
	Oct. 12-14	5000 cfs	3	Friday	100	Sunday	2400				
	Oct. 15-25	8000 cfs	11	Monday	100	Thursday	2400				
	Oct. 26-28	5000 cfs	3	Friday	100	Sunday	2400				
	Oct. 29-Nov. 8	Normal Fall	11	Monday	100	Thursday	2400				
	Nov. 9-11	5000 cfs	3	Friday	100	Sunday	2400				
	Dec. 14-16	5000 cfs	3	Friday	100	Sunday	2400				
	Dec. 17-27	11000 cfs	11	Monday	100	Thursday	2400				
	Dec. 28-30	5000 cfs	3	Friday	100	Sunday	2400				

Note:
1/ These are the theoretical starting and ending times. The actual times will differ due to the transition periods between the flows.
2/ We have assumed 28,000 cfs maximum, however, this may change monthly depending on conditions.

Year	Release Date	Release Rate	Number of Days	Starting 1/		Ending 1/		Release Range		Ramp Rate	
				Day	Hour Ending	Day	Hour Ending	Minimum	Maximum	UP	DOWN
1991	Dec.31-Jan. 10	Discharge C	11	Monday	100	Thursday	2400	8,000	20,000	Low	Low
	Jan. 11-13	5000 cfs	3	Friday	100	Sunday	2400				
	Jan. 14-24	Normal Winter	11	Monday	100	Thursday	2400				
	Jan. 25-27	5000 cfs	3	Friday	100	Sunday	2400				
	Jan. 28-Feb. 7	Discharge B	11	Monday	100	Thursday	2400	5,000	15,000	Low	Low
	Feb. 8-10	5000 cfs	3	Friday	100	Sunday	2400				
	Apr. 19-21	5000 cfs	3	Friday	100	Sunday	2400				
	Apr 22-May 2	Normal Spring	11	Monday	100	Thursday	2400				
	May 3-5	5000 cfs	3	Friday	100	Sunday	2400				
	May 6-16	Discharge D	11	Monday	100	Thursday	2400	3,000	26,200	Low	High
	May 17-19	5000 cfs	3	Friday	100	Sunday	2400				
	May 20-30	15000 cfs	11	Monday	100	Thursday	2400				
	May 31-June 2	5000 cfs	3	Friday	100	Sunday	2400				
	June 3-27	Normal Summer	25	Monday	100	Thursday	2400				
	June 28-30	5000 cfs	3	Friday	100	Sunday	2400				
	Jul. 1-11	Discharge G	11	Monday	100	Thursday	2400	8,000	28,000 2/	High	Low
	Jul. 12-14	5000 cfs	3	Friday	100	Sunday	2400				
	Jul. 15-25	Discharge F	11	Monday	100	Thursday	2400	8,000	28,000 2/	Low	Low
	Jul. 26-28	5000 cfs	3	Friday	100	Sunday	2400				

Notes:
1/ These are the theoretical starting and ending times. The actual times will differ due to the transition periods between the flows.
2/ We have assumed 28,000 cfs maximum, however, this may change monthly depending on conditions.

Dendogram of research discharges.
Fluctuating discharges have approximately the same value as constant discharges on the same level.

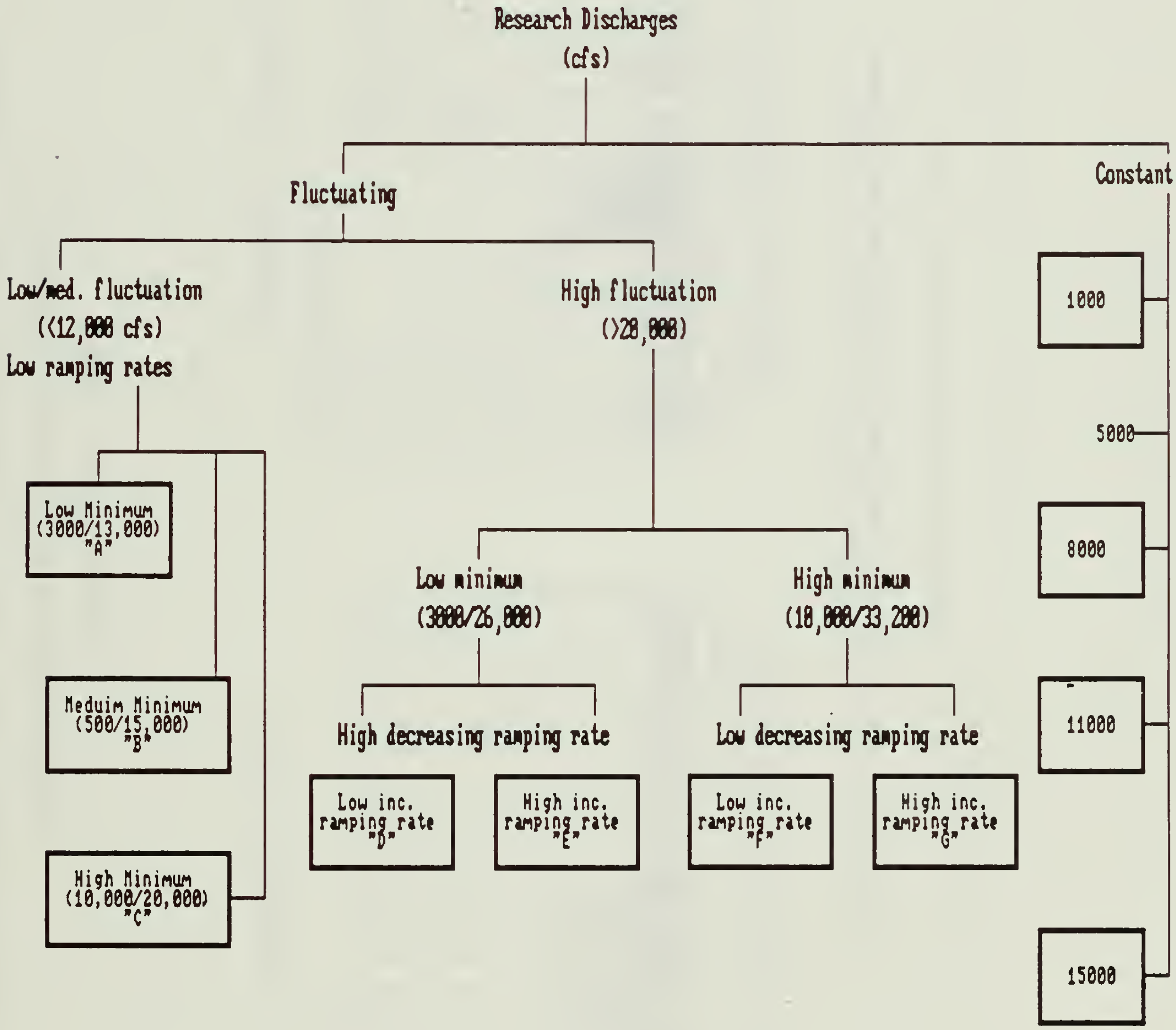


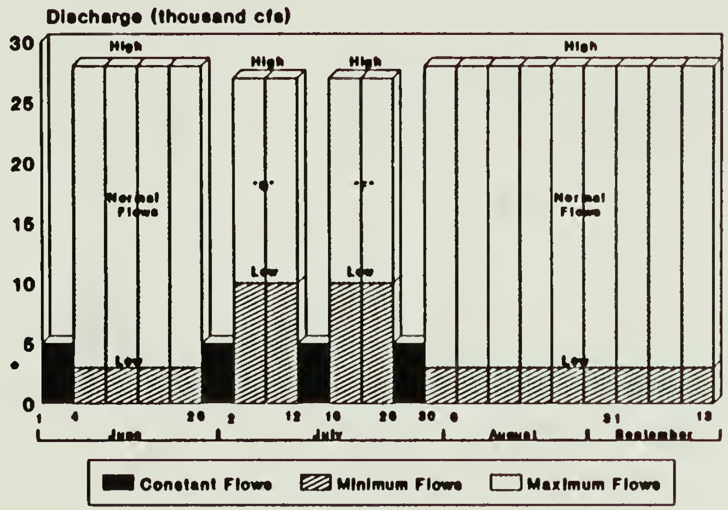
Figure 1. Dendogram of research discharges.

GLEN CANYON ENVIRONMENTAL STUDIES

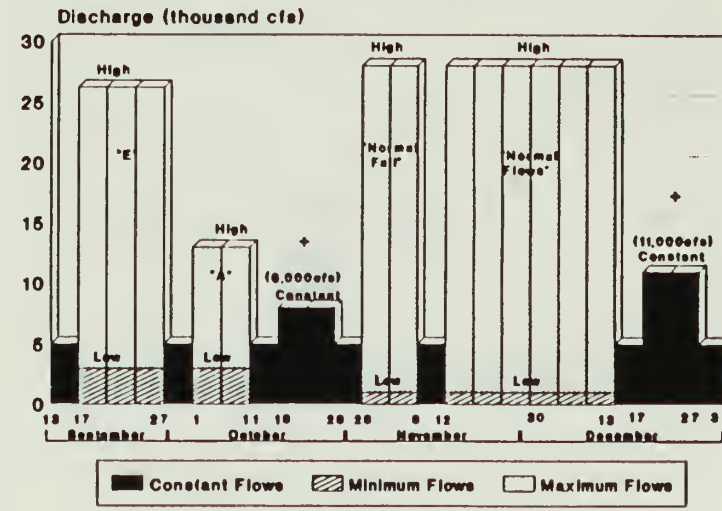
RESEARCH FLOW SCHEDULE

Calendar Year 1990

June - September, 1990



September - December, 1990

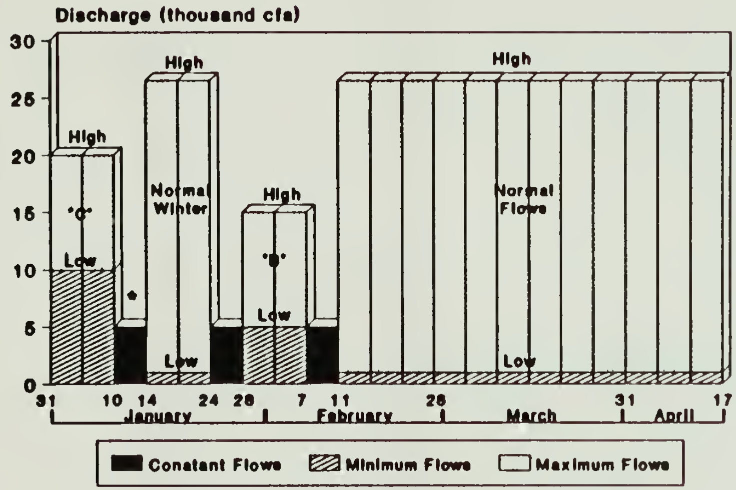


- • The 3-day 5,000 cfs constant flows are scheduled to begin at 12:01 a.m. on Friday and conclude at 12:01 a.m. on Monday
- + The 8,000 cfs and 11,000 cfs constant flows will last 11 days each

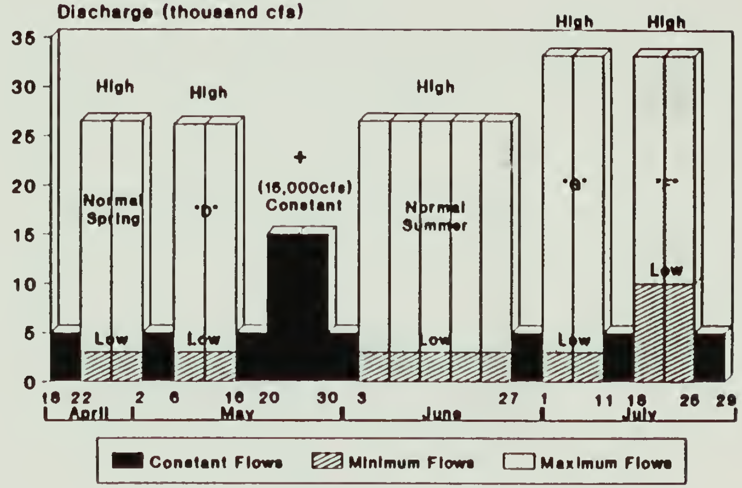
Figure 2. Glen Canyon Environmental Studies research flow schedule for 1990.

GLEN CANYON ENVIRONMENTAL STUDIES
Research Flow Schedule
Calendar Year 1991

January - April, 1991



April - July, 1991



* The 3-day 5,000 cfs constant flows are scheduled to begin at 12:01 a.m. on Friday and conclude at 12:01 a.m. on Monday

+ The 15,000 cfs constant flows will last 11 days

Figure 3. Glen Canyon Environmental Studies research flow schedule for 1991.

STUDY COMPONENTS

GLEN CANYON ENVIRONMENTAL STUDIES

PHASE II

INTEGRATED RESEARCH PROGRAM

GLEN CANYON ENVIRONMENTAL STUDIES
COMPONENTS OF THE
PHASE II
INTEGRATED RESEARCH PROGRAM

I. Introduction

The Glen Canyon Environmental Studies (GCES) Phase II Integrated Research Plan has been developed based on the following assumptions:

1. That the GCES Phase I results are an important and critical component of the process.

2. That the GCES Phase II is based on an ecological system approach structured around specific hypotheses and research flows.

3. That the overall GCES Phase II coordination is a combination of efforts including, but limited to Reclamation, National Park Service, the U.S. Fish & Wildlife Service, the U.S. Geological Survey, the Arizona Game & Fish Department and private and academic interests

The Glen Canyon Environmental Studies Phase II Research Program is structured on ten primary study components and two monitoring components . Each program is based on an assessment of the impacts of operations on the specific resource of question.

The discussion to follow refers to the broad research areas defined in Figure 4 .

II. GCES Phase II Integrated Research Program Study Components

A. Economic Studies

The Phase II economic studies are focused around three primary areas: Power resources; recreation; and, non-use value economics.

The economic studies will be coordinated through the Bureau of Reclamation (Denver Office), HBRS, the power community, Western, Environmental Defense Fund, private contractors and the GCES Office.

Power Resources: The objective of the power resource studies are to understand the potential impacts to the hydroelectric resources at Glen Canyon Dam and the Colorado River Storage Project should a change in the operations of Glen Canyon Dam be made. The Power Resources studies will take into account the issues of electrical resource availability, cost, and repayment relationships.

Recreation: The objectives of the recreation studies is to understand the economic relationship between dam operations and the recreation industry. These studies will focus on three primary areas; fishing, day-use rafting and whitewater rafting. These studies will tier off of the results of the GCES Phase I efforts.

Non-Use Value: The objectives of the Non-Use Value studies are to determine the worth of the resources that are not consumed or monetarily payed for. This includes determination of the value of the individual resource components and will include endangered species and ecosystem relationships.

B. Recreation Studies

The recreation studies will be structured around the GCES Phase I results and the additional concerns that have been raised by the National Park Service and the interested constituent groups.

The recreation studies will be coordinated through the GCES Office, and include the National Park Service, HBRS, and private contractors.

GCES Phase I Studies: The initial recreation studies were completed under the GCES Phase I efforts. The Phase II effort will focus on verification of the Phase I fluctuating flow assumptions and updating the fishery relationships, necessary due to changing fishing regulations.

Carrying Capacity: The objective of the Carrying Capacity study is to determine the relationship of flow releases with the number of recreationists that can be supported in the Glen Canyon Dam to Lee's Ferry area.

Camping Beach Availability: The objective of the Camping Beach Availability study is to determine the relationship of flow releases to the availability of beaches for use by downstream recreationists.

Crowding and Safety: The objective of this study is to determine the relationship between flow levels and the amount of crowding that occurs in the Grand Canyon. In addition, verification of the results of the safety study completed under Phase I will be accomplished.

C. Archeological Studies

The overall objective of the GCES Phase II Archeology studies is to complete the legal requirement to identify archeological and cultural resources that may be impacted by changes in the operation of Glen Canyon Dam and determine if means exist to maintain, stabilize, or document the cultural resources.

The National Park Service, Grand Canyon National Park, will be taking the overall lead on these studies with support provided by Northern Arizona University, the U.S. Geological Survey and the

Native American Tribes of the Navajo, the Hopi, the Havasupi and the Hualapi.

Field Surveys: The initial requirement for the completion of the archeological work will be a field survey of the entire Glen and Grand Canyon study area. Grand Canyon National Park will be the overall coordinator of this effort with field support provided by Northern Arizona University.

Data Evaluation: The evaluation of the data and development of the assessment will be accomplished after the field data are collected. This will involve both in-field evaluation and laboratory and curation work.

Native American Coordination: To ensure that the proper care is taken of the Native American concerns, cooperative agreements will be established with each of the Native American tribes. Specific protocol will be established for the care and handling of spiritual sites, cultural artifacts and human remains.

D. Geomorphology and Geologic Mapping

The Geomorphic and Geologic mapping studies will be conducted to integrate specific areas of the GCES Phase II program:

1. Identification of the impact of flow levels on the context and potential impact of the identified cultural resource remains, and

2. Integration of the large scale geomorphic relationships of the Colorado River with the site specific beach studies being conducted under the sediment transport and beach studies.

The work associated with the Geomorphology and Geologic mapping studies will be accomplished primarily by the U.S. Geological Survey, Geologic Division, Flagstaff, AZ, in coordination with the GCES Office.

Geologic Mapping: The development of a specific geologic map will be coordinated with the Archeology studies to identify the structural location of the cultural resource sites and their relationship to the overall character of the sediment deposits in the Colorado River corridor. Results from this study will be applied to other identified cultural resource sites in the Grand Canyon.

Data Evaluation: This effort will integrate the large-scale geologic and geomorphic studies with the site specific beach and sediment deposit studies being conducted in the Grand Canyon. Additional effort will be made in the integration of geologic relationships in the overall GCES Geographic Information System and the long-term monitoring program for the Grand Canyon.

E. Sediment Transport and Beach Studies

The relationship of the sediment transport and beach formation in the Grand Canyon is of prime interest. The sediment system binds the Grand Canyon together and defines the limits and boundaries of the aquatic and terrestrial ecosystems.

The sediment transport and beach studies are a coordinated, cooperative, effort with technical expertise being provided by the U.S. Geological Survey (Flagstaff, AZ, Tucson, AZ, and Menlo Park, CA), the National Park Service and Northern Arizona University.

Paleoflood Studies: The paleoflood studies will focus on the relationship of the historic sediment deposits and the cultural resource remains.

Beach Evolution Studies: The beach evolution studies are a coordinated approach by the U.S. Geological Survey to evaluate and understand the components of beach evolution in the Grand Canyon. The specific studies that will be developed include:

Sand Inventory
Depositional History of the Sediment Deposits
Eddy Dynamics
Slope Stability
Debris Flow Effects

Sediment Transport Studies: The sediment transport studies are a coordinated approach by the U.S. Geological Survey to evaluate and understand the dynamics of the sediment transport characteristics of the Colorado River through the Grand Canyon. The specific studies that will be developed include:

Flow Model Development
Solute Transport Models
Sand Transport Models
Debris Flow Models
Aeolian Inputs

Beaches and Sediment Deposit Characteristics: These studies will be conducted by the National Park Service in coordination with the U.S. Geological Survey and other offices. The objective of these studies are to select and track the impact of the GCES Research Flows on the changes that occur to selected beaches/sediment deposits in the Glen and Grand Canyon areas. This information will then be integrated with the U.S. Geological Survey work to address the dynamic nature of the sediment deposits in the Grand Canyon.

F. Hydrology Studies

The relationship between the operations of Glen Canyon Dam and the resources of the Colorado River is of prime concern to all the researchers. Understandably, the definition and tracking of the specific flow releases are necessary. A two level hydrological study process will be followed.

Gaging of Flow Levels: Specific hydrologic gaging stations are begin developed along the mainstem Colorado River and the primary tributaries. The hydrologic data program will be coordinated as follows:

Mainstem: Sites at: Glen Canyon Dam, Lee's Ferry, Above Little Colorado River, Grand Canyon (at Phantom Ranch), National Canyon and at Diamond Creek.

In addition, approximately 200 stage recorders will be distributed throughout the Grand Canyon to record information for the Hydrologic flow models and for prediction of stage levels at specific sampling sites.

Tributaries: Stage and flow level recorders will be placed on each of the major tributaries to the Colorado River through the Grand Canyon. Each site will record data which will be added to the GCES hydrologic data base.

Glen Canyon Dam Releases: The actual releases from Glen Canyon Dam are required to verify the flow levels studied and to understand the dynamic nature of the flow patterns. Two primary study efforts will be conducted:

Historic Review of Glen Canyon Dam releases
Review of the GCES Research Flows

G. Water Quality and Productivity Studies

The objective of the Water Quality and Productivity studies is to develop the data base of information necessary to understand the impact of the operation of Glen Canyon Dam on the Colorado River aquatic environment. These studies will focus on four areas; the physical chemistry relationships, the biological chemistry relationships, the limnological impacts of and on Lake Powell and

the implications to the aquatic diptera and the food web of the aquatic ecosystem.

The water quality program will include expertise from the U.S. Geological Survey, the Arizona Game & Fish Department, Reclamation, and the National Park Service.

Physical Chemistry: The U.S. Geological survey will collect and analyze the physical water quality characteristics for samples collected in Lake Powell and in the Colorado River. Monthly sampling will occur at each of the mainriver and tributary sampling sites along with a series of synoptic surveys tied to specific GCES Research Flow scenarios.

Biological Chemistry: The Arizona Game & Fish Department will focus on the collection and analysis of water samples from Lake Powell and from the mainstem Colorado River. The Arizona Game & Fish work will be tied directly to the aquatic productivity of the Colorado River food chain.

Lake Powell Historical Limnological Review: The Bureau of Reclamation has been collecting water quality data on Lake Powell during the filling stages. The consolidation of that data is going to be accomplished in order to understand the relationship between Lake Powell management and the limnological relationships.

Aquatic Diptera: The objective of this work by the National Park Service is to understand the dynamics of a key component of the aquatic food web, the diptera, and how it relates to the overall food availability for the aquatic and avian species.

H. Trout Dynamics

The objective of the trout studies is to better understand the relationship of low and fluctuating flows, trout population dynamics and the survival of the eggs and larvae deposited in the Colorado River.

The majority of the trout dynamic studies will be completed by the Arizona Game & Fish Department with additional technical expertise provided by Northern Arizona University and private consultants.

Trout Ecology: The trout ecology studies will focus on the relationship between the operations of Glen Canyon Dam and the growth and survival characteristics of the trout population.

Trout Stranding: The issue of trout stranding on the exposed spawning bars has been a major concern because it results in the loss of adult and juvenile trout.

Spawning Survival: Northern Arizona University is studying the impact of time of exposure of the spawning bars and the buried trout eggs to the survival rate. Flow levels directly expose the spawning bars and impact the eggs maturity.

Trout Strain Evaluation: An issue of concern has been whether a specific strain of trout could be utilized in the Lee's Ferry area as a means to reduce stranding. An evaluation will be made of whether specific strains of trout could be used in the Lee's Ferry area to alleviate the stranding of trout.

I. Native and Endangered Fish Studies

The objective of the Native and Endangered fish studies is to understand the population ecology of the fish and identify how the fish respond to the operations of Glen Canyon Dam.

The Native and Endangered fish studies are a cooperative effort between the Arizona Game & Fish Department, the Fish & Wildlife Service, the National PArk Service, Arizona State University, the Navajo Nation, and Reclamation.

Native Fish Studies: The native fish studies will be conducted primarily by the Arizona Game & Fish Department. Work will concentrate on understanding the ecological relationship between flow levels, species dynamics, productivity, and habitat. Work on the native fish will be focused on three areas:

Main Channel of the Colorado River
Tributaries to the Colorado River
Little Colorado River

Endangered Fish Studies: The endangered fish studies are designed to address the requirements of the Fish & Wildlife Service conservation measures and the needs of the GCES program. Work under the Endangered Fish Studies will be accomplished by the Arizona Game & Fish Department, the U.S. Fish & Wildlife Service, the National Park Service, the Navajo Nation, Reclamation and private contractors. Specific studies include:

- **Endangered Fish Workshop and literature synopsis**
- **Taxonomic Status of the genus *Gila***
- **Propagation of the genus *Gila***
- **Development of a Habitat Management Plan for the Little Colorado River**
- **Ecological Studies of the genus *Gila***
  - **Mainstem**
  - **Tributaries**
  - **Little Colorado River**
    - **Habitat Studies**
    - **Early Life History Studies**
    - **Adult Movement Studies**
    - **Adult and Juvenile Studies**
- **Studies on the Development of a Second Spawning Population of the *Gila* in the Grand Canyon.**

Development of the long-term Monitoring Plan for the genus Gila in the Grand Canyon.
Development of one-in-twenty flood release logic

The Conservation Measures work will be a coordinated effort and will focus on understanding the ecological relationships in the Grand Canyon.

J. Bald Eagle Studies

The objectives of the Bald Eagle Studies are to determine the relationship between the operation of Glen Canyon Dam, the resulting flow levels in the Grand Canyon and the availability of trout for food in Nankoweap Creek. The accessibility of nankoweap Creek to spawning adult rainbow trout is important as a food source for the endangered Southern Bald Eagle.

The work associated with the Bald Eagle work will be accomplished by the National Park Service, Arizona Game & Fish Department and the U.S. Fish & Wildlife Service.

Bald Eagle Surveys: Surveys will be conducted in the Grand Canyon and on Lake Powell to determine the number of Southern Bald Eagles that inhabit the Nankoweap Creek area during the winter months and feed on the spawning trout. Control surveys will be conducted on Lake Powell.

Trout Access Surveys: Surveys and measurements will be taken of the accessibility of Nankoweap Creek to trout. Specific flow levels and water quality characteristics will be measured.

K. Long-Term Monitoring Program

An important product to be developed from the GCES Phase II work is a long-term monitoring program for the critical resources of the Grand Canyon. The objective of the long-term monitoring program is the development of a scientifically rigorous program whereby the resources of the Grand Canyon can be charted and reviewed to identify long-term response to operations and other modifications that may occur as a result of the Glen Canyon Dam - Environmental Impact Statement.

The development of the GCES Phase II long-term monitoring program is being coordinated by the GCES Office with technical expertise being provided by each bureau and agency associated with the GCES Phase II program.

Long-term Monitoring Plan: The long-term monitoring plan will include documentation in several areas; sites, timing, data required, analysis to be performed, prior data, and critical factors to impact.

L. Geographic Information System

The primary long-term monitoring tool and resource integrator will be the GCES Phase II Geographic Information System (GIS). The GCES Phase II GIS is being developed at thirteen sites located within the Glen and Grand Canyon areas. The GIS sites represent approximately 61 river miles of the 280 + miles of the Glen and Grand Canyon areas. These sites have been selected by the scientists as representing resource areas that either represent **critical** resources, **representative** resources or have been identified as having some **legal or cultural** significance.

The GCES Phase II GIS program is being coordinated through the GCES Office with technical support provided by the Reclamation Denver Office. Technical support on the selection of sites, resource classes and integration processes is being handled by the National Park Service, the Fish & Wildlife Service, the U.S. Geological Survey, Arizona Game & Fish, the Native American tribes, and other offices with specific natural resource requirements.

The components of the GCES Phase II GIS development include:

- **Selection of Study Sites**
- **Acquisition of Aerial Photography - Black & White and Color Infrared**
- **Surveying of the Study Sites**
  - **Geodetic**
  - **Land**
- **Development of the Orthomaps**
- **Development of the Resource Class overlays**
- **Transfer tapes**

At the completion of the GCES Phase II GIS development, tapes of the thirteen sites will be provided to the various resource agencies who actively utilize GIS technology in their management of the resources of the Grand Canyon.

III. Summary

The GCES Phase II Research Program is an integrated approach to studying and understanding the relationships between the operations of Glen Canyon Dam and the ecological components of the Grand Canyon. The study plan items identified in this section comprise the broad components of the overall work plan.

The specific study components can be separated into those factors that are directly impacted by the operation of the Dam and those that are indirectly related to the operations of the facility.

August 90

GLEN CANYON ENVIRONMENTAL STUDIES
PHASE II
TECHNICAL STUDY PLANS

TITLE	PRINCIPAL INVESTIGATOR
I. SEDIMENT & HYDROLOGY	
A. Sediment transport	
1. Grand Canyon Sediment transport.	
a. 1990-INSTALLMENT OF GAGES	Jim Bennet
b. Flow modeling	USGS
c. Solute transport modeling	Menlo Park CA
d. Sand transport modeling	IA
e. Tributary in-puts	
f. Aeolian inputs	
B. Beaches and sediment deposit	
1. The influence of variable discharge regimes on Colorado River sediment deposits below Glen Canyon Dam.	Beuss/Avery Bodhi et al NPS/CPSU
2. Grand Canyon beach evolution.	Julia Graf USGS/IA
3. The relationships between Glen Canyon Dam operations and Colorado River paleoflood deposits in Glen and Grand Canyons, Arizona.	Larry Stevens NPS/CPSU IA
4. The impacts of Glen Canyon Dam on riparian vegetation and soil stability in the Colorado River Corridor, Grand Canyon, Arizona.	Larry Stevens NPS/CPSU

C. Hydrologic data and data-base maintenance proposal.	Bob Hart USGS IA
1. Historical review of dam releases	

II. WATER QUALITY AND LIMNOLOGY

1. Limnology of Lake Powell and Lake Mead and related Releases (Historical Review).	GCES Contract Review
2. Grand Canyon water quality. a. Colorado River water quality b. Lake Powell water quality	Bob Avert USGS IA
3. The ecology of aquatic diptera in the Colorado River below Glen Canyon Dam.	Larry Stevens NPS/CPSU IA
4. AGF Water quality and productivity. a. Colorado River water quality b. Lake Powell water quality	Dennis Kubly AGF CA

III. GEOMORPHIC/GEOLOGIC STUDIES OF THE COLORADO RIVER IN THE GRAND CANYON

A. Surficial geologic maps.	Rich Hereford USGS IA
B. Geomorphic/Geologic evaluation.	Ivo Lucchitta USGS IA

IV. BIOLOGICAL RESOURCE

A. Trout Studies.	
1. Ecosystem process and trout studies under phase II	Dennis Kubly AGF CA
2. Lees Ferry Stranding Study.	Dennis Kubly CA
3. Egg alevin survival (spawning study).	L. Montgomery K. Tinnen NAU CA

4. Evaluation of trout strains at Lees Ferry	Dennis Kubly AGF/GCES Contract Lead
B. Multiple Level Withdrawal Studies.	
V. NATIVE AND ENDANGERED SPECIES	
A. Native Fish Study.	Dennis Kubly AGF/CA
B. Humpback chub and other endangered fish studies.	
1. Taxonomic status of the genus Gila. (Conservation Measure 1)	Bob Williams BOR Contract
2. Maintenance of hatchery stocks of Little Colorado River humpback chub. (Cons. Measure 2)	Bob Williams BOR Contract
3. Ensure that flood releases from Glen Canyon Dam occur with a frequency of not greater than one in twenty years. (Cons. Measure 3)	R. Peterson BOR
4. Development of a management plan for the Little Colorado River. (Cons. Measure 4)	Mike Tremble Navajo Nation CA
a. Navajo Nation	
b. Glen Canyon Environmental Studies	GCES
5. Conduct research to identify impacts of Glen Canyon Dam operations on the humpback chub in the mainstem and tributaries. (Cons. Measure 5)	
a. Little Colorado and other tributaries	Stuart Leon FWS IA
b. Early life history & habitat studies.	Dennis Kubly AGF CA

c. Adult habitat and movement.	Bob Williams BOR Contract
d. Little Colorado River Chub Studies.	Paul Marsh Arizona State University Navajo Nation
6. Establish a long-term monitoring program to assess the relationship of project operation to the humpback chub (Pending Completion of Research). (Cons. Meas. 6)	FWS,AGF, BOR, Nav. Nation NPS
7. Establish a second spawning population of humpback chub in the Grand Canyon (Pending completion of research). (Cons. Meas. 7)	GCES Lead
C. Endangered species workshop	GCES Contract Lead
D. Avian Studies.	
1. The effect of fluctuating flows from Glen Canyon Dam on bald eagles and rainbow trout at Nankoweap Creek in Grand Canyon National Park, Arizona.	Bryan Brown NPS/CPSU IA
a. Trout effects	Bill Liebfried NPS/CPSU IA

VI. RECREATION

A. Influence of discharge on availability of camping beaches in Grand Canyon National Park.	Jerry Mitchell NP/GRCA IA
B. Recreational Carrying Capacity, Lee's Ferry River Reach.	Chuck Wood NPS IA
C. Influence of discharge on recreational values including crowding & congestion and the effect of flows on observed boating accidents in Grand Canyon National Park.	Linda Jalbert GRCA/NPS

D. Review of Phase I/Recreation Studies.	GCES Contract Lead HBRS

VII. ARCHEOLOGY

A. Survey design for Archeological Survey along the Colorado River, Grand Canyon National Park, AZ	Jan Balsom NPS/GRCA IA
1. Field Survey (NAU)	
2. Data evaluation	CPSU/NAU
B. Native American Coordination.	
1. Navajo Nation	
2. Hopi Tribe	
3. Havasupai	
4. Hualapai	

VIII. ECONOMICS

A. Power Resource Studies.	Mike Rolutti
1. Power Modeling	BOR
2. Resource evaluation	Contract
3. Repayment	
B. Recreation Economics.	GCES Office
1. Fishing	HBRS
2. Day-use Rafting	
3. Whitewater Rafting	
C. Resource (non-use) Economics.	GCES Office
1. Evaluation	HBRS

IX. LONG-TERM MONITORING PROGRAM AND DATA INTERPRETATION

A. Long-term monitoring components	GCES Coordinator
B. Geographic Information System Program.	GCES
1. Aerial photos-contract	Coordination
2. Orthomap development-contract	w/Remote
3. Themes & resources classes	Sensing Office, Denver

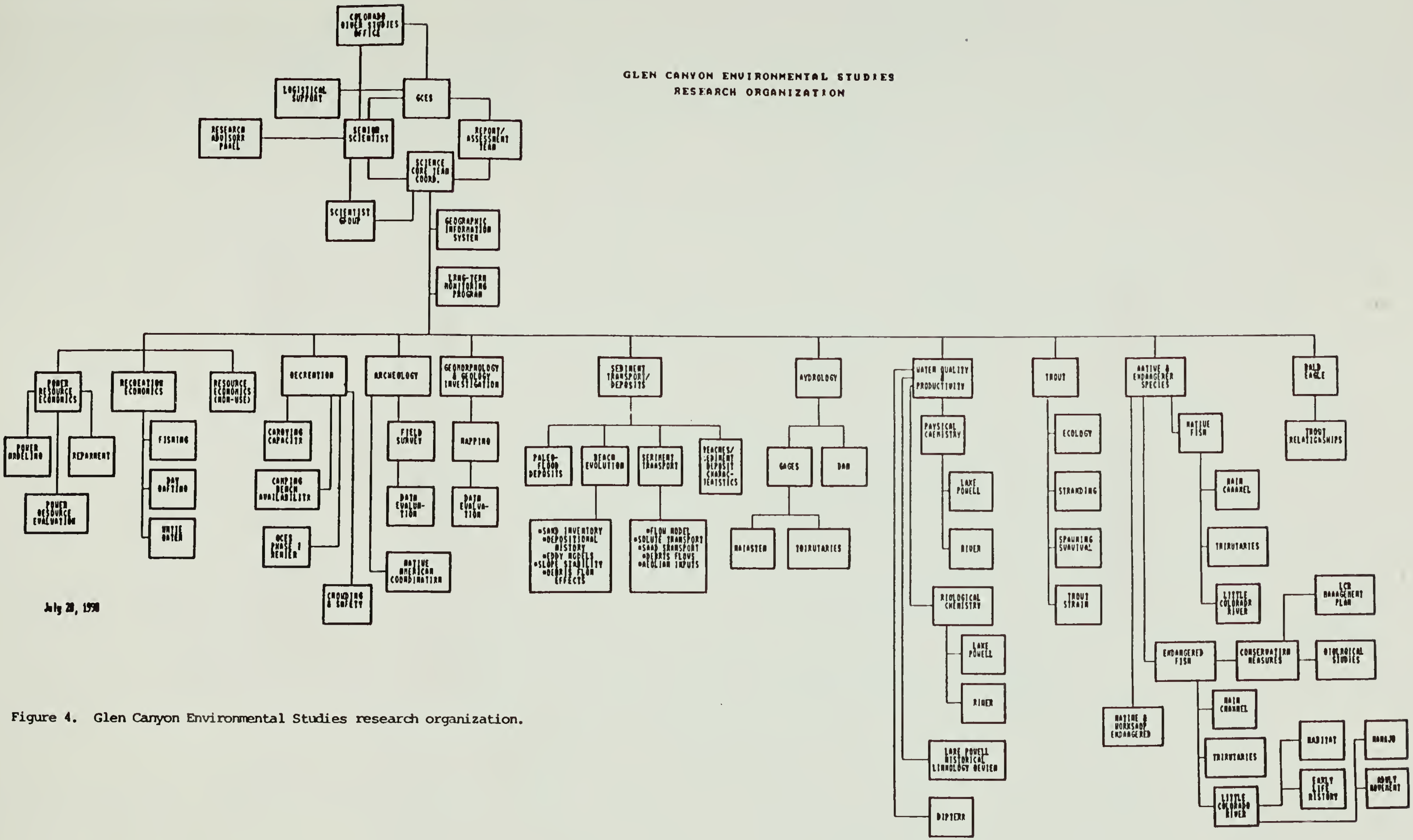


Figure 4. Glen Canyon Environmental Studies research organization.

SEDIMENT AND HYDROLOGY

GLEN CANYON ENVIRONMENTAL STUDIES

PHASE II

INTEGRATED RESEARCH PROGRAM

SEDIMENT AND HYDROLOGY STUDIES

I. Issues

The <u>sediment and hydrology</u> studies are a critical element to the overall completion and integration of the Glen Canyon Environmental Studies (GCES) Phase II program. A large effort was expended during Phase I of the GCES program to determine the relationship between flow levels and the downstream movement of sediment through the Grand Canyon. This information was applied to the dynamics of beach formation and destruction.

At the completion of the Phase I effort it was determined that additional data and analysis would be required if the effects of fluctuating flows were to be determined. The primary areas of concern dealt with:

A. The relationship of low and fluctuating flows on the sediment and beach dynamics.

B. The relationship of dam operations on the historic and long-term sediment deposits in the Grand Canyon.

C. The determination of the overall sediment budgets for the Colorado River in the Grand Canyon, and

D. The need to have a consistent hydrologic and historic data base for the Colorado River.

II. Objectives

The broad objectives of the GCES Sediment and Hydrology Studies stated as follows:

A. Determine the relationship between the operation of Glen Canyon Dam and the transport of sediment through the Grand Canyon.

B. Determine the overall sediment budget for the Grand Canyon by defining the contributions from tributaries, side canyons, and the river channel.

C. Determine the relationship between the operations of Glen Canyon Dam and the dynamics of sediment deposit (beach) aggradation and degradation.

D. Determine the historic relationships in sediment transport and deposit and apply those relationships to the remaining sediment deposits.

E. Determine the historic relationships of Glen Canyon Dam operations and use as the basis, along with other hydrologic data, in the development of a Colorado River hydrologic data base for long-term monitoring.

III. Components of the GCES Phase II Sediment and Hydrology Studies

The components of the GCES Phase II Sediment and Hydrology Studies can be separated into three areas and are depicted on Figure 5.

A. Sediment Transport Studies - evaluation of the impact of Glen Canyon Dam discharges on the downstream movement of sediment through Glen and Grand Canyons.

B. Beach and Sediment Deposit Studies - evaluation of the influence of Glen Canyon Dam discharges on the formation and destruction of beach and sediment deposits in the Glen and Grand Canyon areas. These studies include:

1. Influence of fluctuating flows on sediment deposits
2. Beach evolutionary processes
3. Influence of Glen Canyon Dam operations on paleoflood deposits
4. Impact of Glen Canyon Dam operations on riparian vegetation and soil stability in the Grand Canyon

C. Hydrologic Data Base Development - collection, evaluation, and development of the hydrologic data base for the Colorado River through the Grand Canyon. This will include the integration of existing data and data from Glen Canyon Dam operations.

IV. Organization of the GCES Sediment and Hydrology Studies

The overall GCES Sediment and Hydrology studies will be guided by a technically focused sediment group defined as the Sediment and Hydrology Coordination Group. This group will be composed of representatives of the research study groups, representatives from their respective offices and additional expertise as required.

The Sediment and Hydrology Coordination Group will be responsible for the coordination of the individual research reports, and development of an integrated GCES Sediment and Hydrology report.

Representation on the Sediment and Hydrology Coordination Group will include, but not be limited to, the following groups:

- GCES - Sediment Research Advisor (and/or Senior Scientist)
- GCES Office
- Reclamation - Denver Office
- U.S. Geological Survey
  - Tucson
  - Flagstaff
  - Menlo Park
- National Park Service
- Contractors (as necessary)

Primary leadership will be with the GCES Sediment Research Advisor under the scientific direction of the GCES Senior Scientist or a designated alternate. Coordination of the Sediment and Hydrology Coordination Group technical requirements will rest with the GCES Office.

V. Products to be Developed

The GCES Sediment and Hydrology Coordination Group will be responsible for the coordination of three levels of reports:

A. Individual Research Reports - as defined in Study Plan

B. Integrated GCES Sediment and Hydrology Report - a synopsis and integration of the specific studies developed under the GCES Phase II program.

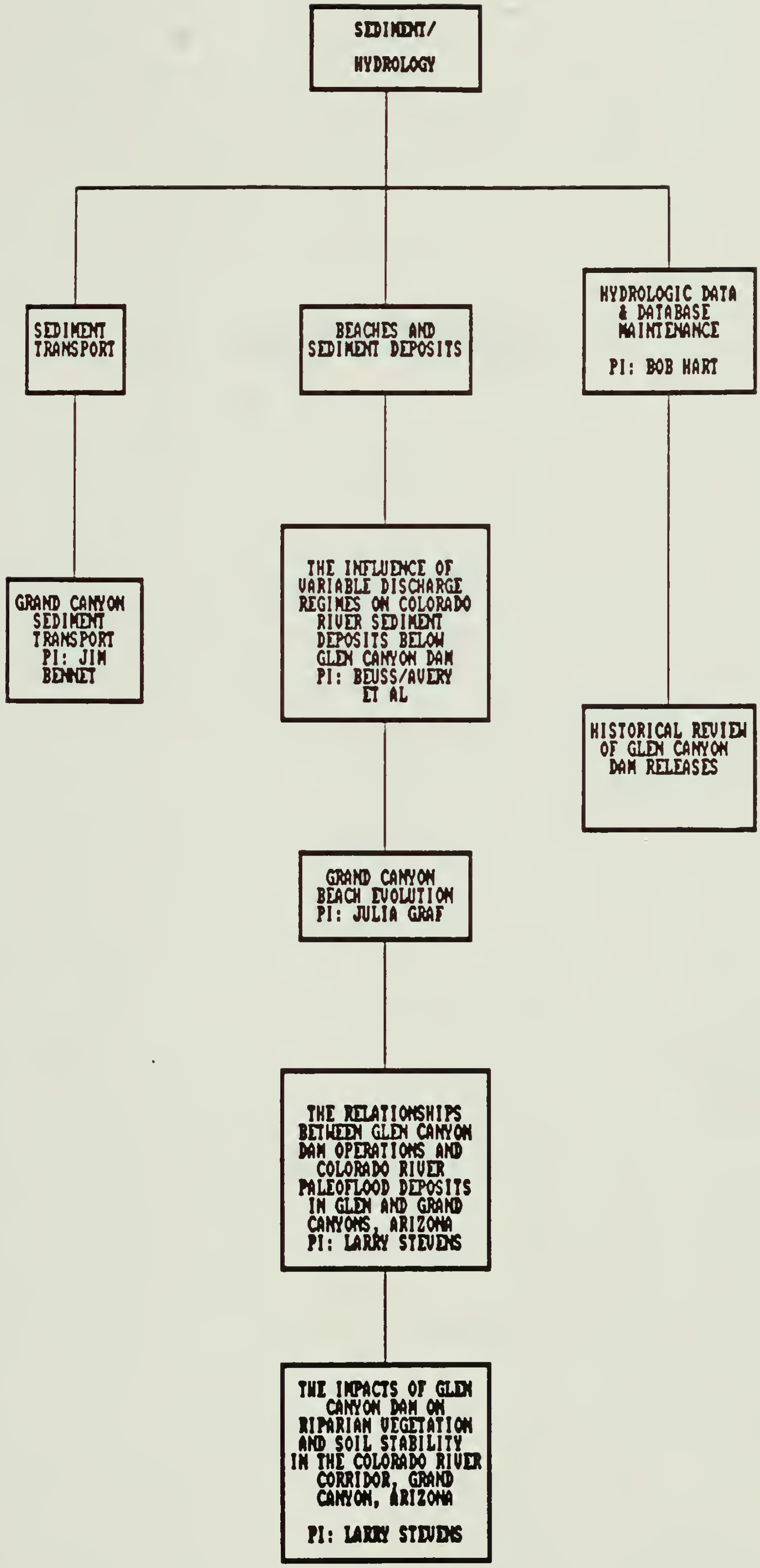


Figure 5. Glen Canyon Environmental Studies Phase II Sediment and Hydrology Studies.

A. SEDIMENT TRANSPORT

PROPOSAL: GRAND CANYON SEDIMENT TRANSPORT

United States Geological Survey

March 28, 1990

A. Abstract

This proposal is presented for consideration for inclusion in the Environmental Impact Statement investigations of the Glen Canyon Environmental Studies, Phase II to address hypotheses H.3, "How do discharge fluctuations, minimum discharges, and rates of change of fluctuating discharges influence the transport of sediment in the Canyon,". Its objective is to develop a sand-transport model for the canyon which will accurately reproduce all pertinent processes and allow prediction of the effects of various dam-operation scenarios on transport of the sediment. Three models are required: A physically-based, predictive-flow model, a conservative solute-transport model, and a sand-transport model. The development also requires quantification of existing sand deposits in the channels, beaches, and bars, and prediction or measurement of inputs from tributaries, debris flows, and aeolian sources. The flow-and-transport models will provide information necessary to investigate hypotheses H.1, H.4, H.6, H.7, H.8, and H.9, and this investigation will require information developed in at least hypotheses studies H.1 and H.7. The suite of models developed in this investigation and H.1 will be essential to determining the optimum augmentation procedures of hypothesis H.20. In addition to the suite of models, the investigation is planned to result in one map, three basic data reports, and eight interpretive reports.

B. Introduction

This proposal is presented in response to a March 2, 1990 request for submissions to address individual hypotheses concerning the effects of the operation of Glen Canyon Dam on resources in Grand Canyon National Park (GCNP) and Glen Canyon National Recreation Area (GCNRA). The request is issued by the US Bureau of Reclamation with the intention of obtaining information pertinent to a U.S. Department of the Interior mandated Environmental Impact Statement (EIS). U.S. Geological Survey (USGS) scientists believe that a decadal-scale interdisciplinary investigation of pertinent riverine and riparian processes will be required to adequately answer the questions raised by the EIS and has prepared a comprehensive proposal to address the pertinent issues. This submission presents pertinent aspects of sediment-transport studies to be completed during the first phase of the more comprehensive investigation. A copy of the complete proposal is included in the USGS submission package.

