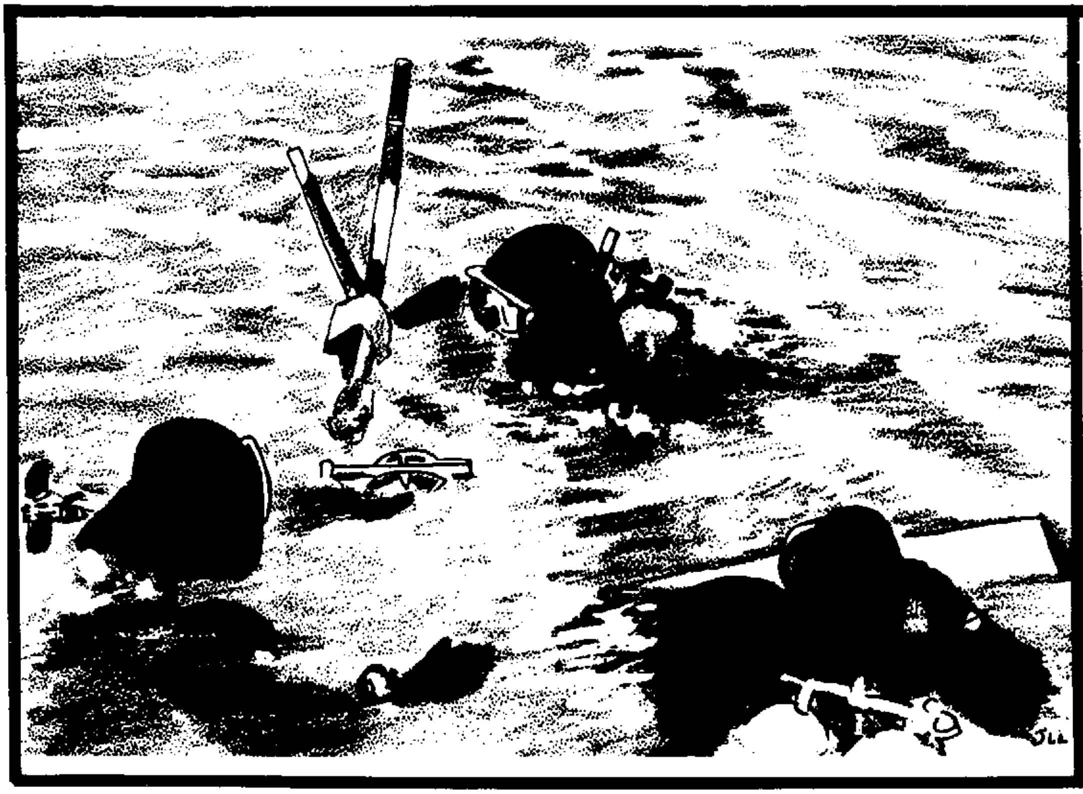
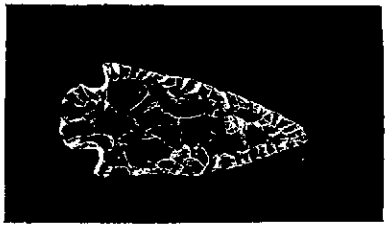
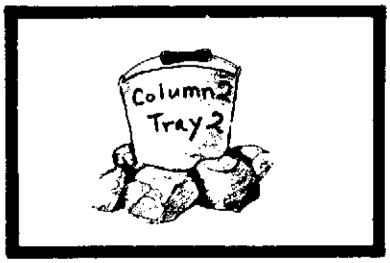
The Final Report of the

National Reservoir Inundation Study







Volume I · Summary

Final report of the national reservoir inundation study, v.1.

THE FINAL REPORT
OF THE
NATIONAL RESERVOIR INUNDATION STUDY
VOLUME I

by
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The final report resulting from the National Reservoir Inundation Study funded by the Bureau of Reclamation, U.S. Army Corps of Engineers, National Park Service, and Soil Conservation Service

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(v.1)

PREFACE

The National Reservoir Inundation Study began in early 1976 and research operations ended in September 1980. The strength of the core team of National Park Service researchers varied from three to six archeologists at any one time, with a total of nine individuals having participated in the project. This report is a product of all of their efforts, although only six took part in its actual writing. Those former team members not credited with final authorship include Thomas Hopkins, Wayne Prokopetz, and Cathryn Tarasovic.