1. Problem Statement

This proposal addresses hypothesis H.3 "How do discharge fluctuations, minimum discharges and rates of change of fluctuating discharges influence the transport of sediment in the Canyon." The salient characteristics of hydraulic controls and flow in the study area must be understood physically and modeled mathematically before the effects of dam operation on the riverine and riparian environment can be correctly assessed. To relate observations of key parameters and processes to the flow conditions and flow histories responsible for them requires several factors. These include the ability to calculate dam-induced stage variations accurately as a function of location and time, the ability to calculate the downstream transport of nonreacting dissolved materials, the ability to calculate the rate of sediment transport as a function of hydraulic parameters, and the ability to mathematically identify the locations and amounts of sediment deposits. In addition, at the begining of the study or prediction period, existing channel sediment deposits must be inventoried, and throughout the period, the amounts, timing, and composition of external supplies must be measured or predicted.

2. Objectives

The objective of this study is to develop models capable of predicting stage, discharge, and conservative solute-transport, and a sand-transport model so that the the effects of various dam operation scenarios on the riparian zone in the Grand Canyon can be determined. Supporting objectives include (1) determination of the amounts and distribution of sand stored in the main channel and (2) determination of sediment- supply rates to the riparian zone of the Colorado River in the canyon from: (a) Plateau tributaries with large volumes of sediment in storage in their valleys, (b) debris flows from tributaries in the Grand Canyon, and (c) aeolian sources above the riparian zone in the canyon.

C. BACKGROUND

Before flow regulation, snowmelt runoff produced high flows in May-June, with an annual peak discharge at Lees Ferry in June ranging from 25,300 to 220,000 ft^3/s and averaging 93,400 ft^3/s. Local July and August rainstorms produced discharge peaks that were lower and of shorter duration than the snowmelt-runoff hydrograph. Annual runoff volume averaged 11.7 and ranged from 2.5 to 19.2 million acre-feet in the years 1922-1962. Suspended-sediment load typically also reached peaks during the spring-summer runoff season and during tributary runoff events in July and August. September-March was typically a period of low flow, with the lowest flows (5,000-6,000 ft^3/s) usually occurring in December-January. During the filling phase of the reservoir (1963-1980), flows remained within the powerplant capacity except for short periods in 1965 and 1980. Average annual peak discharge in the period 1963-1980 was about 29,000 ft^3/s. Since the reservoir filled, flows have exceeded powerplant capacity for significant parts of the years 1983-1986 (during GCES I), nearly reaching the predam annual average peak discharge in June 1983.

In the main channel, large-scale bed geometry is controlled by the bedrock geology (Dolan and others, 1978). Schmidt and Graf (1989, table 2) found that bedrock geology, bed slope, and the width-depth ratio defined 11 distinctive subreaches between Lees Ferry and Diamond Creek. Size and shape of tributary fans and the number and location of sand deposits were found to be characteristic of these subreaches. Channel geometry and bed-material data were collected from 1983 to 1986 as a part of GCES I. In addition to the cross sections measured at gaging stations during discharge measurements, 200 river cross-sections between gages were measured in 1984. At each cross-section, a seismic reflection survey of the bed was also made to determine the depth of sediment over bedrock or boulders. Longitudinal profiles of the reach between Lees Ferry and Diamond Creek made in 1983 and 1984 show a flow-depth range in the thalweg of from about 5 to about 105 ft at an average discharge of 25,000 ft^3/s (Wilson, 1986). Depth can change abruptly, with near vertical drops of as much as 50 ft in gorges formed in metamorphic and igneous rocks (Wilson, 1986).

A side-scan sonar survey of the channel bed was made along with the 1984 longitudinal profile; about 85 percent of the channel bottom was mapped. Bed-material samples collected at locations between gaging stations and aerial photographs taken at relatively low flow (5,000 ft^3/s) in 1984 were used to determine the correspondence of sonar patterns with bed-material types. The side-scan sonar data were used to prepare a planimetric map of the channel bed with areas of boulders and bedrock, smooth bottom, and sediment waves identified (Wilson, 1986).

In 1980, the USBR collected stage data for 48 hours at 6 sites and calibrated a storage-routing model. The model used was Streamflow Synthesis and Reservoir Regulation (SSARR) developed by the U.S. Army Corps of Engineers (1975). The calibrated model was found to underestimate peak discharge and overestimate trough discharges. The model calibration was checked with stage data from a 3.5-month period of unsteady flow in late 1985 and early 1986 (Lazenby, 1986). Model estimates for sites between those used in calibration were not verified.

Sediment data were collected at gages at Lees Ferry and near Grand Canyon from 1928 to 1965 and 1925 to 1972, respectively. For GCES I, samples were collected at three temporary gaging stations for about 6 months in 1983 and 4 months in 1985-86. Sediment data collected at gaging stations has been evaluated by a number of investigators (Leopold and Maddock, 1953; Pemberton 1986; Graf and Burkham, in preparation; and others). A decreasing trend in bed elevation starting in about 1940 may be the result of decreasing sediment yields from tributaries caused by flood-plain storage (Burkham, 1986). Rating curves for sand sizes developed by Pemberton (1986) were used in a mass-balance model (Randle and Pemberton, 1986) to estimate the amount of sediment lost from the canyon during the floods of 1983-85, but uncertainties in the ratings and in estimates of tributary input for such models are typically so large that the computed values are within model error.

Tributaries with drainage basins largely within the canyon deliver sediment ranging in size from clay to large boulders, commonly by debris flows. The occurrence of debris flows in Grand Canyon has been documented in several drainages (Cooley and others, 1977; Webb and others, 1989), and debris flows appear to be a primary reason for the distribution of rapids on the Colorado River (Webb and others, 1988). Historical photographs, which can be used for documenting debris flows, have been taken along the Colorado River corridor (Turner and Karpiscak, 1980). These include photographs taken by Robert Brewster Stanton in 1890 (Smith and Crampton, 1987) at approximately 1-mile intervals, photographs by Jack Hillers of the Powell Expedition taken in 1872 (Fowler, 1972) and by extensive photographs taken during a USGS expedition in 1923. Aerial photographs, which were taken as early as 1935, also allow direct documentation of debris flows. However, aerial photography is only available parkwide starting in 1965. Changes in debris fans and rapids caused by these flows can alter the geometry, and therefore change the hydraulics of the channel over fairly long reaches. The pool above Crystal Rapid extends for about a mile upstream, almost to the next rapid. Because rapids are the primary hydraulic controls, an understanding of the magnitude and frequency of debris flows is important to modeling of flow through Grand Canyon. Webb and others (1989) suggest that the potential for debris flows may vary depending on the bedrock geology in tributaries. The potential for debris flows may be a function of climate (Webb, 1987).

Tributaries within the study area contribute sediment with a large range of particle sizes to the channel. This sediment not only adds to the supply available for beach building, it is also an important determinant of water quality, because of the silt and clay components, and of channel geometry, because of the coarse component. The relative importance of these factors is different for each tributary. The tributaries can be broadly categorized as those that originate outside the canyon and drain large plateau areas and those that originate within the canyon. Although flow in the plateau tributaries may become hyperconcentrated (Beverage and Culbertson, 1964), characteristics of the source areas, processes of sediment erosion and delivery, and processes of transport are different from the tributaries that originate within the canyon which are characterized by debris flows. Three plateau tributaries--the Paria and Little Colorado Rivers and Kanab Creek--account for much of the total drainage area between Glen Canyon Dam and Lake Mead and probably for a large portion of the sediment delivered to the mainstem. Studies of flood plains of streams on the Colorado Plateau have shown that these streams have undergone alternating periods of channel cutting and flood-plain development and that sediment yield to the Colorado River is in part controlled by these cycles of storage and erosion (Hereford 1986, Graf, Hereford, and Webb, in preparation). Estimation of the amount of sediment supplied to the Colorado River from these basins requires determination of the amount of sediment stored in flood plains and an understanding of these long-term cycles. Although some sediment data have been collected on each of these streams, the interannual variability is very high, and these data do not cover periods of significant change in flood-plain storage characteristics.

and sediment models. An accurate knowledge of bed topography and bed roughness is essential to an accurate flow model of any type. Despite the 200 cross sections measured in 1984, existing channel geometry is sparse compared to the variations that occur over short distances. Also, most existing information does not extend above about the 25,000 ft³/s level. Although some phtography exists, we propose that flow be dropped to about 1,000 ft³/s for a period long enough to allow it to become reasonably steady at the downstream end of the study reach (probably 4-5 days) and that high-resolution stereo photographs be taken from the dam to Pearce Ferry (about river mile 280). The low discharge will expose significant areas, particularly midchannel gravel bars and sandy deposits in eddies and along the banks, in reaches of moderate to large width. These photos will be the source of data on the geometry of the channel from the maximum flood level to all but the deepest parts of the pools and will allow bed materials and surficial deposits along the channel banks to be identified and mapped. Bed material information from the photographs must be supplemented with information on bed material characteristics from the areas not exposed during the low flow. Underwater video during clear, low flow will be investigated and used, if feasible, in combination with depth soundings.

For flow and sediment-transport model calibration, 50 portable stage gages will be distributed along the river. The amplitude and shape of the free surface wave at these 50 sites will be compared to model predictions. Parameters in the friction model will be adjusted in standard engineering fashion to remove any discrepancies. Because accurate transport predictions are required, precise cross-sectional areas must be obtained. Therefore, a major effort will be made to obtain both accurate bed topography and water-surface elevations. The bed topography does not change

D. METHODS

1. Sampling Design

The approach required employs both field and theoretical methods in a way that is carefully adapted to the specific characteristics of the Colorado River. The main-channel flow model will begin with development of a simple cross-sectionally averaged, long-wave propagation algorithm in which the dominant effects of bed and bank roughness are accounted for in a partially stochastic manner. The scale of the river is such that the bed topography cannot be resolved using the 200 available cross sections. The river, therefore, will be divided into segments based on its geomorphological characteristics, and cross-sectional profiles falling within each segment will be used to obtain a representative mean topography and variance around this mean. In combination with information from aerial photos and previous studies of bed material type, these variances will be used to calculate effective flow resistance. The general approach will follow that developed by Wiberg and Smith (1987) for streams with high relative roughness. Although a substantially better understanding of the fluid mechanics of the system is required, development of predictive-flow models (as opposed to the flow-simulation models such as used in GCES I) is mandatory when transport problems and especially sediment-transport problems are of concern.

Information required for flow and conservative constituent models includes bed geometry, bed material grain-size and distribution, and stage. A considerable start on obtaining the needed information was made in GCES I, but additional information is required to develop more representative flow significantly in the short term with discharge in the range of powerplant flows. In contrast, the effects of bed roughness on the flow as reflected in the water-surface elevation depend on discharge and on its temporal variations. Once predictions of these water-surface elevation fluctuations have been confirmed, the accuracy of the model for transport must be tested using dye studies. Model output will be tested by comparing predicted and measured dye-concentration time series at about 12 stations. Data will be collected during as many as four of the research flows planned for the EIS period.

The sand inventory provides an estimate of the extent and distribution of existing resources and of initial conditions for sand transport calculations. This effort is described in detail in the USGS proposal addressing hypothesis H.1.

Although some preliminary mapping and stratigraphy has been done in the basins of the Little Colorado and Paria Rivers, and Havasu and Kanab Creeks, data are not as yet sufficient to fully describe the amount, location, and character of flood-plain deposits. Completion of the mapping and description of the deposits is an important step in developing an understanding of sediment yield from those basins. Monitoring of flow, sediment, and channel changes at gaging stations during runoff on the four streams mentioned above is required to determine fluxes and loads for input to the mainstem flow and sediment-transport models. In addition, repeat photography and resurvey of cross sections at other points along the tributary channels is proposed after significant flow events.

The magnitude and frequency of debris flows throughout GCNP is poorly understood. Monitoring changes in debris fans and development of a model for the size and occurrence of debris flows is, therefore, a necessary aspect of main channel flow and sediment-transport modeling. The frequency of debris flows will be determined for selected ungaged tributaries. Because debris flows are infrequent in any given tributary (Webb and others, 1989), an historic time period of approximately a century will be chosen for analysis. The magnitude of debris flows will be estimated for flows that occur during the course of the study and for certain historic flows. This will be done using several techniques, including estimation of velocities from runup or superelevation evidence and estimation of discharge from local cross-sectional areas (Webb and others, 1989). Rheological models of debris flows will be investigated to determine if an existing method or model can be applied to the tributaries. The magnitude of a debris flow is also related to the size of the slope failure that initiates it and the amount and size of material that is mobilized from the channel. Discharges also can be estimated for certain historic debris flows, such as the Crystal Creek debris flow of 1966, because high-water marks can be determined from photographic evidence and debris entrained in cactus, small caves, or under overhanging rock walls.

Direct measurements will be made of beaches and rapids that are affected by debris flows during the course of the study. An example of historic evaluation is the debris flow of 1966 in Crystal Creek that substantially changed Crystal Rapid. The extent of changes to this rapid can be quantitatively determined by photogrammetric evaluation of aerial and oblique photographs that were taken before and after the debris flow. An example of a more recent debris flow is that of 1989 at mile 127.5, which created a new rapid and beach. Benchmarks installed at mile 127.5 will allow direct monitoring of the effects of future flows.

Reconnaissance surveys early in GCES I revealed that almost all beach sand grains showed evidence of aeolian transport, which could indicate the importance of this mechanism of sand supply to the main channel. Because of the extensive exposures of sandstones within the canyon and because of exposures of unconsolidated sand and silt above the current high water level, there is potential for significant contributions of sediment to the main channel and the riparian area by aeolian transport. This effort will estimate the annual contribution by this mechanism by deploying a network of sediment traps designed to capture sand entering the riparian zone from canyon walls and platforms above.

2. Response curves

Sediment-transport data collected at the gaging stations during the research flows may be used in the construction of response curves. However, the strong dependence of sediment transport in the canyon on prior flow history and scheduling of non-quantifiable distributed source inputs (to name just two of the many pertinent independent variables) plus the proven unreliability of previously derived sediment transport rating curves in the study area suggest that this might be an unprofitable line of endeavor. A better solution would be to use the models developed to investigate alternative dam operation scenarios, although the reliability of this approach will be greatly enhanced towards the end of Phase II of the proposed USGS study.

3. Process of Integration With Research Study Plan

The flow models developed under this proposal are necessary to predict stage at locations between stream gages so that the degree and duration of inundation of spawning bars (H.4, H.6) campsites (H.8, H.9), and backwaters (H.1, H.7) will be known for various levels of operational discharge. The integrated flow-and-transport models are necessary to predict water-quality constitutent delivery timing and concentrations (H.4, H.6, H.7) and sediment supply timing and amounts to eddy models (H.1) for beach nourishment and for redistribution of materials supplied by tributaries, debris flows, and from beach erosion. Long-term data necessary for verification of the integrated flow-and-transport models developed under this proposal will be collected and archived under another USGS EIS-related proposal (directed at no individual hypothesis), and the synoptic water-quality data collected under hypothesis H.7 will be invaluable in discriminating subtle short-term transport phenomena. The channel sand-deposit inventory necessary for this proposal and that of the beach and bar study of hypothesis H.1 must be carefully coordinated to determine an accurate sand budget for the study area and because sand in channel transport at high flow may later become a deposit on a beach, and sand eroded from a camping bar (H.8, H.9) by propeller wash or human activity is an input to the main channel. In addition, not only are the tributary, debris-flow, and aeolian supply elements of this proposal necessary to the successful completion of the main-channel sediment-modeling element, but accurate estimation of debris-flow contributions of sediment of all sizes also is necessary to the flow-modeling element because debris flows provide most of the important hydraulic controls in the canyon. Finally, the sediment delivery and multidimensional eddy-transport (H.1) models developed under this phase and later phases of the more comprehensive USGS study will be indispensible to creating the various operating scenarios necessary to determine the optimum augmentation procedures of hypothesis H.20.

E. Tasks and Research Timetable

This proposal requires efforts in seven major areas: (1) One-dimensional (1-D) flow modeling, (2) 1-D solute-transport modeling, (3) 1-D sand-transport modeling, (4) main-channel sand inventory, (5) plateau tributary inputs, (6) debris-flow inputs, and (7) aeolian inputs. Scheduling, products, and budgets for item (4) are covered under USGS proposal H.1 and activities described for some of the elements below often overlap other elements.

FY 1990:

1. 1-D Flow Modeling:

Conduct reconnaissance for location of 50 recording stage gages, install gages, and operate for research flows. Conceptualize and test predictive, incised-river flow mathematics. Digitize coarse geometry and roughly calibrate engineering-flow model.

2. 1-D Solute-Transport Modeling:

Procure dye and dye-sampling equipment and plan measurements. Development of engineering conservative solute-transport model.

3. 1-D Sand-Transport Modeling:

Collect data at mainstem and tributary-gaging stations and collect geometry for 1-D and multidimensional sand-transport models at cableways. Design and staff full-time 24-hour sediment sampling program at National Canyon gage. Design engineering sand-transport model.

5. Plateau Tributary Inputs:

Monument representative cross sections of reaches for resurvey following floods. Monitor flow and sediment transport at tributary gaging stations.

6. Debris-Flow Inputs:

Initiate GIS data base required for development of debris flow potential model.

7. Aeolian Inputs:

Design, manufacture, and deploy above the riparian zone 50 traps for wind-blown sand.

FY 1991:

1. 1-D Flow Modeling:

Complete stage sampling at 50 gages for research flows. Design and implement predictive, incised-river flow model based on modern environmental fluid mechanics. Digitize final-flow geometry and test engineering model against complete research data set from 50 stage gages.

2. 1-D Solute-Transport Modeling:

Complete dye sampling at 12 stations for up to 4 research flows. Complete calibration of engineering conservative solute-transport model. Conceptualize mathematics for predictive incised-river transport model.

3. 1-D Sand-Transpot Modeling:

Complete National Canyon sampling effort. Continue data collection at gaging stations and develop statistical representation of bed composition surveys for 1-D and multidimensional models. Calibrate 1-D engineering sand-transport model using FY 1990 gaging-station data and test against corresponding FY 1991 data.

5. Plateau Tributary Inputs:

Complete map of Paria River flood plain sediments and commence mapping of Kanab Creek and LIttle Colorado River flood-plain sediments. Complete writing of report on flood frequency of Paria River related to climate changes. Analyze data and report on tributary inputs to main channel model.

6. Debris-Flow Inputs:

Develop preliminary GIS model of debris-flow potential. Prepare data report containing information from measured debris flows and interpretive report analyzing the same data.

7. Aeolian Inputs:

Collect data from 50 traps and prepare basic-data report quantifying inputs to main channel sand-transport model.

F. Products

FY 1990:

1. 1-D Flow Modeling:

Installation of 50 temporary recording stage gages and incorporation of research flow data into study data base.

2. 1-D Solute-Transport Modeling:

Completion of plan for dye sampling at 12 stations for research flows.

3. 1-D Sand-Transport Modeling:

Incorporate National Canyon data into study data base.

5. Plateau Tributary Inputs:

USGS interpretive report on flood frequency of Paria River as related to climate change.

FY 1991:

1. 1-D Flow Modeling:

Interpretive reports:

(1) Predictive modeling of flow in deeply incised rivers, (2) Modeling of flow on the Colorado River between Lake Powell and Lake Mead (3) Statistical representation of bed geometry and flow resistence in the Colorado River.

2. 1-D Solute-Transport Modeling:

Interpretive report:

Conservative transport under unsteady flow in the Colorado River in the Grand Canyon. Basic-data report on dye transport during research flows.

3. 1-D Sand-Transport Modeling:

Interpretive report:

Sand transport at National Canyon gage in Grand Canyon under variable flow regimes.

5. Plateau Tributary Inputs:

Map of Paria River flood-plain deposits and interpretive report on the input of sand and silt-sized sediments from plateau tributaries to the Colorado River in the Grand Canyon.

6. Debris-Flow Inputs:

Interpretive report describing debris-flow hydrographs, water contents, and particle-size distributions for selected tributaries. Data report for hydrographs etc., from same tributaries.

7. Aeolian Inputs. Basic data report on annual aeolian sand inputs to mainstem Colorado River.

G. Budgets

The hastily assembled budget figures below are based on anticipated events that depend on plans and decisions not under our control. We, therefore, recommend these be considered rough estimates, which in the metaphor of GCES II, we believe are in the vicinity of our 75-percent confidence level.

The budget includes an 8-person sediment-sampling crew stationed at the National Canyon gage for about 12 months at a cost of about $475,000. Costs will be substantially reduced if attempts to calibrate an automatic sampler and develop a local sediment-transport model are successful. Crew can then be cut back to the minimum to maintain calibration. Costs for 4 measurements of solute transport with rhodamine WT dye are included. For those measurements, we have counted on being able to obtain labor for the cost of travel only. The dye itself is a substantial part of the cost cost ($245,000). As plans solidify, better estimates of dye quantity may reduce this cost.

	FY 1990	FY 1991
1. Salaries	$156,000	$426,700
2. Equipment and supplies	10,800	277,000
3. Travel	36,600	105,000
4. Sample analysis	12,000	30,000
5. Subcontracts	-------	-------
Total	$215,400	$838,700

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B. BEACH AND SEDIMENT DEPOSIT STUDIES

A PROPOSAL TO STUDY THE INFLUENCE OF VARIABLE DISCHARGE REGIMES ON COLORADO RIVER SEDIMENT DEPOSITS BELOW GLEN CANYON DAM

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National Park Service

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A PROPOSAL TO STUDY THE INFLUENCE OF VARIABLE DISCHARGE REGIMES ON COLORADO RIVER SEDIMENT DEPOSITS BELOW GLEN CANYON DAM

A. ABSTRACT

The impacts that the fluctuating discharges from Glen Canyon Dam have on downstream beach/bank stability are of central concern for the management of both riparian habitat and river recreation in Glen and Grand Canyons. We propose to study fluvial erosion by (1) synthesizing and evaluating previously-gathered survey and discharge data; (2) developing a site-specific erosion model based on bank-stored groundwater movement, incorporating tractive and mass wasting processes; and (3) testing the model with detailed empirical studies in the Colorado River corridor. Field data will be collected during the Bureau of Reclamation's proposed discharge tests in 1990 and 1991. Subsequent refinement of the erosional model will serve in short term management decision-making until longer-term studies of sediment routing and transport are developed by the U.S Geological Survey. A monitoring program will be recommended to assess the effectiveness of discharge management actions based on the results of this endeavor.

This proposal will benefit both students and faculty as well as the reputation of Northern Arizona University and the University of Arizona, and will assist the National Park Service, the Bureau of Reclamation and the U.S. Geological Survey develop a comprehensive assessment of beach stability under alternative flow regimes for the Glen Canyon Environmental Studies Phase II research effort.

B. INTRODUCTION

1. Problem Statement

The operation of Glen Canyon Dam directly influences the stability of fluvial sediment deposits in lower Glen and Grand canyons through hydraulic erosion and aggradation (Schmidt and Graf 1987; Water Science Technology Board 1987; Stevens and Waring 1988; Schmidt et al. in prep.). Although numerous investigators have studied topographic changes of sand bars along the Colorado River in Grand Canyon, these data have not been compiled to determine erosion rates or responses of sediment bars to specific discharge regimes (Howard 1975; Howard and Dolan 1981; Beus et al. 1985-1989). Observations on beach degradation processes in the Grand Canyon suggest that seepage-driven mass erosion on steep beach faces, and tractive force-based surface erosion on mildly sloped, submerged beaches, or a combination of both, predominate during conditions of fluctuating low flows, and generally predominate over aggradational processes. The purposes of the proposed research are to compile and analyze existing data, and to develop and test a site-specific model which will permit the evaluation of alternative discharge regimes on the relative erosivity of Grand Canyon beach deposits. All data collected from this project will be made available to other interested researchers or agencies, particularly the U.S.Geological Survey (USGS) for use in the development of a system-wide sediment transport model.

Although development and testing of a beach erosion model will not encompass the entirety of the sediment routing process in the Grand Canyon, our research will provide dam and resource managers with significant information on the relative impacts of alternative discharge regimes on the stability of fluvial sediment deposits in the Colorado River corridor. This project will be completed in time for incorporation into the Bureau of Reclamation's Environmental Impact Statement. Moreover, our research will benefit studies of riparian groundwater dynamics and vegetation. This project will require integration with proposed long-term USGS sediment transport modeling, scheduled for completion in about 10 years (J. Graf pers. comm.).

2. Specific Objectives

The objectives of this research are to compile and analyze existing survey data, and to model and measure the effects of discharge regimes (mean or minimum, daily range, and ramping rate) on bank-stored groundwater movement through sediment deposits and sediment profile stability. Data will be collected during the controlled discharge study periods of 1990 and 1991 at the three validation sites, and after each of the proposed discharge tests at 36 sites in Glen and Grand canyons (including the testing sites) (Patten 1990).

1. Compile and integrate all existing data on sand bar erosion in this system to document the effects of past dam operations on sediment distribution and rates of change or equilibration.

2. Prepare a site-specific, first approximation model of the hydraulic forces that influence the susceptibility of Colorado River beach/bank deposits to erosion.

2a. Use existing literature and field observations to develop a "definition sketch" conceptual model of the basic erosion processes and variables applicable to beach deposits in the Colorado River in the Grand Canyon.

2b. Model differential head change associated with discharge parameters that influence sediment deposit erodibility of Colorado River beaches.

2c. Model the seepage/tractive forces associated with discharge parameters that influence sediment deposit erodibility of Colorado River beaches.

2d. Model the effects of erosion on bank stability (slope texture).

2e. Combine the above models to generate predictions regarding erosion/aggradation expected during the proposed GCES-II research flows (Patten 1990).

3. Implement a field testing program during the Glen Canyon Dam controlled release program to quantify the effects of discharge parameters, and to calibrate and refine the model.

4. Use the above information to assess the effects of alternative dam operations on channel margin deposit stability for management decision-making.

5. Review/improve beach monitoring efforts to provide relevant, long-term information on beach stability.

6. Monitor the intensity of recreational use and impacts on study beaches during the test discharges.

3. Integration with Research Study Plan

This study will address several of the Research Questions (RQ) posed by Patten (1990) for GCES-II and will incorporate expertise from the USGS, NPS, the NPS Cooperative Park Study Unit at Northern Arizona University (CPSU), the Bureau of Reclamation (BR), and Northern Arizona University (NAU) itself. GCES Research Question (RQ) 1 directly involves dam operation impacts on beach stability. This project will also attempt to predict local-scale beach and/or bank changes, until completion of the U.S. Geologic Survey master sediment transport model (RQ 3). In addition, this project will help determine the risk status of the numerous pre-dam terraces that contain cultural sites (RQ 10). Thus, this project will address Research Questions 1, 3, and 10 (part).

C. BACKGROUND LITERATURE, PREVIOUS AND RELATED WORK

Glen Canyon Environmental Studies

The Glen Canyon Environmental Studies Phase II (GCES-II) was initiated to determine the effects of low and fluctuating discharges from Glen Canyon Dam on downstream resources, and to provide information for the on-going Environmental Impact Statement (EIS) on dam operations. The research goals and objectives of this effort have been identified in the GCES-II research plan (Patten 1990). BR has proposed to conduct a series of two-week controlled discharge tests in 1990-1991 to determine the impacts of dam operations on downstream resources (Patten 1990). These discharge tests will provide an ideal opportunity to collect data and test hypotheses relating resource conditions to discharge regimes.

Relevance of the Study

The normal operations of Glen Canyon Dam involve substantial changes in discharge and delivery rates over short- and long-term time scales, including hourly, daily, monthly, seasonally, yearly, and longer cycles (Schmidt and Graf 1987). Discharge interactively affects sediment stability, beach soil quality, bankstored water movement, vegetation dynamics, and recreation processes at each temporal scale. At present, virtually the full range of annual discharge may occur within a single 24-hour period in this system, and may be repeated on a daily basis. Considerable beach survey data have been collected (but not compiled) since the early 1970's in this system (Howard and Dolan 1981; Beus et al. 1985 et subsequ.; Schmidt and Graf 1987; Stevens 1989b; Rubin et al. 1990; Schmidt et al. 1990); however, little study has been devoted to short-term responses of sediment deposits to dam operations.

Compilation and synthesis of historical topographic information will be useful to GCES-II because it will demonstrate adequacy of existing data to answer the question of long-term adjustment of erosion rates. Although beach surveys began in the early 1970's, present knowledge of the stability (aggradation, degradation, and rates of change) of fluvial deposits is based on annual or biennial surveys of approximately 35 beaches in the Grand Canyon, most of which are intensively used by whitewater recreation parties. Few studies document short-term (daily, weekly) impacts of dam operations to beach/bank erosion in the Colorado River corridor. Stevens (1988) attributed significant erosional impacts to Grand

Canyon beaches to a brief, high discharge on two consecutive days in May, 1982. Also, measurements made during a four-day period of constant discharge at 5000 cfs in October, 1989 (Stevens in prep.) suggested that tractive erosion on shallow gradient beach faces, and slope failure at the downstream and eddy return channel mouths, are common, conspicuous forms of erosion on the five beaches studied. River stage typically dropped faster than bank-stored groundwater drained, and differential head may facilitate slope failure of high angle banks. Improved knowledge of short-term adjustment of beach profile changes would provide the BR and NPS with improved predictive power to evaluate management alternatives under consideration in the Bureau of Reclamation's Environmental Impact Statement process.

<u>Modeling Discharge and Beach Aggradation/Degradation</u>

Beach Aggradation/Degradation: Fluvial sediment routing is a complex and dynamic process involving: entrainment through stream flow; transport of sediments as suspended loads and bedloads under various hydraulic conditions (e.g. clear versus turbid water); deposition and temporary storage of sediments in ephemeral formations (bars, beaches, channel deposits). Erosion of fluvial banks and beaches (<u>sensu</u> Howard and Dolan 1981) is commonly observed along impounded, sediment-starved rivers (Petts 1984). Erosion is directly attributable to mechanical slope failure (slumping) of periodically inundated surfaces and to hydraulic tractive erosion, particularly under fluctuating discharge regimes in which bank-stored groundwater levels vary rapidly. When river level drops, movement of bank-stored water exerts seepage forces on beach faces (Figure 1).

Bankstored Groundwater Movement: Fluctuation of bank-stored groundwater head is influenced by river stage, saturation status of sediments, texture and stratigraphy. By knowing stratigraphy and texture, steady and unsteady seepage analysis can be used to model stress due to seepage and slope stability. Loeltz and Leake (1983) used an hydraulic-analysis method (comparative river and groundwater heads measured in piezometers in aquifers with known hydraulic conductivities) to model groundwater recharge in the lower Colorado River.

Mass erosion results when a combination of gravitational and hydraulic (static and dynamic) forces exceeds the ability of a sediment mass to resist failure, and is a function of internal cohesion and friction between sediment grains (Figure 1B). Resistance to erosion is greatly influenced by hydrostatic pore pressures and seepage conditions. The ability to predict mass failure for given granular materials under given hydraulic conditions is well developed in the geotechnical (soil mechanics) literature. In particular, mass stability theories have been widely applied in evaluating the susceptibility of earth dams to failure under various hydraulic and hydrodynamic conditions (e.g. rapid pool drawdown).

Li and Desai (1983) developed a finite element analysis to determine stresses and seepage from earth dams to differential head variation. This analysis has been extended by Budhu and Wu (1990, in prep.) to incorporate the effects of variable discharge on erosion, and sequential slope stability. The beach material composition and associated hydraulic conditions can be described for Colorado River beaches and thus the analysis of Budhu and Wu (1990, in prep.) will be applicable. A beach, typically, will be discretized into a finite element mesh and elements will be removed successively to model the erosion front. The river stage will be varied from zero to maximum dam discharges and the stresses, strains and stability of the beach will be computed as each element or group of elements is removed.

Fluvial (Tractive Force) Modeling of Erosion: As the stage of the Colorado River rises, erosive capacity of beach sediments by flowing water (tractive forces) increases (Figure 1A). Several well-established, theoretically-based formulae exist for estimating sediment transport rates under a variety of conditions. In general these formulae have been accompanied by considerable predictive error, but they do accurately portray relative erodibility under differing conditions. Also, sediment transport prediction methods developed for the sand-sized ranges tend to be more accurate than methods developed for larger sediment sizes. The situation in the Grand Canyon is simplified by the fact that relatively "clear-flow" inputs can be assumed when modeling erodibility of beaches; however, this assumption will be evaluated using field data during periods of turbid flow. The model developed by Budhu and Wu (1990, in prep.) incorporates the effects of tractive (shear stresses) on the erodibility of a soil mass by introducing the tractive stresses into the formulation of mass failure and so it is applicable here.

Overall, the conditions relevant to modeling beach erosion can readily be described. Beach sediment particle size and associated mechanical properties (porosity, permeability, cohesion, internal friction) are easily quantifiable. Water table conditions can be monitored using shallow wells. Net erosion can be quantified using precise surveys, erosion pins, strain gauges, and/or sediment traps. Important near-shore hydraulic conditions can be measured in the river, such as stage, discharge, average velocity and site-specific velocities.

D. METHODS

1. Broad Sampling Design

Integration of Historical Data: All previously-collected survey data, aerial photographs and discharge records will be collected from agencies and individuals who worked in the Grand Canyon between 1974-1989. These data are available at the offices of the GCES, USGS-Arizona District, or through the libraries of Northern Arizona University and/or Middlebury College if not through selected individuals. Aerial photographs taken by BR in 1984, 1988, 1989 and 1990 will be analyzed to determine reach scale changes in sand bars. Methods for photograph analysis will be similar to those described by Schmidt and Graf (1990). Other, previous data, much of which consisted of one or more profiles/site, will be compiled as well, although not all may be useable in this synthesis. A critical question to be addressed in this analysis is whether the style of change observed at survey sand bars is representative of other changes within reaches. This question will be addressed using data where several beaches are located within a single reach, such as the Eminence Break and Saddle Canyon sites within the lower Marble Canyon section (Schmidt and Graf 1987).

Discharge data describing operations of Glen Canyon Dam are available from GCES (discharge at Glen Canyon Dam) and the USGS (gaging stations at Lees Ferry, Grand Canyon, Paria River and the Little Colorado River). These data will be compiled during the summer and autumn of 1990, and analyzed for the periods bracketed by survey data. Within each of these periods, data concerning range of fluctuations, average daily minimum and maximum flow, ramping rates and other relevant flow characteristics will be determined. Data will be compiled into Arc-Info format, and integrated into the BR GIS mapping effort based in Denver, Colorado. This effort is necessary for long-term monitoring of study beaches for use by the NPS at the conclusion of GCES-II. Benchmark controls and data transfer will require detailed coordination with the BR GIS project manager in Denver, Colorado (Mike Pucherelli). Benchmark coordination will necessitate a river trip to resolve problems in interpretation of surveys conducted by different individuals. In some cases, benchmarks have been changed or washed away. Supplemental surveying may be necessary to determine the relation between benchmarks used in different surveys.

In the course of obtaining these data, discussions will be held with these researchers. All individuals involved in previous studies will be invited to comment and review the draft report of this task, and the invitation of coauthorship will be extended to any individuals who contribute to this effort.

Beach Erosion Model Development: Development of a site-specific, first approximation beach erosion model will be based on integration of soil mechanics/slope failure and groundwater movement models with open-channel sediment transport models. Model development will be accomplished through collaboration between experts from NAU, UA, NPS (CPSU and GRCA), BR and USGS. Model development initially will be driven by existing empirical data on soil particle size distribution, beach and bank topography, current velocities and stage-discharge relationships.

Groundwater flow in vertical cross sections normal to the river will be studied to model groundwater responses to river stage changes using the approaches of Loeltz and Leake (1983) and Lappala et al. (1987). The Lappala et al. (1987) model combined a non-linear form of Darcy's law and the law of conservation of fluid mass, with the total hydraulic potential as the dependent variable. Bankstored groundwater movement will be modeled cooperatively by the USGS, the NPS Water Resources Division (NPS-WRD), NAU and UA, and will require coordination efforts by the Co-PI's. Participation of the NPS-WRD staff at Ft. Collins, CO, and USGS WRD staff in Tucson, AZ are required for coordination, site preparation, data collection, and data analyses. In addition to data on groundwater head change in piezometers and pressure transducer data, thermal data collected during the test flow periods may be used to verify water movement as opposed to head adjustment.

Study Site Selection: Study sites will be selected and surveyed for model calibration and for a corridor-wide empirical survey of the impacts of proposed discharge tests. Three validation sites representing different depositional conditions will be selected for interdisciplinary studies and calibration of the various models considered here (Table 1). In addition to validation sites, a large array of sites will be selected for a system-wide survey of the effects of discharge tests. Each of these sites will contain the maximum diversity of beach microenvironments found in each of Schmidt and Graf's (1987) 12 reaches, including (where possible): eroding versus aggrading faces, low versus high gradient slopes, return channel versus reattachment deposits, fine (silt) versus sand substrata, as well as terraces above the 40,000 cfs stage. This array of sites will provide an evaluation of discharge effects throughout the system.

Study Site Preparation: Field preparation of study sites will be accomplished under the direction of the Co-P.I.s and Dr. John C. Schmidt (post-graduate researcher), with the assistance of NAU graduate and undergraduate students, NPS volunteers, and participants from NPS, NPS-WRD (Ft. Collins), CPSU and the USGS. One 16-day, two-boat motorized river trip with 18 staff divided into two survey crews will embark on a site preparation trip in late August, 1990. In addition to two boatmen and a cook (provided by BR), each survey crew will consist of 2 surveyors, 2 rodmen, 2 scour pin setters, 1 depthfinder operator, 1 photograph station setup crew/photographer, and 1 data recorder. The crew will survey approximately 20 beaches not yet surveyed for this project (1-2 in each of Schmidt and Graf's 1987 12 reaches), including validation sites, using electronic surveying equipment. Each validation site will be instrumented as outlined below, and all sites will be photographed for long-term monitoring purposes.

Canyon-wide Survey Sites: The topography of 36 study beaches surveyed during this project will be mapped to a 1:50 scale using electronic surveying equipment (Table 1). About half of the total number of beaches have already been mapped and instrumented by the NPS, and detailed information on the locations and benchmarks of completed sites will be provided to the Co-P.I.'s by the NPS prior to the river trip 1 (Table 1, Table 2). Fine (3mm) stainless steel scour wires will be implanted in a grid into the beach surface of each site. Wires will be implanted at 5m intervals, with micro-gridding in selected geomorphic settings, to a depth of 1m along the transect lines of this grid. Beach surface level will be measured at the time of surveying. Geomorphic settings of particular interest (e.g. cutbank faces, low gradient/low stage beach faces, return channels, dune crests, etc.) will be identified grid network of nodes at 1 m intervals will be established. These scour wires will serve as easily-censused, short-term stations during the GCES-II/EIS program. The wires will be inconspicuous to the public, but will be readily relocated using a metal detector. An automatically operated photographic station will be established at three sites to document the intensity of recreational use and monitor topographic changes.

Validation sites: Each of the three validation sites (Colorado River Miles -6.5R, 44.7L, 194.1L) will be surveyed and mapped during Trip 1 (Table 2). Current velocity will be measured at 3 depths with a Marsh-McBirney velocity meter from grid nodes established during surveying. The validation sites will be located near USGS temporary gages to document river stage change (Graf pers. comm.). A transect normal to the river on the beach will be instrumented with pressure and temperature sensors in a vertical plane. Each transect will consist of five clusters of sensors located at logarithmically increasing distance from the channel edge. Each cluster will include 3-4 pressure transducers, 6-8 thermal sensors, and a piezometer.

Data recording equipment at each validation site transect will consist of a data logger, 4 multiplexers and a data storage module which will be buried above the high water line. The data will be downloaded to portable computers for transport and processing. Sites will be staffed continuously during most of the test-flow periods by one person to monitor equipment and to determine the short-term equilibration rates of profile change. During installation of probes, saturated hydraulic conductivity will be measured in situ using a Guelph permeameter. Undisturbed sample cores of beach sediments will be collected for laboratory analyses of saturated hydraulic conductivity and soil moisture tension curves during site set-up.

Field Data Collection at System-wide Surveys: Beginning in mid-September, 1990, the effects of each planned discharge test will be assessed during the 3-day evaluation flows (trips 2-18, Table 2). Three motorized craft, each with a crew of 6 will be strategically positioned throughout the Canyon (Mile -15, Mile 65 and Mile 145). Crews will consist of a boatman and a cook (logistics costs paid by GCES), a crew foreman, a proficient surveyor/rangefinder operator, a data entry technician, a depthfinder operator and two scour pin readers. At the commencement of low water, each crew will proceed to the first study site in their reach, census scour wires and survey subaqueous deposits. Channel depth will be measured using metric tapes or a depthfinder mounted on the motorized raft, and tracked with a rangefinder from profile lines on shore. All census data will be recorded by hand and then entered on a laptop computer as a backup. Each crew foreman will spend one day after the trip in debriefing and transmitting data to a crew leader who will serve as a data manager, at the conclusion of each evaluation run. Each site will be rephotographed from a permanent monitoring point. During the next 3-4 days, all 12 sites in each crew's reach will be similarly monitored.

A fixed-wing overflight will be conducted once every three days by the crew leader during the evening hours in the test discharges to monitor the intensity of recreational use on the study beaches. The number of visitors will be recorded on each site and these data will be used as covariates in parametric analyses of variance. The reliability of overflight data will be assessed by comparison with remote photographic data at three sites.

Field Data Collection at Validation Sites: Beginning in early September 1990, each of the three testing sites will be staffed continuously by one research assistant during the test flow periods to maintain recording equipment and to conduct other geomorphologic studies. These persons also will monitor equipment and will conduct daily assessments of topographic changes on the beach surfaces to determine equilibration rate of beaches during test flows. Additionally, current velocities will be measured under different flow regimes on microsites of geomorphologic interest for the tractive erosion portion of the model using current meters. Sites will be rephotographed for monitoring following each research flow.

Analyses: Historic survey data will be compiled into Arc-Info format and integrated with the BR GIS mapping effort.

Sediment texture samples will be returned to the laboratory and dried at 60°C. Laboratory textural analyses of sediment samples will involve sieving. Fifty intact sediment cores will be subjected to bulk density, infiltration and water-holding capacity analyses at a certified soil analysis laboratory. Saturated infiltration and other characteristics of these samples will be determined by USGS cooperators for the groundwater modeling effort. Beach aggradation/degradation data will be compiled to generate site maps and volumetric changes of beach sediment during each discharge test. Volumetric change of the beaches will be analyzed using a blocked (sites), two-factor (mean and range of discharge) analysis of covariance (distance from Glen Canyon Dam), provided parametric assumptions are met. The nonparametric blocked (sites) Friedman Test will be employed if parametric assumptions are not demonstrated (Conover 1980: 299-305). Contrast of slow versus fast ramping rates will be evaluated _a posteriori_. Random subsampling of 5% of the data will be used to compare computer-entered data with that preserved in hard copy. Data will be stored in ASCII format in a NAU VAX computer account for future analyses of this data.

Assessment of Dam Operations on Beach/Bank Erosion: Following compilation and error detection of field data, the erosional model will be refined to accurately represent field conditions. Evaluation of flow release effects on beach/bank stability will be undertaken. Alternative scenarios generated by the EIS public involvement process will be evaluated through the refined erosion model to provide specific recommendations and predictions on operational effects.

Refinement of Monitoring Protocol: The above results will be used to refine the beach monitoring program currently being conducted by several agencies and universities. Development of the best methodology (sites, survey techniques and timing) for monitoring the effectiveness of operational changes in reducing erosion rates will be addressed, and a report will be prepared to serve as a handbook for future NPS monitoring of beach erosion.

Post-test Surveying: Following completion of the test flows a river trip will be conducted to resurvey the sites using electronic surveying equipment (Trip 20, Table 2). One 16-day, two-boat motorized river trip with 18 staff divided into two crews will embark on a site preparation trip on or about 20 August, 1991. In addition to two boatmen and a cook (provided by BR) and an NPS coordinator, each survey crew will consist of 2 surveyors, 2 rodmen, 3 scour pin readers, 1 depthfinder operator, 1 photo station photographer, and a general assistant. The crews will resurvey and rephotograph all the study sites, including validation sites.

Study Site Clean-up and Equipment Recovery: A single boat, 5-person motorized raft trip will be conducted early in 1992 to recover equipment and clean up the study sites (Trip 21, Table 2). An NPS coordinator may accompany this trip to oversee clean-up efforts.

2. Response Curves

Results will be presented in the response curve format requested by Patten (1990). Data collected will be used to generate three-dimensional response curves of the effects of "normal" versus prescribed discharge patterns on sediment storage in beaches. These response curves will depict minimum (or mean) discharge on the x-axis, range of discharge on the z-axis, with relative sediment volume change on the y-axis. Separate 3-dimensional surfaces will be used to contrast slow versus fast ramping rate tests.

3. Logistical Support Requirements

The GCES-II office in Flagstaff, Arizona will coordinate the rafting logistics to study sites. One 16-day, 18-person, two-boat motorized survey river trip will be required to complete site preparation in August, 1990. Three 6-person, single-boat motorized trips will be required during each test flow. One 16-day, 18-person, two-boat motorized river trip will be required in August, 1991 to resurvey the sites and resolve benchmark controversies. Lastly, one 5-person motorized trip will be conducted following completion of the study to recover equipment and clean up study sites.

The project will require several forms of support from the National Park Service. Securing FAA permission for overflight surveys of recreation intensity will be the responsibility of GRCA Resource Management staff, who will also coordinate the necessary logistical arrangements. Permission to conduct motorized river travel during the autumn "no motor" season will be required from GRCA. Although helicopter transport of equipment or crew is not anticipated at present, emergencies such as equipment failure, may necessitate helicopter service. Similarly, although river access to validation sites will be the responsibility of the GCES office and the Cooperator, NPS boat or raft access to the validation sites may be requested. Additionally, other NPS volunteers may be requested to participate in field data collection, space permitting.

This project will require several forms of support from other agencies and logistical support, surveying assistance, and equipment will be requested from the BR and the USGS. Bankstored groundwater movement will be cooperatively studied and modeled by a group of scientists from the NPS, USGS and the co-PI's. Two staff from the USGS-WRD District office in Tucson, Arizona (Dr. S. Leake and Dr. M. Carpenter) will participate with approximately 0.25 FTE participation each in the groundwater monitoring and modeling efforts. Travel, lodging and per diem will be paid for by GCES-II, but salary will be paid by USGS. Water quality data will be collected and analyzed by the USGS (Hart). Existing literature, maps and data will obtained from the BR and the USGS.

E. TASKS AND RESEARCH TIMETABLE

The schedule and deliverables required for this project are outlined in Table 4.

F. DELIVERABLES

The schedule and deliverables required for this project are outlined in Table 4. The final data report will consist of four parts in the format required by NPS (NPS 1989). (1) A synopsis of historical data compilation, analyses of erosion rate changes and a documentation of data achieving efforts and accessibility. (2) Groundwater movement/erodibility modeling and model refinement, including validation site data and analyses, will be discussed in detail. (3) Beach survey maps and analyses of field data from test discharges will be presented for the system-wide study and included in appendices of the final report, with results discussed in detail. (4) Management implications will be reviewed in the light of GCES-II/EIS information needs, and make specific recommendations on EIS alternatives. An assessment of the relative erodibility of beaches under alternative flow regimes will be prepared for managing agencies. An operations model, capable of evaluating beach erodibility under alternative flow regimes, may be developed for the cooperating agencies, depending on the success of the overall modeling effort.

Results of historical data compilation, modeling efforts, empirical studies, and management consequences of the findings will be published in peer-reviewed, scientific journals, such as Science, the Journal of Geomorphology, or Applications of Ecology.

G. BUDGET

Costs not included which will be paid for by GCES include the following: logistical expenses of two each 16-day, 2-boat, pre- and post-discharge test survey trips (in August 1990 and August 1991); three each single-boat motor trips/discharge test x 18 (18 tests = 54 motor trips) in 1990-1991; shuttles to Lees Ferry or Diamond Creek from Flagstaff; 3 fixed-wing overflights/flow test; helicopter or boat transport for three 1-person crews at the validation sites on a bi- or tri-weekly from 8/90 to 7/91. Salaries have been adjusted for cost of living increases.

ITEM	FY90	FY91	FY92	TOTAL
Personnel	49,199	330,099	46,762	426,060
Travel	8,290	14,847	600	23,737
Equipment	34,135	--	--	34,135
Supplies	64,997	1,500	--	66,497
Analyses	1,705	1,705	--	3,410
Management and Documentation	6,500	4,500	5,500	16,500
Total Direct Costs	164,826	352,651	52,862	570,339
Indirect Costs (20% Overhead)	32,966	70,530	10,572	114,068
Grand TOTAL	197,792	423,181	63,434	684,407

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Table 1: Candidate beach erosion study sites. Miles refer to distance from Lees Ferry, Arizona (Stevens 1983). River reach sections refer to designations of Schmidt and Graf (1987). Codes are: little (-H) or much (+H) historical profile information available; low (LR), moderate (MR) or high (HR) recreational use intensity; small (SS), medium (MS) or large (LS) relative size; uniform (UG), moderate (MG), or diverse (DG) geomorphic settings.

MILE	REACH	CODE
	Tailwaters	
-10.5*		-H,LR,LS,MG
-6.0R*		-H,HR,SS,UG*
-3.5L		-H,MR,LS,DG
	Permian Section	
2.6L		H,MR,MS,UG
8.0R*	(Badger Camp)	-H,MR,LS,MG
8.0L	(Jackass Camp)	+H,HR,LS,MG
	Supai Gorge	
16.3L*	(Hot Na Na Camp)	H,MR,SS,UG
20.1L*	(North Canyon)	H,HR,MS,UG
23.0L	(23 Mile Camp)	H,HR,MS,MG
	Redwall Gorge	
24.7R		-H,HR,MS,MG
26.2L		-H,MR,SS,UG
29.2L	(Shinumo)	+H,HR,MS,UG
33.0L*	(Redwall Cavern)	+H,HR,LS,MG
34.9R		-H,LR,SS,UG
37.3L		H,LR,SS,MG
	Lower Marble Canyon	
40.2L		-H,LR,LS,MG
43.1L	(Anasazi Bridge)	H,MR,LS,DG
43.8L	(President Harding)	+H,MR,LS,MG
44.8L*	(Eminence Break)	+H,HR,LS,DG
47.0R*	(Saddle Canyon)	+H,HR,LS,DG
50.0R		-H,HR,LS,MG
50.0L		-H,LR,MS,MG
51.5L*		H,LR,LS,DG**
55.6R	(Upper Kwagunt)	+H,LR,LS,DG

Furnace Flats

64.0L		-H,LR,LS,MG
71.0R		-H,LR,MS,UG
75.7L*		+H,HR,LS,MG

Upper Granite Gorge

81.5L*	(Grapevine Camp)	+H,HR,MS,UG
84.1R	(Clear Creek)	-H,MR,SS,UG
107.7L	(Upper Bass)	-H,MR,SS,UG
108.1R	(Lower Bass)	+H,HR,LS,MG
117.0L		-H,MR,SS,UG

Aisles

120.1R	(Lower Blacktail Camp)	H,HR,MS,UG
122.1R*	(122 Mile Camp)	+H,LR,LS,MG
122.5L	(Forester Camp)	+H,MR,LS,DG

Middle Granite Gorge

132.0R	(Stone Creek)	-H,HR,MS,UG
136.7L*	(Pancho's Kitchen)	+H,HR,MS,UG
134.7L	(Owl Eyes)	-H,MR,MS,UG

Muav Gorge

145.1L		-H,LR,SS,UG
148.5L	(Matkat Hotel)	-H,HR,SS,UG
150.4L	(Upset Hotel)	-H,HR,SS,UG
157.4R		-H,HR,SS,UG
158.4R		-H,HR,SS,UG

Lower Canyon

166.5L	(National Canyon)	+H,HR,LS,MG
191.3L		-H,LR,MS,DG
194.1L*		H,MR,LS,DG**
208.7L	(Granite Park)	+H,HR,LS,MG
213.0L	(Pumpkin Spring)	+H,HR,MS,UG

Lower Granite Gorge

220.0R		+H,HR,MS,MG
222.1L		-H,HR,MS,MG
225.2R		-H,LR,MS,DG

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* Site already prepared for data collection by NPS
** Proposed validation sites

Table 2: Research river trip schedule for 1990-1991. Unless otherwise noted, each trip will carry 6 crew members and will last for 7 days.

FY90		FY91												FY92
A	S	O	N	D	J	F	M	A	M	J	J	A	S	MAR-APRIL
25-08*			08-14			07-13		02-08			11-17			18-02$
	13-19			13-19			18-24		16-22		25-31	25-08*		
	27-03			27-02					30-05					
		11-18			10-16					27-03				
		25-31			24-30									

* Full electronic survey trip, 18 crew.
$ Equipment recovery and site restoration trip, 6 crew.

Table 3: Potential field survey crew members and validation site monitors (others to be selected upon approval of this project.)

NAME
Jeffe Aronson
Paula Becker
Peggy Benenati
Shawn Browning
Kelly Burke
Neil Cobb
Brian Cluer*
Stacey Griffith*
Kevin Johnson
Mat Kaplinski**
Michael Kearsley*
Diana Kimberling
William Leibfried
Hillary Mayes
David McCormack*
Theodore Melis*
Robert Melville
Nancy Nelson
Alan Peterson
Joseph Shannon
Teresa Yates
Gwen Waring

* Potential crew foremen or alternates
** Crew leader

Table 4: Schedule for completion of tasks and deliverables (in bold) for beach erosion studies in the Grand Canyon.

COMPONENT(S) OR DELIVERABLE(S)	DUE DATE
Pre-study Oral Presentation, secure equipment, complete crew training for field data collection	15 August, 1990
Study site setup trip (Trip 1)	25 August-7 September, 1990
Normal summer flow evaluation (Trip 2)	11 September, 1990
Test flow "E" evaluation (Trip 3)	25 September, 1990
First quarterly report (QR)	1 October, 1990
Test flow "A" evaluation (Trip 4)	9 October, 1990
Constant 8,000cfs test flow evaluation (Trip 5)	23 October, 1990
Fall normal flow evaluation (Trip 6)	6 November, 1990
Interim fall (seasonal) flow evaluation (Trip 7)	20 November, 1990
Annual progress report, annual oral report, QR, annual management report	by 31 January 1991*
Early winter normal flow evaluation (Trip 8)	11 December, 1990
Constant 11,000cfs flow evaluation (Trip 9)	25 December, 1990
Test "C" flow evaluation (Trip 10)	8 January, 1991
Normal winter flow evaluation (Trip 11)	22 January, 1991
Test "B" flow evaluation (Trip 12)	5 February, 1991
Normal early spring flow evaluation (Trip 13)	16 March, 1991
Normal spring flow evaluation (Trip 14)	31 March, 1991
QR	1 April, 1991
Test "D" flow evaluation (Trip 15)	14 May, 1991
Constant 15,000cfs flow evaluation (Trip 16)	28 May, 1991

Normal summer flow evaluation (Trip 17).............25 June, 1991

Test "G" flow evaluation (Trip 18)...................9 July, 1991

Test "F" flow evaluation (Trip 19)..................23 July, 1991

QR..1 August, 1991

Summer, 1991 post-discharge test survey trip
(Trip 20)............................20 August-4 September, 1991

QR...1 October, 1991

Final oral report, alternatives and implications
discussion meeting..........................15 October, 1991

Draft final data and management reports..........15 January, 1992

Study site equipment recovery and clean-up
trip (Trip 21).............................15-31 March, 1992

Report on study site clean-up trip................15 April, 1992

Final data and final management report..............15 June, 1992

Executive summary...................................1 July, 1992

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* Between 1 December 1990 and 31 January 1991, depending on availability of data

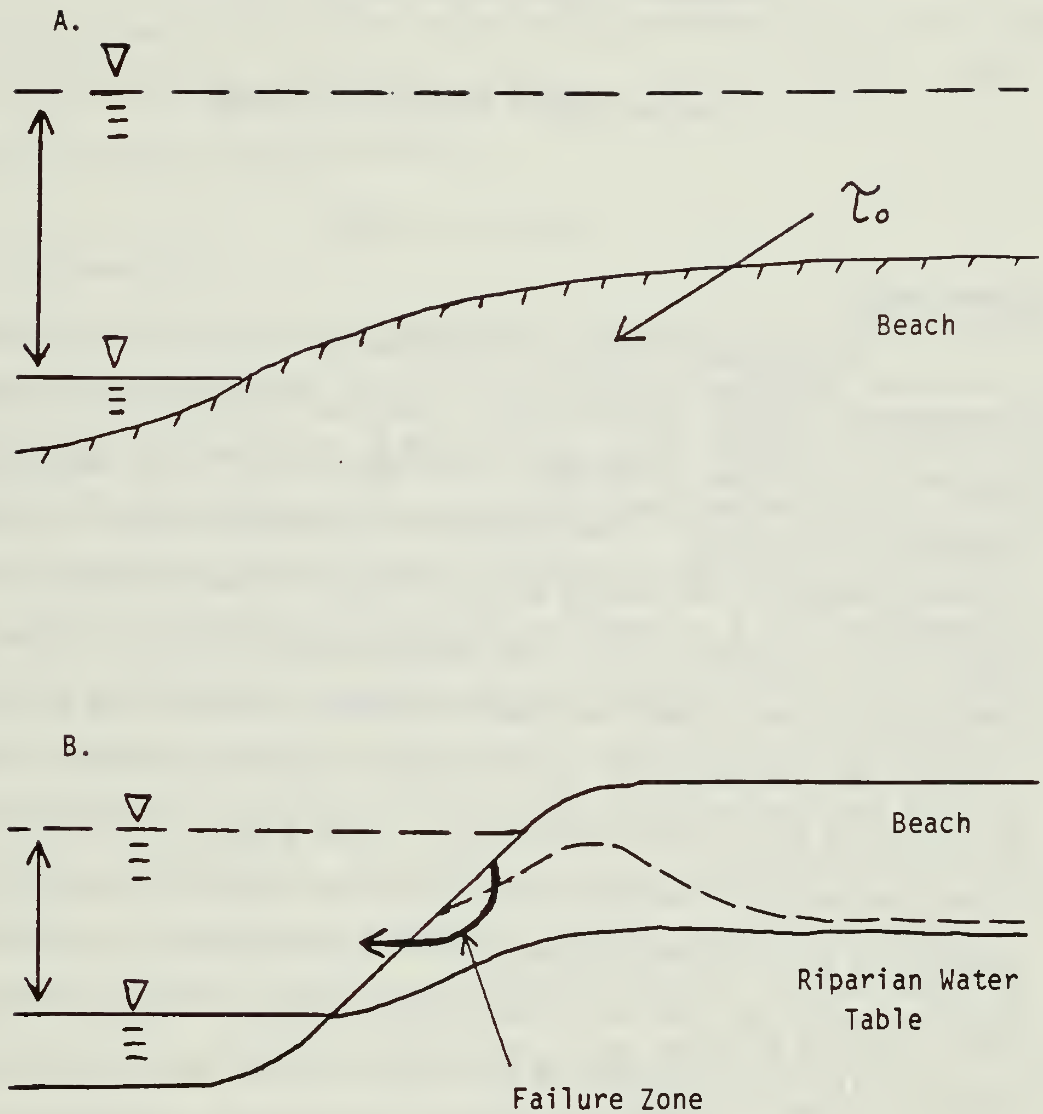

Figure 1: Concept of beach erosion. A. Tractive force erosion; B. Mass erosion.

PROPOSAL: GRAND CANYON BEACH EVOLUTION

United States Geological Survey

March 28, 1990

A. Abstract:

This proposal addresses hypothesis H.1 of the Glen Canyon Environmental Studies research plan, "How significant are discharge fluctuations, minimum discharges, and ramping rate in the degradation or aggradation of beaches?" The objective of proposed studies is to attain an understanding of the status and evolution of sand deposits used for camping and as substrate for riparian vegetation that will enable differentiation of natural and man-influenced processes and effects, and to permit the prediction of future changes resulting from both influences. The objective will be addressed by five study elements: (1) an inventory of sand currently in beaches or available for beach-building; (2) the development of a preliminary descriptive understanding of evolution of beach deposits; (3) the evaluation of the effect of debris flows on beaches; (4) the development of predictive models for beach evolution and the calculation of sand bar change for a wide range of flow scenarios; and (5) the preliminary determination of the significance of ground-water movement into and out of storage in sand deposits to beach stability. Concurrent progress toward the goals of hypothesis H.3 (main channel sand transport) is required for the successful completion of H.1 goals. Results of H.2 (other factors in beach stability) are required to separate the flow-induced beach changes from other factors causing beach change.

Successful completion of studies addressing the H.1 hypothesis is needed to address many of the other hypotheses, particularly H.6 (native fish), H.7 (water quality and stream production), and H.9 (location, number, and surface area of camping beaches).

B. Introduction:

This proposal is presented in response to a March 2, 1990 request for submissions to address individual hypotheses concerning the effects of the operation of Glen Canyon Dam on resources in Grand Canyon National Park (GCNP) and Glen Canyon National Recreation Area (GCNRA). The request was issued by the U.S. Bureau of Reclamation with the intention of obtaining information pertinent to a U.S. Department of the Interior mandated Environmental Impact Statement (EIS). U.S. Geological Survey (USGS) scientists believe that a decadal-scale interdisciplinary investigation of pertinent riverine and riparian processes will be required to adequately answer the questions raised by the EIS and have prepared a comprehensive proposal to address the pertinent issues. This submission presents pertinent aspects of studies of beach evolution processes to be completed during the first phase of the more comprehensive investigation. A copy of the complete proposal is included in the USGS submission package.

1. Problem Statement

This proposal addresses hypothesis H.1 "How significant are discharge fluctuations, minimum discharges, and ramping rate in the degradation or aggradation of beaches?" The completion of Glen Canyon Dam in 1963 and the filling of Lake Powell in 1980 changed the behavior and characteristics of the Colorado River in the Grand Canyon. Because dam operation allows power to be generated on demand, the dam is valuable as a "peaking" facility. Release of water in response to power demand has resulted in flows that are extremely unsteady--daily flow range is commonly 10,000 ft^3/s or greater. Managers of Grand Canyon National Park and Glen Canyon National Recreation Area are concerned about maintaining the riparian and riverine environments in the face of flows and sediment loads that are very different from those of the unregulated system. Camping beaches and other sand deposits in the riparian zone are of particular concern because recreation and natural resources depend on their existence, size, and location. To operate the dam to minimize adverse impacts, managers must have the answers to such complex questions as how long camping beaches can be maintained under normal powerplant flows and whether beaches can be rebuilt by floods. These questions can be answered only after predictive models for sediment transport through the system and for sediment aggradation and degradation in eddy beaches have been carefully developed and thoroughly tested.

The relation between dam releases and eddy sand storage would not be fully understood even if main-channel sand storage and transport were modeled accurately. Processes of transport and deposition of sediment within eddies and across the boundary between the main channel and eddies must also be understood. Predictive models of these processes must be developed if evaluation of flow-release alternatives is the goal because the short duration and site-specific characteristics of any study limit other methods of evaluation to a narrow range of conditions.

Fluctuating stage causes water to move into and out of storage in sediments adjacent to the river. Features such as cracking, slumping, and spring sapping have been observed and attributed to ground-water movement. Although studies of beach change have been carried out in the past, little work has been done to relate ground-water movement in the sediments to beach stability and none relating strain within the beaches to water-level fluctuations.

2. Objectives

The ultimate objective of the proposed study is to attain an understanding of the status and evolution of sand deposits used for camping and as substrate for riparian vegetation that will enable differentiation of natural and man-influenced processes and effects, and to permit prediction of future changes resulting from both influences. The specific objectives are: (1) to determine the amount of sand available within the river corridor; (2) to develop a preliminary descriptive understanding of bar evolution; (3) to evaluate the effect of debris flows on sand bars; (4) to make a preliminary set of model calculations of bar change for a wide range of flow scenarios for bars typical of the Grand Canyon; and (5) to make a preliminary determination of the effect on beach erosion of ground-water movement into and out of storage in the sediments.

3. Process of Integration with Research Study Plan

The sand inventory provides an estimate of the extent and distribution of existing resources and of initial conditions for sand budget calculations. Documention of the areal and volumetric distribution of existing sand deposits is essential for addressing hypotheses H.1 and H.3 for two reasons. First, sediment distribution must be known on a regional scale to evaluate changes through time in the entire canyon. This information is crucial for evaluating the effects of the discharge regime. For example, if the models of hypothesis H.3 show that sand is being lost at an insignificant rate, then flows could be optimized for beach-building without adverse effects. In contrast, if the sand in the canyon is being depleted at a rapid rate, then the positive aspects of the large flows that build the beaches will have to be balanced against the fact that floods rapidly deplete the supply of sand. Second, the location of sand deposits must be known on a local scale, to provide input for the channel transport models of hypothesis H.3 and the beach aggradation and degradation-modeling studies discussed below.

The mainstem flow- and sand-transport models (H.3) will predict the amounts and timing of the inputs to the three-dimensional eddy-flow and transport models used to understand the evolution of individual beaches. Also, information obtained during the dye (H.3) experiments proposed for the main channel transport studies will be essential to the eddy-modeling effort. Time series of dye concentration obtained in eddies during this experiment will provide information about exchange rates between the eddies and the mainstem. Because one of the central goals of the eddy modeling is to predict the exchange of various constituents between the eddy and the mainstem, the dye information will provide a method for model verification.

If instability caused by movement of water into and out of deposits during unsteady flow is found to be significant, then this process will have to be considered in models that predict sand erosion. Beach aggradation and degradation measured or predicted in this element of the study must be evaluated with respect to changes caused by other processes, such as recreational use (H.2).

Eddies are believed to be important areas of influence of the chemical and biological characteristics and temperature of the water. Predictions of exchange of water between the main channel and the eddies are needed to determine the effect of discharge fluctuations on water quality and stream productivity (H.7). Eddies are also thought to be important to native fish (H.6) because of the chemical, physical and biological characteristics of those zones. Flow and bed evolution models must be developed to predict how these zones will change in size, depth, accessibility, and number under different discharge patterns.

Although preliminary counts of location, number, and surface area of sand deposits usable for camping (H.9) can be made from photographs and estimates of stage at given discharges or from inventories made on raft trips, ultimately the full suite of main channel and eddy models (H.1 and H.3) will be required to predict changes in these important factors in response to different discharge patterns under variable conditions of sediment storage and input.

C. **Background:**

In the mainstem, large-scale channel geometry is controlled by the bedrock geology (Dolan and others, 1978). Schmidt and Graf (1989, table 2) found that bedrock geology, bed slope, and the width-depth ratio defined 11 distinctive subreaches between Lees Ferry and Diamond Creek. Size and shape of tributary fans and the number and location of sand deposits were found to be characteristic of these subreaches. Schmidt (1987) found that susceptibility of sand deposits to erosion is related to deposit type, reach geometry, and fan geometry. About 35 camping beaches have been surveyed since 1975. Surveys from before the 1983 flood (Howard and Dolan, 1980) suggested that sand deposits had become stabilized to powerplant operations. The 1983 and subsequent floods, however, reworked sand deposits -- some deposits aggraded and others degraded (Schmidt and Graf, 1989). A short period of fluctuating flows in the fall and winter of 1985-6 following high steady flows resulted in significant erosion, especially of those deposits that had experienced aggradation during the floods of 1983, 1984, and 1985 (Schmidt and Graf, 1989). Since 1987, two of the 14 beaches have been significantly affected by flows from nearby tributaries.

The occurrence of debris flows in Grand Canyon has been documented in several drainages (Cooley and others, 1977; Webb and others, 1989), and debris flows appear to be a primary reason for the distribution of rapids on the Colorado River (Webb and others, 1988). Debris flows in tributary basins affect the geometry of the main channel. Changes in debris fans and rapids caused by these flows can change the geometry, and therefore sand distribution, in a localized area, and they can change the hydraulics of the channel over fairly long reaches. In addition, debris flows directly affect the stability of beaches near tributary mouths (Schmidt and Webb, unpublished data) and may indirectly affect beaches by changing the configuration of flow in eddy systems. For example, a new beach has formed at mile 127.5, where a debris flow from a small drainage formed a new constriction and rapid in August 1989.

Previous work on depositional history of beaches has focused on 10 bars, and the internal structure and deposition history of one eddy bar has been studied in detail (Rubin, Schmidt, and Moore, in preparation). The work determined the time of formation of the bar, eddy geometry, and flow patterns at the time of bar formation, type, and migration direction of bedforms active on the bar surface, and timing of fluvial and aeolian reworking of the bar surface.

One of the critical elements of a scientific solution to the problems in Grand Canyon is a careful, physically-based understanding of the dynamics of lateral separation eddies and the exchange processes between these features and the mainstem. A general mathematical model which focuses on understanding the physical processes active in lateral separation eddies is under development by the USGS. This model will be used extensively in this phase of the study.

D. Methods:

- 1. Broad Sampling Design

At least five major categories of investigations in addition to those included under points of the research plan are necessary to understand the relation between powerplant releases and aggradation and degradation of beaches in Grand Canyon. These include making an inventory of the amount of sand in storage in sand bars along the channel, determining the depositional history of existing deposits, developing models of flow and sand transport in the eddies, determining the effect of debris flows on sand deposits, and investigating the effects of variable stage on beach-slope stability.

Volumes of sand in representative beaches will be surveyed by land-based seismic-reflection equipment and a 20-foot vibrocorer. A combination of bathymetric surveys and topographic surveys of exposed deposits is needed to define the geometry and changes in geometry for the proposed eddy modeling. Three eddies will be selected in this phase for detailed surveying, measurement of characteristic velocities, and other parameters. The selected eddies will cover a range in those characteristics found to be significant (width-depth ratio, expansion ratio, deposit characteristics). Sites already in the beach monitoring set probably will be selected, because some history of those zones is available. In any event, the annual surveys of the camping beaches and associated eddies will provide information for model comparison and to monitor changes in vegetation, grain-size distribution, and topography. These data will enable others to assess the importance of such factors as vegetation cover, camping use, wind, and other factors on beach stability.

Depositional history of the beaches provides information about the processes that create the bars. Examination of internal structures can be used to identify sites of deposition and erosion, determine whether sand was deposited from suspension or as bedload, determine whether flow was steady or oscillatory, and determine the time and flow events that created the bars. These observations are of critical importance for those deposits that were formed at discharges greater than those likely to be available for future study. In addition, morphologic/volumetric changes exhibited by the sand deposits in the past and during the course of future studies are a direct record of the effects of dam operations. Not only are these observations essential for the testing of any predictive models, but observations of depositional processes can be used to guide the modeling approach, and the historical volumetric observations can be used to assess dam operations regardless of capabilities or limitations of any predictive models. The proposed work will be directed at determining the origin of several additional bars. The results will allow generalization of the flow processes that create the bars.

The depositional history of at least three beaches will be determined by a combination of trenching and vibrocoring, comparison of photographs, and comparison of topographic survey data. This work will be coordinated with the eddy modeling of phase II of the more comprehensive USGS study. Bars will be selected for internal examination on the basis of previous topographic data and suitability for eddy-modeling examples. A combination of bathymetric surveys and topographic surveys of exposed deposits is needed to define the geometry and changes in geometry for the proposed eddy modeling. Three eddies will be selected in this phase for detailed surveying, measurement of characteristic velocities, and other parameters. The selected eddies will cover a range in those characteristics found to be significant (width-depth ratio, expansion ratio, deposit characteristics). Sites already in the beach monitoring set probably will be selected, because some history of those zones is available. In any event, the annual surveys of the camping beaches and associated eddies will provide information for model comparison and to monitor changes in vegetation, grain-size distribution, and topography. These data will enable others to assess the importance of such factors as vegetation cover, camping use, wind, and other factors on beach stability.

The comprehensive USGS study involves the development of detailed three-dimensional flow and transport models of the eddies, which build the beaches. Initial phases of this work will be completed during the EIS. There are three parts to the modeling effort—a flow model, a sediment-transport model, and a coupled flow-sediment transport-bed evolution model. The goals are to be able to predict the flow field in a given eddy, exchange rates of sediment (or any other conservative or nonconservative constituent) between the eddy and the mainstem, the equilibrium topography of the eddy deposit for a given discharge, and the adjustment of a given topography to a variation in discharge.

The proposed flow modeling essentially "cascades" from a steady, two-dimensional solution to a steady, three-dimensional solution, and finally to an unsteady, three-dimensional solution that retains the direct effect of the vortex street along the eddy fence. Flow model results are fields of velocity and boundary shear stress suitable for use as input to advection-diffusion computations for distributions of suspended sediment or other constituents. This calculation, along with a treatment of sediment moving as bedload, makes up the second element of the proposed modeling. The goal of the sediment-transport model is to make good predictions of sediment fluxes, both in the main channel and in the eddies. The bed-evolution model involves starting with some initial bed configuration, running the flow and sediment-transport models in order to evaluate patterns of erosion and deposition, and then predicting what the bed will look like at some later time using those patterns. This process is repeated iteratively to examine the adjustment of the beach deposit to various types of flow.

Initially, the model will be tested by predicting flow patterns and equilibrium shape of an eddy deposit in a simple channel expansion beginning with a flat bed (Schmidt, Rubin, and Ikeda, in press). This first test of the model will employ laboratory data. The next phase of verification will involve investigating the response of the eddy deposit to various temporal variations in stage and discharge, again probably using laboratory data. However, some testing may use data collected in a small-scale natural eddy. In addition, model predictions will be compared to depositional patterns observed during the study.

To apply the model to a suite of eddies in Grand Canyon, detailed bathymetric surveys will be obtained. Model verification at the sites of interest will also be obtained through comparison of beach adjustment (predicted and measured) for some of the planned research flows. The high-flow, high-amplitude scenario may be the most useful in this regard.

The effects of debris flows on beaches will be evaluated for those that occur during the period of study and for historic debris flows where information of sufficient quality exists. Direct measurements will be made of beaches that are affected by debris flows during the course of the study. An example of a recent debris flow occurred in 1989 at mile 127.5, which created a new rapid and beach. Benchmarks installed at mile 127.5 will allow direct monitoring of the effects of future flows on the beach.

Ground-water flow in vertical cross sections normal to the river will be studied to develop an understanding of the response of the ground-water system to river stage changes. Variably-saturated flow will be simulated to appropriately simulate the movement of the free surface in beach sediments. Sites representing different conditions will be selected and instrumented to collect data required for calibration of three independent models. Head changes in the saturated zone and temperature of ground water will be measured during unsteady flow scenarios. Properties of sediments that need to be defined for model development (saturated hydraulic conductivity and relations between water content and pressure) will be measured in the field or laboratory, as appropriate.

2. Response Curves

The response curve approach does not apply to some aspects of this short-term proposal, which is aimed at building the base of background knowledge and information required for development of physically-based models of the eddy/main channel system, particularly elements such as sand inventory. Response curves should by used with caution for those aspects for which the approach is applicable. Sand-deposit response to imposed flow condition is strongly dependent on the history of flow, sediment transport, and tributary input over a long period of time. In the short term, deposits can respond in the same way to very different imposed flow conditions or can respond differently to the same imposed flow condition because of different histories of flow and tributary input. Other factors, such as recreational use, vegetation, and wind action, also influence the way in which sand deposits respond to flow. Simple relations between flow variables, such as range, magnitude of the daily high or low discharge, and ramping rate, and measures of sand bar response, such as average change in elevation, developed from a few observations made over a short period of time may not represent longer-term response of the bar. Also, the response of a resource, such as camping beaches, is determined by the integrated response curves of many factors, and until the physical process is understood, one can only surmise how these curves should be integrated.

3. Logistical Support Requirements

River trip support is required for 2 river trips in 1990 and 3-5 in 1991, beyond the beach survey trip which is scheduled for three weeks in September 1990. A motor boat will be required for work in the reach just below the dam. Transportation to and from Flagstaff is assumed to be included in the river support. Logistical support for the field aspects of the ground-water movement study are included in the proposal addressing H.1 submitted by GCNP.

FY 1990:

One river trips of about 3 weeks, 1 motorized raft each, with about 5-6 scientific crew; a small powerboat for local bathymetric surveys. One trip in a powerboat capable of carrying 20-foot core barrels, about 300 lbs of gear, and about 4 people will be required for testing of seismic and vibro-core techniques in the reach upstream from Cathedral Wash.

One river trip of 3 weeks with oar or motor boats; about 5-6 scientific crew.

FY 1991:

Three river trips of about 3 weeks each; motorized rafts; 5-6 scientific crew; at least one with small powerboat.

One trip of 3 weeks with oar or motor boats and about 5-6 scientific crew.

E. Tasks and Research Timetable:

FY 1990:

1. Sand inventory:

The sand inventory of the entire canyon is expected to be a long-term effort. FY 1990 effort will consist of one raft trip for testing of field methods and data collection on exposed parts of sand deposits, and one raft trip dedicated to surveying the submerged channel bottom. This latter survey will provide data not only for the sand inventory but also will provide critical channel geometry and bed material information for the main channel modeling. If methods are successful, information will be provided on sand volumes of a few bars by the end of 1990, three eddy-main channel reaches will be surveyed and bed material information obtained, and bed material and geometry data will have been collected in a few characteristic reaches of the main channel. Additional beaches and main channel reaches will be measured in FY 1991. Perhaps 5-10 sand bars can be measured in that time and some charaterization made of geometry and bed materials characteristic of distinctive reaches (Schmidt and Graf, 1989, table 2, p. 25).

2. Depositional history:

Observations and interpretations of at least four additional bars will be made. Dating of sediments from cores may provide data on long-term bar stability. The work will determine whether are not existing models of reattachment bar origin are applicable to other bars and will enable the development of a descriptive model of separation bar origin and evolution.

3. Eddy models:

Analysis and interpretation of flume data already collected and the descriptive model of bar evolution developed from internal structures will provide data to guide the physical modeling effort. An initial version of a computational model for flow, sediment transport, and bed evolution in lateral separation zones should be completed in FY 1990. Comparison of model results with data collected in controlled situations (laboratory flumes) will be made. Comparisons to flume data will guide further model development.

4. Debris flow effects:

Four beaches known to have been greatly changed by debris flows or other types of tributary flow will be monitored to determine the response of sand deposits to the changes.

5. Slope stability:

Three sites representing different conditions will be selected for study. Equipment will be selected, obtained and installed. Monitoring of water level changes and strain in beach sediments during unsteady flow will provide data for development of a ground-water flow model and related models of slope stability.

FY 1991:

1. Sand inventory:

Successful techniques will be used to determine thickness and volume of additional sand deposits and to describe geometry and bed materials of the channel. New techniques will be tried if others have proven unsuccessful.

2. Depositional history:

Description of internal structures of 5-10 bars will be completed, and descriptive models of bar evolution refined.

3. Eddy models:

A comparison of model calculations to measurements in a natural separation zone will be made along with a set of model calculations for a wide range of flow scenarios. Further model development will depend on successes of the program to this point.

4. Debris-flow effects:

The set of four beaches will continue to be monitored, and a preliminary report describing changes determined from surveys and by photo comparison will be prepared.

5. Slope stability:

Additional data will be collected for the study of unsteady flow and bank stability. Ground-water flow models will be completed for a few test bars.

F. Products:

FY 1990:

1. Sand inventory:

--Evaluation of field techniques for determining thickness of bar deposits. If successful, these will provide preliminary estimates of bar thickness and sand volumes in a few bars.

--Carbon-14 dating of vibrocore sediments will give the first data on long-term bar stability/instability.

--Report on sand inventory.

2. Depositional history:

--Report on origin, structure, and evolution of a reattachment bar.

--Observations and interpretations on internal structures on at least 4 additional bars; will enable development of a preliminary model of separation bar origin and evolution.

--Report detailing the observations of age and internal structure of bars.

3. Eddy models:

--Report on eddy model development.

--Comparison between model predictions and flume measurements -report late 1990 or early 1991.

--Report on flume experiments on bar development in recirculating flow.

--Report on relation between character of sedimentary structures at reattachment points and irregularly periodic flow.

--Report documenting observed changes in camping beaches and associated eddies.

FY 1991:

1. Sand inventory:

--Report on additional reaches of river surveyed.

2. Depositional history:

--Detailed determination of internal structures in 5-10 bars, and descriptive models of bar evolution.

3. Eddy models:

--Report on eddy model development.

--Comparison between model calculations and measurements in natural separation zone.

--Report late in 1991 giving model computations for a wide range of flow scenarios-relating directly to the impact of flows on eddy beach deposits.

4. Debris-flow effects:

--Report giving preliminary observations on the effect of debris flows and other tributary flows on adjacent beaches, describing changes at 18-mile, 20-mile, 127.5 mile, and National Canyon.

5. Slope stability:

--Report on results of field studies and flow modeling to determine the effect of unsteady flow on beach stability.

G. Budget:

The hastily assembled budget figures below are based on anticipated events that depend on plans and decisions not under our control. We, therefore, recommend these be considered rough estimates, which in the metaphor of GCES II, we believe are in the vicinity of our 75-percent confidence level.

	FY 1990	FY 1991
1. Salaries	$ 64,000	$215,300
2. Equipment and Supplies	38,400	48,100
3. Travel	33,600	33,900
4. Sample Analysis	1,400	3,000
5. Subcontracts	none	none
Total	$137,400	$300,300

H. Literature Cited:

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A PROPOSAL TO STUDY
RELATIONSHIPS BETWEEN GLEN CANYON DAM OPERATIONS AND COLORADO RIVER PALEOFLOOD DEPOSITS IN GLEN AND GRAND CANYONS, ARIZONA

National Park Service

Grand Canyon National Park/ Grand Canyon, Arizona

28 March, 1990

Submitted to:

U.S. Department of the Interior Bureau of Reclamation

Glen Canyon Environmental Studies Office

Salt Lake City, Utah

A PROPOSAL TO STUDY

RELATIONSHIPS BETWEEN GLEN CANYON DAM OPERATIONS

AND COLORADO RIVER PALEOFLOOD DEPOSITS

IN GLEN AND GRAND CANYONS, ARIZONA

A. ABSTRACT

Paleofloods in the Colorado River are responsible for the deposition of massive sediment deposits throughout the wider reaches of the river corridor in Glen and Grand Canyons. These deposits are important because they support relict stands of riparian phreatophytes (Prosopis, Celtis, Fallugia and associated plant and animal species), cover cultural resources (Anasazi Indian ruins), and serve as reservoirs of fine sediments and nutrients in the eroding river corridor. This study proposes to evaluate paleoflood frequency, stage-discharge relationships, paleoflood deposit distribution, rate of erosion due to dam operations, and biological significance to relict plant species.

B. INTRODUCTION

Problem Statement

The present-day geomorphology of the Colorado River corridor was shaped, to a large extent, by its largest floods, with dam operations reworking sediments derived from those events and from tributary floods (Kieffer 1988; Schmidt and Graf 1988; Webb et al. 1988). The 1884 flood-of-record for the Grand Canyon reach of the Colorado River was estimated to have reached 300,000cfs by the U.S.

Geological Survey using the indirect slope-area measurement method (Anderson and White 1979). Five years after that flood, Robert B. Stanton made an extensive series of photographs of the Colorado River corridor in the Grand Canyon as part of his 1889-90 surveying expedition. Although heretofore unrecognized, massive fine-grained paleoflood terraces are abundant in the wider reaches of the river corridor, and these deposits were deposited by floods of unknown magnitude. Whether these terraces are attributable to the 1884 flood-of-record or to previous paleoflooding events is presently unknown. These terraces are important for several reasons: 1) they provide evidence of maximum flood stages and, through geochronological techniques, return intervals for large floods -- information of considerable concern in dam and reservoir management (Baker 1983; Ely and Baker 1986; Ely et al. 1988); 2) these terraces serve as an enormous reservoir of fine sediments and soil nutrients that are contributed to the modern river system at rates regulated by dam operations; 3) these sediment deposits are typically covered by extensive, relictual stands of phreatophytes (*Prosopis glandulosa*, *Acacia greggii*, *Celtis reticulata*) that comprise a unique old high water zone habitat along the river and probably developed as a direct result of paleoflooding; and 4) these sediments underlie or cover numerous cultural sites (presently under study by the National Park Service) which may erode as a function of dam operations.

This proposal will study the paleoflood hydrology and the 1884 flood-of-record in the Colorado River reach in Grand Canyon National Park, to determine the magnitude and frequency of paleoflooding, and the interactive effects between maximum flooding events and dam operations on contemporary channel geometry, sediment supply, riparian ecology, and cultural resources. These studies will emphasize dam and habitat management issues related to paleoflood frequency and paleoflood sediment deposits in the present-day Colorado River corridor in Grand Canyon National Park.

<u>Specific Objectives</u>

1. Determine the extent, composition and distribution of fine sediment deposits derived from paleoflooding flooding events, and their susceptibility to re-entrainment under normal dam operations.

2. Determine the minimum stage/discharge of the Holocene flood terraces and correlation with the 1884 flood-of-record discharge stage.

3. Determine the flood frequency using available historical documentation and dendrochronological, organic and geochemical dating techniques.

Justification

This project will provide valuable or critical information on flood frequency, dam and reservoir management, and the impacts of dam operations on paleoflood sediment deposits, geomorphology, ecology, and archeology of the Colorado River corridor in the Grand Canyon (Baker 1983). The following justifications support these contentions.

1. Accurate assessment of flood frequency is essential for both short-term and long-term multi-purpose management of large impoundments. Short-term management benefits include evaluation of present reservoir storage capacity, adequacy of crisis planning and management, and habitat and recreation management in downstream reaches, crisis planning and management. For example, if the flood-of-record is, in fact, a 100-year event, managers should expect relatively high mitigation costs as part of dam management criteria. However, if the ca. 300,000cfs stage has only been exceeded once in the past 15,000 years (as preliminary data suggest), the risks and costs of catastrophic flooding may be considerably less.

2. Extreme flooding events shape channel geometry, including rapids, and transport debris flow materials in the mainstream through short duration, extreme values of stream power/sheer stress (Baker 1983). How long the major rapids of the Grand Canyon have persisted in their present configuration is presently unknown;

however, recent and planned photographic comparisons suggest that, in the absence of major tributary events, some rapids have remained essentially unchanged since Powell's time. There may be no way for dam operations to influence the aggradation of coarse materials in some rapids (e.g. Hance Rapid, Horn Creek Rapid, Lava Falls Rapid). Such information may be valuable in long-range recreation management, and estimation of long-range bed-level change and sediment transport potential in this system.

3. The absence of higher elevation paleoflood sediments in the mouths of tributaries in the Grand Canyon bears testimony to the frequency of removal by tributary flooding. By determining the age of the maximum paleoflood event, this study will refine Webb's (1988) predictions regarding the frequency of tributary debris flow events in this system.

4. Arid-lands fluvial systems are geomorpho-hydro-ecological disequilibrium environments, houses built on sand (Bull 1988). Massive deposits of fine-grained paleoflood sediments are stored in perched terraces throughout the wider reaches of the Colorado River corridor. Fine sediments may only be deposited during flash-flooding events of tributaries during low-velocity mainstream discharges, or during extremely large floods which create large backwaters above and below constrictions. These sediments are contributed to the main channel at rates related to dam operations, and may serve in beach rebuilding during high discharges.

Knowledge of the amount and availability of sand will provide predictive power as to the persistence of the substrate for numerous riverine resources (riparian vegetation, wildlife habitat, recreation, and cultural and paleontological remains).

5. The distribution of fine, paleoflood sediments strongly influences the distribution of Prosopis glandulosa, Acacia greggii, and numerous other semi-riparian plant species. These species combined form a fragile, distinctive and native old high water zone (OHWZ) vegetation community along the river. The OHWZ comprises more than 50% of the riparian habitat along the Colorado River in the Grand Canyon (Stevens 1989). Knowledge of the distribution, volume, age, nutrient status, and susceptibility to erosion of the paleoflood sediments that underlie the OHWZ community will contribute to riparian habitat and recreation management in Grand Canyon National Park.

6. The information gathered in this project will contribute to on-going studies by the U.S. Geological Survey on debris flow periodicity, mainstream sediment storage, and discharge-related erosion. The stated research goal of the U.S.G.S. is to "understand the system", and this study is entirely consonant with that long-term research approach. This study will also contribute to on-going studies by the Arizona Game and Fish Department, U.S. Fish and Wildlife Service, and National Park Service on discharge-related fisheries habitat distributions, water quality, fluvial

habitat characteristics, nutrient and soil moisture availability, vegetation growth, recreation, and camping beach erosion rates.

Integration with GCES Research Study Plan

This project will interface with the GCES-II/EIS research effort on several levels. Dam operations effects on the stability of pre-dam deposits is highly relevant to Research Questions (RQ) 1, 2, 3 (ersosion and sediment transport and vegetation interactions), and 10 (cultural resource site stability; Patten 1990). Fine sediment deposits serve as a nutrient reservoir, with relevance to RQ 7 (water quality and nurtrient cycling). This study is relevant to long-term monitoring, planning and management concerns, as these paleoflood deposits appear to have a limited residence time in this system.

C. BACKGROUND LITERATURE AND PREVIOUS WORK

Knowledge of flooding history, magnitude, and frequency is essential for management and regulation of large river systems, and such information is also essential for understanding contemporary processes in fluvial systems. Large floods affect all aspects of channel geometry and equilibrium sediment distribution, subsequent channel deposit dynamics, fluvial ecosystem dynamics, and other riverine resources, and such has undoubtedly been the case in the Grand Canyon (Baker 1977; Baker and Kochel 1988; Bull 1988 Turner and Karpiscak 1980; Howard and Dolan 1981; Keiffer 1985; Kochel 1988; Komar 1988; Clark et al. 1987; Webb et al. 1987; Kochel 1988;

Stevens and Waring 1988). Although attempts to reconstruct stage/discharge relationships for large floods have a long history (Costa 1986), significant advances have been made only in the past decade (Baker et al. 1983; Kochel and Ritter 1987; Kochel and Baker 1988; Mayer and Nash 1987 O'Conner and Webb 1988). These recent, innovative approaches have resulted in several important studies throughout the southwestern U.S., however, they have not been utilized along the main channel of the Colorado River in the Grand Canyon.

In drainages where fine sediments are abundant, slackwater deposits are periodically incorporated into flood terraces. This often occurs during rare, high-magnitude discharge events. Terrace deposits represent minimum water surface elevations for flood stage, and are therefore considered conservative indicators. Using flume experiments, Kochel and Ritter (1987) determined that slackwater sediments located within bedrock-controlled channels normally result in discharge-underestimates of 10% to 20%. The abundance of sediment deposits found within the bedrock-controlled mainstream of Colorado River in Grand Canyon National Park offer an excellent opportunity to determine the magnitude of the maximum flooding events in the drainage.

The Hydraulic Engineering Center Model for Water Surface Profiles (HEC-2) is considered to be the state-of-the-art technique for paleoflood stage reconstruction in natural channels, and has been extensively tested throughout the world (Feldman 1981). This equilibrium flow approach to estimating flood frequency employs geologic evidence of flood stage and other data to estimate the inundated area. The assumptions associated with the HEC-2 model of flood reconstruction include: "(1) flow in the channel during high-stage is steady; (2) flow is gradually varied, implying a hydrostatic pressure distribution; (3) flow is one-dimensional; and (4) river channels have small slopes, say less than 1:10 (Feldman 1981:355)." In addition, assumptions must be made concerning the stability of channel geometry since the occurrence of the paleofloods studied, and the overall hydrologic stability of the drainage. Criticism of HEC-2 has primarily focused on violation of assumptions, particularly use of this model in unconstrained channels (e.g. Graf 1988). HEC-2 has been successfully used throughout the Southwest in structurally constrained channels (e.g. O'Connor and Webb 1988). Several reaches of the Colorado River with distinct paleoflood terraces are characterized by constrained channels, low gradients, and conforming to the other assumptions of the HEC-2 model have been identified in Grand Canyon National Park. Replication of the reaches will permit evaluation of stage estimation reliability.

D. METHODS

Sampling Design

Site Selection: Several sites have been selected for intensive surveying: CR Miles -3, 2, 51, 54, and possible 198. These site were chosen because they provide reasonable bedrock control of channel geometry, extensive remnants of paleoflood deposits, and they have few anthropogenic sources of contamination and disturbance, or known cultural resource sites. Sampling sites will thoroughly searched for evidence of cultural remains prior to any sampling activity. Because the samples of interest in this study are uniformly-textured silt deposits, any fragments larger than 1mm are readily detected, and sites with evidence of contamination will be avoided. If any cultural remains are detected, sampling will be delayed until a trained archaeologist is brought in to evaluate the site. A total of approximately 100 0.5kg samples of paleoflood sediments will be collected for geochemical/ geochronological analyses (described below). Samples will be collected from natural, pre-existing cutfaces eroded by contemporary drainages in the paleoflood deposits. No excavation will be undertaken, except for cleaning of cutbank surfaces prior to sample collection. In addition to preventing unnecessary disturbance to cultural sites, these precautions will prevent collection of samples that are not pertinent to this study. Samples will be removed using a clean plastic scoop, placed in labled plastic bags, and returned to the laboratory where they will be air-dried and cold-stored until analyses are conducted.

Objective 1: Data will be gathered to document: 1) where paleoflood sediments are stored; 2) the volume of sediment stored in selected study reaches; and 3) the susceptibility of paleoflood sediments to re-entrainment, as evaluated by cutbank and other deposit features, and vegetation cover. Reaches containing flood-deposited sediments will be mapped at a 1:10000 scale using 1990 aerial photographs of the river corridor between Lees Ferry and Diamond Creek (CR Mile 225.5) during river trips in winter and spring, 1990. Sediment volume will be estimated in study reaches by examining profiles of these deposits in eroded tributary channels. In general, paleoflood terraces are most likely to occur just above and just below channel constrictions. In addition, a centennial photo-rematching expedition is planned in January 1990 by a U.S. Geological Survey crew (Webb and Turner), and participation on that trip will permit data collection and correlation of the flood-of-record with previous paleoflood features in the river corridor at a time when vegetation cover is minimal.