The coordinators for the different agencies involved in the funding and monitoring of the project, who provided much in the way of support and constructive criticism, include Ward Weakly of the U.S. Bureau of Reclamation, Dick Leverty of the U.S. Army Corps of Engineers, Jim Warren and Nancy Cole of the U.S. Soil Conservation Service, and Cal Cummings of the National Park Service. Cal served as my supervisor through most of the complicated setup and execution of the project and was a constant source of guidance and moral support. Appreciation is also extended to Bob Lister, who served as Chief of the Southwest Cultural Resources Center during a part of the study, and Dick Sellars, who took over as Chief of the Center during the latter phase of the program. We were lucky enough to receive consistent backing at our Regional Director level from all four incumbents in that office during the course of the study: Joe Rumberg, John Cook, Lorraine Mintzmeyer, and Bob Kerr. Wayne Cone, who was the Associate Regional Director during most of the study, is also thanked for persevering through what I'm sure he felt to be an endless report writing stage.

Other National Park Service archeologists who contributed their time for review and comment on many subcontracts and on our design of various portions of the research include: Larry Nordby, Ted Birkedal, Bruce Anderson, Ron Ice, Steve Hallisey, George West, and Jim Bradford. Dave Battle offered suggestions and assistance on structural conservation problems.

Outside researchers who were continually inputting advice and became involved at different points themselves in contracted research include Curt Schaafsma, Erv Garrison, Alan May, John Foster, Steve Gluckman, Rob Edwards, and Jean Stafford, to name but a few. All deserve our sincere thanks and appreciation for their efforts.

The areas of responsibility and contribution of those listed as authors of the final report are listed below in alphabetical order. It should be noted that we are being specific only about core team contributors to this summary volume. Authorship of the technical reports in Volume II is fully credited in that volume, including separate acknowledgment sections for each work.

Toni Carrell, in addition to her technical report contributions in Volume II, proved to be an excellent coordinator for the study's involvement in research on the West Coast. She was responsible for all input on the issues of human, faunal, and "other" impacts to cultural resources as a result of impoundment and followed through on dating and analysis impacts. Toni also handled, with a great deal of competence, the most complicated set of financial accounts the Center has ever seen.

Steve Fosberg initially designed the laboratory experiment and did much of the early background research on biochemical processes. He wrote the first version of the chemical system section in Chapter 3.

Larry Murphy came to the project in its final stages and designed and conducted an elegantly simple and effective experiment on wet/dry cycling which has produced a very high level of data returns for time and cost input. Larry's extensive background in underwater archeology and diving technology also made him an excellent choice for writing the technical report in Volume II on the applications of underwater archeological methods to reservoir mitigation programs.

Sandy Rayl took over the implementation of the biochemical aspects of the study after Steve Fosberg's departure for the U.S. Forest Service. Like the mechanical aspects of the study, the biochemical demanded that the researcher involved become conversant with the language of chemists, soil scientists, hydrologists, and other curious and arcane disciplines. She did an admirable job, as did Steve and John, in coping with a large amount of nonarcheological data. Sandy, in addition to her technical contributions, wrote most of the material on biochemical reservoir processes and impacts in Volume I.

John Ware was heavily involved in the design of the format of this report. In addition to his authorship of part of Volume II for which he is already credited, he wrote the mechanical processes and impacts section of Volume I. It should also be noted that John first conceptualized the large-, medium-, and small-scale framework of presentation of research results and pointed out our initial blind spot in regards to impacts on general environmental data from the reservoir construction process.

Darlene Romero served as secretary for the Inundation Study for the full length of the project and has returned for more punishment in the same position with the newly formed Submerged Cultural Resources Unit of the National Park Service. Simply said, Darlene was indispensable. For a year Barbara Hamm was part of the Unit, and in addition to taking over many secretarial duties, she was stuck with the frustrating and thankless job of keeping up with countless versions and rewrites of technical reports.