Textural analyses of 50 samples of paleoflood sediments will be compared with extensive data on modern riverside sediment texture to determine the proportion of sediments available for bed- versus suspended-load transport (Stevens and Waring 1988; Stevens 1989 unpublished). On the basis of preliminary data, approximately 50% (by mass) of the paleoflood sediments are available for main channel storage and beach building under present dam operations. The remainder, consisting of fine silt and a small proportion of clay, is highly susceptible to transport out of the system as suspended load. Susceptibility to re-entrainment will be measured by placing statistically suitable numbers of 1.0m scour wires into cutbanks and other exposures of paleoflood sediments to monitor erosion rates under normal dam operations (National Park Service Erosion Work Plan 1990). Eight to ten scour wires will be implanted at each of 30 sites and surface changes will examined after each of the proposed discharge tests on the NPS Erosion measurement trips (Patten 1990). These data will be analyzed using a blocked (sites), one-factor (discharge regime) analysis of covariance (soil texture and slope angle).

Objective 2: Evaluation of stage/discharge relationships will be based on the elevation of paleostage evidence, including slackwater sediments, silt lines, and driftwood deposits. Stage/discharge relationships will be intensively surveyed using a total station electronic-distance-measurement (E.D.M.) instrument in several study reaches mentioned above. The reaches selected for surveying will meet the assumptions of the HEC-2 Model (straight, low gradient, bedrock-constrained channels with little tributary input) and several reaches contain known, datable Quaternary deposits.

Data from these surveys will be used to reconstruct paleoflood discharge using the HEC-2 computer software package (HEC-2 1982) developed by the Army Corps of Engineers. The primary capability of this program lies in the determination of water surface profiles within man-made and natural channels. Through input of: 1) ground-surface profile data at several cross-sections;

2) estimation of Manning's channel roughness coefficients; 3) channel expansion/contraction coefficients; and 4) distances between cross-sections, discharges associated with given elevations of paleostage indicators will be accurately estimated (Feldman 1981). This surveying effort is best performed during the winter season when leafy phreatophyte vegetation is at a minimum (e.g. January-February), a time consonant with the U.S. Geologic Survey Stanton Centennial Expedition.

Regression of maximum flood stage and annual discharge volume data from the Lees Ferry gage may allow approximation of the volume of water associated with the maximum paleoflood. This estimation will be of interest to managers concerned with the storage capacity of Lake Powell in extreme run-off years, and particularly through time as reservoir sedimentation decreases storage capacity.

Objective 3: A variety of methods will be used to date and correlate flood deposits and debris, including thermoluminescence, sediment geochemistry and texture, X-ray diffraction, ^{14}C, dendrochronology, palynology techniques and historical records.

1) Thermoluminescence (TL) analysis will be performed on silt sieved from flood-deposited fine sediments using a reference 1.0kg surface sample and a paired 1m-depth 1.0kg sample, (Berger and Huntley 1982; Berger 1985, 1988; Huntley et al. 1985). As many as 4 pairs of samples may be subjected to TL analysis.

2) Sediment texture/geochemistry will be evaluated on 50 0.5kg samples by sieving and analyses of trace metal constituents, magnesium, aluminum and sulphur concentrations. These analyses will aid in geochemically distinguishing flood events.

3) X-ray diffraction on 10 selected samples will reveal clay structure as a further aid in distinguishing different flood deposits.

4) 14C dating will be performed on 20 or more carbon-bearing samples (i.e. driftwood, charcoal not associated with archeological sites, Neotoma middens, and Prosopis cores).

5) Based on preliminary data on annular ring formation in Celtis reticulata, dendrochronological analyses will be performed on 3 cores from 100 or more trees situated at the pre-dam high water line throughout the river corridor, and compared against similar dendrochronological data for Celtis from tributaries.

6) Ten sediment samples collected from flood deposits will be subjected to palynological analyses to determine abundance and species composition of pollen, which may serve as a useful environmental indicator. This survey will be expanded if significant quantities of pollen are found in sediment samples.

7) Ground-truthing of the flood-scour lines from historic photographs rematched during the Stanton Centennial Research Project (January-February 1990) will permit clarification of the relationship between the flood of record and paleoflood discharge levels.

Response Curve Analysis

Response curves will be established to evaluate the erodibility of pre-dam sediment faces as part of the National Park Service Erosion Work Plan (1990). The erodibility of predam deposits that exist at or near the post-dam normal high water line (ca. 800cms) will be graphed against mean and range of discharge. Slow versus fast ramping rates will be graphed independently to evaluate the rate of stage change effects on pre-dam deposit stability.

Logistical Support Requirements

Approval to perform the required research is requested from the National Park Service. In addition, permission to recharge EDM batteries at Phantom Ranch is requested.

Logistical support is requested from the Bureau of Reclamation, including: rental of 2 inflatable rafts and rafting accessories (extra and repair items, first aid, commissary, etc.), 1.3 hired boatmen/women, shuttle support, and a depth-gage for measuring river bottom profiles. The U.S. Geological Survey is requested to provide an EDM with several reflectors. If this is not available, an EDM will be rented from other sources. Also, a fathometer is requested, with accessories needed to run the device.

E. TASKS AND RESEARCH TIMETABLE

To be of use in the GCES-II/EIS decision process, this project must be completed within one year. Several factors will permit timely completion of this project. Some samples have already been collected as a part of previous soil studies in this system, and these samples await funding for dating.

Data collection on the Stanton Exped.17 January-22 February, 1990

(Limited data collection may continue into the spring of 1990)

First quarterly report (QR) submitted...............1 April, 1990

Mapping and HEC-2 modeling completed.................1 July, 1990

Dating analyses completed, 2nd QR submitted........1 August, 1990

Data compilation completed, 3rd QR submitted......1 October, 1990

First draft of final report submitted...........15 November, 1990

Final report submitted............................1 January, 1991

F. DELIVERABLES

Quarterly and annual reports will be submitted to the NPS and the GCES offices. The final report will address the interrelationships between dam operations, paleoflood frequency, magnitude and sediment deposits, and the role of large flooding events on fluvial geomorphology and ecology. The results of this project will be prepared for submission to a major peer-reviewed scientific journal, such as Science, the Geological Society of America Bulletin, Geology, or Water Resources Research.

G. BUDGET

The following budget includes per diem for 4 volunteers during field data collection, as well as dating costs. No logistical support is requested from GCES-II/EIS.

Personnel

Per diem (5 researchers for 30d @ $10.00/d)........$1500.00

Equipment

Sample equipment (shovels, bags, data sheets,
etc.).......................................$100.00
Tree coring equipment (corer, wood slats, glue,
data sheets, etc.)..............................$300.00
Data entry, xeroxing, report preparation, office
supplies, etc...............................$700.00

Travel

None

Analysis

Geochemistry/geochronology sampling:
Geochemistry/textural analyses (50 samples
@$50.00/sample).............................$2500.00
Thermoluminescence (8 samples @ $500.00 ea.)..$4000.00
X-ray diffraction (10 silt samples @$125.00
ea).......................................$1250.00
^{14}C (5 *Neotoma* middens, 15 driftwood or
other organic samples, @ $250.00 ea)........$5000.00
Palynological analyses (10 samples
@$100.00 ea)...............................$1000.00
Map preparation (12 days @$10.00/hr)................$960.00

Subcontracts

None

GRAND TOTAL $18260.00

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THE IMPACTS OF GLEN CANYON DAM ON RIPARIAN VEGETATION AND SOIL STABILITY IN THE COLORADO RIVER CORRIDOR, GRAND CANYON, ARIZONA

National Park Service

Grand Canyon National Park

and

Cooperative Park Studies Unit

Northern Arizona University

(Lawrence E. Stevens, Project Coordintor)

1 July, 1990

Submitted to:

The Bureau of Reclamation

Glen Canyon Environmental Studies Office

Salt Lake City, Utah

A PROPOSAL TO SURVEY THE IMPACTS OF GLEN CANYON DAM ON RIPARIAN VEGETATION AND SOIL STABILITY IN THE COLORADO RIVER CORRIDOR, GRAND CANYON, ARIZONA

A. ABSTRACT

The effects of Glen Canyon Dam operations on riparian plant community development, and interactions between soil stability and riparian vegetation will be evaluated through field surveys and field experiments. (1) Historical information on river corridor vegetation will be compiled. (2) Mapping of soil and vegetation attributes through the Bureau of Reclamation's Geographic Information System will be coordinated to achieve long-term monitoring and management objectives. (3) Plant community development (species composition, ecesis, growth rates and mortality) will be evaluated and monitored in characteristic geomorphologic settings. (4) The interactive effects of discharge on riparian vegetation characteristics and beach/bank stability will be evaluated, as will (5) dam operation effects on listed, endemic, exotic and other species. (6) These results will be used to refine NPS riparian vegetation monitoring protocol. This studies will provide data on vegetational development, fluvial/ terrestrial ecosystem interactions, distribution, and the risk status of endemic species and populations needed to make decisions regarding short-term and long-term management of discharge effects on this riparian system.

B. INTRODUCTION

1. Problem Statement

Regulated discharge below large impoundments facilitates the development of riparian vegetation, thereby enhancing wildlife habitat and recreational opportunities (Carothers et al. 1979; Turner and Karpiscak 1980; Nilsson 1985; Stevens 1989a,b). Construction of Glen Canyon Dam accidentally resulted in the development of profuse riparian vegetation that now supports a great diversity of wildlife and sustains significant recreational use in Glen and Grand canyons (Turner and Karpiscak 1980; Johnson and Carothers 1982). Recent studies suggest that this riparian vegetation is dynamic, rapidly changing, and is significantly influenced by dam operations (Stevens and Waring 1988; Stevens 1989a,b); however, monitoring has been limited in extent and poorly controlled. The purposes of this proposal are to improve understanding discharge effects on riparian vegetation and soil stability, develop a vegetation data base, and develop a monitoring protocol suitable for long-term management.

2. Specific Objectives

1. Compile historical information on riparian and desert vegetation in the Colorado River corridor between Glen Canyon Dam to Lake Mead, Arizona.

2. Facilitate mapping of riverine soils and vegetation in the Bureau of Reclamation's Geographic Information System (GIS) basemap.

3. Evaluate the status of plant community development by establishment and censusing of detailed study plots in characteristic habitats in the Colorado River corridor between Glen Canyon Dam and Lake Mead, Arizona, to serve as easily-censused monitoring sites for system-wide evaluation of long-term vegetation changes.

4. Determine the interactions between discharge from Glen Canyon Dam operations, riparian vegetation characteristics and beach/bank stability.

   a. Determine dam discharge effects on soil moisture availability.

   b. Determine discharge effects on streamside vegetation growth and structure.

   c. Determine discharge effects on the interaction between vegetation and bank soil stability.

5. Determine whether dam operations are influencing:

   a. Federal or state listed, or candidate species, endemic species, or other plant species of concern in the river corridor;

   b. The invasion rates of exotic plant species (especially <u>Tamarix</u> <u>ramosissima</u> and <u>Alhagi</u> <u>camelorum</u>) in the river corridor and in tributaries.

6. Refine the NPS vegetation monitoring program to guarantee that it serves long-term management purposes.

   a. Identify operational changes (if any) that can be used to improve vegetation management in this system.

   b. Identify temporal trends, species and associations of critical concern to NPS vegetation management, and maximize efficiency of long-term vegetation monitoring efforts.

3. Process of Integration with Research Study Plan

The study proposed here will provide a long-term assessment of interactions between riparian soils and vegetation as affected by dam operations by incorporating data from several other GCES-II/EIS projects. It will address several of the Research Questions (RQ) proposed by Patten (1990). The NPS will participate directly in preparation of the proposed GIS base map. This study will serve as a baseline for evaluating the rate and trajectory of the rapidly developing shoreline plant community along the Colorado River downstream from Glen Canyon Dam. The effects of dam-induced changes in soil water dynamics on plant growth will be explored, and this project will enhance understanding of the role of riparian vegetation in retarding bank erosion of camping, attraction, and cultural resource sites affected by dam operations (RQ 1 and 2). The effects of recreational use on rare or endemic plants will be evaluated through demographic and distribution studies (RQ 11).

C. BACKGROUND LITERATURE AND PREVIOUS WORK

The Glen Canyon Environmental Studies:: Construction of Glen Canyon Dam accidentally enhanced vegetation growth and whitewater recreation along more than 475km of the Colorado River in Grand Canyon National Park (Carothers and Aitchison 1976; Carothers et al. 1979; Turner and Karpiscak 1980; Phillips et al. 1986; Stevens 1989a). Phase I of the Bureau of Reclamation's Glen Canyon Environmental Studies (GCES-I) was initiated to reveal whether Glen Canyon Dam operations had a significant impact on river resources and whether modification of discharge criteria could ameliorate those impacts (Water and Science Technology Board 1987; U.S. Dept. Interior 1988). Although few data were available, GCES-I terrestrial studies concluded that normal (non-flooding) dam operations affected processes such as bank erosion, soil nutrient availability, and soil moisture potential. GCES Phase II was initiated to evaluate the effects of low and fluctuating flows on this system, and an Environmental Impact Statement has been requested concerning the impacts of Glen Canyon Dam operations on downstream resources.

Regional Importance of Riparian Vegetation: Management of riparian habitat is a major concern throughout the United States. Wetlands, including riparian habitats, are among the most biologically productive and recreationally valuable of terrestrial lands. Unfortunately, riparian habitats are poorly managed because of a lack of concern, conflicting management priorities, and inadequate information (Johnson et al. 1985). Despite the fact that riparian habitat comprises 0.04% of the Arizona landscape, it typically supports more than 50% of the species occurring there (Simcox and Zube 1985; Stevens in prep). Riparian vegetation serves as an intermediary state variable between abiotic components and higher trophic levels. It plays a significant role in both aquatic and terrestrial ecosystem dynamics, and provides erosion control and shade for recreationists. Management of riparian habitat requires an efficient, prompt ability to assess changes in attributes through time, criteria which are best met by using field survey techniques and GIS.

Riparian Vegetation in the Grand Canyon: Phreatophyte distribution in the Grand Canyon was studied prior to construction of Glen Canyon Dam. Clover and Jotter (1944) described the phreatophyte distribution in the river corridor prior to impoundment, reporting little streambank vegetation along the river itself and most riparian species restricted to tributaries. Turner and Karpiscak (1980) matched pre-dam photographs and confirmed that little vegetation occurred along the pre-dam river in the annually flooded zone. Establishment of riparian vegetation began soon after closure of Glen Canyon Dam (Turner and Karpiscak 1980). Phillips et al. (1977) compiled a riparian vegetation map of the river corridor. Carothers et al. (1979) described riparian vegetation zonation of the river corridor, noting a xerophyte-dominated talus community (Zone I); a perched, pre-dam "old high water zone" (OHWZ; Zone II) community dominated by <u>Prosopis</u> <u>glandulosa</u> and <u>Acacia</u> <u>greggii</u> and lying above the approximate 3500cms stage; a "back beach zone" with little vegetation and occupying Zone III between the approximate 1150cms and 3500cms stages; and a new high water zone (NHWZ; Zone IV) below the approximate 1150cms stage at the post-dam river edge, and dominated by exotic <u>Tamarix</u> <u>ramosissima</u> and native phreatophytes.

Several authors reported on successional development of riparian vegetation in this system. Martin (1970 unpublished) documented the widespread occurrence of exotic <u>Tamarix</u> <u>ramosissima</u>, and noted the presence of native riparian plant species. Brian (1982) examined the distribution of <u>Salix</u> <u>exigua</u> in the upper Canyon, reporting rapid, widespread expansion of this native, clonal willow into all riverside habitats. Stevens (1985) reported that low-magnitude (1400cms) flooding in 1980 resulted in increased beach erosion and initiated a small-scale germination event. Stevens (1985) also concluded that successional replacement of <u>T</u>. <u>ramosissima</u> by native <u>S</u>. <u>exigua</u> was not induced by invertebrate herbivory. Phillips et al. (1987) also noted continuing change in post-dam riparian plant community composition in this system.

In GCES-I, Pucherelli (1988) reported a rapid increase in riparian vegetation cover in the new (post-dam) high water zone (NHWZ) between 1965 and 1982. Cover was significantly reduced in this new riparian zone in wide reaches during spillover flooding in 1983-1984. Anderson and Ruffner (1988) found that post-dam flooding had little effect on germination or growth of <u>Prosopis</u> or <u>Acacia</u> in the perched pre-dam terraces of the old high water zone (OHWZ). Brian (1988) and Stevens and Waring (1988) reported significant loss of riparian vegetation in the NHWZ as a result of spillover flooding. The latter authors noted that spillover flooding degraded substrata, decreased riparian plant cover and diversity, and stimulated germination. Subsequent studies revealed species-specific, age-related mortality and growth of dominant riparian phreatophytes under various discharge scenarios (Waring and Stevens 1988). The impacts of flooding on riparian vegetation in tributaries and along the river corridor was studied by Stevens (1989a), who concluded that dam-induced substrata changes in soil texture, water availability, and nutrient status were largely responsible for the successional development of the phreatophyte community. He also reported that the river corridor was structurally more similar to the sparsely-vegetated ephemeral tributaries than to the richly-vegetated perennial tributaries. In another study Stevens (1989b) described riparian zonation and community composition of the river corridor vegetation in detail as it existed in 1987 as spillover flooding concluded. Stevens and Waring (1989) and Stevens (1989c) monitored post-1983 ecesis and community development of woody riparian vegetation along the Colorado River in Grand Canyon National Park from 1984 through 1988, reporting that germination of dominant riparian species was induced by flooding, and that exotic Tamarix ramosissima density appeared to have increased as a result of dam operations.

Factors Influencing Riparian Vegetation Development: The suite of factors regulating riparian plant community growth and compositional change (succession) in the Grand Canyon has only begun to be explored (Stevens 1989a). Riparian vegetation develops in response to interrelated physical and biological factors, including: the flooding disturbance regime; the species pool available for colonization; differential propagule abundance; and germination and establishment requirements of constituent species (Koslowski 1984; Reichenbacher 1984; Stevens and Waring 1988; Stevens 1989a). Flooding disturbances are "killing events" (sensu Sousa 1984) that 1) decrease biological organization (i.e. diversity and complexity of trophic structure), 2) lower the "trajectory of ecological succession" by direct reduction of biomass and diversity, thereby returning the ecosystem to an earlier stage of development (Odum 1981), 3) resulting in a "perpetual succession" (Campbell and Green 1968), and 4) expose new patches of habitat and thereby promote germination of phreatophyte species (Stevens and Waring 1988; Waring and Stevens 1988; Stevens 1989a). Alteration of the disturbance regime in regulated rivers may change the course of riparian succession by reducing recruitment, and by affecting biotic interactions. Post-impoundment flooding in regulated river corridors provides insight into the processes that structure phreatophyte communities (Stevens 1989a).

Riparian Soil Stability and Vegetation: The role of vegetation in maintaining riparian soil has received little attention; however, profuse riparian vegetation along the channel margin may improve the stability of fluvial deposits in several ways. Extensive root growth holds fine-textured soils together and may prevent undercutting and lateral erosion. Stem density effects erosion rates by ponding streamflow and slowing current velocity, and also by reducing wind velocity. Duff accumulation may retard eolian transport of soil by reducing exposure to wind action. Lastly, leachates from foliage accumulate on the soil surface and may create hydrophobic soils beneath canopies. Successional vegetation development may reduce the susceptibility of riparian soils to erosion through time as cover, stem density, duff and leachate concentrations accrue. The relationship between erosion rates, particle-size distribution, and riparian vegetation community structure have never been adequately delineated or modeled. In a regulated river system, daily fluctuation and the rate of fluctuation further complicates these relationships. Riparian vegetation typically requires flooding and moist, exposed, silt-sized substrata for germination, but the contribution of vegetation to soil stability is unknown in this system.

Alluvial Soils in the Grand Canyon Reach: Selected riverside terrace deposits along the Colorado River have been surveyed for changing beach profiles since the early 1970's (Howard and Dolan 1981; Scala 1984; Beus et al. 1984 et subsequ.; Phillips et al. 1986; Brian 1988; Pucherelli 1988; Schmidt and Graf 1988; Stevens and Waring 1988; Schmidt et al. in press). These studies revealed dramatic changes in terrace profiles, fluvial sediment texture and geochemistry, and serve as a series of long-term study sites for the Colorado River in the Grand Canyon. Rapid erosion following post-dam flooding from 1983-1986 has rekindled interest in documentation of the interaction between discharge, sediment aggradation and degradation, and sediment/vegetation interactions. However, at present, few of these long-term beach monitoring sites have been surveyed or mapped for vegetation.

D. METHODS

1. Broad Sampling Design

Objective 1: Compile historical information on riparian and desert vegetation in the Colorado River corridor between Glen Canyon Dam to Lake Mead, Arizona.

A bibliography on riparian vegetation, data, characteristics and change in the Grand Canyon will be prepared. All available maps, aerial and oblique photographs, and other historic data and documents will be assembled by contacting all researchers or other individuals who have studied this system, and "hard copy" data will be archived at Northern Arizona University or at Grand Canyon. The Bureau of Reclamation has several sets of aerial photographs from 1965 to 1989 that will be useful in evaluating long-term trends in these study reaches. The U.S. Geological Survey has prepared maps of approximately 15 sites (Graf pers. comm.), and the NPS has prepared maps of several other sites. Where data are available, trends in riparian soil and vegetation development may be determined through time. All data will be compiled into a long-term record for each study reach and incorporated into the proposed GIS where coverage includes the site, or otherwise prepared for easy inclusion into the GIS when that reach is later mapped into the GIS.

Objective 2: Facilitate mapping of riverine soils and vegetation in the Bureau of Reclamation's Geographic Information System (GIS) basemap.

The Bureau of Reclamation has proposed preparation of an ARC/INFO GIS base map for the river corridor, for eventual inclusion as a National Park Service management tool. For this plan to be effective, the National Park Service must participate in GIS planning and data compilation, and coordinate ground-truthing efforts. Initial mapping emphasis will be placed on selected study reaches for which data on bank profiles, vegetation and/or other resources have been gathered during GCES-I studies, as well as sites of special concern (e.g. attraction sites). The NPS will participate in ground-truthing vegetation composition and density, and soil conditinos when the GIS topographic base has been prepared in FY91.

Ojective 3: Evaluate the status of plant community development by censusing detailed study plots in characteristic habitats in the Colorado River corridor between Glen Canyon Dam and Lake Mead, Arizona, to serve as easily-censused monitoring sites for system-wide evaluation of long-term vegetation changes.

Long-term vegetation change in this system will be monitored by establishing or, where previous data exist, redefining a series of permanent, detailed study plots. At 24 sites where erosion studies are to be conducted (Avery et al. 1990; Table 1), a series of (where possible) six 10m x 5m quadrats will be selected in a non-biased manner for intensive study of vegetation change. A rectangular quadrat shape is required because many habitats (e.g. new and old high water zone strip vegetation) are narrow, and rectangular plots are recommended over other plot shapes (Brower and Zar 1984). More, smaller plots will increase system-wide representation, control for significant moisture gradient effects (Stevens 1989a; Stevens and Waring 1989); and permit rapid censusing. Preliminary surveys suggest that this plot size should account for more than 80% of all plant species in a given habitat type; however, species-area sampling will verify the adequacy of this plot size.

Two 18-day river trips will be required to establish these permanent plots. Each boat will carry three 3-person crews consisting of a crew leader/data recorder and two assistants. Quadrat location will be selected randomly within a given habitat type. Quadrats will be established in the following habitat types: riverside strip vegetation (new high water zone), open beach, old high water zone, marsh (return channel), debris fan, and desert/talus slope (a control for dam operations). Quadrat location will be mapped from aerial photographs, and discretely marked with steel wire nodes implanted into the ground surface. Three 0.25m^2 plots will be sampled for litterfall and nutrient (N,P,C) will evaluated in those samples, and mesh bags with ca. 0.5kg of litter will be placed to evaluate decomposition rates. Desert/talus plots will include portions of several under study by Dr. Robert Webb, USGS Tucson, for historical documentation of long-term change (Webb, pers. comm.). Plots will be monitored once in late FY91 and once in FY92.

On each quadrat, all stems or clumps of each species will be mapped in Cartesian coordinates, counted, basal area and cover will be measured, seedling and sapling density will be assessed, and physical characteristics will be recorded (location, geomorphologic setting, stage, substrata texture, human or other disturbances, ground cover, and cardinal exposure. In addition, comparable sets of quadrats will be established in 12 perennial and 12 ephemeral tributary canyons to serve as controls for river corridor sites. One quadrat will be situated in each of three tributary habitats: channel margin, debris fan terrace and desert/talus. Data collected will be comparable to those gathered in the Colorado River corridor. A maximum of 216 long-term vegetation monitoring quadrats will be established, encompassing 1.08ha of river corridor habitat.

Statistical description and analyses of these quadrat data will employ vegetation species richness, basal area or cover, and stem density as response variables in a blocked (Schmidt and Graf 1987 reach characteristics) two-factor (geomorphologic setting and river-versus-tributary) multiple analysis of covariance (cardinal exposure, substrata texture) design. Analysis in vegetation characteristics through time will be accomplished using repeated measures multiple analysis of covariance.

Objective 4: Determine the interactions between discharge from Glen Canyon Dam operations, riparian vegetation characteristics and beach/bank stability.

Objective 4a. <u>Discharge effects on soil moisture availability</u>: Three validation sites have been selected for detailed assessment of bank-stored water movement and soil moisture (Avery et al. 1990). These sites are all large beaches with numerous geomorphologic micro-environments, including various substrata and unvegetated areas as well as dense stands of riparian vegetation. Evaluation of soil moisture changes in response to water table fluctuations caused by dam operations will be undertaken at these sites with the cooperation of the USGS (Healy). In addition to other data collected, soil moisture probes will be implanted at 0.5m-depth intervals to as much as 3.0m depth in a grid than extends from the river edge to the pre-dam flood zone. These sensors will be connected to continuous data loggers set to sample at 20-minute intervals, and will be capable of being down-loaded to a PC computer. Using these data, soil moisture change will be modeled under fluctuating versus constant flow during discharge tests. These data will be analyzed using moisture change as response variables against a multiple regression (MR) of time of day, time in a test, ambient temperature, soil temperature, river stage (USGS data), substrata texture, depth, distance from the river for each discharge test of soil moisture change in relation to discharge characteristics.

Objective 4b. Discharge effects on vegetation: In concert with the above soil desiccation studies, desiccation impacts on vegetation will be measured using a Schollander pressure bomb on 15 replicate samples of coyote willow, seepwillow and tamarisk. These three species are dominants (Stevens 1989b) and represent three conspicuously growth forms (shallow-rooted clonal, shallow-rooted non-clonal, and deep-rooted non-clonal). Samples will be collected at the three validation sites during the last three days of each discharge test. Samples will be selected at random and tests will be performed at 03:30 and again at 13:00 to determine the full range of plant water stress in these three common taxa. Other phreatophyte species will be sampled for water stress during non test-flow periods to develop a comparative understanding of plant water stress in this system. In addition, moisture availability will augmented for three species using watering systems at three sites (Avery et al. 1990), and growth and moisture stress will be evaluated. Plant water potential will be used as a response variable in three separate 3-factor analyses of variance (species, time of day, discharge test). This information will indicate the potential stresses imposed on vegetation by different discharge regimes.

Ecesis (germination and establishment) will be monitored daily at validation sites during the discharge tests to determine if different discharge regimes influence plant establishment. Three 1.0m^2 subplots will be established in each quadrat on validation sites and monitored daily for one month during each season in 1991. Seed rain will be monitored using river surface net samples and seed fall traps (Warren and Turner 1975). I have collected exhaustive notes on the phenology of seed release and seed longevity for all phreatophyte species in this system, and know this timing to be appropriate (Stevens and Waring 1988). Seedling density will be used as a response variable in a blocked (sites) two-factor (mean and range of discharge) analysis of covariance (seed rain). Seed rain will also be experimentally increased in beach, backwater, pre-dam and control sites, with 10 replicates/geomorphologic setting to control for variable or low seed rain. Germination on other quadrats studied by Stevens and Waring (1989) will be monitored at least annually to verify patterns observed on validation sites.

Objective 4c. Vegetation effects on soil stability: Survey and experimental data will be used to determine vegetation effects on soil stability. These approaches will be used to evaluate the effects of vegetation on the stability of fine-grained sediment deposits:

Objective 4c1.) Proposed studies of beach profile change using the scour wire grid approach of Avery et al. (1990) will determine the degree of protection afforded to beach and bank sites by vegetation cover under different gradient and grain sizes. Surface elevation change at each node will be analyzed with vegetation density, soil texture, slope and duff thickness as covariates.

Objective 4c2.) A system-wide, patch dynamics approach to understanding vegetation effects on substrata stability will be employed by experimentally manipulating cover and duff on soil surfaces affected by high range discharge tests in spring and summer, 1991. Four m^2 (2m x 2m) plots will be established at each of 24 sites within the zone affected by dam operations. The sites will extend throughout the river corridor. Each plot will receive one of the following treatments: canopy removed, duff removed and ground surface disturbed, canopy and duff removed/surface disturbed, or control (no removal or disturbance). Volumetric change of plot surface will be evaluated by measuring surface change on 10 scour pins/plot (Avery et al. 1990). Soil texture, soil permeability, vegetation type, and duff thickness will be also be recorded for each plot. Volumetric change of sediment will be analyzed in a nonparametric blocked (sites) one-factor (vegetation treatments) analysis of covariance (soil texture). Particular attention will be paid to comparisons of grass-covered faces with shrub-covered faces by conducting a field survey of erosion rates and patch size of grass versus shrub covered faces. Robust sampling will indicate the variability in stability afforded by vegetation cover in this system.

Objective 5: Determine whether dam operations are influencing selected plant species' distribution and abundance:

Objective 5a. Review the risk status of federal or state listed, or candidate species, endemic species, or other plant species of concern in the river corridor: Listed and endemic plant species' distributions and risk status to dam operations and/or recreational activities will be evaluated. For example, Euphorbia aaron-rossii and a unique, yellow Mimulus cardinalis are two endemic forms that occur in the new high water zone and may be affected by both dam operations and recreation. All other such species will be identified.

Preliminary tree-ring data suggest that Celtis reticulata and Tamarix ramosissima responded to changing hydrologic regimes during the post-dam era. Previous analyses of dendrochronological data for Acacia greggii and Prosopis glandulosa were inconclusive regarding reduced growth in the post-dam environment, primarily because those Fabaceae do not form regular annuli (Anderson and Ruffner 1988). Dendrochronological analysis of a collection of a robust collection of Celtis and Tamarix cores from throughout the river corridor and in tributaries (control sites) will be undertaken, and slabs of approximately 15 Celtis and 50 Tamarix trees will be collected. If these samples suggest that growth has been influenced by dam operations, growth bands (Anderson and Ruffner 1988) will be applied to 30 trees of each species on study sites and control sites to monitor long-term growth responses. Dendrochronological data will be analyzed using a multiple regression approach to compare beta (slope) values of arcsine-squareroot-transformed percentage radial growth data during pre-dam time versus post-dam time, with age of the stem, annual precipitation, annual volume of discharge, and previous year's volumetric discharge. These data will demonstrate the long-term risks or benefits to these species from dam operations.

Objective 5b. Evaluate dam effects on invasion rates of exotic plant species (especially Tamarix ramosissima and Alhagi camelorum) in the river corridor and in tributaries: Repeated censusing of quadrats during the next five years will indicate whether exotic plant species are continuing to invade the river corridor and tributaries, and whether and how dam operations influence that invasion. I have suggested (Stevens and Waring 1990) that dam operations since 1987 have increased Tamarix populations along the lower Colorado River in Grand Canyon, and that increase may translate into increased Tamarix abundance in tributaries. Thus, the tributary sites will also be monitored for seedling establishment or clonal invasion of exotic plant species. Exotic species abundance will be initially described and analyzed through time in a blocked (sites) one-factor (geomorphological setting) analysis of variance.

Objective 6: Refine the NPS vegetation monitoring program to guarantee that it serves long-term management purposes:

Objective 6a. Identify operational changes (if any) that can be used to improve vegetation management in this system: As a result of compilation of the above data and formulation of clear management goals, the NPS will be able to address the issue of which operational alternatives are most favorable for riparian vegetation management. Thus the NPS will be able to make recommendations to the Bureau of Reclamation regarding dam operations.

Objective 6b. Identify temporal trends, species and associations of critical concern to NPS vegetation management, and maximize efficiency of long-term vegetation monitoring efforts: The above studies will permit identification of important issues in vegetation management in the river corridor. Risk status of listed, endemic or otherwise important species will be evaluated and presented in the final report, as will long-term change in riparian vegetation and its regional impacts (e.g. potential loss of Prosopis and Celtis habitats for migrating birds). As a result of this research, Glen Canyon National Recreation Area and Grand Canyon National Park will be better able to define long-range management goals and objectives for this riparian ecosystem, and provide a long-range implementation plan for management of the system.

Efficiency of long-term vegetation monitoring is essential. Review of this sampling program will provide information on the most efficient return time for sampling specific characteristics, and the manpower needed.

2. Response Curves

The response curve approach will consist of an evaluation of discharge and range against several response variables (e.g. soil stability, moisture availability, germination, growth rate, plant water stress, and erosion at validation sites) and will be used to interpret the effects of operational scenarios on interactions between soil stability and vegetation. This approach will be employed, where appropriate, on studies conducted at the three validation sites during the various flow tests.

3. Logistical Support Requirements

Logistical assistance requested from GCES-II will include raft trip support (3 trips in FY91 and 1 trip in FY92, coordination with the BR GIS staff, and coordination with USGS staff at validation sites. Helicopter, raft or hard-hulled boat support may be requested from the NPS to guarantee transport of personnel to and from validation sites if other forms of transport are not available.

E. TASKS AND RESEARCH TIMETABLE

The tasks and research timetable for this project are outlined in Table 1.

F. DELIVERABLES

Quarterly and annual progress reports will be required throughout the period of study (Table 1). Draft and final reports on the results of long-term monitoring sites, field and experimental studies on dam operations effects on vegetation and soil stability, exotic species populations status, and recommended monitoring protocol will be submitted in a form suitable for publication in peer-reviewed environmental science or management journals for publication.

G. BUDGET SUMMARY

Raft logistics and NPS P.I. and biotechnician time are not included in the following budget.

ITEM	FY91	FY92	TOTAL
Personnel	62,547	7,129	69,676
Equipment	1,600	--	1,600
Supplies	16,922	--	16,922
Travel	10,020	2,840	12,860
Analyses	14,098	1,350	15,448
Subcontracts	None	None	None
Total Direct Costs	105,187	11,319	116,506
Overhead (20%)	21,037	2,264	23,301
GRAND TOTAL	126,224	13,583	**139,807**

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Table 1: Research schedule for the riparian vegetation project.

Initial oral presentation to NPS-GRCA	15 October, 1990
River Trip 1 (to establish and permanent quadrats and plots	October, 1990
First quarterly (QR), annual and oral report	15 December, 1990
River trip 2 (to complete plot establishment and set up watering systems	February-March, 1991
Second QR	15 March, 1991
Man three validation sites	April-July, 1991
Third QR	15 June, 1991
River trip 3 (census vegetation/soil stability plots)	September, 1991
Fourth QR	15 September, 1991
Submit draft final report	1 December, 1991
Final oral, annual reports	15 December, 1991
Monitoring, equipment recovery, and clean-up river trip 4	March, 1992
Final report	1 April, 1992

C. HYDROLOGIC DATA BASE DEVELOPMENT

PROPOSAL: HYDROLOGIC DATA AND DATA-BASE MAINTENANCE

United States Geological Survey

March 28, 1990

A. Abstract:

This proposal concerns the collection, storage, and dissemination of hydrologic data that is crucial for all investigations addressing research hypotheses H.1 through H.10. Included data includes the eight existing stations and three proposed additional tributary stations on Bright Angel, Kanab and Havasu Creeks. Hydrologic data for all these sites and any hydrologic data collected by any agency during the Grand Canyon Environmental Study Phase II would be stored in the computerized hydrologic data base of the U.S. Geological Survey. All agencies involved in the Grand Canyon Environmental Study Phase II would have access to this data base directly from offices of the U.S. Geological Survey or by telephone link to the computer network of the U.S. Geological Survey.

B. Introduction:

This proposal is presented in response to a March 2, 1990 request for submissions to address individual hypotheses concerning the effects of the operation of Glen Canyon Dam on resources in Grand Canyon National Park (GCNP) and Glen Canyon National Recreation Area (GCNRA). The request was issued by the U.S. Bureau of Reclamation with the intention of obtaining information pertinent to a U.S. Department of the Interior mandated Environmental Impact Statement (EIS). U.S. Geological Survey (USGS) scientists believe that a decadal-scale interdisciplinary investigation of pertinent riverine and riparian processes will be required to adequately answer the questions raised by the EIS and have prepared a comprehensive proposal to address the important issues. This submission proposes hydrologic data collection and data-base management to serve many of the studies to be completed during the first phase of the more comprehensive investigation. A copy of the complete proposal is included in the USGS submission package.

1. Problem Statement

All hypotheses being addressed by scientists in the second phase of Glen Canyon Environmental Studies (GCES II) will rely on hydrologic data collected by the scientists conducting individual studies themselves and data collected by others. Further, certain elements of basic hydrologic data are applicable to the evaluation of all hypotheses and therefore may be considered an important requirement of the integrated research plan. At present, there is no integrated system of data storage and management that will provide a repository and source of the data needed by all GCES II participants although a GIS-based data-management system is a goal of GCES II, it cannot be available for general use by scientists during the study period.

2. Objectives

The objectives of this effort are to provide hydrologic data for all scientists and agencies in the evaluation of the hypotheses proposed for the EIS, and further to provide an easily accessible centralized data base for the use of all participants.

3. Integration With Other Aspects of the Research Plan

Most agencies participating in the GCES program already have access to the Prime computer system operated by the USGS. Adding the remaining participating agencies and providing training to new users is included in this effort. Systematic hydrologic data collected at specific sites (e.g. gaging station, precipitation stations, etc.) will be entered in the data base as it is received and will be immediately available to all who have access to the computer system. Storage and retrieval of data on stage and discharge will be important for all investigators working on any aspect of hypotheses H.1 through H.10. Water-quality data storage and retrieval will be important to investigators working on hypotheses H.1, H.3, H.6, and H.7. Sediment data will be important to those dealing with hypotheses H.1 and H.3.

C. Background:

Historic data available for all existing and previously discontinued stations are shown in table 1. Historic data are, in most instances, already in the National Water Information System (NWIS) data base opeated by the USGS. Some of the data collected during GCES I are not presently in NWIS but will be entered in the data base as a part of this effort.

D. Methods:

1. Sampling Design

There are two principal issues to be addressed. The first is the routine data collection that will be implemented for GCES II. This includes streamflow, water quality, and sediment data collected at eight existing sites and the data collected at three proposed sites (table 2). All stations will be equipped with satellite telemetry, and data will be entered in the data base within hours of its acquisition for in-situ measurements. The stations shown in table 2 will be operated for the entire period of the EIS. As a part of the more comprehensive USGS study, some mainstem and tributary stations will be continued as part of the long-term monitoring effort although frequency of collection and constituent sampled may change.

The USGS will review and enter data provided by USBR on hourly releases from the dam for the period of record. In addition, for a period of 1 year, continuous records of stage will be collected at 50 sites through the canyon for use in model development for hypothesis H.3. Data from these sites will be incorporated in the data base at approximately 6-week intervals starting in June 1990. In general, stage-discharge relations will not be developed for these temporary stations.

The second issue will concerns establishment of a centralized data base. The USGS has a computer-based hydrologic data system (NWIS) for handling and processing all types of hydrologic data. This data base is operated by existing NWIS software and the only change to the present system will be establishment of a separate partition to handle the GCES hydrologic data. The data base is presently directly accessible at USGS Water

Table 1.--Historic streamflow and water-quality data availability at sites on the Colorado River

Number	Name	Drainage area, in square miles	Period of record (years)	Types of water-quality data collected
09380000	Colorado River at Lees Ferry	111,800	January 1895-1990	Common ions, trace metals, bacteria, sediment discharge, and bedload.
09382000	Paria River at Lees Ferry	1,410.0	October 1923-90	Common ions, trace metals, bacteria, sediment discharge, and bedload.
09383000	Colorado River at Compact Point, near Lees Ferry	112,000	October 1913-90, June 1983 to February 1984,	None.
09383100	Colorado River above Little Colorado River	---------	September 1985 to November 1985	Sediment discharge and bedload.
09401200	Little Colorado River at Cameron	24,000	October 1947 to September 1970[1] October 1974 to September 1986[1]	Common ions, trace metals, bacteria, sediment discharge, and bedload.
09402000	Little Colorado River near Cameron	26,500.0	June 1947-90	Common ions, trace metals, bacteria, sediment discharge, and bedload.
09402500	Colorado River near Grand Canyon	141,600	October 1922-90	Common ions, trace metals, bacteria, sediment discharge, and bedload.
09403000	Bright Angel Creek near Grand Canyon	101.0	October 1923 to March 1974	Common ions.
09404120	Colorado River above National Canyon	---------	July 1983 to November 1983, October 1985 to January 1986	Sediment discharge and bedload.
09404200	Colorado River above Diamond Creek	---------	October 1985 to February 1986	Sediment discharge and bedload.

[1]Water-quality data only.

Table 2.--Existing and proposed surface-water gaging stations on the mainstem Colorado River and tributaries within the study area

Number	Name	Measurements: Continuous data	Measurements: Periodic or event data
		Colorado River	
09379910	below Glen Canyon Dam	Stage QW[1]	None
09380000	at Lees Ferry	Stage[2] QW[1]	Suspended sediment[3] st 1/6 weeks
09383100	above Little Colorado River near Desert View	Stage	Suspended sediment[3] at 1/6 weeks
09402500	near Grand Canyon	Stage[2] QW[1]	Suspended sediment[3] st 1/6 weeks.
09404120	above National Canyon near Supai	Stage QW[1] Suspended sediment	Suspended sediment[3] at 4/day. Bedload 1/week
09404200	above Diamond Creek near Peach Springs	Stage	Suspended sediment[3] at 1/6 weeks.
		Tributaries	
09382000	Paria River at Lees Ferry	Stage[2] Suspended sediment during runoff events	Suspended sediment[3] at 1/6 weeks. Tributsry inflow events detected by stage.
09402000	Little Colorado River near Cameron	Stage[2] Suspended sediment during runoff events	Suspended sediment[3] st 1/6 weeks. Tributary inflow events detected by stage.
09403000[4]	Bright Angel Creek near Grand Canyon	Stage	Suspended sediment[3] at 1/6 weeks.
--------	Kanab Creek near mouth	Stage Suspended sediment during runoff events	Suspended sediment[3] at 1/6 weeks. Tributary inflow events detected by stage.
--------	Havasu Creek near Supai	Stage	Suspended sediment[3] st 1/6 weeks.

[1]QW, quality of water includes continuous monitoring of pH, water temperature, specific conductance, and dissolved oxygen.
[2]Funded by another program.
[3]Requires modification of present operstions.
[4]Former gaging stetion at this site.

NOTE:

1. Distribution of 4-parameter monitor (QW[1]) is minimum level for USGS. If this data is needed by other agencies at sites on this table, additional cost is $6,000 per site, including equipment rental, maintenance, operation, and record processing to publicstion.

2. Distribution of pumping samplers will capture sediment from major tributaries. Additional sites will require $7,000 to $8,000 per site plus cost of servicing trips required and sample analyses costs.

Resources Division Offices in Flagstaff, Phoenix, and Tucson. Any agency can access the data base through a local phone connection from any city with a USGS Water Resources Division Office. The use of the data base will require some training for new users and this proposal includes the provision of necessary training in access and use of the data base in manipulating, analyzing, and presenting information products. The proposal does not include providing substantial technical support in the use of the data in interpretive analyses.

2. Response Curves

This element of the integrated research plan does not directly apply to any response curve, but will enable all investigators access to data that will support their efforts.

3. Logistical Support Requirements

Four raft trips will be required in June for the installation of new stations and equipping of existing stations with sampling/monitoring equipment. Over the course of the study, raft trips at approximately 3-week intervals will be required to maintain the data network through June 1990. After June 1991, requirements will drop to one trip at a 6-week interval. Approximately 12 helicopter trips will be required per year, mostly in the summer months, to retrieve samples after runoff events.

E. Tasks and Research Timetables:

1. Implement data base partition and populate date base with historic USGS data. July 1, 1990.
2. Add additional user agencies to computer system. Grant access and train new users. July 1, 1990
3. Install additional gages. June 30, 1990.
4. Provide centralized data base with access to all participating agencies. July 1, 1990.

F. Deliverables:

1. Current on-line data base. July 1, 1990.
2. Annual data reports--Data report available in May of the year following the end of the water year.
3. Preliminary data available on-line.

G. Budget:

The hastily assembled budget figures below are based on anticipated events that depend on plans and decisions not under our control. We, therefore, recommend these be considered rough estimates, which in the metaphor of GCES II, we believe are in the vicinity of our 75-percent confidence level.

Continuous stage/discharge gages

Colorado River below Glen Canyon Dam:

	FY 1990	FY 1991
Labor	$ 3,150	--------
Equipment	1,300	--------
Travel	1,550	--------
Station operation	1,700	$ 18,000
Analyses	---------	--------
Rental equipment	900	3,000

Colorado River at Lees Ferry:

	FY 1990	FY 1991
Labor	$ 750	--------
Equipment	200	--------
Travel	200	--------
Station operation	2,250	$ 4,500
Analyses	---------	--------
Rental equipment	1,150	1,500

Paria River at Lees Ferry:

	FY 1990	FY 1991
Labor	$ 2,900	--------
Equipment	10,000	--------
Travel	600	--------
Station operation	600	$ 3,200
Analyses	1,000	2,000
Rental equipment	---------	--------

Colorado River above Little Colorado River:

	FY 1990	FY 1991
Labor	$ 1,600	--------
Equipment	3,200	--------
Travel	250	--------
Station operation	200	$ 13,500
Analyses	---------	--------
Rental equipment	500	1,500

Little Colorado River near Cameron:[1]

[1]Paid for by another agency.

Colorado River near Grand Canyon:

	FY 1990	FY 1991
Labor	$ 1,600	--------
Equipment	200	--------
Travel	250	--------
Station operation	1,500	$ 4,500
Analyses	---------	--------
Rental equipment	500	1,500

Bright Angel Creek near Grand Canyon:

	FY 1990	FY 1991
Labor	$ 2,600	--------
Equipment	9,300	--------
Travel	250	--------
Station operation	4,500	$ 13,300
Analyses	---------	--------
Rental equipment	500	1,500

Kanab Creek near mouth:

	FY 1990	FY 1991
Labor	$ 5,300	--------
Equipment	12,500	--------
Travel	250	--------
Station operation	4,700	$ 15,900
Analyses	1,000	2,000
Rental equipment	1,000	3,000

Havasu Creek near Supai:

	FY 1990	FY 1991
Labor	$ 2,600	--------
Equipment	9,300	--------
Travel	250	--------
Station operation	4,500	$ 13,300
Analyses	---------	2,000
Rental equipment	500	1,500

Colorado River above National Canyon:

	FY 1990	FY 1991
Labor	$ 4,000	--------
Equipment	8,500	--------
Travel	250	--------
Station operation	1,700	$ 17,800
Analyses	---------	2,000
Rental equipment	1,000	3,000

Colorado River above Diamond Creek:

	FY 1990	FY 1991
Labor	$ 2,600	--------
Equipment	3,200	--------
Travel	250	--------
Station operation	1,700	$ 17,800
Analyses	---------	--------
Rental equipment	1,000	3,000
Spare equipment	13,840	--------
Rental equipment	500	1,500

50 temporary gages:

	FY 1990	FY 1991
Labor	$ 68,000	$ 88,600
Equipment	6,700	--------
Travel	6,600	13,200
Station operation	6,600	8,000
Analyses	---------	--------
Rental equipment	10,800	19,500

Data-base management:

	FY 1990	FY 1991
Labor	$ 20,000	$ 40,000
Travel	2,000	1,000
Rental (Computer Operations)	600	1,200

Data network and database:

Labor	$115,100	$128,600
Equipment and supplies	68,240	--------
Travel	12,700	14,200
Station operation	29,950	129,800
Analyses	1,600	4,000
Rental	18,950	38,700
Total	$246,540	$315,300

STUDY PROPOSAL -- HISTORICAL REVIEW OF THE GLEN CANYON DAM RELEASES

Prepared by David L. Wegner, Glen Canyon Environmental Studies Program Manager, Glen Canyon Environmental Studies, Flagstaff, AZ

I. INTRODUCTION

Glen Canyon Dam closed its gates in 1963 and began the storage of water in Lake Powell and the controlled releases of water into the Grand Canyon. With the control of the releases at Glen Canyon Dam, the river corridor environmental relationships in the Grand Canyon began to be impacted. To fully understand the changes that have occurred to the resources, a thorough understanding is required of the flow regimes that have impacted them.

The purpose of this study is to develop a useable assimilation and understanding of the flow releases that have occurred at Glen Canyon Dam. The specific purposes can be defined in three general areas. The **first** is to delineate and review the past operations of Glen Canyon Dam. This will require a review of the historical data and data bases and determine how good of release record exists for Glen Canyon Dam.

The **second** purpose is to identify the annual, seasonal, daily and hourly release patterns and compare that to the patterns of flow that would have occurred had Glen Canyon Dam not been in place.

The **third** and last purpose of the study is to develop a data base that can be easily transferred to each of the GCES researchers to be utilized in the development of the specific research study reports.

To date, the records of Glen Canyon Dam releases have been maintained at Glen Canyon Dam on hand recorded data sheets. Recently, the Upper Colorado Region has developed an ASCII computer data base for the data. That data base is being reviewed and will be utilized in the development of this study.

II. Background

The gates at Glen Canyon Dam were closed in 1963. Records on dam releases were initiated as the power generators came on line. Prior to that, the only records of Colorado River inflow to Grand Canyon was available from the U.S. Geological Survey records at Lee's Ferry.

Beginning in 1963 and continuing to present, the operators at Glen Canyon Dam maintain a flow release record at the dam **based on the conversion of electrical releases** to flow levels. In addition, the U.S.G.S. has maintained the gage at Lee's Ferry. In 1989, as part of the GCES program, the U.S.G.S. installed a hydrologic gage immediately below Glen Canyon Dam.

An area of consistent concern throughout the GCES Phase I efforts was the lack of a reliable a useable hydrologic data base for the releases at Glen Canyon Dam. Additionally, a need existed to dissect the flow releases and determine where specific changes in flow operation occurred and then to determine why. That same need exists with the GCES Phase II efforts.

III. Objectives

The objectives of this study are to develop and evaluate the releases from Glen Canyon Dam. Specific objectives are as follows:

A. Document and develop the historic flow releases from Glen Canyon Dam. Ensure that no lapses in data exist.

B. Develop a "user friendly" release data base that can be provided to the GCES Phase II researchers.

C. Review and develop a synopsis of the past operations of Glen Canyon Dam.

IV. Methods

The methods to be followed will include a combination of detective work, statistical analysis, computer manipulation and hydrologic data analysis.

A. Data Acquisition: Work with the Upper Colorado Regional Office, the Denver Office, and the personnel at Glen Canyon Dam to acquire the release flow information.

B. Data Analysis: Review the release records in combination with the U.S.G.S. records from Lee's Ferry to determine consistency and verification.

Additionally, it will be necessary to evaluate the data using statistics, graphics and other forms of hydrologic data analysis.

C. Development of Data Base: Develop a useable Glen Canyon Dam release data base that can be used by the GCES Phase II researchers. This will include an ASCII data file and transferable to a dBase III file.

D. Statistical Review: Frequency analysis and other forms of statistical review will be required to evaluate the annual, seasonal, daily and hourly operation characteristics at Glen Canyon Dam.

V. Tasks and Deliverables

The work identified for this research effort is required prior to the analysis of the other GCES Phase II research programs. The schedule for completion is as follows:

Draft Report w/data base (draft)	-------	June 1, 1991
Final Report w/data base (final)	-------	August 31, 1991

VI. Budget

The budget for this study includes the assumption that this work will be handled either through the GCES Office, the Denver Office or the Upper Colorado Regional Office. If sufficient support cannot be obtained, a contract will be let for this study.

The budget defined for this work is defined at **$ 50,000**. All of this will be a fiscal year 1991 expense.

WATER QUALITY AND LIMNOLOGY

GLEN CANYON ENVIRONMENTAL STUDIES

PHASE II

INTEGRATED RESEARCH PROGRAM

WATER QUALITY AND LIMNOLOGY

I. Issues

The water quality and limnology studies have been developed to provide the data necessary to determine the impact of the water releases from Glen Canyon Dam on the downstream water quality and productivity in the Colorado River.

At the completion of the Glen Canyon Environmental Studies (GCES) Phase I efforts it was determined that not enough understanding existed on the impacts of Lake Powell on the downstream aquatic ecology. During the GCES Phase I efforts a limited amount of water quality information was collected. This information, while valuable, identified that the water quality in the Colorado River below Glen Canyon Dam was influenced in a annual and seasonal way by the limnology of Lake Powell and the release patterns at Glen Canyon Dam. The releases from Lake Powell impact the Colorado River ecosystem and the limnological relationships in Lake Mead.

II. Objectives

The objectives of the GCES Water Quality and Limnology studies are broadly stated as:

A. Review and evaluation of the limnological history of Lake Powell and Lake Mead.

B. Determination of the chemical water quality characteristics in Lake Powell (above the dam) and in the Colorado River.

C. Determination of the physical water quality characteristics in Lake Powell and in the Colorado River and how it impacts the productivity of the aquatic ecosystem.

D. Determination of the impact of the water quality relationships and Glen Canyon Dam releases on the aquatic insect populations in the Colorado River.

III. Components of the GCES Phase II Water Quality and Limnology Studies

The components of the GCES Phase II Water Quality and Limnology studies are separated into two areas and are depicted in Figure 6.

A. Water quality and limnological relationships.

1. Limnology of Lake Powell and Lake Mead
2. Grand Canyon Chemical Water Quality

    a. Lake Powell
    b. Colorado River

B. Aquatic productivity studies and water quality relationships

1. Physical water quality and productivity studies

    a. Lake Powell
    b. Colorado River

2. Aquatic dipteran studies

IV. Organization of the GCES Water Quality and Limnology Studies

The overall GCES Water Quality and Limnology studies will be guided by the GCES Scientific Core Group. The GCES Scientific Core Group will take into account the specific data requirements necessary for the riparian ecology studies, the aquatic studies and the sediment studies.

The Scientific Core Group will be responsible to ensure that the water quality and limnology information is integrated into the GCES aquatic reports, the GCES sediment reports, the GCES final report,

Representation on the Scientific Core Group will include, but not be limited to, the following groups:

GCES Senior Scientist
GCES Research Advisors
GCES Office
National Park Service
U.S. Geological Survey
Arizona Game & Fish Department
Fish & Wildlife Service
Native American Nations
Contractors
Western Area Power Administration

Primary leadership for the Scientific Core Group will be the GCES Senior Scientist or his designated alternate. The GCES Office will provide the coordination and technical support to this group.

V. Products to be Developed

The GCES Water Quality and Limnology studies will be coordinated through the GCES Scientific Core Group. Three levels of scientific reports will be required:

A. Individual Research Reports - as defined in the study plan

B. GCES Final Integration Report - will provide a synopsis of the important facts and concerns.

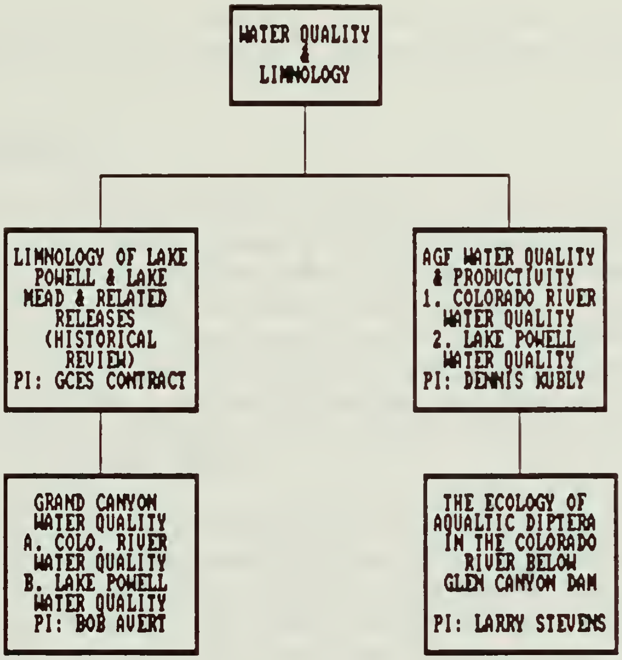

Figure 6. Glen Canyon Environmental Studies Phase II Water Quality and Limnology Studies.

Study Proposal -- Historical Review of the Limnology of Lake Powell and Lake Mead and the Effects that may be Occurring the Grand Canyon

Prepared by: David L. Wegner, Glen Canyon Environmental Studies, Program Manager, Glen Canyon Environmental Studies, Flagstaff, AZ

I. Introduction

The limnology of Lake Powell has been of interest since the gates at Glen Canyon Dam were closed in 1963 and water began being stored in Lake Powell. Approximately 27 million acre feet of water can be stored in Lake Powell with the levels varying due to release requirements, inflow, storage levels and evapotranspiration rates. The limnology of Lake Powell defines the level of aquatic productivity and the levels of aquatic productivity in the Colorado River below Glen Canyon Dam and ultimately the limnological relationships in Lake Mead.

Problem Statement: Glen Canyon Dam controls the release of to the Grand Canyon and consequently the storage levels in Lake Powell. The water quality of the waters released to the Grand Canyon is defined by the water quality conditions of Lake Powell. The limnology of Lake Powell defines the water quality and aquatic productivity levels in both Lake Powell and the Colorado River releases.

The limnology of Lake Powell varies depending on the incipient water quality conditions of the inflow water to Lake Powell, reservoir dynamics, release rates and weather conditions. To determine the range of water quality conditions to expect in the Grand Canyon, it is necessary to understand the limnology of Lake Powell.

Objectives: The objective of this study is to review the historic limnological data base for Lake Powell, the historic limnological data base for Lake Mead, and determine the range of conditions that can be expected for releases from Glen Canyon Dam.

A secondary objective is to determine the water quality input conditions for water quality and temperature models for the Colorado River. This information is required to understand the aquatic productivity relationships in the Colorado River.

Integration with the Research Study Plan: The information generated under this study will be used by the aquatic studies in determining the relationship between aquatic productivity levels and Lake Powell water quality. Secondarily, the information provided by this study will be used in the broad scale U.S.

Geological Survey water quality studies to help decipher changes in the overall water quality relationships in the Grand Canyon.

Information generated under this study may also be used by the GCES research team in their development of any additional multiple level withdrawal studies.

II. Background

The gates ar Glen Canyon Dam closed in 1963. Immediately water began to store behind the concrete dam and Lake Powell was born. From 1963 until June 1980, Lake Powell was in the filling mode. With the closure of Glen Canyon Dam, the character of the water releases into the Grand Canyon changed. Lake Powell tempers the release characteristics of the Colorado River and directly impacts the downstream natural and recreation resources in the Grand Canyon.

During the filling mode of Lake Powell, measurements of the water quality characteristics were made by the U.S. Bureau of Reclamation, the state of Utah, the state of Arizona and several academic and federal organizations. The intent of these measurements was to identify the limnological and aquatic productivity characteristics of lake Powell. The majority of this work was related to developing the fishery in Lake Powell.

The limnology of Lake Powell is dictated by several forces; reservoir volume, inflow levels, weather conditions, inflow water quality characteristics, sediment input, aquatic productivity, and reservoir dynamics. The limnology of Lake Powell directly dictates the water quality levels of the water released through Glen Canyon Dam and into the Grand Canyon. The release water quality conditions define the levels of aquatic productivity in the Glen and Grand Canyon areas and indirectly the use of the river resource by recreationists.

Since 1963 limnological data has been collected in lake Powell. Studies conducted on the potential for adding multiple level withdrawal structures to the intake tubes for the generators at Glen Canyon Dam were conducted under the aegis of the GCES Phase I research program. Since the completion of the GCES Phase I, additional concern has arisen over the release characteristics of the water from Lake Powell and its ultimate impact on the aquatic productivity in the Colorado River below. Additional concern over the potential for operational changes at Glen Canyon Dam, as a result of the Glen Canyon Dam - Environmental Impact Statement requires that a better understanding of the effects of Lake Powell on the downstream water quality and aquatic productivity of the Colorado River below must be completed.

III. Methods

A. Sampling Design

The design of the historical review of the limnology of Lake Powell and Lake Mead will follow a phased approach and will tier from the progressive refinement of the data.

1. Literature Review. The first step in the review will be an extensive review and documentation of the historical information that has been generated on the limnological characteristics of Lake Powell and Lake Mead. This literature review will identify: the type of data; the location of the data; the range of data; and the principle investigator or curator of the data.

2. Data Review. The second step in the analysis of the historic Lake Powell and Lake Mead limnological data will include a review of the data and historic information. An assessment will be made of the quality and quantity of the data. This review will include a statistical analysis of the data and an assessment of its scientific reliability.

3. Data Recommendations. The third step in the analysis of the historic Lake Powell and Lake Mead limnological data will include the development of specific recommendations as to the future use and integration of the limnological data with the other work being conducted under the GCES Phase II research umbrella. The assessment of the data and recommendations will address the "worth" of the data and specific qualifications that must be placed on the use of the data in any scientifically related venue.

B. Response Curve Development

The development of specific response curves based on the data evaluated under the GCES Phase II program will not relate specific Glen Canyon Dam release levels with the limnological relationships. Instead, the response curves will be developed based on the overall level (volume) of Lake Powell and the individual Lake Powell limnological constituents.

C. Logistical Support Required

No specific field logistical support will be required for this study. However, assistance and consequent historic data collection may require support in the form of literature acquisition, documentation and/or evaluation.

IV. Research and Task Timetable

The three phases of the GCES Phase II Historical Review of Lake Powell and Lake Mead limnological data will meet the following timetable:

A. Literature Review of the Historic Lake Powell and Lake Mead limnological data.

Draft Report - September 30, 1990
Final Report - December 30, 1990

B. Data Review of the Historic Lake Powell and Lake Mead limnological data.

Draft Report - December 30, 1990
Final Report - March 30, 1990

C. Data Recommendations from the Historic Lake Powell and Lake Mead limnological data.

Draft Report - March 30, 1990
Final Report - June 30, 1990

V. Products to be Delivered

Three reports will be developed as part of the GCES Phase II research program on the Review of the Historic Limnology of Lake Powell and Lake Mead. These reports include:

A. Literature Review of historic Lake Powell and Lake Mead Limnology information

B. Data Review of the Historic Lake Powell and Lake Mead limnological data

C. Data Recommendations from the Historic Lake Powell and Lake Mead Limnological Data

VI. Budget

The following budget has been identified for the GCES Phase Ii research program entitled Review of the Historic Limnology of Lake Powell and Lake Mead:

Fiscal year 1991: $ 10,000.00

Fiscal year 1992: $ 40,000.00

PROPOSAL: GRAND CANYON WATER QUALITY

United States Geological Survey

March 28, 1990

A. Abstract

This proposal describes a water-quality sampling and analysis plan for the Colorado River between Glen Canyon Dam and Columbine Falls. The proposal considers chemical and biological quality, and describes a synoptic experiment for water-quality measurements and sample collection. The results will provide information for the U.S. Deparment of the Interior Environmental Impact Statement as well as being an essential component of the U.S. Geological Survey comprehensive Colorado River study proposal. The work described here addresses hypothesis H.7 of the Glen Canyon Environmental Studies memorandum dated March 2, 1990. H.7 is concerned with the effects of river discharge on water quality and stream production. The proposal relates also to hypotheses H.3, H.4, H.5, H.6, H.8, H.12, H.17, and H.18 of the same memorandum.

B. Introduction

This proposal is presented in response to a March 2, 1990 request for submissions to address individual hypotheses concerning the effects of the operation of Glen Canyon Dam on resources in Grand Canyon National Park (GCNP) and Glen Canyon National Recreation Area (GCNRA). The request was issued by the U.S. Bureau of Reclamation with the intention of obtaining information pertinent to a U.S. Department of the Interior mandated Environmental Impact Study (EIS). U.S. Geological Survey (USGS) scientists believe that a decadal-scale interdisciplinary investigation of pertinent riverine and riparian processes will be required to adequately answer the questions raised by the EIS and have prepared a comprehensive proposal to address the pertinent issues. A study of this length is necessary for a comprehensive understanding of even the simplest water-quality processes. The water quality is related to flow, temperature and sediment regimes, and processes occurring in Lake Powell. Visitor use also is a major factor in determining the quality of the Colorado River below the dam. This submission briefly presents pertinent aspects of pertinent water-quality studies to be completed during the first phase of the more comprehensive investigation. A copy of the complete proposal is included in the USGS submission package.

1. Problem Statement

This proposal addresses hypothesis H.7, "How are water quality and stream productivity affected by discharge fluctuations and the rate of change in fluctuating discharges?" Water quality, as defined here refers to things in water, ranging from dissolved ions, to higher vertebrates. Prior to the construction of the dam, water quality of the Colorado River was in at least a seasonal equilibrium in that the organisms had evolved within given seasonal chemical, temperature, sediment and flow ranges. Since Glen Canyon Dam, the river system has been in disequilibrium with regard to chemical concentrations and constituents, temperature, sediment, and flow. In fact, the river below the dam is a "new" river, having much clearer and cooler water and a much more erratic flow pattern.

2. Objectives

The water-quality elements of this study include: water and sediment chemistry; biological components such as primary production, benthic invertebrates, bacteria, drift, and algal and macrophyte distribution and abundance; and water-temperature patterns. The study will concentrate on the Colorado River mainstem between the dam and upper Lake Mead. Tributaries such as the Paria and Little Colorado Rivers, Bright Angel, Kanab, and Havasu Creeks also will be included in the study. The overall goal is to understand chemical and biological process and their responses under various flow regimes so that conceptual models based upon flow, water temperature, and seasonal climate patterns can be developed. These conceptual models will be linked to the flow-and-transport models discussed in the comprehensive proposal.

3. Processes of Integration With Research Study Plan:

The water and sediment chemistry part of the water-quality studies will relate to H.3, Sediment Transport; H.4, Effects on Trout; H.12, Rafting/Camping; H.17, Variable Intake; and H.18, Re-regulation of the Dam. Water and sediment chemistry are intimately associated and provide an understanding of these study elements. Water and sediment chemistry also will be key measurements for future evaluations of the river. The biological phase of the water-quality study would specifically deal with H.4; H.5, Wintering Bald Eagles; H.6, Other Fish; H.8, Recreation; H.17; and H.18.

C. Background

Before flow regulation, snowmelt produced high flows in May and June, with an annual peak discharge in June ranging from 25,300 to 220,000 ft^3/s and averaging 93,400 ft^3/s. In addition, local July and August rainstorms produced discharge peaks that were lower and of shorter duration than the snowmelt-runoff hydrograph. The annual peak between 1963 and 1980 (before Lake Powell filled) averaged about 29,000 ft^3/s. Production of electrical power at the dam has caused highly variable flows. While these variable flows are the subject of much controversy, it is not clear as to their subtle effects upon chemical quality in the river. It is for this reason that the proposed synoptic experiments to be outlined later are of such importance.

Liebermann and others (1989) have clearly shown the effects of Lake Powell on dissolved-solids concentrations. Their results show a significant dampening of the dissolved-solids concentration below the dam compared to water entering the lake. Dissolved-solids concentrations in the river since Lake Powell filled in 1980 have ranged between 492 and 645 milligrams per liter (mg/L). Lake Powell also acts as a sediment and a nutrient trap. Prior to the construction of the dam, the river carried high sediment loads. Since completion of the dam, sediment inputs have essentially been eliminated except for bank scour, tributary, and aeolian input. This has had a significant influence on the water chemistry and the river biota. For example, the clearer water leaving the dam permits greater light penetration resulting in increased photosynthesis, which in turn results in greater organic matter production. Aquatic plant production also results in increased uptake of nitrogen, phosphorus, carbon, and trace elements. Such processes result in an equilibrium shift in the availability of these constituents in the river. The effects of these processes on higher aquatic biota are unknown, but are doubtless important. Increased algal production between the dam and Lees Ferry has an impact on downstream water quality because more plant nutrients are removed further upstream than before the closure of the dam. Another important factor is water temperature. Before the dam, water temperature varied with the season. Now water is removed from the hypolimnion of Lake Powell resulting in a water temperature at Lees Ferry of about 46 to 49 °F. Because water temperature is an important controlling factor for aquatic life (Fry, 1947), these essentially constant low temperatures have a effect upon the aquatic biota, as well as the chemistry of the river. Doubtless, the colder water has resulted in higher concentrations of dissolved oxygen and a more diverse community of cold-water organisms.

This discussion has not included the excellent work conducted under GCES I, which is being expanded in GCES II and by the EIS. The work proposed here is designed to build upon these studies, and to provide a long-term approach towards a better process understanding of the water quality in the Grand Canyon of the Colorado River. Such understanding is necessary for long-term management of the river.

D. Methods

A major feature of the water-quality work will be a series of synoptic experiments from the dam to Columbine Falls (about 290 river miles) including major tributaries, eddies, and backwaters. During the synoptic experiments samples will be collected simultaneously at different sites to develop a complete picture of water quality under selected hydrologic conditions. Synoptic experiments are necessary to define the distribution and abundance of those constituents that have the greatest impact on the river water quality, and to identify areas where more detailed research will be required in later phases of the comprehensive study. Because all aspects of water quality will be studied during the experiments, interactions between components can be readily evaluated; for example, trace element and nitrogen and phosphorus concentrations, water temperature, and suspended sediment all influence primary production. An understanding of each component will assist in providing insight into primary production and into nutrient concentrations and the influences of external factors such as flow, water temperature, and sediment concentration.

1. Sampling design

Water Chemistry: The effects of regulated flow on the chemical aspects of water quality in the river are related to two primary factors: 1) general water chemistry, including major anions, cations, nutrients, dissolved organic carbon, dissolved oxygen and related parameters such as radionuclides, and 2) chemistry of suspended and bed sediments and contaminants intimately associated with sediment (table 1). In addition, selected biomatter, such as algae, benthic invertebrates, fish, and macroflora, will be examined and chemically analyzed to determine potential for bioaccumulation of harmful materials. The synoptic experiments conducted under a variety of flow regimes (either regulated or naturally variable dam releases), and on a seasonal basis, will assist in establishing the nature and stability of the water chemistry. They also will assist in establishing the present concentration levels and temporal and spatial distributions of potentially important contaminants, essential trace elements, and biota.

Each major and minor tributary contributes dissolved and sediment-sorbed constituents to the river on a variable basis depending on runoff conditions and land use. These episodic contributions to the river will have a significant effect upon water quality. Correlation of water chemistry constituents with flora and fauna in the river may demonstrate the sensitivity of biota to changing water-quality conditions. However, long-term studies are often needed to evaluate such sensitivities. The

Table 1.--*Selected chemical constituents to be measured during synoptic experiments*

Major cations	Major anions	
Ca	Cl	
Mg	SO_4	
Na	HCO_3/CO_3	
K		
SiO_2		
Nutrients	**Trace elements**	
NO_3	As	Li
PO_4	B	Mn
NH_4	Ba	Mo
	Cd	Ni
Miscellaneous	Co	Pb
pH	Cr	Se
Sp. Cond.	Cu	Tl
D.O	Fe	U
DOC		

chemistry of suspended sediment and bottom materials will have a significant impact on the bioavailability and storage and transport of constituents. Under variable flow conditions, stored sediment and scoured virgin material will be suspended and transported along with associated contaminants.

Because water temperature is an important controlling factor, it will be a primary measurement in this research. We propose to clearly define the temperature patterns of the river mainstem including eddies and backwaters. Temperature will be measured continuously at all gaging stations, and hand-held thermometers will be used at all synoptic experiment sites (table 2). These measurements will be compared to the predictions of existing river-temperature models such as that developed by Ferrari (1986). Variation in water temperature as a result of releases from the dam will have a significant impact on chemical equilibria in the river. This temperature-induced shift in equilibrium of chemical reactions, oxidation-reduction, hydrolysis, condensation/decomposition, precipitation, and complex equilibrium will have a major impact on primary chemical quality and control of overall water quality. In addition, adsorption isotherms of chemical constituents on sediments vary significantly as the temperature changes. Temperature thus will have a substantial impact on the association of those trace elements and other sorbed materials associated with the sediments.

Controlled water releases will have a major effect on the dissolved organic carbon content of the river system, which in turn will impact the equilibrium of reactions with trace metals. The result could be a significant effect on the dissolution/precipitation/adsorption and transport of sorbed materials in the river.

Table 2.--Synoptic-experiment measurements, Colorado River Study

[Numbers in parentheses are footnotes]

Site	Chemistry		Biology				Sediment		Flow	Crew	Special Equipment
	Water	Sediment	AGP	Drift	Benthos	Bacteria	Suspended	Bed			
Below Glen Canyon Dam	4/day (Diel)	1/season bed	4/day (Diel)	4/day (Diel)	1/season (1)	2/day (2)stage	(3)	(3)	Continuous gage; cable measurement 1/day	3	Incubator
Lees Ferry	4/day (Diel)	Suspended, flood only Bed, 1/season	4/day (Diel)	4/day (Diel)	1/season (1)	2/day (2)stage	1/flood	1/season split for chemical	Continuous gage; cable measurement 1/day	7	Incubator
Paria River	4/day, first day; 1/day if steady	Suspended, flood only Bed, 1/season	4/day (4)(Diel)	4/day (4)(Diel)	1/season (1)	1/day; 4/day over flood hydrograph	1/day; 4/day in flood	1/season split for chemical	Continuous gage; measurement 1/day		
Colorado River above Little Colorado River	4/day (Diel)	Suspended, 4/day (Diel); bed 1/season	4/day (Diel)	4/day (Diel)	1/season (1)	None	4/day, stage; 1/day on steady	1/season split for chemical	Continuous gage; cable measurement 1/day	7	
Little Colorado River at mouth	4/day (Diel) 1/day if steady	Suspended, 1/day bed, 1/season	4/day (Diel)	4/day (Diel)	1/season (1)	None	1/day; none if flood	1/season split for chemical	Wading measurement		
Little Colorado River near Cameron	4/day 1st day 1/day if steady	4/day 1st day 1/day if steady	4/day (4)(Diel)	4/day (4) (Diel)	1/season (1)	1/day 4/day over flood hydrograph	1/day; 4/day in flood	1/season split for chemical	Continuous gage; cable measurement 1/day	6	Incubator

See footnotes at end of table.

Table 2.--Synoptic-experiment measurements, Colorado River Study--Continued

Site	Chemistry		Biology				Sediment		Flow	Crew	Special Equipment
	Water	Sediment	AGP	Drift	Benthos	Bacteria	Suspended	Bed			
Colorado River at Grand Canyon	4/day (Diel)	Suspended 4/day(Diel) bed, 1/season	4/day (Diel)	4/day (Diel)	1/season (1)	2/day (2)stage	4/day;stage 1/day on steady	1/season split for chemical	Continuous gage; cable measurement 1/day	7	
Bright Angel Creek	4/day (Diel) 1st day 1/day if steady	4/day 1st day; 1/day if steady; bed 1/seasony	4/day (4)(Diel)	(4) (Diel) 4/day	1/season (1)	1/day 1/day 4/day over flood hydrograph	1/day; 4/day in flood	1/season split for chemical	Continuous stage; measurement 1/day		Incubater; high flow Incubater; high flow measurement and sample from bridge on Bright Angel
Colorado River above Kanab Creek	4/day (5)(Diel)	4/day(Diel) (6); bed, 1/season	4/day (4)(Diel)	4/day (4) (Diel)	1/season (1)	None	4/day;stage 1/day on steady	1/season split for chemical	Continuous stage;(7)	7	Boat (zodiac type with 3.5-horsepower motor. Two sets of heavy, bulky equipment as trail between sites is difficult. Helmet lights.
Kanab Creek at mouth	4/day 1st day (Diel) 1/day if steady	4/day 1st day 1/day if steady; bed 1/season	4/day (4)(Diel)	4/day (4) (Diel)	1/season (1)	None	1/day 4/day in flood if possible	1/season split for chemical	Continuous stage; wading measurement 1/day		
Colorado River above Havasu Creek	4/day (5)(Diel)	4/day(Diel) (5) bed, 1/season	4/day (4)(Diel)	4/day (4) (Diel)	1/season (1)	None	4/day;stage 1/day on steady	1/season split for chemical	Continuous stage (7)	6	Boat (zodiac type) with 3.5-horsepower motor.
Havasu Creek at mouth	4/day (5)(Diel)	4/day(Diel) (5) bed, 1/season	4/day (4)(Diel)	4/day (4) (Diel)	1/season (1)	None	1/day;4/day in flood if possible	1/season split for chemical	Continuous stage; wading measurement(8)	3	
Colorado River at National Canyon	4/day (5)(Diel)	4/day(Diel) (5) bed, 1/season	4/day (4)(Diel)	4/day (4) (Diel)	1/season (1)	None	4/day;stage 1/day in steady	1/season split for chemical	Continuous gage; cable measurement 1/day	6	

See footnotes at end of table.

Table 2.--Synoptic-experiment measurements, Colorado River Study--Continued

Site	Chemistry		Biology				Sediment		Flow	Crew	Special Equipment
	Water	Sediment	AGP	Drift	Benthos	Bacteria	Suspended	Bed			
Colorado River above Diamond Creek	4/day (5)(Diel)	4/day(Diel) (5) bed, 1/season	4/day (4)(Diel)	4/day (4) (Diel)	1/season (1)	2/day stage(2)	4/day;stage 1/day in steady	1/season split for chemical	Continuous gage; cable measurement 1/day	7	Trailers, generator, incubator
Diamond Creek at mouth	4/day (5)(Diel)	4/day(Diel) (5) bed, 1/season	4/day (4)(Diel)	4/day (Diel)	1/season (1)	None	1/day 4/day in flood if possible	1/season split for chemical	Continuous stage; wading measurement 1/day		
Colorado River at Bridge Canyon	4/day (5)(Diel)	4/day(Diel) (5) bed, 1/season	4/day (4)(Diel)	4/day (Diel)	1/season (1)	None	4/day stage; 1/day if steady	1/season split for chemical	Continuous stage (7)	6	Boat
Colorado River at Columbine Falls	4/day (5)(Diel)	4/day(Diel) (5) bed, 1/season	4/day (4)(Diel)	4/day (Diel)	1/season (1)	2/day;even interval	None	1/season split for chemical	Continuous stage; no measurement	6	Boat (prefer USBR house boat; incubator

1To be decided in cooperation with Arizona Game and Fish Department.
2High and low stage.
3Not applicable.
4If diel not applicable, measurement to be taken once a day.
5If diel not applicable, measurements to be taken four times a day at even interval.
6If diel not applicable, measurements to be taken four times a day.
7Three to five sections with sediment samples.
8Four measurements per day if stage changes; once a day if stage is steady.

Nitrogen and phosphorus and some trace metals are important algal nutrients. The most common and conspicuous algae in the river is *Cladophora glomerata*, a green algae that attaches to solid substrates. *Cladophora* production is reported to be most prevalent between Glen Canyon Dam and Lees Ferry, a distance of about 16 river miles. However, primary production may exceed respiration in the river as far downstream as the Little Colorado River, a distance of about 78 river miles below the dam. In this reach, sediment concentration increases and photosynthesis decreases. The following nutrient-chemistry related studies will be conducted:

1) Determine the movement, sources and sinks of nitrogen, phosphorus and trace elements in the river under given flow and seasonal regimes;
2) Determine the locations in the river where nutrient concentrations are high, but primary production is low because of reduced light and other factors. Much of this will be flow dependent and related to suspended sediment concentration which will reduce light penetration into the river;
3) Determine cause-effect relations governing nutrient concentrations in the river.

Although these three items relate to the river mainstem and selected tributaries, an additional need is to determine the nutrient concentrations in upper Lake Mead. It is important to know if the Lake Mead river-reservoir system is starved of nutrients and how nutrient levels vary as flow is regulated.

These are but a few of the specific study tasks necessary to understand the nutrient dynamics of the Colorado River downstream from the dam. Although such studies are important at the moment, they will become more important in the future.

Aquatic biology: We propose to study primary production, drift, and benthic invertebrates because they are a measure of the lower-order food web in the river. Because all life depends on primary production, it is essential to understand the magnitude and extent of such production in the river. We propose to measure primary production mainly between the dam and Lees Ferry, but also as far downstream as Columbine Falls. We will use either the light- and- dark bottle method, or the carbon-14 method.

Drift refers to material moving in the water column either as whole or fragmented organisms and includes all plant and animal material, living or dead. Drift is often difficult to quantify, but does provide insight to types of material moving through the river, and such information will be of great value in future evaluations of river water quality. Drift also provides insight to primary production. Past studies of drift in the Colorado River have been hindered because of net clogging. Thus, some experimentation related to the ratio of net-mouth opening to net-mesh opening will be necessary. Some work has been done using a pumping system to eliminate net clogging. This technique also will be evaluated.

To assess the drift, effects of river scour and other aspects of biological production, and to understand at least the rudiments of the food web in the study area, it is necessary to determine the kinds and relative abundance of benthic invertebrates in the river. This part of the study will be limited to a reconnaissance, and no attempt will be made in the early part of the study to measure biomass, except in a few places where adequate sampling can be accomplished. The various types of invertebrates will be identified and placed into appropriate functional groups using the techniques of Merritt and Cummins (1984).

Synoptic Experiments: The synoptic experiment scheme mentioned earlier will be used for collecting samples for much of the chemical and biological studies. Teams of scientists will be stationed at selected sites along the river and near the confluences with the tributaries. At a predetermined time, the experiment will begin, and measurements and samples of selected constituents will be made every 6 hours over a 48-hour period. Table 2 lists the sites, number of scientists participating, and the measurements and samples to be collected. Participants also will record meteorological conditions, any unusual conditions noted such as beach erosion and take photographs. Process investigations also will be conducted at sites identified from the measurements and samples made during the synoptic experiments.

Analytical considerations: Major cations and selected trace elements will be determined by atomic adsorption and inductively coupled plasma-atomic emmission spectrometric methods developed at USGS laboratories specifically for the analysis of environmental materials (Garbarino and Taylor, 1979; Garbarino and Taylor, 1985).

Semiquantitative reconnaissance and quantitative analysis of trace elements will be performed by a combination of electrothermal vaporization-atomic absorption spectrometry and state-of-the-science inductively coupled plasma-mass spectrometric (ICP-MS) also developed at USGS National Research Program laboratories (Garbarino and Taylor, 1987; Taylor, 1987 and 1989). The ICP-MS technique provides for the direct analysis in water of most of the elements in the periodic table to detection levels ranging from 0.5 to 0.01 micrograms per liter depending upon the specific element. Relative precisions of 5 percent or better can be achieved routinely. Other determinations, including major anions, nutrients, and dissolved organic carbon will be measured using a variety of techniques such as ion chromatography, ultraviolet-visible-infrared adsorption spectrometry, and electrochemical procedures. All suspended and bottom sediment chemical analyses will be performed using procedures similar to those described above after the appropriate sample preparation and separation techniques have been applied.

Either the oxygen light- and dark- bottle or the carbon-14 method will be used for determining primary production (Wetzel and Westlake, 1974). The techniques of Merritt and Cummins (1984) will be used for classification of benthic invertebrates to genus and functional groups. The determination of biomass and secondary production will follow the techniques of Benke (1984). Drift will be measured using nets of particular mouth and mesh openings (Britton and Greeson, 1987), or using a pumping drift collector (K.V. Slack, oral commun., 1990). We are familiar with techniques of collection and analyses used during the GCES I and will use these techniques when applicable to insure that our methods are comparable.

2. Response Curves:

It is difficult to derive response curves for the water chemistry and biota in the river because previous conditions and numerous other independent variables are pertinent to the results observed. For example because increased flows result in decreased light penetration to the river bottom because of increased water depth, and because of increased sediment concentrations. Thus primary production may be reduced during daytime high flows and increased during daytime low flows. In contrast, daytime low flows may dessicate large areas of algae in a river reach resulting in lower total primary production. During low flows, there is less water volume in a reach and thus less total nutrients, so that nutrient availability may limit primary production. Variable flows result in the wetting and drying of the substrate and in the dessication of algae, benthic invertebrates, and fish eggs. This weakens these organisms and results in larger amounts of drift for any subsequent flow conditions. Moreover rapidly increasing flows transport more drift because the organisms are torn from the substrate, and this can occur subsequent to any flow conditions including those which do not dessicate the substrate. The results of such short-term investigations should be used with considerable caution in producing water-quality response curves. As greater understanding is obtained through long-term investigation such as proposed by the USGS, more sophisticated models can be used with greater confidence than response curves.

3. Logistical Support Requirements:

Support is required for one river trip in FY 1990 for about 10 days to select specific sampling sites for the synoptic experiments and to make reconnaissance studies of water quality. In FY 1991, four synoptic experiments will be conducted, one each during October-November, February, May-June, and August. For each, about 71 scientists, sampling and support gear will be positioned in the canyon. Table 2 lists the sites and types of measurements and samples to be collected during each synoptic experiment. Transportation from Flagstaff to river sites and return will be required.

FY 1990:

Power boat for two 3-day trips upstream from Lees Ferry for three scientists. One river trip of about 10 days. Motorized raft with a 6-7 person scientific crew.

FY 1991:

Transportation from Flagstaff to river sites and return for about 71 scientists and associated sampling analysis and support gear. USBR houseboat at or near Columbine Falls to act as base camp for that site. Possible use of that houseboat fro base camp for Bridge Canyon site if motor boat capable of commuting is available.

E. Tasks and Research Timetable:

FY 1990:

Chemical-Quality Reconnaissance: The FY 1990 effort will be a reconnaissance to make field measurements and to collect water samples for laboratory analyses. The trip also will familiarize key personnel with the river environs and will establish specific sampling sites for the synoptic experiments to be conducted in early FY 1991. Sites for intensive chemical study, such as dissolved organic carbon (DOC) and dissolved oxygen (DO) will be located and measurements made.

Biological Reconnaissance: Benthic invertebrate sampling and some primary production measurements will be made on the same river trips as the quality reconnaissance. We expect the primary production measurements to be made in collaboration with the Arizona Department of Game and Fish. Drift samples will be collected at the synoptic sites listed in table 2.

FY 1991:

Chemical Quality: Four synoptic experiments covering six flow regimes will be conducted in FY 1991. The synoptic experiments will be in October-November, February, May-June, and August and will cover the chemical constituents listed in table 1, at the sites listed in table 2. In addition, we will make field measurements and collect water samples at select sites of opportunity during other parts of the year.

Biological Quality: Biological measurements will be made during the synoptic experiments shown in table 2. These will include algal growth potential (AGP), drift, benthic invertebrates, and coliform bacteria. In addition, primary production measurements will be made at sites of opportunity between the dam and Columbine Falls with more intensive measurements being made between the dam and the Little Colorado River.

F. Products:

FY 1990:

A report will be prepared on the reconnaissance studies in the river, including water chemistry, and biological findings.

FY 1991:

1. A report on the findings of the first (October-November) and second synoptic experiment (February 1991) will be prepared.
2. Data for the third and fourth synoptic experiments (May-June and August) will be analyzed and tabulated.

G. Budget: (for total water quality)

The hastily assembled budget figures below are based on anticipated events that depend on plans and decisions not under our control. We, therefore, recommend these be considered rough estimates, which in the metaphor of GCES II, we believe are in the vicinity of our 75-percent confidence level.

	FY 1990	FY 1991
Salaries[1]	$ 41,800	$ 88,000
Equipment and supplies[2]	175,500	27,000
Travel[3]	11,000	644,900
Sample analyses	17,900	248,000
Subcontracts	none	none
Total	$246,200	$1,007,900

[1]Labor includes the cost of 1/2 FTE for logistic coordination of sampling events. No labor costs for the 71 people involved in sampling events or analytical computation or reports are being charged to this project.

[2]Equipment includes only accomodation support of sampling teams (i.e. camp equipment, etc.). All sampling equipment will be provided by USGS. Costs of four zodiac-type boats with 3.5 to 5-horsepower motors for four of the sites are not included. If boats are not available from USBR or NPS, each boat will cost approximately $2,000.

[3]Analyses costs include all water and sediment chemistry, suspended- and bed-sediment samples, bacteria, and AGP. Costs for drift and benthic-invertebrate sample analyses will be determined when other agencies define their needs.

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PROPOSAL: LAKE POWELL WATER QUALITY

United States Geological Survey

March 28, 1990

A. Abstract

This proposal describes a research plan for determining the water-quality characteristics of Lake Powell and the effects on the downstream environment and addresses the potential mitigation alternative H.17, "If a variable intake structure is used on Glen Canyon Dam, what will be the effects of intake at various levels on the downstream ecosystem?" This mitigation alternative was presented in the Glen Canyon Environmental Studies memorandum, dated February 28, 1990. Other alternatives and research hypotheses are presented in this memorandum. Data-collection activities described in this proposal will be used to evaluate the following hypotheses: H.4, Effects of Trout; H.6, Effects on Native Fish; H.7, Primary Productivity; H.8, Recreational Values; H.11, Fishing Activities; and H.14, Recreational Activities.

The objectives of this proposal include 1) determine the general water-quality characteristics of the dam pool, 2) determine temporal and spatial variations in water quality, 3) determine chemical and thermal stratification and distribution near the penstocks, 4) determine factors that affect nutrient levels at the penstocks, 5) determine the standing crop of phytoplankton and zooplankton, and 6) integrate results of this study with concurrent water-quality studies of the downstream environment. The proposal also addresses the integration with other research plans, provides background information, discusses sampling methodology, logistical support requirements, tasks and research timetables, products, and budget.

B. Introduction

This proposal is presented in response to a March 2, 1990 request for submissions to address individual hypotheses concerning the effects of the operation of Glen Canyon Dam (GCD), on resources in Grand Canyon National Park (GCNP) and Glen Canyon National Recreation Area (GCNRA). The request was issued by the U.S. Bureau of Reclamation (USBR) with the intention of obtaining information pertinent to a U.S. Department of the Interior mandated Environmental Impact Statement (EIS). U.S. Geological Survey (USGS) scientists believe that a decadal-scale interdisciplinary investigation of pertinent riverine and riparian processes will be required to adequately answer the questions raised by the EIS and have prepared a comprehensive proposal to address the pertinent issues. This submission presents pertinent aspects of studies of water quality in Lake Powell to be completed during the first phase of the more comprehensive investigation. A copy of the complete proposal is included in the USGS submission package.

1. Problem Statement:

This proposal addresses the potential mitigation alternative H.17, "If a variable intake structure is used on Glen Canyon Dam, what will be the effects of intake at various levels on the downstream ecosytem?" The present operation of Glen Canyon Dam has the penstock intake in the hypolimnion of Lake Powell. This produces water that in summer is colder than the predam river. The nutrient and sediment concentrations of this water are also different than predam river water. The temperature and nutrients in the water discharged below the dam directly affect the primary production of the river which supports other aquatic organisms. The tailwater trout fishery is successful because of the increased primary production and the lower summer river temperature. Other river biota also respond to the quality of dam discharges. An increase in the tailwater discharge temperature may benefit both native fish species and the trout. A mitigation technology that could address the need to control the temperature of the discharge is to retrofit a variable-level intake structure on the dam, similar to that on Flaming Gorge Dam. This would also affect the quality of the discharge and may cause other changes to occur in the ecosystem below the dam (Patten, written commun., 1990). For example, water removed near the surface of the lake will contain more algae and zooplankton and less soluble nutrients.

2. Objectives:

The objectives for this study are: 1) determine the general water-quality characteristics of the dam pool, 2) determine temporal and spatial variations in water quality, 3) determine chemical and thermal stratification and distribution near the penstocks, 4) determine factors that affect nutrient levels at the penstocks, 5) determine the standing crop of phytoplankton and zooplankton, and 6) integrate results of this study with concurrent water-quality studies of the downstream environment.

3. Process of Integration with Research Study Plan:

This study is designed to complement and incorporate other Glen Canyon Environmental Studies (GCES) and USGS research activities on the Colorado River, during the EIS and beyond. The sampling and monitoring of Lake Powell will be coordinated closely with Arizona Game and Fish Department (AGFD) and National Park Service (NPS), to assure that all interests and concerns are covered and that sampling and analysis techniques are compatible.

The water-quality data collected for this study will be useful in evaluating the following hypotheses: H.4, Effects on Trout; H.6, Effects on Native Fish; H.7, Primary Productivity; H.8, Recreational Values; H.11, Fishing Activities; and H.14, Recreational Activities. Water-chemistry measurements of the lake will be important for future evaluations of the river.

C. Background

Lake Powell acts as a sink for sediments as well as to modify incoming loads of nutrients in chemical composition and amount. Several studies of water quality of the river particularly between the dam and Lees Ferry have been made.