The final manuscript was entered on a word processor, a mistake we'll never make again, by Betty Montano, who should be in line for an international award for perseverance. Chris Lopez and Susan Tixier also became involved at some point in the mammoth task of "word processing." Paula Sabloff did the technical editing of Volume I, and Penny Landay accomplished the final proofreading. Penny, along with Joy Roots, proofread Volume II.

In some ways, this report is almost anticlimactic since, in my estimation, the major impact of the study was felt in the overall field of reservoir mitigation during the four years of active research through visits, presentations, and preliminary reports. In any event, these two volumes should present a much needed reference and summation of the results of this interdisciplinary research project.

Daniel J. Lenihan

FOREWORD

This report stems from an initial cooperative effort of the U.S. Army Corps of Engineers, the U.S. Bureau of Reclamation, the U.S. Soil Conservation Service, and the National Park Service to find practical and demonstrable solutions, at the field level, to commonly shared problems faced by field managers in the conservation management of inundated cultural resources.

During the past decade, a great deal of emphasis has been placed at the Federal level on inventorying, evaluating, and salvaging threatened archeological resources. The land managing agencies have come to realize that this is but a part of the larger program of the management of these resources. This multi-agency study seeks to answer the question, "How should we manage the long-term preservation of inundated archeological resources?"

The success of this effort is due, in large measure, to its being conceived, planned, coordinated, and executed by field personnel--the people in closest touch with the "real-world" problems of inundated resources. Through the pooling of funds, specialized personnel, and facilities of the participating agencies, a program more effective than one undertaken by a single agency was developed.

Douglas H. Scovill
Chief Anthropologist

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INTRODUCTION TO THE FINAL REPORT

The final report of the National Reservoir Inundation Study is the third and last in the series of reports published by the project core team. The first was The Effects of Freshwater Inundation of Archeological Sites Through Reservoir Construction: A Literature Search. The second, The Preliminary Report of the National Reservoir Inundation Study, followed in 1977. The present report utilizes the comprehensive research design advanced in the Preliminary Report. It also presents an expanded and more complete bibliography, which includes all of the references originally cited in the literature search. Consequently, this publication may be used independently of the first two; indeed, it supercedes them. An Executive Summary, an encapsulation of the most significant results of the research, has been included in Volume I. Little effort is made at quantifying results in that summary, and it has utility only as an overview. On the other end of the scale, many of the technical reports presented in Volume II contain considerable detail; they will probably be of major interest only to people concerned with those specific topics.

This two-volume report is the result not only of a five-year effort on the part of the study's core team of National Park Service archeologists; it relies also on data gleaned from a whole series of specially contracted reports. Core team archeologists were responsible for developing the generalized research approach used by each contracting investigator in his/her particular geographical or technical area of expertise. Although a systematic set of research problems and test parameters were explicitly outlined to outside researchers, they were given a great deal of latitude for creatively developing the application of this format to their individual specialty areas. They were also asked to document observable impacts to cultural resources resulting from water impoundment in the reservoirs with which they were concerned. Although the Preliminary Report outlined a number of specific things to look for, contractors often expanded on these suggestions and presented many additional observations on the effects of reservoir dynamics on archeological values. This report is consequently a synthesis of a large and complex body of information contributed by many individual researchers.

The first volume of this final report contains a structured presentation of the results of the testing of various hypotheses originally developed or later regenerations of the original hypotheses. Although it addresses only a fraction of the conceivable spectrum of impact possibilities, this summary volume may serve as a model for use by reservoir managers and archeologists to predict and project the occurrence of impacts to cultural resources in impoundment areas. It will also help them to be aware of the data retrieval potential that may still exist in reexamination of sites that have already been submerged by reservoir construction activities.

Volume I is, in this sense, a functional working manual for cultural resources management in reservoir areas. To increase its utility as a management tool, a detailed discussion of the question of mitigation is included. Besides outlining alternatives for reaction to specific inundation events, it discusses the overall question of building cultural resource management concerns into the reservoir construction process.

A second volume of technical reports presents a detailed description of the methodology employed in various specialized components of the study and the substantiating data from which many conclusions were derived. In many cases, there are considerable hard data to back the conclusions reached by the core team. In other cases, the concluding statements are only weakly justified or still open to considerable controversy. Since the study must work from generalized predictive statements to application in particular reservoir situations, there may always be new reservoir-specific variables that have not been considered.