Water-quality data collection on Lake Powell has been done by the USBR since 1964. During 1971-1978, a study was conducted by a consortium of university groups supported by the National Science Foundation (U.S. Department of the Interior, 1981). The findings of this work are presented in a series of project bulletins and have been recently summarized by Potter and Drake (1989). Mayer (1977), investigated the effects of Lake Powell on dissolved silica cycling in the Colorado River, and Jacoby and others (1977), investigated evaporation, bank storage, and water budgets of the lake. Gloss and others (1980), investigated reservoir influences on salinity and nutrient fluxes in the Colorado River basin and discussed the trapping efficiency of sediments and nutrients of the lake. Paulson and Baker (1983) published a nutrient study of Lake Powell. They analyzed data collected from 10 stations on the main channel of the Colorado River and four stations on the main channel of the San Juan River arm, including inflow stations and the dam tailwater. They collected samples for primary production, chlorophyll a, total nitrogen, total phosphorus, and dissolved ammonia, nitrate+nitrite, and orthophosphate concentrations (USBR, written commun., 1989). A more recent report by Liebermann and others (1989), discusses the effects of the lake on dissolved-solids concentrations. Their findings show that storage has greatly reduced the variability in dissolved solids leaving Lake Powell.

Based on a 1989 memo from Bill Vernieu, a physical scientist for the USBR, to Dave Wegner, GCES Program Manager, there has been sporadic data collection on the lake. Nutrient analyses have been made on samples collected from selected tributary arms. Water samples have been collected from the Wahweap Bay area from 1964 to the present. Water-quality measurements with depth have also been made at this location. The memo also states that no organized plankton study has been made on Lake Powell, except during 1987 for a small number of samples collected in Wahweap Bay.

D. Methods:

1. Sampling Design:

During the EIS, the study will include point sampling through the water column in the dam pool at 4-5 locations near the dam. This is to determine spatial variability in water quality in relation to the eight penstocks. Sampling will be done in a 24-hour period at a frequency of every 6 hours to determine diel and seasonal variability. The water-column measurements will include dissolved oxygen (DO), pH, specific conductance, and water temperature. At least six depths in each vertical water column will be sampled for the constituents listed in table 1. Water samples will be collected directly from dam outlet structures at the same frequency and time as lake samples.

It will be possible to get an estimate of water-quality inputs to the lake by analyzing data from two USGS National Stream-Quality Accounting Network (NASQAN) stations located on the Colorado River near Cisco, Utah (09180500) and on the San Juan River near Bluff, Utah (09379500). Even though these gages are upstream in the basin a considerable distance from the lake, the data will still provide some measure of water-quality constituents entering the lake. Only those constituents currently being collected for the NASQAN program on a bimonthly basis at these stations will be used in analysis; no additional samples will be collected from these sites. By agreement with AGFD and NPS, all water samples will be analyzed by the USGS National Water Quality Laboratory. The more comprehensive USGS study includes long-term monitoring of selected sites in the lake for trend determination and consistency with other elements of the study.

Table 1.--*Selected chemical constituents to be measured in Lake Powell*

Major cations	Major anions
Ca	Cl
Mg	SO_4
Na	HCO_3/CO_3
K	
SiO_2	

Nutrients	Trace elements	
NO_3	As	Li
PO_4	B	Mn
NH_4	Ba	Mo
	Cd	Ni

Miscellaneous	Trace elements (cont.)	
	Co	Pb
pH	Cr	Se
Sp. Cond.	Cu	Tl
D.O	Fe	U
Light intensity		
Turbidity		

Biological Samples:

Total and dissolved organic carbon
Chlorophyll a
Phytoplankton
Zooplankton
Fecal coliform bacteria

2. Response curves:

If variable intake structures were installed in the dam, it would be possible to release water from the lake at various levels of the water column. This type of alternative mitigation structure would allow the reservoir manager to release water that might be more beneficial to selected downstream resources. It would be possible to construct response curves for various water-quality constituents and plot their response to different intake elevations. However, such curves should be interpreted with caution because withdrawal of significant amounts of water at prescribed elevations influences the vertical structure of the lake and this effect cannot be predicted without sophisticated hydrodynamic analysis.

3. Logistical Support Requirements:

It will require about five persons to conduct the Lake Powell study. A suitable boat for collecting water samples is needed. It must be large enough for a crew of three with space for profiling and pumping equipment and water-sample storage. It must have adequate speed to minimize traveltime between stations and a power winch adequate to sample to 600-foot depth.

E. Tasks and Research Timetable:

Sampling for the EIS phase of the more comprehensive USGS study will begin in July 1990 and will continue through July 1991. Results of water-quality analyses should be available 1-2 months after collection, depending upon the constituent.

F. Deliverables:

A USGS data report containing analyses of all samples will be published in an open-file report format. This report will be completed by December 1991. An interpretive report will be written describing water-quality characteristics and processes occuring in the dam pool area of Lake Powell. To meet the EIS timeframe of December 1991, this report will be released as an open-file report. All data will be available to USBR, NPS, and AGFD during the study.

G. Budget

The hastily assembled budget figures below are based on anticipated events that depend on plans and decisions not under our control. We, therefore, recommend these be considered rough estimates, which in the metaphor of GCES II, we believe are in the vicinity of our 75-percent confidence level.

	FY 1990	FY 1991
1. Personnel:	$39,400	$157,600
2. Equipment:	$15,500	$ 7,800
3. Travel:	$10,200	$ 22,400
4. Analysis:	$18,600	$ 37,100
5. Subcontracts:	-0-	-0-
Grand Total:	$83,700	$224,900

H. Literature Cited:

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Lieberman, T.D., Mueller, D.K., Kircher, J.E., and Choquette, A.F., Characteristics and trends of streamflow and dissolved solids in the upper Colorado River Basin, Arizona, Colorado, New Mexico, Utah, and Wyoming: U.S. Geological Survey Water-Supply Paper 2358, 64 p.

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U.S. Department of the Interior, 1981, Quality of water, Colorado River basin, Progress Report No. 10: U.S. Department of Interior, 189 p.

GLEN CANYON ENVIRONMENTAL STUDIES

PHASE II

A RESEARCH PROPOSAL

SUBMITTED TO

BUREAU OF RECLAMATION
UPPER COLORADO REGION
SALT LAKE CITY, UTAH

BY

ARIZONA GAME AND FISH DEPARTMENT
2222 W. GREENWAY ROAD
PHOENIX, ARIZONA

APRIL, 1990

ABSTRACT

This research proposal addresses studies which the Arizona Game and Fish Department feels need to be completed during Phase II of the Glen Canyon Environmental Studies as part of the ongoing Environmental Impact Statement. Two research areas, titled (1) Ecosystem-Level Processes and Lower Trophic Levels, and (2) Trout Studies, with a combination of eight major objectives are treated in the proposal. An additional proposal treating native fishes, with emphasis on the endangered humpback chub, is in preparation as part of the Section 7 Consultation on the Operation of Glen Canyon Dam. We emphasize that effects of dam operations on critical biological resources of particular interest to management agencies cannot be determined sufficiently by studying direct impacts on those species. Indirect effects of dam operations on sport and native fishes, originating in controls on water temperature, sediment delivery and transport, nutrient delivery and cycling, and production and distribution of food resources, also must be considered. The importance of these factors to the welfare of fishes is not diminished simply because they do not always cause direct mortality.

INTRODUCTION

The first segment of the Glen Canyon Environmental Studies (GCES Phase I) demonstrated that current operation of Glen Canyon Dam is producing negative effects on some downstream natural and recreational resources (U.S. Department of Interior 1988a, b). Although total concurrence on the magnitude of these effects has not been reached, there is agreement among involved agencies and the Department of Interior that further studies, with emphasis on effects of low and fluctuating flows, are justified on introduced trout, endangered species, and sediments (U.S. Department of Interior 1988b, c). Additional support for an even broader scope of studies was voiced by the National Academy of Sciences committee that reviewed the completed phase of GCES (National Research Council 1987). Research to satisfy these information needs is being conducted to complete both the Environmental Impact Statement and Section 7 Consultation on the operation of Glen Canyon Dam.

The agreed upon approach for the studies is to use a series of controlled flows (steady and fluctuating) as "treatments" whose effects will be measured on the resources of interest. Normal operations flows, which are expected to approach those of 1989 release schedule, will also be evaluated. Broad hypotheses have been generated to test the effects of different driving variables, i.e. magnitudes of fluctuation, discharge minima, and rates of change in discharge (ramping rates), on selected resources. Resource responses will be analyzed, to the extent possible, through construction of response curves relating the direction and magnitude of change in resource states to different levels of the driving variables during a variety of flow regimes.

The following proposal addresses research needs for ecosystem-level processes, lower trophic levels, and trout, which the Arizona Game and Fish Department (AGFD) feels are necessary to answer important management questions concerning the effects of dam operations on these resources. The proposed period of field research is from June 1990 through June 1991, as agreed upon during the GCES Technical Team meeting of March 8, 1990. All or part of the following two research questions are addressed in this research proposal:

(1) How are water quality (nutrients and other characteristics) and stream productivity (algae and invertebrates) affected by discharge fluctuations, minimum discharges, and the rate of change in fluctuating discharges?

(2) How do discharge fluctuations, minimum discharges and rates of change of fluctuating discharges affect trout?

Additional proposed studies to answer similar questions concerning effects of varying flow regimes on native fishes, including the endangered humpback chub, are being developed under the Conservation Measures for the Section 7 Consultation on the operation of Glen Canyon Dam. This proposal is in development and will be forthcoming shortly.

Proposed studies are defined by objective, background information is given, and general methods are provided for the research designs to attain each of the objectives. Certain studies, as originally conceived, have either been modified or dropped from the research program, because of limitations imposed by the agreed upon controlled flow program or the time allocated for this research effort. AGFD also recognizes that critical studies concerning effects of the existing thermal regime in the Colorado River below Glen Canyon Dam need to be completed. We anticipate that these shortcomings will be addressed prior to completion of the Glen Canyon Dam Environmental Impact Statement, either as subjects of mitigation efforts or as additional studies to address concerns arising from the public scoping process and development of alternatives to current dam operations.

The scope of studies and suggested methodologies proposed for ecosystem-level processes and lower trophic levels are preliminary. We recognize that areas of overlap presently exist among studies proposed by different research groups. At least some aspects of these studies will be carried out cooperatively by research personnel of the AGFD, U.S. Geological Survey (USGS), and National Park Service. The Fish and Wildlife, Ecological Services Office (FWS/ES), Phoenix, Arizona, will also provide support for AGFD research activities. We anticipate that, following completion of a cooperative agreement, all organic matter and nutrient analyses will be carried out in the Denver USGS water quality laboratory according to standards agreed upon by all participating agencies.

ECOSYSTEM-LEVEL PROCESSES AND LOWER TROPHIC LEVELS

Problem Statement

The effects of dam operations on aquatic resources in the Glen Canyon Dam tailwater potentially begin with modifications to the physical and chemical environment, progress through successive trophic levels, and culminate in resources of particular interest to the public and management agencies. For example, pre-dam Colorado River waters carried enormous quantities of suspended sediment and had seasonally variable temperatures. Impoundment and deep hypolimnial release have acted to remove most sediment from the dam's outflow and produce perennially cold temperatures in the tailwater. Although tributaries to the Colorado River continue to provide sediment inputs, increased clarity of the water has allowed the development of algal communities not present prior to impoundment. The algal food base and reduced sediment transport in turn allowed the establishment of invertebrate species through stocking and natural colonization. Together the algal and invertebrate communities provide a food base for a cold-water trout fishery which, prior to impoundment, was restricted to a few spring-fed tributaries in Grand Canyon. As trout have flourished due to the changing environment produced by the dam, so have other warm-water sport and native fishes disappeared or been reduced in number and distribution.

The extent to which variable discharges from Glen Canyon Dam affect delivery and cycling of nutrients, transformation and decomposition of organic matter, primary and secondary production, and quality of food resources in the tailwater is largely unknown. Questionable conclusions exist in the literature, such as the statement of Petts (1984) citing Mullan et al. (1976) that ... "Luxuriant growths of filamentous green Algae...below Glen Canyon Dam...have been destroyed by the scouring action of daily discharge fluctuations of up to 140 m^3 per s...". Studies on lower trophic levels conducted during GCES Phase I were limited to those of algal and invertebrate distribution and abundance, effects of discharge on drift rates, diet of *Gammarus*, and effects of desiccation on the filamentous green alga *Cladophora glomerata*. These studies were conducted primarily under high, steady flows, and opportunities to determine the effects of low and fluctuating flows largely were preempted by these flow regimes.

Objective 1.1. Determine effects of different flow regimes on primary production and organic matter and nutrient (nitrogen, phosphorus, and silica) loading rates and budgets for the Glen Canyon Dam tailwater to Lee's Ferry.

Background 1.1. Studies to date on the effects of dam operations on aquatic resources below Glen Canyon Dam have centered on key species or taxonomic groups (Persons et al. 1985, Leibfried and Blinn 1987, Maddux et al. 1987, Usher et al. 1987). Little attention has been given to ecosystem-level processes that ultimately are important determinants of fish production. These processes, including primary production, nutrient uptake and regeneration, and transformation of organic matter between dissolved and particulate states, are affected by dam/reservoir-mediated discharge regimes, water temperature, and inflow chemistry (Petts 1984).

The nutrient supply in waters released from the hypolimnion of Lake Powell through Glen Canyon Dam is undoubtedly an important determinant of primary production in the upper reaches of the downstream tailwater, because external sources of input are largely absent. Water drawn from higher levels would vary from that of the hypolimnion in temperature, dissolved solids concentration, and nutrient and organic matter concentrations [Gloss et al. 1980, B. Vernieu, Bureau of Reclamation (BR), unpublished data]. Number and species composition of zooplankton would differ both as a function of level and timing of withdrawal (Sollberger et al. 1989).

Lake Powell is known to be an effective trap for sediments and nutrients entering from the Colorado River upstream (Gloss et al. 1980, Evans and Paulson 1983, Paulson and Baker 1983), and there is evidence from other reservoir studies (see Kimmel and Groeger 1986) that nutrient levels in Lake Powell may decline as the reservoir ages. It is considered to be oligotrophic, and phosphorus is indicated as the nutrient potentially limiting primary productivity (Gloss 1977, Paulson and Baker 1983).

The Colorado River between Glen Canyon Dam and Lee's Ferry apparently is a highly productive stream with large standing crops of benthic algae and invertebrates (Leibfried and Blinn 1987, Usher et al. 1987). Both zooplankton and phytoplankton communities are present in the tailwater, and the former, which may have its primary source in Lake Powell, apparently persists with little depletion through the 300 miles of river to Lake Mead (Haury 1987).

Predominant benthic primary producers are the filamentous green alga, *Cladophora glomerata*, and its epiphytic diatoms. These algae and the invertebrates which utilize them as food resources, primarily chironomids, oligochaetes, and the amphipod *Gammarus lacustris*, form most of the biomass of organic drift exported out of this reach. Available evidence suggests that the amount of drift exported is at least partly controlled by the magnitude and duration of fluctuating flows (Leibfried and Blinn 1987). The fate of this drift is unknown, but we suspect it may provide a major energy supply to downstream reaches where primary production appears to be limited by restricted light penetration caused by high amounts of suspended sediments (see Usher et al. 1987, Maddux et al. 1987). If so, detrital pathways in the lower river may be enhanced by fluctuating flows, but this enhancement may occur at the expense of upstream consumers of algae and invertebrates.

The Lee's Ferry reach is well suited for studies of production and organic matter and nutrient budgets relative to downstream reaches. Inputs are largely restricted to a single source, the outflow from Lake Powell through Glen Canyon Dam. Individual discharge events, which have a high degree of unpredictability in unregulated streams (Fisher and Likens 1973), are more predictable in this regulated system, and they will be especially so during the period of this study. The relatively small amount of groundwater which enters this reach is probably seepage from the reservoir through the sandstone forming Glen Canyon. The only tributaries entering the reach are highly ephemeral washes with small watersheds. Inflow from these washes and from sheetflow over the cliffs forming Glen Canyon is largely restricted to runoff during occasional summer thunderstorms. The riparian community is limited to a narrow corridor occupying talus slopes and beaches lying between the river and cliffs forming Glen Canyon.

Export of dissolved organic matter and nutrients at Lee's Ferry potentially can be measured as a function of input by allowing sufficient lag time for the water mass to move to this location from the dam. Preliminary results of dye transport studies conducted at a constant discharge of 5,000 cfs indicate rate of movement at this flow to be less than one mile per hour. Rates of transport for particulate components are unknown for this or other discharges; thus, staggered diel measures of both input and output may have to be made to allow for temporal differences in rates of transport due to fluctuating flows and differences among components.

Method 1.1a. Whole system primary production and respiration will be estimated at least monthly using diel dissolved oxygen changes (Odum 1956, Owens 1969, Fisher and Carpenter 1976) as measured by continuously recording instruments in reaches uninterrupted by riffles at low water. Contributions from benthic and planktonic components will be separated, respectively, by short-term incubation of phytoplankton and benthic algae in light-dark bottle combinations and circulating chambers. These measurements will be made along subsets of 20 transects established by the BR to determine sediment degradation rates in the Lee's Ferry reach (Pemberton 1976, Bureau of Reclamation 1986). The transects have been surveyed from established benchmarks several times since before impoundment. Thus, information exists on channel geometry, elevational contours, and substrate particle size distribution. Incubation periods are anticipated to be 2-4 hours, but exact times will be determined by studies conducted prior to the beginning of the controlled flow period.

Coincident measures will be made of incident solar radiation, light penetration at depth, and water temperature. Planktonic and, if possible, benthic primary production will be measured at sufficiently great depths to determine potential for light limitation. Benthic primary production will be measured at both continuously inundated sites and at sites within the zone of fluctuation following methods used in marine intertidal zones (Dawes et al. 1978, Dring and Brown 1982). Production per unit of chlorophyll *a* will be estimated from algal extractions in acetone or methanol and subsequent spectrophotometric determination with correction for degradation products (Wetzel and Westlake 1974).

Measurement of these variables will allow development of multiple regression equations to predict photosynthesis and respiration as functions of photosynthetically active radiation, temperature, and chlorophyll *a* concentration (Busch and Fisher 1981).

Separate equations will be developed for continuously wetted, dried and rewetted, and dried but not rewetted benthic algae. Extrapolations of the equations to areas subjected to these three conditions (from aerial photography and transect measurements) should allow estimates to be made of areal gains or losses in production under different steady and fluctuating flows.

Logistical Support: All field and laboratory measurements will be made by AGFD and FWS/ES personnel. Permits for research in the Lee's Ferry reach will be requested from the National Park Service, Glen Canyon National Recreation Area. Laboratory space and equipment are being provided by BR. Evaluation of areas affected by fluctuating flows for this and other objectives using BR transects will require that temporary staff gages and depth recorders be emplaced by USGS and that BR provide data on elevation/bottom area relationships for the transects.

<u>Method 1.1b.</u> Organic matter (including zooplankton) and nutrient inputs from Lake Powell will be measured by sampling waters passing through Glen Canyon Dam on a schedule complementary to that for primary production estimates; exports will be

sampled at Lee's Ferry, approximately 15 miles downstream. Stratified samples from a minimum of six depths (to include epilimnion, metalimnion, and hypolimnion when stratified) also will be taken from the reservoir above the dam to determine how input concentrations would change if water were drawn at different depths. Groundwater inputs from some springs already have been measured; the remaining springs will be sampled during the study. All aqueous inputs will be quantified both for concentrations of constituents and volume of inflow. Riparian inputs of organic matter will be measured as lateral transport following Fisher and Likens (1973). Throughfall and direct leaf input are expected to be insignificant relative to other inputs, because there is little lateral projection of riparian vegetation over the streambed.

Organic matter samples will be divided by passage through nets and filtration into three fractions: coarse particulate organic matter (CPOM, >1000 microns in diameter); fine particulate organic matter (FPOM, >0.7 microns and <1000 microns); and dissolved organic matter (DOM, <0.7 microns). Acid-rinsed Whatman GF/F glass-fiber filters will be used to separate FPOM from DOM. Zooplankton will be identified to at least the level of genus and enumerated. Nitrogen and phosphorus will be analyzed as total (Kjeldahl nitrogen and total phosphate phosphorus) and dissolved [nitrate-nitrite nitrogen, ammonia nitrogen, and soluble reactive (ortho)phosphate phosphorus] fractions separated by filtration through 0.7 micron glass-fiber filter. Silica will be measured from filtered water.

Each fluctuating flow collection series will be made initially to capture drift during the rising, maximum, falling, and minimum portions of the daily hydrograph. Comparative steady flow measurements will be made on the same schedule. Some constituents, in particular inputs of dissolved nutrients, may not exhibit diel variation. If this is confirmed, their collection will be reduced to once during the 24-hour sampling period. All FPOM and dissolved constituents will be measured from subsamples of well-mixed bulk samples. At the Lee's Ferry station, CPOM sampling will be attempted prior to the period of controlled flows with a large-bore diaphragm pump operated from a boat passing in a transect across the river. The pump hose will be alternately raised and lowered in a sinusoidal wave while the boat passes across the transect. This method was used during the October 1989 controlled flows and proved successful for collecting drifting *Cladophora*. Very few invertebrates were collected by this method, however, so an alternative method using a towed, metered net (mesh size 1000 microns) will be employed for comparative purposes. The most successful of these methods, measured by the diversity and mass of CPOM constituents, will be used during the controlled flows study.

Methodology for field preservation, storage, and laboratory determination of organic matter and nutrient concentrations will be as agreed upon by the participating agencies, but will conform to current standards of the Environmental Protection Agency and

American Public Health Association. Drift of the amphipod, *Gammarus lacustris*, will be separated from the remaining CPOM for use in the study of life history and secondary production (see Objective 1.2).

Budget calculations and comparisons will be patterned, to the extent possible, after Fisher and Likens (1973) with modifications as proposed by Cummins et al. (1983) and those made necessary by daily flow fluctuations, e.g. integration of daily import/export curves. Emphasis will not be on close estimation of annual budgets, but rather how these budgets are affected by dam-mediated flow regimes. We will attempt to measure the detrital storage pool, which we expect to be concentrated by hydraulics in large eddies and backwater areas, but are unsure how effectively this can be done. Measurements of mainstream discharge will be taken from Glen Canyon Dam and/or the two continuous recording USGS gages in the reach. We anticipate that a standardized relationship for these stations will be developed during the course of this study.

Logistical Support: We presently have permission for access to Glen Canyon Dam and the area of the drift tubes where sampling occurs. This permission will have to be extended for the duration of the study. Permission to access the area of Lake Powell inside the buoys above Glen Canyon Dam will be requested if deemed necessary.

Objective 1.2. Determine the life history, secondary production, and causes of mortality for the amphipod, *Gammarus lacustris*, in the Glen Canyon tailwater to Lee's Ferry.

Background 1.2. *Gammarus lacustris* is an important component in the diet of trout below Glen Canyon Dam (Persons et al. 1985, Maddux et al. 1987) and other deep hypolimnial release dams in western U.S. (Mullan et al. 1976, Johnson et al. 1987). Fluctuating releases from the dam increase drift rates of the amphipod (Leibfried and Blinn 1987), which apparently results in greater consumption by trout (Maddux et al. 1987). Thus, to the extent that the amphipod population can sustain the additional mortality resulting from fluctuating releases, these flow regimes may provide at least some short-term benefit to trout feeding and growth (Maddux et al. 1987).

Another potential source of mortality in *G. lacustris* is stranding in the "tidal zone" created by daily discharge fluctuations from Glen Canyon Dam. The amphipod has limited tolerance for water temperatures above 18 C (Smith 1973) that may occur in dry zones or isolated pools left by the receding river. Tolerance to desiccation is unknown, but large-scale mortality by stranded individuals has been observed on numerous occasions in the Glen Canyon Dam tailwater (D. Kubly, AGFD, personal observation).

No information is available on the life cycle, growth, or production of *G. lacustris* in the Glen Canyon tailwater. Furthermore, there is little information on the ecology of this amphipod in running water, although numerous studies have been conducted on congeners (see Marchant 1981 for a review). Without this information the short-term versus long-term costs and benefits to trout production from increased amphipod mortality cannot be assessed. Trout may well benefit from increased supplies of amphipods in the short term, but be forced to accept other, less energy-rich food resources in the long term if amphipod mortality and export via drift exceeds capacity for production.

Studies conducted on *Gammarus* diets indicate that in lotic environments these amphipods generally subsist mainly on allochthonous detritus, although small amounts of algae and animal remains are also consumed (Hynes 1954, Moore 1975, Marchant and Hynes 1981). *G. lacustris* may be more herbivorous than other congeners (Moore 1977), and in the Glen Canyon Dam tailwater this species appears to prefer some diatom species over other diatoms and filamentous green algae (Blinn et al. 1986).

The Colorado River below Glen Canyon Dam assumedly receives small allochthonous organic matter inputs, because the associated riparian zone is limited by aridity and bordering bedrock. Occasional flushes of organic matter may arrive from the few ephemeral tributaries entering the reach, but these inputs are very sporadic and rare. Preliminary indications from organic matter analyses of water entering the reach through Glen Canyon Dam suggest that coarse particulate matter is absent, and that the dissolved fraction is predominant (AGFD unpublished data). Therefore, the Lee's Ferry reach population of *G. lacustris* may well depend almost entirely on autochthonous primary production for its food resources.

Method 1.2a. Collections of *G. lacustris* and other benthic invertebrates will be made at least monthly by stratified sampling from sand, gravel, and rubble substrates with and without vegetation (Gosse 1981) using a Ponar dredge or other suitable sampling device. These samples will be taken to the maximum depth possible from among the same 20 transects (Resh 1975) used for estimation of primary production. If necessary, these samples will be supplemented with those from artificial substrates used to determine colonization rates of algal and invertebrate populations (see Objective 1.6). Subsamples of amphipods (minimum of 200 individuals) will be divided into size frequency classes by measurement with a dissecting microscope and ocular micrometer. Potential recruitment will be estimated from fecundity measures of sampled females and their mean densities. All individuals in each size frequency class and the remaining individuals will then be held at 90 C for dry weight and burned at 500 C for ash-free dry weight. Standing crop estimates will be calculated from mean densities by substrate type (weighted by estimated areal proportions of substrate types in the Lee's Ferry reach, data from M. Yard, GCES Flagstaff) multiplied by mean ash-free dry weight. Secondary production will be estimated by the size-frequency method (Hynes and

Coleman 1968, Hamilton 1969, Benke 1979) with approximate 95% C.L. for production and production/biomass ratios calculated following Krueger and Martin (1980).

<u>Method 1.2b</u>. Relative mortality (or losses *via* export) of different size/age classes will be determined as instantaneous rates calculated from differences in logarithms of abundances between successive sampling periods (Marchant 1981). Partitioning of these losses (potential or realized) will be estimated for stranding, drift, fish predation, and old age.

Potential mortality due to stranding will be estimated seasonally from perforated trays containing local substrates set in transects across the zone of fluctuations and in stranding pools. Amphipods will be collected and placed in the trays as water recedes during a daily fluctuating flow cycle. Covered control trays will be placed at elevations that are continuously inundated. Prior to the rising water reaching the experimental trays, they will be removed and amphipod mortalities will be enumerated. Control trays will be retrieved at the time the last experimental trays are removed. In order to investigate longer periods of exposure, such as occur during extended weekend and holiday flows, additional trays will be placed above the level of the maximum flow. These trays will be removed after intervals of two and three days. Additional control trays will be emplaced to be removed at these same times. Dead and living amphipods will then be preserved separately and removed to the laboratory for evaluation of size, sex, reproductive condition, and gut contents.

We will attempt to estimate actual mortality from the above measurements and collections of amphipods deposited in the zone of fluctuation during single cycles. Fine-meshed seines will be laid over substrates on the same transects used to evaluate potential mortality. These seines will be held in place by cleaned rocks or artificial substrates. Following recession of the water line the nets will be retrieved and all amphipods will be collected. Actual mortality will then be estimated as the percentage mortality occurring in experimental trays multiplied by the number of amphipods obtained from nets.

Losses due to drift (not necessarily mortality) will be estimated from sampling under Method 1.1b. This measure admittedly may provide overestimates of drift losses from the reach, because amphipods also exhibit upstream movements (Elliott 1971, Meijering 1977). In order to compensate for this factor, we will attempt to measure upstream and downstream movements simultaneously with bidirectional shrimp traps covered with 1 mm mesh Nitex.

Mortality due to fish predation will not be measured absolutely, but analysis of trout gut contents taken over 24 hour periods of fluctuating and steady flows will provide an index of feeding rates to be compared against the flow regimes and time of day. Flow regimes will be partitioned into four compartments: (1) rising limb; (2) maximum flow; (3) falling limb, and; (4) minimum flow. Time of day will be divided into three compartments: (1) sunrise and sunset; (2) mid-day, and; (3) night. Only amphipods found in the anterior half of the stomach will be counted in an attempt to exclude feeding at times other than those being evaluated.

Method 1.2c. The diet of *G. lacustris* retrieved during mortality experiments will be analyzed by excision of guts and microscopic determination of contents. Individuals used for analysis will be separated by size class, substrate of origin, and length of exposure. Visual estimates of gut fullness will be made, and contents will be enumerated and classified both taxonomically and with respect to probable origin (benthic, planktonic, and terrestrial). Particular attention will be given to the dependence of the amphipod on *Cladophora* and its epiphytic diatoms.

Objective 1.3. Determine the effects of fluctuating flows on algal and invertebrate colonization rates, standing crops, and community composition.

Background 1.3. One aspect of the effects of fluctuating flows on benthic algae and invertebrates that is little understood is the degree to which varying periods of desiccation during different seasons inhibit the successful colonization and growth of different species (see Ward 1976, Armitage 1984, Decamps 1984, Petts 1984). Usher et al. (1987) found that the standing crop of *Cladophora glomerata* and its epiphytic diatoms decreased significantly with depth in the Glen Canyon Dam tailwater, but did not relate depth to time of exposure. In laboratory experiments having continuously inundated and 12 hour desiccation treatments, they also observed mortality and reduced standing crops of the desiccated filamentous alga. Similar experiments have not been conducted on any of the benthic invertebrates in the Glen Canyon Dam tailwater.

Method 1.3. Our study design for colonization studies involves the use of artificial or cleaned natural substrates set in transects (see Method 1.2a) across the entire vertical and horizontal distance of the fluctuating water line. Lowest substrates will be continuously inundated, whereas those at the high water line will be exposed for a maximum amount of time dictated by the periodicity of flow changes and the ramping rates. Therefore, the design represents a "space-for-time" substitution analysis for effects of varying periods of desiccation on colonization and growth of benthic algae and invertebrate taxa.

Since the period necessary to measure colonization will undoubtedly exceed that of any controlled flow period (11 days), measured effects will be restricted to those realized from differing cumulative periods of exposure and desiccation. In order to measure the cumulative period of exposure, depth monitors and temporary staff gages will have to be emplaced on the transect lines. Present flow cycles probably will allow only comparisons of continuous inundation, intermediate exposure, and high exposure. Measured variables for this study will be the species composition and biomass or densities of benthic algae and invertebrate taxa on substrates from different levels after sequentially increasing periods of exposure and desiccation. Substrates will be emplaced in a block design with random removal from rows set at the same stage (elevation) in order to allow replication and statistical analysis of differences attributable to period of desiccation.

We recognize that these measures will not effectively separate differences in colonization and growth (gains) from those of drift and active movements (losses) off of the substrates. Thus, the observed differences will be net changes attributable to both effects. However, integration of these results with those of benthic primary production under varying periods of exposure (see Objective 1.1) should provide important corollary information for algae and allow additional important information to be gathered on other invertebrates than the amphipod, *G. lacustris*.

Objective 1.4. Determine the effects of different levels of exposure and desiccation on the nutritive quality of exposed algae.

Background 1.4. Effects of exposure and desiccation on algal and invertebrate species may be negative to production in one reach of the river, but benefit production in other reaches. For example, increased drift from the apparently autotrophic reach below Glen Canyon Dam may provide organic matter and nutrients for heterotrophic downstream reaches where primary production is limited by decreased light penetration from suspended sediments. Also, increased decomposition rates caused by exposure and desiccation may actually improve the nutritive quality of some food resources.

Cladophora is considered to be a poor quality food resource for trout, because the digestive systems of these fish are limited in their capacity to extract nutrients from the coarse, filamentous alga (Montgomery et al. 1986). It is also little used, at least prior to decomposition, by the amphipod, *G. lacustris* (Blinn et al. 1986). Upon subsequent drying and wetting, however, partial decomposition of the alga may make it more digestible and release nutrients which allow colonization and increases of bacteria further increasing nutritive quality. These same effects may be important to the conditioning *Cladophora* in a manner similar to that observed for leaves in north temperate streams (Kaushik and Hynes 1971). Usher et al. (1987) observed that the filamentous form of *Cladophora* resulted in layering upon stranding, and that this layering provided a moist, underlying environment resistant to desiccation. We observed this effect during the October 1989 controlled flow period and also noted that the algal filaments, both surface and underlying, underwent substantial decomposition.

Rainbow trout in the Colorado River below Glen Canyon Dam consume large quantities of the filamentous alga (Maddux et al. 1987). Several hypotheses have been given for this unexpected level of consumption, including lack of alternate food resources and indirect nutritive benefits gained from epiphytic diatoms and invertebrates growing on and within the filamentous algal mats. We propose to evaluate the hypothesis that some periods of exposure and desiccation may actually increase the nutritive quality and digestibility of the filamentous alga for trout.

Method 1.4. In order to determine the effects of different periods of exposure and desiccation on the nutritive quality of benthic algae, cobble-size stones or artificial substrates containing abundant growths of *Cladophora* will be removed from the river and subjected to exposure and desiccation. Triplicate samples from three rocks/substrates will be removed after periods of 6 hrs, 12 hrs, and 1, 2, 3, 5, and 7 days. These samples will be kept in the dark and chilled during transport to the laboratory. All analyses will be completed within 12 hours of removal from the field. Variables to be analyzed include chlorophyll *a*, phaeophytin, protein, lipid, and carbohydrate.

NOTE

THE OBJECTIVE TIMETABLE AND LITERATURE CITED REFERRED TO IN THIS STUDY PLAN ARE LOCATED WITH THE ARIZONA GAME & FISH DEPARTMENT'S TROUT PROPOSAL

A PROPOSAL TO STUDY
THE ECOLOGY OF AQUATIC DIPTERA
IN THE COLORADO RIVER BELOW GLEN CANYON DAM

A. ABSTRACT

Aquatic Diptera (Chironomidae and Simuliidae) are cornerstone resource species for higher aquatic and riparian trophic levels in the Colorado River corridor between Glen Canyon Dam and Lake Mead, Arizona. Little is known about the phenology, standing crop, taxonomy, dietary requirements, ecological role, or impacts of dam operations on these important taxa. In this proposal, we propose to conduct field surveys to determine the ecology and trophic importance of aquatic Diptera, and the impacts of dam operations on these populations in the Colorado River corridor downstream from Glen Canyon Dam. In addition, protocol will be used to monitor aquatic Diptera population dynamics in Grand Canyon.

B. INTRODUCTION

1. Problem Statement

Growing concern over the impacts of river regulation on environmental resources in the Colorado River corridor below Glen Canyon Dam encouraged the Department of Interior to develop the Bureau of Reclamation's Glen Canyon Environmental Studies Phase II (GCES-II) and, most recently, an Environmental Impact Statement. Following completion of GCES Phase I, the National Academy of Science recommended that further studies integrate interactive phenomena and processes at the ecosystem level in this system (Water Science and Technology Board 1987). Although management concerns have focused on the stability of sediment deposits and fisheries, other critical ecological components of this system include aquatic Chironomidae and Simuliidae. These aquatic Diptera taxa provide an important food base for fish and terrestrial fauna, linking the aquatic and terrestrial components of this ecosystem (Stevens and Waring 1988), but management strategies for aquatic Diptera may differ from those for sediment and fisheries. Consequently, aquatic Diptera deserve attention in the GCES-II/EIS research program. This study will greatly increase our knowledge of aquatic/terrestrial trophic relationships in the Colorado River ecosystem.

2. Specific Objectives

This study of aquatic Diptera is designed to elucidate the ecological significance and effects of discharge on aquatic Diptera in the Colorado River corridor downstream from Glen Canyon Dam through the following objectives:

Objective 1: Use existing collections and the present study to identify the species of aquatic Diptera that occupy the Colorado River corridor in Grand Canyon National Park, determine phenology, and provide the NPS with a reference collection.

Objective 2: Use standing crop studies in wide versus narrow reaches of the Colorado River (Schmidt and Graf 1987) to determine standing crop, dominance, phenology and habitat requirements of the dominant aquatic Diptera taxa.

Objective 3: Determine the trophic significance of aquatic Diptera in this fluvial ecosystem.

Objective 4: Determine the potential impacts of dam operations on aquatic Diptera taxa using survey and observational data, and experimental techniques .

Objective 5: Develop protocol to assist the NPS in monitoring aquatic Diptera in this system.

3. Integration with Research Study Plan

This proposal is designed to compliment and interact with studies proposed by Arizona Game and Fish Department on standing crop of macroinvertebrates in the Lees Ferry reach addressed by Patten (1990) in Research Questions (RQ) 4 and 6, and on aquatic productivity by the U.S. Geological Survey (RQ 7). This proposal bridges an important trophic interactions link between the aquatic and terrestrial ecosystem not otherwise addressed in GCES-II studies.

BACKGROUND

1-2. Literature, Previous and Related Work

Studies Outside the Grand Canyon: An enormous literature exists on the role of aquatic Diptera in stream systems; however, studies on the effects of river regulation on aquatic Diptera in the southwestern United States are few. Pearson (1967) compared the macroinvertebrate fauna of lotic environments in the Green River below Flaming Gorge Dam before and after impoundment. Invertebrate densities were highest immediately below the dam (mean density = 68,321/m^2) but the invertebrate community consisted of few species. A Baetis mayfly, chironomid midges, simuliid gnats and oligochaetes strongly dominated the tailwater invertebrate community. Species richness increased strongly with distance from the dam. Of a total of 76 taxa collected in the river prior to impoundment, nine species (mostly previously rare species) were extirpated, and 10 to 21 new species colonized the dam-altered environment. New arrivals to the system included taxa such as Arcynopteryx sp., Paraleptophlebia pallipes, and Hyallela sp. which colonized from nearby cool-water tributaries.

Pearson (1967) also evaluated behavioral (as opposed to catastrophic) drift of stream invertebrates in the Green River below Flaming Gorge Dam at several sites. Baetis (Baetidae) mayflies and simuliid gnats dominated the drift assemblage, with chironomid midges, various Trichoptera, and oligochaetes occurring less predictably. Multiple regression analyses indicated that drift was correlated with time of day (nocturnal drift predominated), temperature/dissolved oxygen, and invertebrate density. No correlation was observed between water level fluctuation and drift.

Studies in the Grand Canyon: River regulation by Glen Canyon Dam decreased turbidity and permitted increased algal growth on Colorado River-bottom substrates, changes which have apparently been responsible for greatly increased expansion of aquatic Diptera populations in the Grand Canyon reach. The aquatic macro-invertebrate fauna of the Colorado River corridor in the Grand Canyon is impoverished as compared to the fauna collected in the tributaries (Polhemus and Polhemus 1976; Stevens 1976 and pers. obs.; Hofknecht 1981; Blinn et al. 1988) and other systems (Polhemus and Polhemus 1976). Surveys of predominantly aquatic macroinvertebrates during the 1970's revealed a depauperate taxa as compared to other river systems and tributaries within Grand Canyon (Polhemus and Polhemus 1976; Table 1). Despite the depauperate nature of this river system, the few invertebrate taxa present play a disproportionately important role as food resources for higher trophic levels (Stevens and Waring 1988; Figure 1).

Among the few studies published on aquatic macroinvertebrates in the Grand Canyon reach, Hofknecht (1981) reported on the seasonal fluctuations in macroinvertebrate communities in the river prior to 1981. He reported limited invertebrate fauna in the "intertidal" zone of the river corridor at the mouths of tributaries. Carothers and Minckley (1981) documented the importance of chironomids in fish diets in the Colorado River.

Several Glen Canyon Environmental Studies Phase I projects examined other invertebrate taxa. Although quantification of invertebrate drift has been limited, drift is believed to be critical to fish population dynamics. Larval aquatic Diptera (Chironomidae and Simuliidae) of the Colorado River and its tributaries in the Grand Canyon play a large, if not over-whelmingly important, role as food resources for exotic and native fish, and adult Diptera feed hundreds of terrestrial insectivore species in the dam-regulated river corridor. Blinn and Leibfried (1988) reported that chironomid larvae were numerically dominant over Gammarus lacustris in the Colorado River drift, and comprised as much as 85% of the standing crop of drifting invertebrates. They also observed that in macroinvertebrate drift: 1) chironomids made up more than half the standing crop of macroinvertebrates in the river; 2) chironomid drift was not associated with fluctuating discharge but was associated with the amount of Cladophora glomerata in the drift; 3) macroinvertebrate standing crop decreased below the Little Colorado River (RM 61), from summer to winter, and was low in creek mouths relative to the mainstream; and 4) macroinvertebrate standing crop was positively correlated with Cladophora glomerata standing crop spatially and seasonally.

Haury (1988) documented the presence and distribution of 33 zooplankton species between Glen Canyon Dam and Diamond Creek (RM 226). He found no evidence of decreased zooplankton abundance with distance downstream, and suggested that backwaters may serve as refugia for some zooplankton species. Whether or not this may also be true for macroinvertebrates remains to be documented.

In contrast to the cold-water Colorado River, tributary streams in the Grand Canyon host a diverse assemblage of aquatic invertebrates, including one or more flatworm species, snails, zooplankton, and numerous Collembola, Ephemeroptera, Plecoptera, Odonata, Hemiptera (with numerous semi-aquatic taxa), Coleoptera, Trichoptera, Lepidoptera (Pyralidae), and Diptera, including numerous semi-aquatic taxa (Polhemus and Polhemus 1976; Stevens 1976; Hofknecht 1981). Contributions of macroinvertebrate standing crop from tributaries into the mainstream are unknown but may be important in the lower reaches where Cladophora density declines. Water temperature, water quality, substrate, and flooding strongly influence these populations, but taxonomic studies and ecological analyses are few.

Adult chironomid population fluctuations were examined by sweep-netting Tamarix ramosissima and Salix exigua stands in the river corridor from 1980 through 1984, and bagging whole branches in 1980 and 1982 (Stevens 1985; Stevens and Waring 1988). Chironomid densities were significantly higher on Salix as compared to Tamarix. Sweep-netting studies from 1980 through 1985 in the Grand Canyon showed that adult chironomid populations were lowest during years of high discharge and extreme fluctuations (Stevens and Waring 1988), but seasonal patterns were not discerned. Anecdotally, simuliid populations increased dramatically in the Lees Ferry area in 1984, presumably when Cladophora-free cobbles were most available for larval colonization after the 1983 flooding event (Stevens, pers. obs).

A Pilot Survey: A preliminary survey was undertaken in October, 1989 by Stevens (pers. comm.) to determine if and how dam operations influenced post-1986 aquatic macroinvertebrate distribution in the Grand Canyon reach. He made the following observations:

1) Chironomid larvae were not found in the "inter-tidal zone", above the approximate 4,000cfs stage, but simuliid larvae and pupae occurred rarely up to the approximate 12,000cfs stage.

2) Chironomid larvae were associated almost exclusively with Cladophora in the river, whereas simuliid larvae and pupae were associated almost entirely with bare rock surfaces.

3) Cladophora abundance and frequency on the floor of the river declined rapidly below the Little Colorado River mouth, and was virtually non-existent in the lower Canyon.

4) Species richness of chironomids in the river increased significantly downstream, with apparent dominance by Cricotopus (2 species) in the reach between Lees Ferry and Little Colorado River, whereas simuliid diversity remained relatively constant, with only one species apparent through most of the river corridor.

5) Larval chironomid and simuliid diversities and densities were high in tributaries, differed greatly among tributaries, and populations originating in the tributaries contributed significantly to the mainstream densities at the mouth of Diamond Creek (Simuliidae) and perhaps elsewhere.

6) Exposure by fluctuating discharges forced aquatic Diptera from their preferred substrates and both taxa were surprisingly vagile.

With regard to long-range impacts of dam operations, the above observations suggest that aquatic Diptera play an enormously important role in the trophic dynamics and interactions between aquatic and terrestrial components in the Grand Canyon (Figure 1). A fluctuating discharge regime that removes fine sediments and limits Cladophora distribution should favor simuliid populations in the river. In contrast, a constant discharge regime may increase Cladophora distribution and therefore chironomid density, depending on slope-area relationships of the river channel at different stages. Increased simuliid populations may decrease visitor satisfaction in the river corridor because simuliids are biting flies, and may decrease food availability for aerially-feeding birds and bats, as well as waterfowl. These insectivorous taxa serve as the primary food species for rare and endangered peregrine falcon, and their abundance has undoubtedly helped make the Grand Canyon home to the largest breeding population of peregrine falcon in the 48 contiguous states (Carothers pers. comm.). Possible effects on food resource availability for native and exotic fishes are unclear at present; however, wintering bald eagle presently rely almost exclusively on rainbow trout as a food resource, and trout diet is presently comprised largely of aquatic Diptera, especially Simuliidae. A discharge scenario that maintains a higher suspended sediment load in the river would probably decrease Cladophora distribution, and therefore decrease both chironomid and simuliid population densities. For these reasons, the study of aquatic Diptera in the Colorado River is timely and relevant to understanding the effects of Glen Canyon Dam operations on downstream resources.

D. METHODS

1. Broad Sampling Design

Objective 1: Use existing collections and the present study to identify the species of aquatic Diptera that occupy the Colorado River corridor in Grand Canyon National Park, determine phenology, and provide the NPS with a reference collection.

Simuliid and chironomid specimens in different life history stages will be obtained from the Arizona Game and Fish Department (AGF), the U.S. Geological Survey (USGS) synoptic studies, and the present study (Objective 2 below). The taxonomy of Simuliidae is rather well-known and reasonable keys exist for identification of larvae, pupae and adults (McAlpine et al, 1981; Peckarsky et al. 1985). Simuliid larval and adult specimens will be preserved in 70% ethanol and returned to the laboratory for preparation and identification, and identities will be verified at the U.S.D.A.'s Insect Identification Laboratory in Beltsville, Maryland.

The taxonomy of the Chironomidae is complex as compared to that of the Simuliidae, and chironomid specimens will require rearing and detailed preparation prior to identification (Townes 1945; McAlpine et al. 1981; Oliver and Roussel 1983; Wiederholm 1983, 1986). Rearing procedures will include maintenance of midge egg masses and larvae in vials containing water and small quantities of a nutrient mixture (ground alfalfa and "dog kisses" (Sublette pers. comm.). Larval, pupal and adult stages will be photographed and an illustrated key will be developed for monitoring purposes. Chironomid specimens will be preserved in 70% ethanol and slides of mouthparts and genitalia will be prepared in the laboratory. Specimens will be identified to species level, where possible, and verified by a qualified post-doctoral taxonomist.

Objective 2: Use standing crop studies in wide versus narrow reaches (Schmidt and Graf 1987) to determine standing crop, dominance, phenology and habitat requirements of the dominant aquatic Diptera taxa.

The standing crop, dominance, phenology and habitat requirements of aquatic Diptera will be assessed from the fall of 1990 to the fall of 1991 by censusing larval and adult fly populations in and along the river. Sampling will be conducted, by either ourselves, the USGS, or AGF, once every six weeks to assure overlap of generations for Chironomidae and Simuliidae. Sampling will be conducted, for the most part, at USGS synoptic studies sites or AGF tailwaters sampling sites. Wide-reach study sites will include:

just downstream from Glen Canyon Dam, the Lees Ferry area, the Little Colorado River confluence area, and a site near Granite Park not used by the USGS. Narrow-reach sites will include a site near South Canyon (not used by the USGS), the Grand Canyon gage near Phantom Ranch, the Havasu Creek station, and the Diamond Creek gage.

Five stages will be sampled at each site (upper-littoral, mid-littoral and lower littoral, < 1,000cfs and at the thalweg, as determined by Lowrance X-16 depthfinder) at each site. Samples will be collected using a Surber sampler where sufficient current exists, and a hand pump will be employed for low velocity sampling sites. At least eight samples well be collected at each stage, with the thalweg sample collected by Ponar dredge. Diving will be attempted seasonally during clear water flows to determine distribution of aquatic Diptera in the channel. Drift will be sampled with a 250 micron plankton tow suspended in the current at each site. Terrestrial sampling will include sweep-netting, black and white lighting, and spot sampling. Data included with each sample will include site, date, time of day, depth, water temperature, velocity, dissolved oxygen concentration, pH, substrate type, and microsite habitat conditions.

Seasonal river trips will be conducted at intervals between the USGS synoptic sampling periods, but the first trip will overlap with USGS sampling to compare sampling techniques. Thus research river trips will be conducted in October and December, 1990, and in April and July, 1991. Selected tributaries sampled by the USGS or AGF will also be surveyed for aquatic Diptera during these trips. Analysis of large tributaries is important because tributaries may play an increasingly important role in Diptera standing crop in the lower reaches of Grand Canyon. In all cases, sampling protocol will match that employed by the USGS and the AGF. Subsamples of collections made by the USGS and AGF will be obtained from each synoptic studies station.

A basket sampler (Britton and Greeson 1987: 158-159) will be used to contain silt, fine gravel and cobble substrates, to be placed at each sampling site matching the AGF and USGS protocol. These artificial substrates will be subsampled once every six weeks for standing crop of algae and macroinvertebrates.

All samples and subsamples gathered by USGS or AGF will be returned to the laboratory for sorting. Data will consist of species richness, density, and dry biomass standing crop. Dominance and phenology will be measured using taxonomic and abundance data.

Gut content analyses will be performed on several larval specimens of dominant aquatic Diptera species in each season to determine the importance of periphyton and phytoplankton species. All algal specimens will be stained with Lugol's iodine solution and preserved in 5% formalin, and identified to species level. Gut contents will be compared with phytoplankton and periphyton associated with Cladophora samples from these sampling times.

Data will be analyzed using parametric repeated measures and nonparametric statistical tests, with taxonomy, niche parameters, site, and season as predictors. The contrast between the zone of fluctuating discharge and the sublittoral zone is predicted to be significant, indicating a significant impact of dam operations on aquatic Diptera production.

Objective 3: Determine the trophic dynamics and significance of aquatic Diptera in this fluvial ecosystem (Table 2).

The role of aquatic Diptera in diets of native and introduced fish and other consumers will be reviewed and/or assessed using existing or collected stomach contents. These analyses will allow us to determine the trophic importance of aquatic Diptera to fish. Stomach contents of exotic and native fish species will be secured from collections made by the AGF and other ichthyological researchers.

The role of aquatic Diptera in the diets of terrestrial insectivores will be established by seasonal censusing of stomach contents of two **Bufo** species, four common lizard species, common avian insectivores, and bats in at least three wide reaches (Table 2). Ten specimens of selected terrestrial vertebrate taxa will be collected and either given an emetic or sacrificed, and stomach will be preserved in 70% EtOH. Specimens will be returned to the laboratory for sorting and identification.

Parasite loads in aerially-feeding vertebrates are known to be high in this system, and a pilot survey of aquatic Diptera/parasitism relationships will be undertaken. The significance of parasitism will be verified by dissecting 10 specimens each of white-throated swift and violet-green swallow, and western pipistrelle. Avian parasites will be identified by a qualified avian parasitologist. If the vector(s) are likely to be aquatic Diptera, parasite infestation will be assessed in aquatic Diptera populations using specimens collected during the field surveys (above). Other avian species (e.g. ruby-crowned kinglets, Say's phoebe, and others) may be collected if data warrant more extensive examination of the problem. Implications of dam management on vector population densities and peregrine falcon will be assessed.

The caloric value of Cladophora glomerata, selected diatom species, and selected aquatic Diptera taxa will be measured using microbomb calorimetry. Upstream and downstream values will be compared to determine whether caloric value changes with distance from the dam. These data will be used to evaluate aquatic energy dynamics in this system.

Objective 4: Use survey, observation and experimental data to determine the potential impacts of dam operations on aquatic Diptera taxa.

Observational and survey data collected in the above objectives will be used to determine whether and how dam operations influence aquatic Diptera standing crop and species composition. Behavioral responses and mortality effects of dewatering and desiccation will be evaluated by observation during controlled discharge tests, and tested experimentally in stream tanks at NAU and at Lees Ferry. The behavior (especially movement) of chironomid and simuliid larvae will be observed in basket samplers containing suitable substrates for both taxa, and compared with controls not subjected to dewatering. The basket samplers will be subjected to several treatments, including immersion at two depths, daily desiccation for 12 hours, and desiccation for two and four consecutive days/week, with continuous immersion as a control. At least 12 replicates will be run per treatment. Movement out of Cladophora (chironomids only) and into the water column or into fine sediments will be documented. Return to Cladophora following rewatering will also be documented. This experiment will be conducted from inflatable pontoon rafts with a supporting structure anchored in the current and a pulley system to raise or lower basket samplers. The experiment will be conducted for the life cycle of the dominant taxa, and will be replicated twice. Drift addition to populations will be eliminated by screening in-current water. Standing crop of larvae and emerged adults will be evaluated using multiple analysis of variance, with immersion schedule as predictor variable.

Objective 5: Develop protocol to assist the NPS to monitor aquatic Diptera in this system.

Based on results of these studies and experience gained with sampling methodology, a sampling program will be developed for long-term monitoring of aquatic Diptera populations in this system. Sampling protocol, preservation techniques and data analyses will be clearly defined and presented in a manual, along with identification sheets for each dominant species in the river.

2. Response Curves

The response curve approach emphasized by Patten (1990) may be used to evaluate discharge impacts on aquatic Diptera populations when the behavioral responses and mortality effects of dewatering and desiccation are known. The "inter-tidal zone" standing crop is most susceptible to direct discharge effects, but until we know how much standing crop is invested in that zone, we will not be able to determine the significance of those impacts. Understanding those relationships is of paramount importance in this study. Likewise, determination of the impacts of operational changes on aquatic and terrestrial insectivores is likewise dependent on standing crop in the "littoral" versus the "sublittoral" zone.

3. Logistical Support Requirements

The CPSU at Northern Arizona University will be responsible for overseeing this project, requiring 0.05 FTE from the Unit Leader. The National Park Service at Grand Canyon National Park will be responsible for collection permits, logistical support (motorized river craft) for the Lees Ferry experiments, and review of the study. Temporary housing will be required for laboratory analyses at Lees Ferry, and is requested from NPS-GRCA or GLCA during the summer, 1991. Permitting is required from Glen Canyon National Recreation Area for data collection in the Lees Ferry reach.
The BR GCES office is requested to provide river trip logistics, the loan of a depthfinder, 2 Ponar dredges and occasional permission to use the BR sport boat for river transport in the Lees Ferry reach. USGS and AGF are requested to provide subsamples of benthic and *Cladophora* for our analysis.

F. DELIVERABLES

Deliverables include post-trip and quarterly reports, and annual written and oral summaries of research in 1990 and 1991, as well as draft and final reports, a reference collection of photographs and specimens of aquatic Diptera for the NPS, and a monitoring protocol report (Table 3).

E. TASKS AND RESEARCH TIMETABLE

The schedule of tasks and research timetable are identified in Table 3.

G. BUDGET SUMMARY

The following budget does not include logistical costs for river trips, which will be paid by the Bureau of Reclamation.

ITEM	FY90	FY91	FY92	TOTAL
Personnel	7,232	64,286	11,031	82,549
Travel	1,311	6,522	560	8,393
Equipment	7,500	--	--	7,500
Supplies	1,750	9,740	550	12,040
Analyses	--	12,000	--	12,000
Subtotal	17,793	92,548	12,141	122,482
Overhead	3,559	18,510	2,428	24,497
TOTAL	21,352	111,058	14,569	**146,979**

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__________________. 1986. Chironomidae of the Holoarctic Region, keys and diagnoses, Pt. 2: pupae. Ent. Scand. Suppl. 28: 1-482.

Table 1: Macroinvertebrates occurring in the Colorado River in Grand Canyon National Park (data from Stevens 1976, and subsequent observations; Leibfried and Blinn 1988).

Platyhelminthes:	Planariid flatworm (one species)
Oligochaeta:	Oligochaete, species unknown Semi-aquatic lumbricids (at least 3 species)
Mollusca:	Aquatic snail(s), including _Physa_ Sphaeriid? freshwater clam
Amphipoda:	_Gammarus_ _lacustris_ (introduced)
Ephemeroptera:	Baetidae (one species)
Hemiptera:	Corixidae
Coleoptera:	_Hydrophilis_ near _triangularis_ (Hydrophilidae) Hydrophilidae sp. 1
Diptera:	Simuliidae (at least 3 species) Chironomidae (_Cricotopus_ _globistylus_, _C_. _annulator_, and other genera, at least 6 species)

Table 2: Dominant insectivores observed or expected to rely primarily on aquatic Diptera for food in the Grand Canyon.

INVERTEBRATES

Arachnida:	Salticidae, Clubionidae, Lucanidae, *Misumenops*
Formicidae:	*Pogonomyrmex californicus*
Reduviidae:	*Zelus renardii*, *Emesaya brevipenis*, and others
Coccinellidae:	*Hippodamia convergens*

FISH

Salmonidae:	*Onchorhynchus kissimee*
Cyprinidae:	*Gila cypha*

AMPHIBIANS

Bufonidae:	*Bufo punctatus*
	Bufo woodhousei
Hylidae:	*Hyla arenicolor*

REPTILES

Iguanidae:	*Uta stansburiana*
	Urosaurus ornatus
	Sceloporus magister
Teiidae:	*Cnemidophorus tigris*

BIRDS

Numerous Anseriformes
Spotted Sandpiper and other Charadriiformes
White-throated Swift
Black-chinned and other Hummingbirds
Violet-green and other Swallows
Ruby-crowned Kinglet
Common Bushtit
Various Warblers
Say's Phoebe and other flycatchers

MAMMALS

Numerous bats, especially *Pipistrellus hesperus* and *Myotis* spp.

Table 3: Tasks and research timetable for deliverables.

Initiate monthly sampling efforts; sampling site confirmation, equipment purchases	1 September, 1990
First quarterly report (QR)	15 October, 1990
Autumn sampling trip	October, 1990
Winter sampling trip	December, 1990
Second QR submitted	15 December, 1990
1990 annual and oral report	15 January, 1991
Third QR submitted	15 March, 1991
Spring sampling trip	April, 1991
Fourth QR submitted	15 June, 1991
Summer sampling trip	late June, 1991
Lees Ferry experiments conducted	June-August, 1991
Fifth QR submitted	15 September, 1991
Draft final report submitted	15 November, 1991
Second annual and oral report submitted, final report submitted	15 January, 1992
Draft monitoring protocol report submitted	15 February, 1992
Final monitoring report submitted, post-project oral report	15 April, 1992

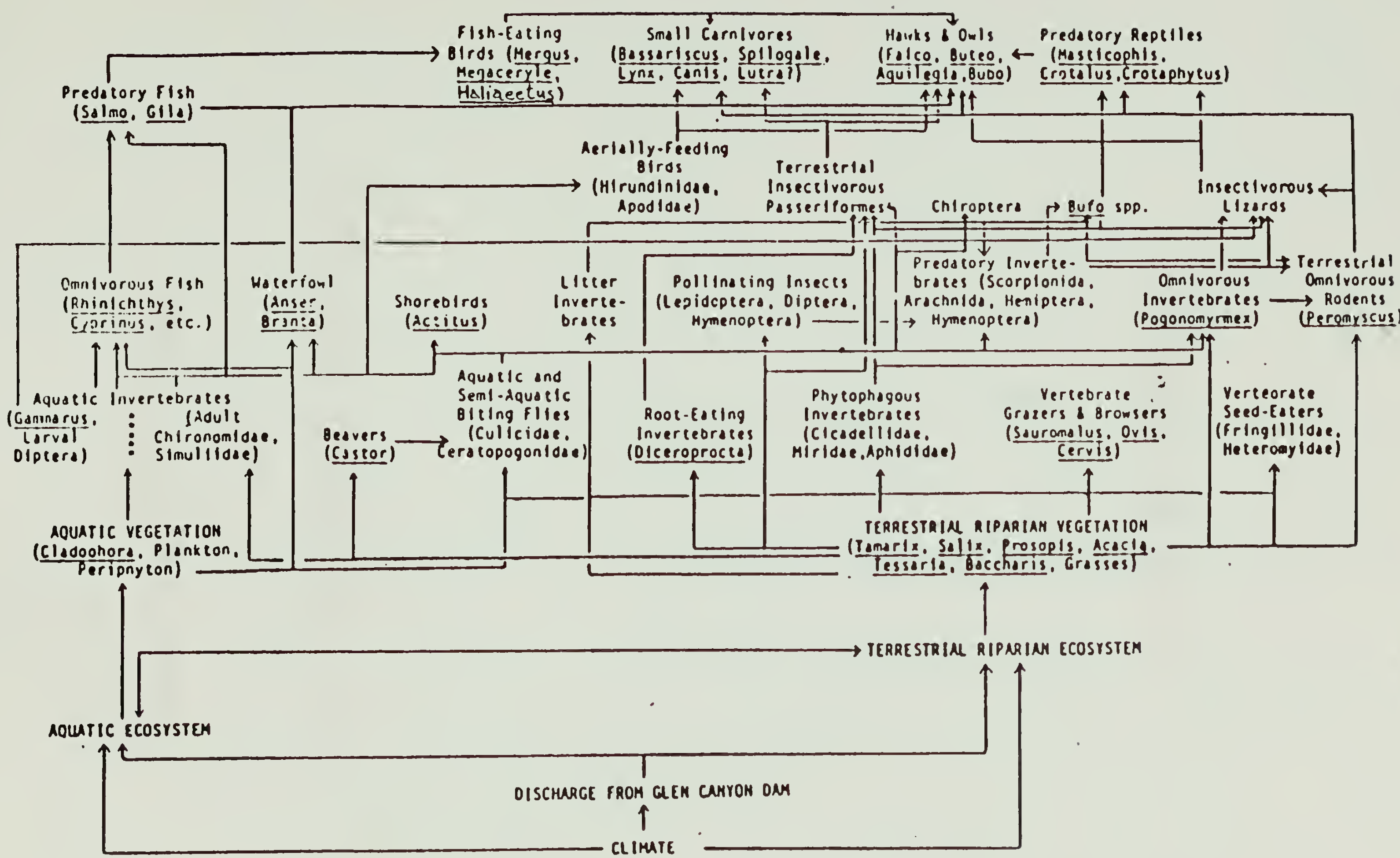

FIGURE 1: OBSERVED AND PROBABLE INTERACTIONS BETWEEN AQUATIC AND TERRESTRIAL COMPONENTS IN THE COLORADO RIVER RIPARIAN ZONE IN GRAND CANYON. AFTER STEVENS AND WARING (1988).

GEOMORPHIC AND GEOLOGIC

GLEN CANYON ENVIRONMENTAL STUDIES

PHASE II

INTEGRATED RESEARCH PROGRAM

GEOMORPHOLOGY AND GEOLOGIC INVESTIGATIONS

I. Issues

The geomorphology and geologic studies being conducted under the Glen Canyon Environmental Studies (GCES) Phase II research program have been developed because a need exists to understand the relationship between the operation of Glen Canyon Dam and the overall geomorphic and geologic environment in the Grand Canyon.

Several specific studies are being conducted on selected beaches in the Grand Canyon in an attempt to understand the causal relationships between the river flow and sediment deposition. A gap in our understanding is how the overall system responds to changes in operations and the reasons for the positioning of the sediment deposits in the Grand Canyon. The geomorphic components of the Colorado River corridor define the long-term sediment deposit relationships.

Additionally, the GCES archeology studies need to understand why the sediment deposits that have covered the cultural resource sites are now eroding away and how that is related to the operations of Glen Canyon Dam. The geomorphic and geologic character of the cultural resource sites will help to define their future in the Grand Canyon.

II. Objectives

The broad objectives of the GCES Geomorphic and Geologic Studies are stated as follows:

A. Determine the geomorphic relationship of the sediment deposits in the Unkar Delta area of the Colorado River and apply them to the archeological sites located in the Unkar Delta area.

B. Apply the knowledge gained at the Unkar Delta site to other cultural resource sites in the Grand Canyon.

C. Apply the knowledge gained at the Unkar Delta sites to other sediment deposits located in the Grand Canyon.

D. Develop a geologic map of the Unkar Delta area and locate the archeological sites in relation to the Colorado River. Identify geologic keys for understanding the potential for future erosion.

III. Components of the GCES Phase II Geomorphic and Geologic Studies

The components of the GCES Phase II Geomorphic and Geologic Studies can be separated into two primary areas and are defined in Figure 11.

A. Development of geologic maps of the Unkar Delta area

   1. Identify key geologic zones
   2. Identify location of archeological sites in relation to the geologic and sediment zones

B. Development of the Geomorphic history of the Unkar Delta area and apply to cultural resource and sediment studies.

   1. Identify key geomorphic relationships
   2. Apply geomorphic understanding to archeological and sediment studies

IV. Organization of the GCES Geomorphic and Geologic Studies

The overall organization of the GCES Geomorphic and Geologic studies will be guided by the GCES Scientific Core Group. Coordination will also occur with the GCES Sediment and Hydrology Team and the GCES Archeology Team.

The GCES Scientific Core Group, the GCES Sediment and Hydrology Team, and the GCES Archeology Team will take responsibility for the integration of the geomorphic and geologic studies into the overall GCES technical reports.

The Geomorphic and Geologic studies will be represented, as necessary, at the GCES Scientific Core Group meetings, the GCES Archeology Team meetings, and at the GCES Sediment and Hydrology meetings. The GCES Senior Scientist (and/or the GCES Sediment Research Analyst) and the GCES Office will have the ultimate responsibility to ensure that the Geomorphic and Geologic studies are integrated into the overall GCES program.

V. Products to be Developed

The GCES Geomorphic and Geologic studies will be responsible for the completion of the following reports:

A. Individual Research Reports - as defined in the Study Plan

B. Integrated GCES Technical Report - provide a synopsis of the results of the Geomorphic and Geologic studies for inclusion in the GCES final reports.

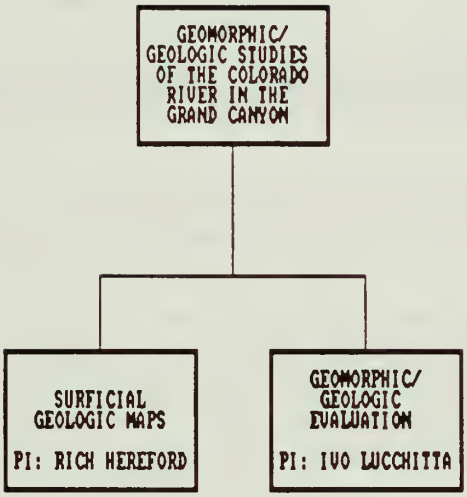

Figure 11. Glen Canyon Environmental Studies Phase II Geomorphic and Geologic Studies.

United States Department of the Interior

BUREAU OF RECLAMATION
UPPER COLORADO REGIONAL OFFICE
P.O. BOX 11568
SALT LAKE CITY, UTAH 84147

REPLY
REFER TO

GLEN CANYON ENVIRONMENTAL
STUDIES OFFICE

AUG 09 1990

RECEIVED
FLAGSTAFF, AZ

UC-824

AUG 03 1990

Memorandum

To: Benjamin A. Morgan, Chief Geologist, U.S. Geological Survey, National Center, MS-908, 12201 Sunrise Valley Drive, Reston VA 22092

From: ACTING Regional Director
Bureau of Reclamation

Subject: Intra-agency Acquisition No. 0-AA-40-09520 Entitled Intra-agency Acquisition for Support to the Glen Canyon Environmental Studies Archeological Surveys in the Grand Canyon (Intra-agency Acquisition)

Enclosed is a duplicate original of the subject Acquisition. The price of this Acquisition shall not exceed $236,682. Funds in the amount of $236,682 are hereby reserved to cover payments which may be due under this Acquisition during fiscal year 1990.

Also, enclosed is a notice of designation of Technical Representative for Mr. Dave Wegner. Mr. Wegner is located in the Glen Canyon Environmental Office, Flagstaff, Arizona, and will be responsible for clarifying all technical matters regarding the Acquisition. He can be reached at (602) 527-7363 or FTS 765-7363. Administration of the Acquisition will be handled by Mr. Ray Madsen of the Upper Colorado Regional Office. He can be reached at (801) 524-3267 or FTS 588-3267.

Please follow the requirements given in paragraph 9 of the Acquisition narrative when requesting payment from the Bureau of Reclamation.

Please acknowledge receipt of this notice of Acquisition award and notice of designation of Technical Representative by signing and returning the enclosed duplicate of this memorandum to the Bureau of Reclamation, Attention: UC-824, PO Box 11568, Salt Lake City, Utah 84147. We look forward to working with you.

RICK L. GOLD

Enclosures 3

bc: Deputy Assistant Commissioner - Administration
Attention: D-7800 (w/Acquisition)
Director, Administrative Service Center
Attention: D-2322 (w/original Acquisition)

bcc: UC-119 (w/o encls)
UC-333 (w/Acquisition)
UC-823 (w/original Acquisition)

BUREAU OF RECLAMATION
UPPER COLORADO REGION

INTRAAGENCY ACQUISITION
SUMMARY AND SIGNATURE SHEET

(1) Number: 0-AA-40-09520
Modification No.: ______

Performance Period:

From: See Block 10 To: September 30, 199

Effective Date: See block 10

2) Acquisition Title:

Intra-agency Acquisition for Support to the Glen Canyon Environmental Studies Archeological Surveys in the Grand Canyon

3) Authority: Pursuant to the Economy Act, 31 U.S.C. 1535 (1982), as amended.

4) Requesting Agency:
Name, Program Director/TR, Address, Zip

Bureau of Reclamation
Upper Colorado Region
PO Box 11568
Salt Lake City UT 84147

(5) Servicing Agency:
Name, Program Director/TR, Address, Zip

Ms. Rita Raines
U.S. Geological Survey
National Center, MS 908
12201 Sunrise Valley Drive
Reston VA 22902

6) Accounting and Appropriation Data:

060 0594 0901 324 0000
4013000
255S

(7) Funding:
Amount Reserved for Current Fiscal Year
$ 236,682

( ) Firm-Fixed Price
(xx) Cost Reimbursement
( ) Aggregate Ceiling Amount Not to Exceed $ 236,682

FY Funding Negotiated
FY-90 $ 236,682
FY-__ $ ______
FY-__ $ ______
FY-__ $ ______
FY-__ $ ______

8) Remarks:

(9) Submit Invoices To:

See Paragraph 9 of the Acquisition Narrative

10) Requesting Agency Authorization:

Rick L. Gold
Signature

8-3-90
Date

Name FOR Roland Robison
Title Regional Director

(11) Servicing Agency Authorization:

[signature]
Signature

5/17/90
Date

Name for Benjamin A. Morgan
Title Chief Geologist

INTRA-AGENCY ACQUISITION NO. 0-AA-40-09520
FOR
SUPPORT TO THE GLEN CANYON ENVIRONMENTAL STUDIES
ARCHEOLOGICAL SURVEYS IN THE GRAND CANYON

PROGRAM NARRATIVE

1. BACKGROUND. The Glen Canyon Environmental Studies (GCES) program was initiated in 1982 by the Department of the Interior (Department) as a component of the Environmental Assessment developed for the uprate and rewind program of the generators at Glen Canyon Dam. The objectives of the GCES program are to identify, quantify, and evaluate the impacts of the operation of Glen Canyon Dam on the natural and recreational resources in the Glen and Grand Canyons. The GCES program is a coordinated effort with expertise supplied by appropriate Federal, State, academic, and private interests.

The initial phase of the GCES program was completed in 1987 with publication of the final technical report, completion of the National Academy of Sciences review, and an analysis by the Department. The Department determined that additional data was required before any operational changes at Glen Canyon Dam could be evaluated properly. While the Phase II technical GCES studies were being developed, the Secretary of the Interior determined that an Environmental Impact Statement (EIS) was required.

Initiation of the EIS process requires that additional technical studies be initiated. Chief among these are studies associated with the archeological, geomorphic, and sediment resources of the Grand Canyon.

This Acquisition identifies the data requirements and personnel support required to evaluate the surficial geology, geomorphology, and archeological resources in the Grand Canyon along the Colorado River corridor.

2. OBJECTIVES. The objectives of this Acquisition are as follows:

(a) Provide geomorphological scientific support to the GCES related to the response of the Colorado River, through the Grand Canyon, to the operation of Glen Canyon Dam.

(b) Development of broad and site-specific surficial geologic/geomorphic maps of selected archeological areas along the Colorado River corridor in Grand Canyon National Park.

(c) Coordination with the GCES technical study teams on the design and development of the Geographic Information System for the geomorphic characteristics as related to the sediment deposits in the Grand Canyon.

3. <u>STATEMENT OF WORK</u>. The specific work items associated with this Acquisition will be discussed as related to each of the study objectives. In each case, the expertise required by the GCES program has been identified.

(a) **Objective 1.** Provide geomorphological expertise for the GCES in terms of the response of the Colorado River through the Grand Canyon to the operation of Glen Canyon Dam.

The GCES integrated research program requires a thorough understanding of how the Colorado River responds to the operation of Glen Canyon Dam and the regulation of the natural river flows. Since closure of the dam in 1963, the character of the annual water volume, water quality, sediment load, and other hydrologic variables has changed. The impact of the operational changes to the geomorphology of the Colorado River corridor has been extreme. Before evaluation of the impact of any flow modification on the river related resources, it is necessary to understand the long-term and broad-scale changes to the geomorphic environment that have occurred.

The work identified under objective 1 will include but not be restricted to the following:

1. Identify how the erosion and deposition patterns of the Colorado River within the Grand Canyon have responded to the operations of the Glen Canyon Dam.

2. Provide a thorough geologic/geomorphic discussion of why and how the changes have occurred and the significance of the changes to the overall Colorado River geomorphic system.

3. Identify the broad geomorphic trends that are likely to arise during future Glen Canyon Dam operations.

4. Identify potential geomorphic thresholds that might result from extreme and normal operations of Glen Canyon Dam.

5. Coordinate geomorphic studies with the sediment transport and deposit studies that are being conducted by the United States Geological Survey (USGS) Water Resource Division and other GCES scientists.

(b) **Objective 2.** Develop large- and very large-scale surficial geologic maps showing late-Cenozoic deposits and surfaces in selected archeological areas along the Colorado River corridor in Grand Canyon National Park.

Since the closure of Glen Canyon Dam in 1983, sediment deposits in the Grand Canyon have been subjected to varying degrees of stress. Along the river corridor through the Canyon, the National Park Service has identified numerous archeological sites which are covered by terrace forming alluvium. In 1983, 1984, and 1985, extreme high water releases were made from Glen Canyon Dam, resulting in a destabilization of the deposits in the river corridor alluvium. Since the establishment of strongly fluctuating flow in 1988, there has been accelerated erosion of the deposits along the river corridor, with the result that archeological sites are being exposed to river flows. Because of the impacts related to dam operations, the Bureau of Reclamation (Reclamation) is required to perform a complete class III archeological survey through the entire Grand Canyon river corridor and to identify the river-related impacts. Of primary importance to this understanding is the development of site-specific geomorphic/geologic maps of and near selected archeological areas.

The work identified for Objective 2 will include the following:

1. Preparation of a large-scale geomorphic/geologic map of the Furnace Flats area of the Grand Canyon at a scale of 1:5,000. This map will cover the river corridor from the Palisades Creek downstream to Unkar Delta (a distance of approximately eight miles from River Mile 65 to River Mile 73) and will be used to locate the archeological sites in the area.

2. Development of a very large-scale geomorphic/geologic map at scale of 1:1,500 of the entire Furnace Flats area (River Mile 71.5) describing how the river corridor and general Grand Canyon geology define the stability of the archeological areas. Both the 1:5,000 and the 1:1,500 maps will be coordinated in terms of geologic units.

3. Identify additional map areas in support of the archeological surveys to be completed by Reclamation and the National Park Service. If the areas are determined to be of importance to the overall GCES goals, then the USGS will be asked to prepare a feasibility report on the extent of the maps and the estimated cost of preparation.

(c) **Objective 3.** Coordination of the surficial geology and geomorphology studies with the other GCES technical study requirements and the development of a long-term Geographic Information System (GIS) that incorporates the geologic/geomorphic data base.

The GCES technical programs are developing the technical data bases required for long-term management of the Glen Canyon Dam. Inherent in the design and final products of the study is the development of a basic GIS for the Grand Canyon. The GCES portion of the GIS will be the development of selected nodes of information. The identified nodes are selected areas in the Grand Canyon where substantial amounts of data already overlap or where selected areas of additional study are identified.

A selection process with the primary GCES core researchers will be made. At the completion of the GCES program, the GIS system will be provided to the National Park Service for maintenance and further development. The requirements of objective 3 include the following:

1. Coordination of selection and development of nodes of the GCES Geographic Information System.

2. Coordination with other GCES technical teams.

4. DELIVERABLES. The specific deliverables required under this Acquisition are as follows:

1. Large-scale (1:5,000) surficial geologic map of the Palisades Creek to Unkar delta showing significant archeological sites and geomorphic/geologic features.

2. Very large-scale (1:1,500) surficial geologic maps with topographical control of the Furnace Flats area as related to the National Park Service archeological study areas.

3. A review of the recent changes produced by Glen Canyon Dam on the geologic and geomorphic regimen of the Colorado River in the Grand Canyon.

4. Annual reports, due October 30th, of pertinent activities accomplished during the preceding fiscal year and recommendations for action as related to future research efforts.

5. A report listing recommendations based on the geologic and geomorphic studies in the GCES/GIS program. Assistance in establishing the specific long-term monitoring nodes.

5. EXPERTISE REQUIRED. The completion of the objectives and work tasks identified in this Acquisition will require specific USGS expertise. In order to complete the detailed mapping of the National Park Service archeological resource sites, the services of Mr. Richard Hereford of the Flagstaff office will be required. The broad scale mapping requirements will be the responsibility of Dr. Ivo Lucchitta. Mr. Hereford and Mr. Lucchitta will collaborate on the geomorphic analysis. Coordination of their work requirements will be through the USGS Western Region office with specific GCES coordination provided by the GCES Flagstaff Office and the GCES Program Manager.

Time commitments are estimated as follows:

Personnel	FY-90	FY-91
Lucchitta	1/2 time	1/2 time (option)
Hereford	1/2 time	1/2 time (option)

6. TIME FRAME. This Acquisition will be in effect for fiscal year 1990, with an option for fiscal year 1991 if the Glen Canyon Dam Environmental Impact Statement process is unfinished or if the GCES program requires additional USGS support. If additional services are required, Reclamation and the USGS will negotiate and develop a modification to this Acquisition.

7. PROPERTY. The equipment utilized under this Acquisition must satisfy Reclamation requirements as related to property in the possession of contractors, grantees and cooperators. The purposes of the clauses and requirements identified in this section are to provide for a consistent and complete understanding of the equipment requirements as related to this Acquisition.

Property Identification. Government-owned property means all property owned by or leased to the government or acquired by the government under the terms of the contract. It includes both government-furnished property and contractor-acquired property as defined below.

(a) Government-furnished property is property in the possession of or directly acquired by, the government and is made available to the contractor.

(b) Contractor-acquired property is property acquired or fabricated by the contractor or otherwise provided by the contractor for performing a contract and to which the government has title.

Nonexpendable Property. Equipment which is complete in itself and does not ordinarily lose its identity or become a component or part of another piece of equipment when put in use. Nonexpendable personal property includes the following:

(a) Any single item, having a useful life of 1 year or more, which is acquired at a cost of, or valued at $50.00 or more;

(b) Sensitive items identified by the contracting office, regardless of acquisition cost;

(c) All office furnishings and furniture.

Property Identification. The contractor is required to identify and label all government property and to keep it separate and distinct from all other property in the contractor's possession. No government property shall be or become a fixture or lose its identity by incorporation in or attachment to property not owned by the government except when required to be incorporated into or attached to an end product to be delivered under the contract.

Property Records. The contractor shall establish and maintain adequate control records for all government property provided/acquired under the contract including any that may be in the possession or control of any subcontractor.

Separate records must be established and maintained for each contract in accordance with the requirements of this section.

Nonexpendable Property Records. The official records must be kept in such condition that at any stage of the contract performance the status of government property can be readily ascertained. The contractor's property control system must provide a means of locating any item of government property within a reasonable time. Property fabricated by the contractor from government-owned materials must be recorded as government property immediately upon fabrication. Property fabricated from contractor-owned materials must be recorded as government property at the time title passes to the government as provided by the contract.

For each item of nonexpendable government property the contractor is required to maintain an individual item record containing the following minimum information:

1. Contract number
2. Name of item
3. Government identification number (Project control Number)
4. Manufacturer's name
5. Manufacturer's serial number
6. Manufacturer's model number
7. Acquisition document reference and date
8. Guarantee and warranty lapse date
9. Location
10. Unit price

Accessory and component equipment that is attached to, part of, or acquired for use with a specific item of equipment must be recorded on the record of the basic item. Any accessory or component that is not attached to, part of, or acquired for use with a specific item of equipment must be recorded separately. Useable accessory or component items that are permanently removed from items of government property must also be separately recorded.

Property Inventory. The contractor is required to perform annually a physical inventory of nonexpendable government property in his possession or control and to require such inventories of any subcontractors that are in possession of government property provided under contract. The results of the inventory shall be reconciled with the property records. Any differences between quantities determined by physical inspection and those shown in the property accounting records shall be investigated to determine the cause of the difference. The contractor shall, in connection with the inventory, verify the existence, current utilization, and continued need for the property. The contractor shall submit the results of the physical inventory within 30 days of completion annually.

The contractor is required to submit to the Contracting Officer the following information:

1. A list of all items of nonexpendable property provided under contract. This shall include the name, make, identification number, and the acquisition cost or value of each item.

2. A list of all discrepancies disclosed by the inventory.

3. Identification of all items of property no longer required for performance of the contract.

Personnel who perform the physical inventory shall not be the same individuals who maintain the property records or have custody of the property unless the contractor's operation is too small to do otherwise.

Property Inventory Upon Completion or Termination of the Contract. Immediately upon completion or termination of the contract, the contractor is required to perform a physical inventory for disposal purposes of all government property, and to require similar action of any subcontractors in possession of government property applicable to the terminated or completed contract within 30 days after the contract completion or termination, unless the Contracting Officer specifically approves, in writing, an extension of time. The prime contractor shall submit a final inventory of government property (including subcontractor property) in the form and detail as prescribed below:

Form. Separate records are required for government-furnished property and for contractor acquired property and for each of the following property categories:

1. Real property
2. Nonexpendable personal property
3. Expendable personal property
4. Materials
5. Salvage
6. Scrap

Detail Required. Each item of nonexpendable property must be completely identified with sufficient detail to permit verification by reference to the covering reimbursement voucher or, if furnished by the government, transfer, shipping, or other documents. To the extent to which they apply, the following particulars are required for all items:

1. Government identification number
2. Make, model, serial number, and national stock number when available
3. Commercial description, adequate for screening and disposal purposes
4. Acquisition document number
5. Unit cost
6. Quantity
7. Location (contractor's facility or other site)
8. Condition
9. Designation as to who has title

Disposal of Property. Disposal of property will be directed by the Contracting Officer or a designated representative of the Contracting Officer, in accordance with the terms of the contract. The contractor shall not make disposition of any property except as so directed in writing.

8. FUNDING. Reclamation will provide fiscal year 1990 funding under this cost reimbursement Acquisition, in the amount of $236,682. The dollars identified are only to be allocated to specific work identified in this Acquisition. It is estimated that the following staff are required:

Personnel	FY-90	FY-91
Lucchitta, I.	1/2 time	1/2 time (option)
Hereford, R.	1/2 time	1/2 time (option)

The decision on fiscal year 1991 work will be made during fiscal year 1990 and will be based on the expected data and analysis requirements of the Glen Canyon Dam Environmental Impact Statement. If fiscal year 1991 work is required, it will be specified as a modification to this Acquisition.

9. PAYMENTS. Payment will be made by Reclamation though the Online Payment and Collection (OPAC) method. The USGS should reference Reclamation's agency location code 14-06-0905 on all OPAC billings.

Reclamation has consolidated primary financial management support services in its Denver office. However, it is still necessary to send billings to the initiating contracting office for approval prior to the completion of the dollar transfer. Prior to initiating each OPAC billing, the USGS shall furnish a cost breakdown, using form UC-443 (copy included in this Acquisition) to the following addresses:

Bureau of Reclamation
Upper Colorado Region
Attention: UC-824
PO Box 11568
Salt Lake City UT 84147

Bureau of Reclamation
Project Manager - GCES
PO Box 1811
Flagstaff AZ 86002

Supporting cost data shall be attached to form UC-443, and shall be broken down into direct and indirect charges. Cost breakdowns for each submitted OPAC billing shall identify costs incurred as defined by these categories:

(a) Labor
(b) Travel
(c) Supplies and Equipment
(d) Support
  1. Computer
  2. Mapping Support
  3. Subcontracts

Reclamation and the USGS will meet at least annually to review the billings and other costs expended to insure appropriateness as related to GCES program goals.

10. MODIFICATIONS. Authority to modify an intra-agency acquisition on behalf of Reclamation is expressly limited to the Regional Director, Acting Regional Director, or Contracting Officer. Authority of the Technical Representative is set forth in the designation of Technical Representative memorandum and is subject to limitations that do not include the authority to modify an intra-agency acquisition.

This Acquisition may be modified by bilateral agreement between the parties. Any modification made to this Acquisition shall be confirmed in writing prior to performance of the change. The USGS assumes all risks, liabilities, and consequences of performing additional work outside the specified scope of work without prior approval from one of the above-specified entities.

11. TERMINATION. Either party may terminate this Acquisition upon 60 days' written to the other party. Reclamation shall pay for all work which, in the exercise of due diligence, the USGS is unable to cancel prior to the effective date of termination. Payments under this Acquisition, including payments made under this article, shall not exceed the ceiling amount elsewhere specified in this Acquisition.

12. CONTINGENT UPON APPROPRIATIONS. The liability of Reclamation under this Acquisition is contingent upon appropriations and reservations of funds being made therefor.

ONLINE PAYMENT AND COLLECTION BILLING

BILLING AGENCY: DATE:______________

____
____
____
____
____

AGENCY BILLED:

Bureau of Reclamation
Administrative Service Center
Accounting Service Center Division
Attention: D-2322
P.O. Box 27045
Lakewood CO 80235-0045

CONTRACTING OFFICE:

Bureau of Reclamation
Upper Colorado Regional Office
Attention: UC-823, UC-824
P.O. Box 11568
Salt Lake City UT 84147-0568

OPAC DOCUMENT REFERENCE NUMBER:______________

CUSTOMER AGENCY LOCATION CODE: 14-06-0905

AGREEMENT/ACQUISITION NO.:______________

BILLING PERIOD:______________

AMOUNT:______________

DESCRIPTION OF ITEMS BEING BILLED (INCLUDE SUPPORTING DOCUMENTATION):

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________

BILLING AGENCY CONTACT:

PREPARED BY:______________

TELEPHONE NO.:______________

AQUATIC RESOURCE

GLEN CANYON ENVIRONMENTAL STUDIES

PHASE II

INTEGRATED RESEARCH PROGRAM

AQUATIC RESOURCES STUDIES

I. Issues

The aquatic resources studies reflect the Glen Canyon Environmental Studies (GCES) continuing requirement to understand and predict the impacts that the operation of Glen Canyon Dam is having on the trout resources in the Colorado River. With the closure of Glen Canyon Dam in 1963, a different environment was created - an environment that allowed for the development of a cold water trout fishery. The primary reason for the opportunity for developing a trout fishery came about due to a decrease in the normal water temperatures and a reduction in the sediment supply to the area. The potential for a trout fishery was further enhanced when the Arizona Game & Fish Department developed the aquatic food base necessary to maintain the trout.

At the completion of the GCES Phase I efforts, it was determined that additional information was needed on the trout population dynamics in the Lee's Ferry area. Primary areas of concern focused on:

A. The relationship of low and fluctuating flows to the trout population and cold water ecological dynamics.

B. The relationship of low and fluctuating flows on the trout spawning success and survival.

C. The relationship of low and fluctuating flows on the stranding on trout, and

D. The development of a more extensive data base for the evaluation of multiple level withdrawal structure for Glen Canyon Dam.

II. Objectives

The broad objectives of the GCES Aquatic Resources studies are stated as follows:

A. Determine the relationship between the operation of Glen Canyon Dam and the trout population dynamics in the Lee's Ferry area.

B. Determine the relationship between the operation of Glen Canyon Dam and spawning success.

C. Determine the relationships between the operation of Glen Canyon Dam and the stranding of trout, and

D. Determine a better information base for evaluation of a multiple level withdrawal structure for Glen Canyon Dam.

III. Components of the GCES Phase II Aquatic Resource Studies

The components of the GCES Phase II Aquatic Resources studies can be separated into two areas and are represented in Figure _7_.

A. Trout Studies - evaluation of the impact of Glen Canyon Dam discharges on the Lee's Ferry trout population. This is to include evaluation of effects associated with all life stages and ecological relationships. Specific studies include:

1. Ecosystems processes and trout
2. Lee's Ferry trout stranding
3. Egg and alevin survival in the spawning redds
4. Trout strain evaluation

B. Multiple Level Withdrawal Structure Studies - continued evaluation of the biological, limnological and physical impacts of modifying the intake structures at Glen Canyon Dam to allow for withdrawal of Lake Powell water at warmer levels.

IV. Organization of the GCES Aquatic Resources Studies

The overall organization of the GCES Aquatic Resources studies will be guided by the GCES Scientific Core Group and the Aquatic Coordination Team with an Aquatic Resources subgroup set up to ensure integration of the Aquatic Resources studies. The GCES Scientific Core Group is composed of representatives from the offices involved in the GCES technical studies. The Aquatic Resources subgroup will include representatives from Arizona Game & Fish, Northern Arizona University, GCES and other associated researchers.

The Scientific Core Group and the Aquatics Coordination Team will be jointly responsible for the integration of the aquatic resources studies into the overall GCES technical reports.

Representation on the Aquatic Resources subgroup will include, but not be limited to, the following groups:

GCES - Aquatics Research Advisor (and/or the GCES Senior Scientist)
GCES Office
Reclamation - Upper Colorado Regional Office
Arizona Game & Fish Department - Phoenix and Flagstaff

Northern Arizona University
National Park Service
Contractors (as required)

Primary leadership of the Aquatics Resource subgroup will be the GCES Aquatics Advisor or a designated alternate. The GCES Office will provide coordination and logistical support.

VI. Products to be Developed

The GCES Aquatics Resource subgroup, the GCES Aquatic Coordination Team and the GCES Scientific Core Group will be responsible for the completion of the following reports:

A. Individual Research Reports - as defined in the Study Plan

B. Integrated GCES Aquatic Resources Report - synopsis of the aquatic resources studies and identification of areas of conflict or concern.

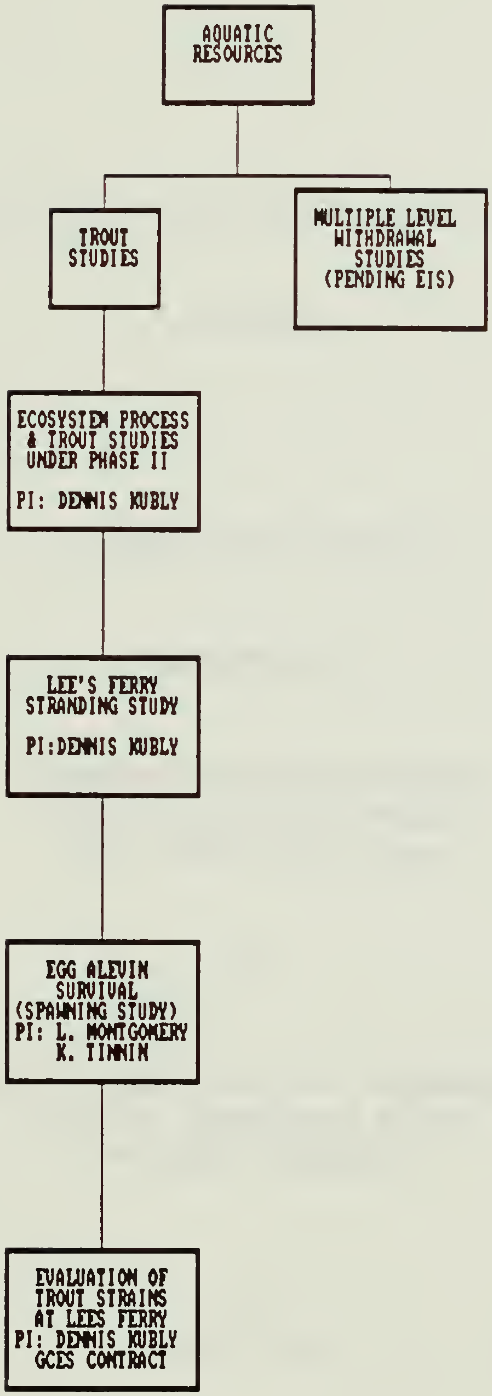

Figure 7. Glen Canyon Environmental Studies Phase II Aquatic Resources Studies.

GLEN CANYON ENVIRONMENTAL STUDIES

PHASE II

A RESEARCH PROPOSAL

SUBMITTED TO

BUREAU OF RECLAMATION
UPPER COLORADO REGION
SALT LAKE CITY, UTAH

BY

ARIZONA GAME AND FISH DEPARTMENT
2222 W. GREENWAY ROAD
PHOENIX, ARIZONA

APRIL, 1990

TROUT STUDIES

Problem Statement

Flow regimes from Glen Canyon Dam potentially affect trout populations in the tailwater both directly and indirectly. Direct effects include stranding and desiccation of all life stages, from fertilized eggs to adults, and displacement of individuals from preferred habitats during such activities as feeding and reproduction. Stranding is a known source of mortality for tailwater trout and their progeny, and displacement may cause increased energy expenditure, reduced food intake, movement into less productive downstream reaches, and disruption of normal reproductive activities. Stranding also produces indirect effects on trout through desiccation, mortality, decreases in production, and increased propensity for drift of algal and invertebrate food resources utilized by the fish.