In some cases, the original hypotheses outlined in the research design of the <u>Preliminary Report</u> have been regenerated. Sometimes testing results suggested a different approach; at other times enough new relevant variables were discovered to necessitate changing hypotheses even before they reached the testing stage. The data used to confirm or nullify the original hypotheses and develop final conclusions come from three basic sources. These are: 1) continued examination of the existing literature--much of it in disciplines other than archeology, 2) additional empirical evidence from field observation of inundation impacts both by project personnel and contracted researchers, and 3) laboratory experimentation with associated field-based experiments. Much of the quantifiable data returns have resulted from controlled laboratory experiments. These have all been conducted in a manner which will permit them to integrate as efficiently as possible with field observations of inundation processes in the real world.

To make the results as meaningful as possible, we have gone to lengths to be explicit about the nature of our final generating data for the stated conclusions. In some cases, the data is quantitative, in others qualitative. In the final analysis, the question of reliability will ultimately be left to the archeological and managerial professionals who utilize this document in the management of cultural resources.

This report should be seen, therefore, as a holistic model for understanding the interaction of reservoir dynamics on archeological resources, accompanied by a coherent presentation of possible alternatives for ameliorating adverse effects that result from this interaction. It by no means should be taken as the final word on reservoir impacts, and one should remember that its value as a management tool derives from the sum of its parts rather than the unquestionable validity of any particular section. As the awareness of the understanding of reservoir impacts develops, more and more questions will be asked, and many of the conclusions reached will be subjected to changes in emphasis and substance. The reader should conceive of this report as a living document subject to reevaluation and change and as a generalized base-line or jumping-off point for dealing with any particular reservoir situation.

EXECUTIVE SUMMARY

Much confusion has surrounded the question of inundation, especially its impact on archeological resources. While some people have argued that everything about to be flooded should be left alone (to serve as a data bank for the future), others have said that anything about to be flooded should be excavated (to save it from possible destruction). Often, both viewpoints would be found in Environmental Impact Statements generated within the same agency. Dialogue on the subject was degenerating to partisan rhetoric, with archeological contractors arguing for extensive site excavation as the only viable mitigation tool and reservoir managers defending the preservation of sites through flooding.

In 1975, four Federal agencies decided to resolve the conflict through intensive research. They proposed the formation of the National Reservoir Inundation Study in hopes that it would answer two questions: In what way does the construction of a reservoir affect the archeological resources surrounding it? And, how can the effects of inundation on archeological resources be mitigated?

The National Park Service archeologists who became the Inundation Study's core team did not report to construction agency officials and were not involved in reservoir salvage contracts; thus they had minimal personal bias regarding the outcome of the study. From this perspective, they were able to make reasonably objective observations on the issues and have come to the conclusions listed below. These are purposefully couched in general terms, for specifics would require an unwieldy amount of qualifying statements.

OBSERVATION #1

The overall effects of reservoir inundation on archeological resources in any given drainage area are unquestionably detrimental in nature. The subjection of a resource base that is highly sensitive culturally, such as archeological sites in a river drainage, to the radical environmental changes incurred by inundation results in large-scale destruction of data-bearing elements of the resource. Seeing the inundation process as a means of creating data banks for the future has limited utility in light of the impacts that develop and the subsequent loss of access to the data base.

OBSERVATION #2

The traditional response of the archeological community to the threat of inundation is often ill-conceived and parochial in nature. Conducting large-scale, site-specific excavations on the basis of a priority listing of the "most important" sites leaves much to be desired and is happily also coming under fire within the discipline itself. Much more attention should be focused on the intersite environmental data base which is the aspect of the human behavioral record that is most susceptible to devastating impact. Additionally, archeologists should devote much more attention to the overall susceptibility of impacts to different elements in the archeological record instead of assuming that inundation affects archeological values equally. Research proposals for mitigation should show a greater interest in and understanding of reservoir processes and the consequences for different aspects of the archeological record.