Stranding and displacement of trout and desiccation of their algal and invertebrate food resources occur during temporal fluctuations in discharges from Glen Canyon Dam. Summer month fluctuations have one maximum and one minimum discharge during a diel cycle, but two maxima and minima are common through the months of November through April (Stevens 1988). Equivalent diel fluctuations (equal ranges) also may occur around various mean flows during different seasons of the year.

Discharge fluctuations produce concomitant changes in river stage (depth), wetted area, and current velocity. Changes in stage create an alternately dewatered and inundated "tidal zone", thereby potentially decreasing the amount of available trout habitat and subjecting varying areas of nearshore habitat and their inhabitants to alternating desiccation and inundation. Changes in current velocity affect the transport capacity of the river and have the ability to broadly alter the degree of downstream export of both inorganic and organic matter. Seasonal differences in responses of biological resources to varying flow regimes may be important, but have been little investigated, and their confounding effect was a bane to interpretation for several studies conducted during Phase I of the Glen Canyon Environmental Studies.

Objective 2.1. Determine the potential loss of trout spawning, defined as areal loss of spawning bars and exposure of redds, at various flows in the reach of the Colorado River between Glen Canyon Dam and Lee's Ferry.

Background 2.1. Experimental studies on desiccation of redds in the sluiceways at Glen Canyon Dam during GCES Phase I showed that rainbow trout embryos and/or pre-emergent alevins suffered much higher mortality under fluctuating flows (10 hours of daily dewatering) than they did under steady flows (Maddux et al. 1987). These results were comparable to those of previous studies when applied to pre-emergent alevins (Reiser and White 1983, Neitzel et al. 1985).

Field studies in the Colorado River below Glen Canyon Dam during the Phase I period of predominantly high, steady flows revealed that approximately 28% of rainbow trout returned to the creel at Lee's Ferry came from natural reproduction. These studies also indicated that natural reproduction, occurring in both mainstream and tributary habitats, is responsible for a considerably higher proportion of trout in the Colorado River in Grand Canyon National Park (Maddux et al. 1987).

Instream flow analysis suggests that many spawning bars in the reach of the Colorado River from Glen Canyon Dam to Lee's Ferry begin to be exposed to the atmosphere at discharges of 8,000-10,000 cfs (Persons et al. 1985). The proportional loss of this habitat at specified flows is presently unknown. Surveying of spawning bars was initiated during the controlled 5,000 cfs flow period of October 1989. Two bars, at RM 14 and RM 8, were surveyed and evaluated for sediment particle size distribution and degree of embeddedness. At least one more spawning bar, at RM 4, will be surveyed and evaluated for substrate prior to measurements of trout or redd distribution during the Phase II controlled flow program.

Successful natural reproduction of trout in the Glen Canyon Dam tailwater has several prerequisites related to flows. First, flows must cover spawning substrates for a sufficient period of time to allow the trout to emplace redds and fertilize eggs. Second, redds must remain moist and oxygenated for development to hatching and emergence. Third, suitable habitats (low current velocity and continuously inundated) and food (zooplankton, small benthic or drift organisms) must be available for fry to develop. Successful reproduction also may be precluded by lack of suitable substrates for emplacement of redds. Sediment degradation resulting in removal of finer sediment fractions has occurred in the Glen Canyon Dam tailwater (Pemberton 1976) leaving many spawning bars covered by cobble-sized rocks. Kondolf et al. (1989) contend that adequate spawning exists in the Lee's Ferry reach, but they did not consider the interaction between fluctuating flows and access to that substrate. Only cursory observations have been made of redd placements in the Glen Canyon tailwater (Gosse and Gosse 1985, Persons et al. 1985, Maddux et al. 1987).

Method 2.1. The purpose of this procedure is to measure the area of spawning bars in the Lee's Ferry reach available at different river stages and to determine the extent to which trout utilize successively higher zones for spawning under different flow regimes. Topographic surveys of spawning bars will be completed during the first 5,000 cfs controlled flow period in June 1990. Survey information will be used to construct spawning bar maps having both elevation contours and distribution of median substrate particle sizes and degree of embeddedness.

Wetted perimeters of measured spawning bars will be determined at controlled steady flows of 3,000, 5,000 (June 1990), 8,000 (October 1990), and 11,000 (December 1990) cfs. The lowest of these flows has been removed from the current schedule, but we hope that a 2-3 day period can be provided prior to December 1990. Markers will be emplaced along the upper shoreline and perpendicular distance to wetted perimeters will be measured at each controlled flow. In this manner, stage zones (elevational contours) can be recaptured during successive flow regimes. Redd placement within stage zones from 3,000 to 11,000 cfs and above can then be determined under different fluctuating flows. Measurement of redd distribution and presence or absence of eggs will allow an evaluation of trout responses to both fluctuating and steady river stages.

Proportional loss of spawning habitat under different flow regimes will be derived from information on redd distributions on measured bars and changes in spawning bar number and area as determined from ground-truthed aerial photography or video imagery. Lost spawning area as measured by a selected set of spawning bars will be relative and not absolute. Additional valuable information on the absolute amount of lost spawning area can be gained by aerial photography or low level video imagery. Ground truthing of surveyed bars will allow planar area exposed on unsurveyed bars to be estimated if photography can be done from a fixed elevation above the river. Aerial photography will also provide information on distribution of other aquatic habitat types and could be used to measure the areal extent of exposed algal beds at measured flows.

Logistical Support: We will require a surveyor and equipment from USGS to complete the topographic surveys of spawning bars.

Objective 2.2. Determine the rate of stranding and mortality of naturally reproduced and stocked trout under different flow regimes in the Glen Canyon Dam tailwater downstream to Lee's Ferry.

Background 2.2. One of the most conspicuous direct effects of fluctuating flows on trout in the Glen Canyon Dam tailwater is stranding and mortality. During the period 2030 hours October 18-0430 hours October 19, 1984, discharge from Glen Canyon Dam was deliberately decreased from 24,000 cfs to 5,000 cfs (Maddux et al. 1987). Discharge was then held at approximately 5,000 cfs for three days to evaluate trout stranding under a simulated low, steady weekend/holiday flow period. Surveys during October 19-21 resulted in the observation of more than 800 stranded trout in the tailwater reach to Lee's Ferry. Of the trout observed, 639 were examined and only 85 (13%) were found to be alive. In some pools, mortality exceeded 95% of stranded individuals, whereas in other pools all trout were alive at time of collection. Lengths of stranded trout varied between 102 mm and 577 mm, but most individuals were adults in reproductive condition.

Anterior vertebrae from trout collected during the stranding period were examined for presence of an oxytetracline dye mark indicative of their being stocked. Only 9% of stranded trout had vertebrae lacking the dye mark and, thus, were naturally reproduced. This percentage was in marked contrast to a value of 27.5% for naturally reproduced trout taken by electrofishing and through the creel during the predominantly steady flow period of 1984-1986. Unfortunately, the percentages of stranded naturally produced and stocked trout could not be compared, because they were derived from groups of trout with considerably different size frequency distributions. Assuming size and age are

related, the two groups undoubtedly represented different cohorts which may have varied considerably in proportions of stocked and naturally reproduced fish.

<u>Method 2.2a</u>. Evaluation of trout stranding in the Lee's Ferry reach commenced during December of 1989 and has continued to present under normal operations. Daily surveys are begun during periods of lowest flow and continue until high flows inundate the stranding pools. To the extent possible, all stranded trout, both alive and dead, are collected from the pools. Predation or scavenging are enumerated and predators are noted if seen or determined from tracks or other evidence. Length, weight, sex, and

reproductive condition are measured for all individuals, excepting those that have deteriorated too far to provide reliable values. Entire viscera are removed from dead trout for subsequent analysis of fecundity and gut contents. Heads and anterior vertebrae are removed from these individuals for assessment of presence or absence of oxytetracycline dye marks as an indication of source, i.e. stocked or naturally reproduced. Live trout are marked with Floy streamer tags to determine subsequent movements and fidelity to the area of the stranding pool.

Measurements of size, dyemarks, fecundity, and gut contents of stranded trout will allow comparison of this subpopulation with those collected during seasonal electrofishing sampling and through the creel. Although electrofishing has inherent biases in the size distribution of trout sampled, we believe it is the best method to answer the question of whether stranded trout form a biased subset of the tailwater trout population. Fecundity measures of dead trout will allow a calculation of lost reproductive potential in the Lee's Ferry trout population. Gut contents of stranded trout will be compared with those of trout taken from adjacent mainstream areas by electrofishing. Comparison of degree of fullness and food resources consumed should provide data for an evaluation of differences in energy intake between stranded and free-roaming trout.

Method 2.2b. All stranding pools are given a site identification number and surveyed initially for morphometric measures of area, volume, maximum depth, etc.

Measurements of water temperature, specific conductance, pH, and dissolved oxygen are made of the pools and adjacent mainstream in order to assess probable causes for differences in mortality among stranding pools. Since mortality rates vary markedly among the pools during a given flow regime, response curves of mortality rate against flow characteristics may well be meaningless. We anticipate that measurement of these limnological variables will allow elaboration of the causative factors for these differences in mortality and a more meaningful evaluation of the relationship between mortality and flows.

Objective 2.3. Determine the effects of fluctuating flows on age/growth relationship of stocked rainbow trout in the Glen Canyon Dam tailwater downstream to Lee's Ferry.

Background 2.3. Knowledge of the relationship between age and growth is a necessary prerequisite of the analysis of trout production in the Colorado River below Glen Canyon Dam. The perennially cold outflow waters from the hypolimnion of Lake Powell apparently negate seasonality of growth in trout sufficiently so that ordinary measures, such as scale or otolith annuli, apparently cannot be used (Persons et al. 1985). A second detracting factor is that a commonly used method of capture in the Colorado River, electrofishing, has, in the past, produced damage to a significant number of individuals and probably restricted their growth (Sharber and Carothers 1988).

Analysis of length frequency histograms and recaptures from limited numbers of marked trout have provided rough estimates of growth during the first two to three years of life (Persons et al. 1985, Maddux et al. 1987), but this is insufficient in a fishery where emphasis is being placed on production of "trophy trout" of greater size and age. Only by marking large numbers of individuals early in life and following their growth for an extended period can a statistically sound estimate be made of the age/growth relationship.

The information to be gained from releasing a large number of marked fish is not, of course, limited to the measurement of growth. Recapture of these fish allows estimates of exploitation rate and by extension fishing mortality, which are important parameters in the setting of stocking rates and other fisheries management practices.

The sluiceways at Glen Canyon Dam are concrete canals which carry leakage water out of the dam and deliver it to the Colorado River. They were utilized successfully during the first phase of GCES to determine the effects of fluctuating flows on mortality of trout eggs, embryos, and pre-emergent alevins. Similar man-made streams have been used under experimentally produced fluctuating flows to investigate the ecology of trout fry, although important caveats apply to extrapolations on conditions in the natural habitat (Irvine 1987). Trout coincidentally left in the dam sluiceways were observed to grow well and suffer low mortality. These observations suggest that the sluiceways can be used as experimental units to evaluate rearing success and early growth for trout held under conditions of steady and fluctuating :low regimes. Conventional methods for collection of young (small) trout are largely without utility in a large river such as the Colorado below Glen Canyon Dam. Therefore, evaluation of early growth and survivorship of trout can most effectively be conducted in these off-site habitats.

Although it is commonly held that age of trout living in the perennially cold Glen Canyon Dam tailwater cannot be determined by conventional methods, only limited effort has been expended towards analysis of otoliths, opercles, or scales. Recent developments in the use of light and electron microscopy on otoliths for aging suggest that they may be used as age markers for stocked fish providing cohorts are subjected to changes in water temperature at different times prior to release. Daily growth rings can be analyzed for recovered otoliths to determine from which cohort each individual originated provided stocked fish are also marked externally. If this methodology is successful, it will provide a much better long-term mark than fluorescent pigments presently being used.

Method 2.3a. Since the end of the Phase I GCES investigation, modification of the electronics used in electrofishing of trout in the Glen Canyon Dam tailwater has reduced considerably the injury rate (ca. 40% to 3-9%, independent trials) from this sampling method (Sharber and Carothers 1988 and unpublished). Therefore, provided electrofishing is used expeditiously and with limited frequency, this method of sampling can provide much needed information on changes in the trout population with an acceptable level of impact.

Since May of 1989, all rainbow trout stocked in the Lee's Ferry reach have been marked with a fluorescent pigment. Three different pigments--green, pink, and yellow--have been or will be applied to all individuals stocked during the period 1989-1991. Returns of marked fish and size measurements will be gained from electrofishing and angler catches via creel surveys. We anticipate that growth of these fish will be followed during monitoring activities following completion of the EIS. Recent creel surveys by the Arizona Game and Fish Department suggest that nearly 75% of the trout caught by anglers in the Lee's Ferry reach are returned to the river. This is especially true of smaller fish, and the proportion may well increase with the newly imposed regulations (slot limit 16-22 inches, two fish bag limit). Given this rate of return and lack of harvest, it will be impossible to gain sufficient data on growth without complementary electrofishing sampling.

Method 2.3b. Approximately 2,000 trout fingerlings of the size stocked in the Glen Canyon tailwater will be divided equally between the two sluiceways. Portions of one of the sluiceways will be partially dewatered by pumps on a daily cycle mimicking that of dam operations. Trout will be fed a commercial diet in per capita amounts equivalent to that administered under hatchery conditions, i.e. rations will be adjusted to account for mortalities during the study period. Every two weeks for a period of six months or more counts will be made of remaining individuals and collections will be made to measure lengths and weights. Behavioral observations will also be made to document movement patterns of fish living under the two flow regimes. At the end of the study period, all remaining individuals will be collected, measured, tagged, and introduced to the tailwater. Growth will be followed by measurements of all individuals returned to the creel and from electrofishing.

Method 2.3c. We propose to double mark trout stocked in the Glen Canyon Dam tailwater during 1991. These individuals will receive the third of three fluorescent pigment marks available and be subjected to a period of temperature change during their time in the hatchery. Although evaluation of the success of this methodology will not be completed during GCES Phase II as presently scheduled, this evaluation will provide important information on a much needed method for aging trout through the period of time (probably five years or more) necessary for them to attain trophy size. If use of otoliths proves successful, we anticipate this method will be incorporated into trout monitoring following the completion of the GCES program.

Objective 2.4. Determine the behavioral responses of trout in the Glen Canyon Dam tailwater to different steady and fluctuating flow regimes.

Background 2.4. Changes in river stage, current velocity, and wetted area that accompany fluctuating flows potentially affect the behavioral patterns of adult trout during such activities as reproduction and feeding. Male trout typically occupy and defend defined areas of spawning bars containing suitable substrates for spawning. If flows decline during this activity, these individuals may be forced from these areas and reproductive activity will be curtailed until another site is found or higher flows return.

In like manner, trout often feed at positions of limited current velocity, such as "eddy fences", where short bursts of speed will carry them into currents carrying drifting organisms suitable as food (Li and Brocksen 1977). As discharge from Glen Canyon Dam rises and falls, these preferred sites may be dewatered or flow hydraulics may change sufficiently to force the fish to move to a new location. These changes may operate directly on the fish or indirectly by changing the distribution of drifting food resources.

Small trout of fry to fingerling size may be impacted by changing flow regimes even more than juvenile to adult stages. Emerging fry typically return to the substrate during a limited period of endogenous feeding. When they begin exogenous feeding, fry seek areas of slack water, typically nearshore, until increased swimming ability is developed.

These behaviors appear to be fixed, and there is little opportunity for changes that would allow the young fish to find new refuges as river stage rises and falls.

Method 2.4a. Radio telemetry will be used to determine the behavioral responses of adult trout to constant and fluctuating flow regimes. The study will be conducted cooperatively with personnel from the BR's GCES office in Flagstaff and the FWS/ES office in Phoenix. It will utilize the same or equivalent equipment (transmitters, receivers, boats) as that proposed for habitat and movement studies on humpback chub. Timing of the study may have to be adjusted to allow sharing of equipment between trout and humpback studies, but all trout evaluations will occur during periods having sequential constant and fluctuating flows.

Trout will be implanted with transmitters at least five days prior to evaluation of their behavior. Implanted individuals will be tracked for a minimum of three days during both constant and fluctuating flow periods. These periods will be sequential in order to disallow effects attributable to seasonal changes in reproductive condition, food resource availability, etc. Tracking will include both diurnal and nocturnal activity patterns in order that diel behaviors not attributable to flow changes can be segregated from responses to fluctuating discharge.

To the extent possible, triangulation will be used to assess location of trout when stationary. When locations are determined satisfactorily, measurements of depth, distance from shore, current velocity, substrate, and cover will be made. Whenever possible, locations will be marked by triangulation to landmarks on shore, so that transects of habitat variables (depth, substrate, current velocity) can be measured later under equivalent flow conditions. If trout are displaced by measuring activities, no additional measurements will be made for a period of at least one-half hour.

Method 2.4b. If necessary, measurements of adult trout habitat availability in the Lee's Ferry reach will be made at steady flows of 3,000 cfs, 5,000 cfs, 8,000 cfs, and 11,000 cfs on transects used during previous instream flow modeling. The necessity of making these measurements will be determined by agreement between AGFD, FWS/ES, and BR. We suggest the possibility here because of questions concerning changes that might have occurred in the Lee's Ferry reach subsequent to floods in 1983 (Wegner 1988) and our concern for whether present information can be used to make decisions on the effects of dam operations on trout. If the decision is made to gather more habitat information, we suggest that additional transects be established at the two USGS gaging stations and their measurements incorporated into the database on trout habitat availability.

Method 2.4c. Methods for evaluating the effects of fluctuating flows on egg to fry stages are provided in Montgomery (1990). AGFD will provide support to Ms. Tinning, Dr. Montgomery's graduate student, in the completion of this effort.

TASKS AND RESEARCH DELIVERABLES

Suggested timing of research tasks by flow periods and objectives with methods as delineated in the text of this proposal are presented in Figure 1. Some modifications undoubtedly will have to be made in the timing of tasks as dictated by reviews of this proposal and overlap with other proposals for this research program.

DELIVERABLES

Quarterly progress reports will be made to the BR and GCES Senior Scientist during the course of this research program. An annual progress report with a suggested due date of June 30, 1991, will be delivered if so desired. To the extent possible, we have attempted to ensure that field research will be staggered in ending dates, so that data analysis and report preparation for all research objectives need not be concurrent. This approach will allow the completion of a draft report by September 30, 1991, and a final report by November 30, 1991. The report will be comprised of four major sections: (1) Ecosystem Level Processes and Lower Trophic Levels; (2) Trout Studies; (3) Native Fish

Studies, and; (4) Integration and Recommendations. Format for the report will be as required by the BR and GCES Senior Scientist.

BUDGET

A complete budget and staffing matrix for proposed research will be submitted with the native fish proposal.

Figure [illegible] Methods Matrix for Proposed Studies during the Period June 1, 1990 - June 30, 1991.

FLOWS	OBJECTIVES/METHODS									
	1.1/ 1.1a	1.1/ 1.1b	1.2/ 1.2a	1.2/ 1.2b	1.3/ 1.3a	2.1/ 2.1	2.2/ 2.2a	2.2/ 2.2b	2.3/ 2.3a	2.4/ 2.4a
JUN 1-4 (5,000 cfs)	X	X				X			X	
JUN 5 - JUL 12 (Normal Operations)	X	X			X					X
JUL 13-15 (5,000 cfs)			X		X					X
JUL 16-26 (3,000-26,200 cfs/E)	X	X		X	X		X	X		X
JUL 27-29 (5,000 cfs)	X	X			X					X
JUL 30-AUG 9 (10,000-33,200 cfs/F)			X		X					X
AUG 10-12 (5,000 cfs)					X					X

Figure 1. Flow by Objectives/Methods Matrix for Proposed Studies during the Period June 1, 1990 - June 30, 1991.

FLOWS	OBJECTIVES/METHODS									
	1.1/ 1.1a	1.1/ 1.1b	1.2/ 1.2a	1.2/ 1.2b	1.3/ 1.3a	2.1/ 2.1	2.2/ 2.2a	2.2/ 2.2b	2.3/ 2.3a	2.4/ 2.4a
AUG 13-23 (10,000-33,200 cfs/G)	X	X			X					X
AUG 24-26 (5,000 cfs)	X	X			X					
AUG 27-SEP 27 (Normal Operations)					X					
SEP 28-30 (5,000 cfs)	X	X							X	
OCT 1-11 (Normal Operations)	X	X								X
OCT 12-14 (5,000 cfs)										

Figure 1. Flow by Objectives/Methods Matrix for Proposed Studies during the Period June 1, 1990 - June 30, 1991.

FLOWS	OBJECTIVES/METHODS									
	1.1/ 1.1a	1.1/ 1.1b	1.2/ 1.2a	1.2/ 1.2b	1.3/ 1.3a	2.1/ 2.1	2.2/ 2.2a	2.2/ 2.2b	2.3/ 2.3a	2.4/ 2.4a
OCT 15-25 (8,000 cfs)						X				X
OCT 26-28 (5,000 cfs)	X	X								X
OCT 29-NOV 8 (3,000-13,000 cfs/A)	X	X		X		X	X	X		X
NOV 9-11 (5,000 cfs)							X	X		
NOV 12-DEC 13 (Normal Operations)	X	X								X
DEC 14-16 (5,000 cfs)	X	X							X	X
DEC 17-27 (11,000 cfs)						X				X

Figure 1. Flow by Objectives/Methods Matrix for Proposed Studies during the Period June 1, 1990 - June 30, 1991.

FLOWS	OBJECTIVES/METHODS									
	1.1/ 1.1a	1.1/ 1.1b	1.2/ 1.2a	1.2/ 1.2b	1.3/ 1.3a	2.1/ 2.1	2.2/ 2.2a	2.2/ 2.2b	2.3/ 2.3a	2.4/ 2.4a
DEC 28-30 (5,000 cfs)										X
DEC 31-JAN 10 (5,000-15,000 cfs/B)	X	X		X	X	X	X	X		X
JAN 11-13 (5,000 cfs)	X	X			X		X	X		
JAN 14-31 (Normal Operations)					X	X				
FEB 1-3 (5,000 cfs)					X					
FEB 4-14 (10,000-20,000 cfs/C)	X	X			X	X	X	X		

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PROPOSED GCES BUDGET - YEAR I

I. Personnel Services:

GCES Coordinator - 1 person year @ $27,000	$27,000
Biostatistician -1 person year @ $24,500	24,500
Wildlife Specialist II - 3 person years @ $26,500	79,500
Wildlife Specialist I - 3 person years @ $18,000	54,000
Wildlife Assistant II - 6 person years @ $17,000	51,000
Information Processor II - 1 person year @ $13,900	13,900
TOTAL PERSONNEL SERVICES	$249,900

II. Employee Related Expenses:

O.25 of personnel services costs	$62,475
GRAND TOTAL LABOR COSTS	$312,375

III. Travel and per diem[1]

Vehicle mileage - 100,000 miles @ 0.45 mile	$45,000
Boat hour expenses - 1,000 hours @ $15 hour	15,000
Commercial Airlines	3,000
Department Aircraft	9,000
Per diem - according to state policy	20,000
GRAND TOTAL TRAVEL AND PER DIEM	$92,000

[1] Costs assumes BR logistic support for down river trips

III. Equipment

Vehicles - 3 4X2 trucks @ $11,000	$33,000
Boat - 1 17 Ft. outboard @ $9,000	9,000
Laboratory equipment	
microscopes, spectrophotometer, ovens, pumps, etc.	17,500
Miscellaneous field equipment	13,500
Personal computers - 3 Compaq 386 @ $5,000	15,000
Software - Word/data processing, graphics	10,000
EQUIPMENT GRAND TOTAL	$98,000

IV. Professional Services

Water quality analysis	$40,000
Otolith analysis (humpback chub)	10,000
Miscellaneous services (stomach, invertebrates identification)	10,000
GRAND TOTAL PROFESSIONAL SERVICES	$60,000

TOTAL DIRECT COSTS	$562,375
Indirect costs 0.08% direct costs	$44,990
GRAND TOTAL PROJECT COSTS-YEAR 1	$607,365

PROPOSED GCES BUDGET - YEAR 2

I.	Personnel Services, ERE Year 1 total factored by 5% for inflation	$327,994
II.	Travel and per diem Year 1 total	92,000
III.	Equipment	20,000
IV.	Professional Services Year 1 total factored by 5% for inflation	63,000
TOTAL DIRECT COSTS		$502,994
Indirect Costs 0.08 of direct costs		$42,240
GRAND PROJECT TOTAL - YEAR 2		$543,234

PROPOSED GCES BUDGET - YEAR 3

Total Year 2 budget factored by 5% for inflation	$570,395
Total 3 year budget for GCES	$1,720,994

SURVIVAL OF EGGS, ALEVINS AND FRY OF RAINBOW TROUT RELATIVE TO FLUCTUATING FLOWS AT LEES FERRY, COLORADO RIVER

A Proposal To

Glen Canyon Environmental Studies
Bureau of Reclamation

From

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Associate Professor of Biology
Department of Biological Sciences
Northern Arizona University
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W. Linn Montgomery
Associate Professor

Henry O. Hooper
Associate Vice President
Research and Graduate Studies

15 March 1990

INTRODUCTION

The fifteen mile stretch of the Colorado River between Glen Canyon Dam and Lees Ferry, Arizona, is the site of an economically important trout fishery. Despite the fame of the fishery among sports fishermen, it appears to be dependent upon stocking rather than natural reproduction. Adequate spawning substrate exists within the Lees Ferry stretch of the river (Kondolf et al. 1989), but extensive sampling of drift in the river never captured trout fry (Blinn et al. 1986). Phase 1 of the Glen Canyon Environmental Studies estimated that natural reproduction accounts for no more than 27% of fish caught at Lees Ferry (Maddux et al. 1987); the Arizona Game and Fish Department annually stocks >100,000 trout within this reach of the river (Reger 1989). Thus, there appears to be a problem with the success of natural reproduction occurring at Lees Ferry. Poor recruitment of naturally spawned trout, particularly rainbow trout (Oncorhynchus mykiss), may be related to the fluctuating flow regime caused by the hydroelectric power operations of Glen Canyon Dam.

Young fish pass through a series of "critical periods," when shifts in habitat or ecology are generally accompanied by increased rates of mortality. Critical periods in the early life history of trout include: survival and hatching of eggs, survival and shifts to exogenous foods by alevins (sac fry), emergence of free-swimming fry, and acquisition of suitable habitat by fry.

Fluctuating flows of the Colorado River may have impacts on several life history stages and critical periods. According to Reiser and White (1983), dewatering of salmonid eggs in redds (nests) has little effect on hatching success, provided that the substrate retains a moisture content of at least 4%. Moisture content of sediments is a function of sediment size and type, and there has been considerable alteration of sediment size and composition since closure of the dam (Kondolf et al. 1987, 1989). Changes in temperature experienced by exposed eggs may also be detrimental; Neitzel and Becker (1985) found that embryos survived 8 hrs of exposure to 25 C but only 2 hrs at 26.5 C.

In contrast to eggs, dewatering causes high mortality among alevins (Reiser and White 1983). The alevin life history stage is generally a 10-14 day period when the gills are developing and the yolk is still the primary food source. These small fish are probably highly susceptible to desiccation. Becker et al. (1982) demonstrated that nearly all (96%) pre-emergent alevins were killed by 1 hr of daily dewatering over a 22 day period. As with eggs, changing temperatures in dewatered redds may influence alevins; pre-emergent alevins survived 4 hrs at 23.5 C, but only 1 hr at 25.0 C (Neitzel and Becker 1985). The size of the gravels and sediments surrounding a redd also influence alevin success; small pore size physically impairs their movement and prevents their emergence from spawning beds (Hausle and Coble 1976).

The emergence of fry out of the redd and into a free swimming stage is also a period when there is high potential for mortality. During the day, trout fry are generally dispersed and occupy territories in low velocity waters (stream margins, backwaters, side channels), many of which contain vegetative cover (Moore and Gregory 1988 for cutthroat trout; DuBois and Naiman 1980 for brook trout). Heggens (1988) found that brown trout fry hid more in the substrate during the day than at night, and moved to inlets or outlets of the enclosures at night. Brook trout fry tend to cluster together at night close to the shoreline in a Quebec river (Morin et al. 1982). Increases of as little as 4-14 cm/sec in water velocity also displaced brown trout fry downstream at night (Heggens 1988). Fluctuating water levels at Lees Ferry would alternately flood and expose fry habitat and produce rapid and significant changes in water velocity over short periods.

Thus, a general survey of literature on early life history of salmonids suggests that (a) eggs are quite resistant to desiccation, (b) alevins are very sensitive to varying conditions of immersion, temperature and substrate size, and (c) fry require habitats and water velocities which differ from mainstream environments inhabited by juvenile and adult fish. In addition, most studies of these life history stages have been performed under laboratory conditions or in geographic locales with environmental conditions quite distinct from those encountered at Lees Ferry.

We propose to study the effects of fluctuating water flows on egg mortality, hatching, alevin survival, and fry ecology and mortality at Lees Ferry. This work would differ from previous work in combining field and laboratory studies on a major river in an arid environment. Results will allow accurate estimates of the effects of various flow regimes on several important components of reproduction and recruitment by rainbow trout.

OBJECTIVES

Our primary objective is to determine how fluctuating discharge influences early life history stages of rainbow trout spawned at Lees Ferry. Through field surveys, laboratory experiments and field tests of a lab-derived model, we will address four primary questions:

1. What physical conditions (moisture, temperature, etc.) occur in the spawning gravels at Lees Ferry, and how do they change with fluctuating flows?

2. What are the mortality rates of trout eggs and alevins held in the laboratory under conditions they might experience at Lees Ferry during the spawning season?

3. Is the survivorship of eggs and alevins at Lees Ferry similar to that predicted from the laboratory tests? If not,

what additional factors affect survivorship?

4. Where do recently hatched fry occur at Lees Ferry and what is the likely impact of fluctuating flows on fry in nature?

PLAN OF ATTACK

Our approach can be subdivided into 5 phases, although activities described in several phases may be undertaken simultaneously.

Phase 1. We will conduct a thorough search of literature relating to early life history stages of salmonids in order to determine previous knowledge about this topic, methods that have been developed for such studies, and particularly important problems that must be addressed. This work will be initiated immediately and will be conducted in cooperation with the Arizona Game and Fish Department.

Phase 2. We will describe various physical characteristics of two spawning sites at Lees Ferry. These sites (Miles 8 and 13.5) have been chosen on the basis of gravel composition and observations of redds containing eggs. Data will be collected February-May 1990 and September 1990-March 1991. These include periods of spawning and emergence.

Data will be collected within the upper 0.5 m of substrate at several points along transects reaching from below the lowest likely water level (corresponding to 3000-5000 cfs) to the highest likely water level (corresponding to 25000-30000 cfs). Transects will be established in areas containing suitable spawning substrate as described by Kondolf et al. (1989).

Surface and subsurface substrate temperatures will be measured periodically along transects during day and night, and will be correlated with river discharge. Air temperatures will be measured 10 and 30 cm above the surface at locations where substrate temperature is recorded. During the spawning season, subsurface will be monitored with recording thermographs.

Moisture content of gravels and sediments will be measured at points along the transects. Samples of subsurface substrates will be weighed in the field and again after drying in the laboratory. Samples will be taken at regular intervals after exposure to describe the relationship between duration of exposure and moisture content.

Surface water flow will be measured along selected transects, and at various intervals after submersion, with a Marsh-McBirney flow meter. This will allow us to estimate lags between time of submergence and attainment of maximal discharge over a particular point. Water flow through the gravels will be estimated by measuring the rates of dissolution of salt or plaster of paris tablets.

Phase 3. Mortality of eggs and alevins held at various combinations of temperature, periods of exposure and moisture will be evaluated using artificial stream tanks in the laboratory. Experiments will mimic physical conditions recorded during initial surveys (Phase 2) at Lees Ferry. Water temperature will be maintained at 10 $\pm$ 1 C, under a 12:12 light:dark cycle. Air temperature is set at 12 C and 20 C during night and day periods, respectively. Depending on availability, strains of trout used in the experiments and subsequent field tests (see below) will match those that have been or are being stocked into the Lees Ferry area (strains of rainbow trout used in the last 5 years are Belaire and Kamloops; Davies 1989).

Eggs will be placed in Whitlock-Vibert boxes (or similar containers) and buried in substrata obtained from spawning sites at Lees Ferry and held in containers constructed of fiberglass screen. Fluctuating flows will be simulated in the stream tanks by raising and lowering racks of these artificial redds to cause exposure of 0, 5, 10 and 16 hrs per 24 hr period. Egg and alevin mortality will be assessed for different periods of exposure.

The product of these experiments will be a model that relates survival of eggs and alevins to various realistic combinations of temperature and exposure. Experiments will be conducted during Summer and Fall of 1990, so that the model can be largely completed prior to the 1990-1991 spawning season.

Phase 4. The model produced from Phase 3 will be tested in the field at Lees Ferry during Winter-Spring 1990-1991. Trout eggs will be placed in the same type of containers as were used in laboratory experiments, and will be buried at locations along experimental transects which differ in frequency and duration of exposure by virtue of their different heights above lowest water. Egg and alevin mortality will be monitored to assess the accuracy of the model, and to identify (but not formally measure) any additional phenomena that might affect survivorship (such as microbial infections or predation on eggs or alevins while in the redds).

Phase 5. Field surveys of fry will be conducted during spawning seasons of 1990 and 1990-1991. Habitats potentially available to fry (mainstream shore, backwaters, shallows with emergent vegetation, etc.) will be surveyed by seine, backpack electrofishing, and snorkeling. Where fry occur, estimates of their density will be made during several cycles of fluctuations in order to estimate the impact of fluctuations on fry populations. In addition, hatchery-reared fry will be released in what appear to be suitable habitat, and their densities monitored during a series of fluctuations. These data will test the idea that fry may be stranded and killed or swept out of suitable habitat under a regime of rapidly fluctuating discharge. When possible, field surveys will be conducted during periods when specific flows are scheduled for GCES research purposes.

TIMETABLE

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                        1990          /          1991
                 A M J J A S O N D J F M A M J J A S

Phase 1          ..............

Phase 2          .....     ............

Phase 3           ....     ........

Phase 4                             ..........

Phase 5                             ..........

Report prep.     I       x     x     x     x      FD
     (I - initiation; x - progress reports; FD - final draft)
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<u>Comments on Timetable</u>

Phase 1 (literature review) will be completed, except for publications appearing in late 1990 or 1991, by 1 November 1990, and will form a portion of the preliminary report due on that date.

Phase 2 (physical characteristics) will be initiated as soon as funding is available (expected later March early April 1990), and will be continued during months when spawning activity, egg and alevin development, and fry emergence are most likely (April-May, September-March).

Phase 3 (laboratory studies) will begin April-May 1990 or as soon as eggs are available. We are presently identifying sources of eggs from hatcheries in more northerly states, in order to extend our experimental capabilities into summer. This phase will continue through Fall 1990.

Phases 4 and 5 (field tests) will take place at Lees Ferry during January-June 1991. Results will be incorporated into the final draft report.

Reports will be submitted to GCES, with a copy to the appropriate branch of AGFD, by the first day of August 1990, November 1990, February 1991 and May 1991. The final draft report will be submitted on 1 September 1990, or at an earlier date if deemed desireable by GCES personnel.

BUDGET

PERSONNEL:	Year 1	Year 2	NAU*
Principal Investigator			
1 month/yr	-0-	-0-	$7728.00
Grad Res. Asst. (Academic yr)			
9 months/yr x $750/mo	$6750.00	$7087.00	
Grad Res. Asst. (Summer)			
3 months/yr x $1000/mo	3000.00	3150.00	
[* - 5% increase in yr 2]			
Field technician 8 hr/d x $4/hr			
Yr 1: 45 days	1440.00		
Yr 2: 60 days		1920.00	
EQUIPMENT:			
Marsh-McBirney Flow Meter	2150.00	-0-	
SUPPLIES:			
Whitlock-Vibert boxes	300.00	-0-	
200 @ $1.50			
Hatchery-produced eggs & fry	140.00	140.00	
$7/1000 x 20,000			
Thermograph rental	1350.00	1350.00	
Xerox and interlibrary loan	300.00	100.00	
TRAVEL:			
Gas for personal vehicle (15 mi/gal)			
300 mi RT x 30 RT in Yr 1	660.00		
x 15 RT in Yr 2		330.00	
PER DIEM:			
Food: $20/d x 60 d x 2 persons	2400.00	2400.00	
Lodging: $40/d/2 persons x 25 d	1000.00	1000.00	
TOTAL DIRECT COSTS:	$19,490.00	17,477.00	
INDIRECT COSTS (20% TOTAL)	3898.00	3495.00	
CONTRIBUTED BY N.A.U.			7728.00
TOTAL REQUEST:	$44,360.00		

* -Northern Arizona University contributions

JUSTIFICATION

PERSONNEL:

The PI (Montgomery) will contribute at least 1 month of time to this project per year.

Support is requested for a single graduate assistant, K. Tinning. Ms. Tinning will be supported half-time during the academic year and full time during the summer. She will, in fact, devote more than half time to her research during the school year.

GCES requires that an assistant accompany Ms. Tinning at all times in the field; funds requested in this proposal would be used exclusively for a companion in the field.

EQUIPMENT:

We request purchase of a Marsh-McBirney current meter; this instrument will receive regular use throughout the project, and no similar instrument is presently available for our use.

SUPPLIES:

We request funds for purchase of Whitlock-Vibert boxes for experiments that will begin in Year 1 and extend into Year 2. If containers of a different design are selected, funds will be used for purchase of materials and construction. We estimate use of 1000 eggs per month during laboratory studies and 2000 per month for field experiments. We also request support for rental of three recording thermographs. These will be buried in gravels to accurately determine fluctuations in temperature experienced by eggs in redds. Finally, Xerox and interlibrary loan assistance is requested because NAU's journal holdings in aquatic biology are limited.

TRAVEL and PER DIEM:

We request funds to cover gas for Tinning's personal vehicle during trips to Lees Ferry/Page. Because Tinning and the field assistant must on the river research sites throughout day and night of most field research periods, we have requested funds to cover lodging only for days at the beginning and end of field sessions and for occasional days during extended summer field sampling periods. During other times, they will camp.

INTERAGENCY COOPERATION

The PI (Montgomery) will contribute at least one month of time per year to the project. Additional technical assistance in the laboratory at NAU will be provided through student wage funds provided by the University to the PI. The Arizona Game and Fish Department has offered to supply additional manpower for field studies, if and when needed. This will be particularly important during the period of field experimentation in Year 1-2. AGFD has already assisted with computer literature searches.

Nau and PI will provide one stream tank and space in the NAU Animal Care Facility for laboratory experiments. GCES has offered the use of an additional stream tank, as well as a boat and motor at Lees Ferry. PI will also supply Ms. Tinning with: any necessary snorkeling gear for fry studies in Yr 2; underwater still and video cameras; film; life vests; collecting equipment (nets, electroshocker, etc.).

NAU and PI will provide an analytical laboratory with microscopes, balances, glassware, etc. Data analysis will be performed on PC's in PI's lab at NAU (SYSTAT statistical package) or on the NAU mainframe (various statistical packages available). Word processing, graphics and other report preparation support will be provided through NAU.

Any additional costs for travel will be covered through on campus Organized Research funds available to PI.

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STUDY PROPOSAL -- IMPACTS OF A MULTIPLE LEVEL WITHDRAWAL STRUCTURE ON THE ECOLOGY OF LAKE POWELL AND THE COLORADO RIVER

Prepared by: David L. Wegner, Glen Canyon Environmental Studies Program Manager, Glen Canyon Environmental Studies, Flagstaff, AZ

I. INTRODUCTION

The releases from Glen Canyon Dam have modified the downstream ecosystem. These changes have largely come about due to modification of the temperature regimes and nutrient dynamics. The seasonal dynamics of an unimpounded river have been muted due to physical hydrology changes in Lake Powell. The releases from Lake Powell come from the hypolimnion, a depth ranging from 175 to 240 feet from the surface of Lake Powell.

A trout fishery has become established below Glen Canyon Dam due to the colder water releases. Unfortunately, the release of cold water has reduced the amount of useable mainstem Colorado River area available to the endangered fish Gila cypha, the humpback chub. The cold water releases seem to most impact the larval and juvenile humpback chub life stages due to temperature stress and reduction in the aquatic productivity and consequently food for the humpback chub and other native fish species.

A means of modifying the temperature releases from Glen Canyon Dam could be through the use of multiple level withdrawal structures. These structures would "pull" water from higher up in the Lake Powell water column and the releases made downstream would be warmed.

II. Background

The use of multiple level withdrawal structures on dams is not a new concept. They have been used extensively by the Corp of Engineers and on other Bureau of Reclamation dams. Of most important note is the multiple level withdrawal structures that have been retrofit to Flaming Gorge Dam on the Green River in Utah and the structure that is being planned for Shasta Dam in California.

The multiple level withdrawal structures on Flaming Gorge Dam were retrofit in 1978 in an attempt to increase the water temperature to enhance trout growth. The structures were retrofitted successfully and have performed as designed. Trout growth in the Green River below Flaming Gorge Dam has increased substantially.

A problem with too warm of water exists at Shasta Dam in California. In this case, a multiple level withdrawal structure is being designed to draw water from lower in the water column to decrease the downstream temperature releases and lessen the impact on the Salmon.

Under the GCES Phase I program, a prototype study was completed on the feasibility of utilizing a multiple level withdrawal structure on Glen Canyon Dam (Ferarri, et al, 1987). The study determined that the water temperature could be raised but that exact replication of pre-dam temperatures was not possible. The work done in Phase I was a feasibility level effort and NO work was done on evaluation of the impacts of a warmer water withdrawal on the limnology of Lake Powell, Lake Mead or on the water quality in the Colorado River downstream.

III. Objectives

The objectives of this study can be broadly stated as follows:

A. Conduct a thorough literature review of the application of multiple level withdrawal structures in the United States and elsewhere.

B. Develop a biological and limnological assessment on the potential impacts to the ecology of Lake Powell, the Colorado River and Lake Mead as a result of using multiple level withdrawal releases.

C. Conduct a verification of the results of the GCES Phase I Multiple Level Withdrawal study to ensure that the proper techniques, procedures and results were applied.

The effort associated with this study will be integrated into the other Aquatic Resources study and the Water Quality and Limnology Studies.

IV. Methods

The methods to be used in this study will include the following:

A. Literature Review

The literature review will be conducted utilizing the best available library services to search out, obtain and review the present state of knowledge on the use and application of multiple level withdrawal studies. The review will include but not be limited to:

1. Location
2. Type and application
3. Success / Failure
4. Cost

B. Biological and Limnological Assessments

The biological and limnological assessment will require the acquisition of the historic Lake Powell and Lake Mead

STUDY PROPOSAL -- EVALUATION OF TROUT STRAINS FOR LEE'S FERRY

Prepared by: David L. Wegner, Glen Canyon Environmental Studies Program Manager, Glen Canyon Environmental Studies, Flagstaff, AZ

I. Introduction

Concern has been expressed by the power community that a possible solution to the trout stranding problem would be the selection and planting of a strain of trout in the Lee's Ferry area that exhibits a narrower range of spawning times and preferences. This reduction in range of spawning could help to lessen the amount of time that potential trout stranding would occur.

The intent of this study is to evaluate, through the literature, the potential for selecting a new or refined strain of trout that could be used in the Lee's Ferry area. This evaluation will take the form of a literature review and development of a recommendations report.

II. Background

The Arizona Game & Fish Department began stocking rainbow trout in the Lee's Ferry area in March 1964. The strains of rainbow stocked at that time were not noted. The first defined strain of rainbow trout stocked at Lee's Ferry came about in 1981 when a strain of Plymouth trout were planted. Since that time Kamloops and Bel Airs strains have been stocked. The Kamloops strain has not proven to be successful in the Lee's Ferry area. Presently, approximately 150,000 fish per year have been stocked into the Lee's Ferry waters.

Under the present use levels, harvest rates cannot be maintained in the fishery without supplemental stocking. Under Arizona Game Fish studies conducted as part of GCES Phase I, it was determined that approximately 27 % of the trout caught in the Lee's Ferry area were "naturally" reproduced fish. This figure may be high due to the abnormally high flow levels that existed during the GCES Phase I efforts.

The primary spawning period begins in October and lasts through March, however some levels of spawning occurs year round. Stranding occurs when the fish are in a spawning mode. They move up onto the spawning bars during high flow releases and get trapped as the water is lowered. The loss of these spawning fish has caused a great deal of concern from the fishing public and an important loss to the trout population.

A possible, though unresearched, solution may be the planting of a strain of trout that spawns during a narrower time window and hence would require a higher spawning flow for a shorter period of time.

III. Objectives

The objectives of the trout strain evaluation study are as follows:

A. Conduct a literature review of the types of trout strains available for planting.

B. Develop a report on the biological and physiological relationships and requirements associated with each identified trout strain.

C. Identify where specific trout strain manipulation has been attempted and the success level.

IV. Methods

The methods to be used in the evaluation of trout strains will be composed of the following:

A. Literature Reviews - include professional literature, "gray" literature, and interviews.

B. Biological and Physiological Requirements - include a thorough analysis of the literature and discussions with professionals in the field.

V. Delivery Timetable

The information developed under this program will be utilized by the Aquatics Resource Group in their analysis of the trout resources in the Lee's Ferry area. The following products will be required:

Draft Report - June 01, 1991

Final Report - September 01, 1991

VI. Budget

It is intended that this work will be incorporated into the Arizona Game & Fish work program. If that is not possible, a contract will be issued for this effort.

The amount of money projected to be required for this effort is $\underline{\$ 50,000.00}$.

limnological information, the Flaming Gorge reservoir information and other pertinent data. The assessment should include but not limited to:

1. Biological
   a) Downstream impacts
      - fisheries
      - aquatic productivity
      - water quality
      - riparian ecosystems
   b) Lake/Reservoir impacts
      - fisheries
      - aquatic productivity
      - shoreline ecosystems

2. Limnological
   a) Downstream impacts
      - downstream reservoirs
      - density currents
      - chemistry & water quality
   b) Lake/Reservoir impacts
      - physical chemistry
      - algal populations
      - hydrodynamics

C. Verification Studies

A verification of the results from the GCES Phase I Multiple Level Withdrawal study will require:

1. Evaluation of the data bases
2. Evaluation of the assumptions
3. Evaluation of the analysis process

V. **Deliverables and Timetable**

The deliverables required for this study will follow the general timetable of the other Aquatic Resources studies:

Draft Report -- (w/data)	September 10, 1991
Final Report -- (w/data)	December 01, 1991

VI. **Budget**

It is anticipated that this work will be accomplished in close coordination with the Water Quality and Limnology Studies and the other Aquatic Resource studies. It is further assumed that this work will be accomplished by the Denver Office of the Bureau of Reclamation or by contract.

The anticipated budget for this effort is **$ 50,000.00**.