OBSERVATION #3

Site protection is a viable alternative to the "excavation only" syndrome, but only in very specific circumstances. Rarely should preservation be seen as an answer in itself. Rather it should be accompanied by partial site excavations since some of the more vulnerable elements of the data base will almost always be lost. Both resource managers and archeologists should also understand that site protection is rarely a less expensive option than field testing and limited excavation. This myth has caused much misunderstanding among both communities. What is often not considered is that an indefinite commitment to preservation involves not only major initial expenses but also an indefinite commitment to maintenance of the preservation mechanisms selected.

OBSERVATION #4

There is a critical lack of understanding of the importance of reservoir zones with regard to differential effects on cultural resources. The deep-water zone is the least susceptible to most impact phenomena. It also, however, is the area that will present most problems to future researchers due to loss of access. Attempts at preservation will be most workable in this zone aside from the accessibility question. The most critical impact zone is the area subjected to shoreline fluctuation of the water level and wet/dry cycling. The most complete destruction can be expected here. The zones subjected to occasional flooding during high-water periods or those outside of the flood pool, however, are also potentially high-impact areas. Inundation Study research has demonstrated that the problem of human vandalism is extemely severe in those zones which are often considered to be the least affected by many researchers.

OBSERVATION #5

Postinundation managerial action must play a much larger part in the mitigation process. Whatever strategy towards mitigating impacts to archeological resources is taken during the preimpoundment period, the obligation to intelligently manage and protect these values does not evaporate when the dam is built and the reservoir is functioning. It is given that, in almost all cases, many sites will not be excavated as part of a mitigation plan. When significant cultural resources remain intact to be subjected to flooding events, a serious attempt should be made through managerial action to create an environment most conducive to their survival. This may involve restricting areas to dredging operators or strengthening protection patrols in areas where archeological sites at pool level are made more accessible to the public due to boating activities.

OBSERVATION #6

Communication between reservoir planning and construction personnel and archeologists should be greatly increased. There are points in the reservoir construction process where increased dialogue and commitments may result in increased protection of resources at reduced expense to the taxpayer. One point is during the preauthorization planning phase where the release of funds for preliminary archeological inventory could eliminate potentially serious impacts through avoidance. Another time that communication should be much greater is during the creation of the mitigation plan. Archeologists rarely consult in depth with reservoir scientists about the reservoir processes that will come into play in the areas where they plan to conduct archeological research. This report should provide a jumping-off point to the archeologists for relating the findings of this study to their particular reservoir impact mitigation problems. It is most useful, however, when accompanied by dialogue with hydrologists, soil scientists, and structural engineers. Communication between archeologists and managers during the operation and maintenance phase is also too rare an occurrence. Valuable insights can be gained regarding the presence of archeological sites in relation to high-energy beach zones, susceptibility of the soil matrix in which sites are located to erosion, possible means of protection, etc. Such communication is a two-way street, and it should be noted that the archeologist is not the only one who benefits from this exchange. A greater sensitivity to the nature, fragility, and problems associated with cultural resources can only benefit a reservoir scientist or manager and could well be incorporated as a part of their on-the-job training.

In as concise an outline as possible, the higher level manager should be made aware of several overall conclusions of the Inundation Study:

1. Reservoir construction due to its nature involves impacting the most culturally sensitive land areas in the nation. Drainages in prehistoric and historic times have been the loci of all major human activity patterns in the New World.

2. The Inundation Study has shown that these resources are unquestionably adversely affected from the reservoir construction process.

3. Inundation Study results have definitely indicated that different archeological values are differentially affected by inundation.

4. Existing mitigation plans are often conducted without proper attention being paid to differential impacts on the basis of reservoir zones.

5. Site protection and preservation is a viable option in some circumstances, but it cannot be expected to result in significant savings over site excavation or sampling.

6. Archeological concerns should be worked into the construction process earlier than they have been. A model for rethinking approaches to mitigation is offered in Volume I (Chapter 5) of this report.

7. Communication must be improved between archeologists and reservoir construction specialists. This might be effected through the creation of formal training programs coordinated by construction agency archeologists.

8. Steps should be taken to ensure that archeological considerations are not abandoned after water has been impounded. Managerial action taken during the operation and maintenance phase can be critical to preservation of a significant representation of the resource base.

CHAPTER 1: INTRODUCTION

THE ISSUE

It is well documented that in the New World, river drainage systems have served as loci for subsistence transportation and communication activities (Willey 1966, Neill 1964, Taylor 1964, Williams and Stoltman 1965). In the twentieth century, a greatly increased demand for water and electricity resources in the United States precipitated a boom in reservoir construction activity, with its associated inundation of these culturally sensitive drainages.

The primary response of managers and archeologists to this stimulus has been to engage in reactive salvage programs. In many cases the archeology conducted on "threatened" sites was hasty and graced by little in the way of productive research designs (Taylor 1964, Binford 1964). But salvage archeology appeared to be the logical response to a national policy which was formulated in the following legislation:

The Antiquity Act of 1906: Provides for Federal control of all archeological resources on federally owned or controlled lands.

The Historic Sites Act of 1935: Declares that it is national policy to preserve historic and prehistoric sites, buildings, and objects of natural significance.

The Reservoir Salvage Act of 1960: Requires that any agency of the United Stated that undertakes dam construction must provide written notice to the Secretary of Interior who shall then cause a survey conducted for archeological sites.

The Historic Preservation Act of 1966: Authorizes establishment of a National Register which includes districts, sites, and objects of archeological significance. Any project utilizing Federal funds or permits (such as reservoirs) must consider adverse effects on National Register properties.

<u>The National Environmental Policy Act of 1969</u>: Requires that an Environmental Impact Statement be prepared for all federally licensed or sponsored projects which significantly affect the environment.

<u>The Reservoir Salvage Act of 1960 as amended (Moss-Bennett)</u>: Provides authorization to construction agencies to spend construction funds on mitigation of impacts to archeological sites.

During the 1960s, serious questions began to be raised over the issue of "salvage archeology" in the research community. Representatives of land managing agencies and institutional archeologists also were concerned that no alternatives seemed to exist to total salvage versus total destruction. It was also increasingly realized that the archeological recovery process itself was extremely destructive. As the issue progressed into the early '70s, it became intertwined with the overall conservation ethic that was coming to the fore in the archeological community. A key article proposing a conservation approach to cultural resources management (Lipe 1974) was written, following the lead of other papers that challenged the organizational structure of public archeology (Struever 1968). The 1974 Conference on Cultural Resource Management held in Denver gave birth to the American Society for Conservation Archeology, which became an officially organized forum for propagating a "conservation ethic" in archeology. This discussion has now advanced to the point that schemes and approaches for conducting "nondestructive" and "minimal impact" archeology are being proposed (Lyons & Ebert 1978; Judge 1979).

Although the nature of salvage archeology and its associated concept of archeology by contract (as opposed to grants generated by an interested researcher) underwent intense scrutiny, criticism was based primarily on methodological grounds. No one challenged the idea that the whole concept of emergency data retrieval might not be the only mitigation option. Many of the basic assumptions about what happens to archeological data in reservoirs were not reevaluated. This was in spite of the fact that as early as 1960, Donald Jewell had specifically noted in American Antiquity that we should consider again what had really transpired at sites which had been submerged in reservoirs (Jewell 1961).

Growing concern on the Federal agency level, however, was prompted in the early '70s by those involved with review of Environmental Impact Statements for reservoir construction. It was noted that many of the writers of these statements were basing their projections of potential impacts on entirely contradictory assumptions. Some claimed that everything remaining in the ground would be destroyed after inundation, while others worked on the premise that archeological sites inundated in reservoirs would be mostly preserved for posterity. On the one hand, some envisioned the end result of inundation as an unavoidable adverse impact, and on the other hand, others perceived impoundment as a mechanism for the creation of pristine data banks for the use of future archeologists at the termination of the projected life of the reservoir.

The one unifying element to both of these claims was the fact that they were based on a total lack of systematic supporting data. In May 1975, several principal representatives of the Bureau of Reclamation, U.S. Army Corps of Engineers, Soil Conservation Service, and National Park Service met to discuss the initiation of a special research program aimed at addressing the question of impacts on archeological sites as a result of freshwater inundation. It was felt that intelligent reviews of Environmental Impact Statements and subsequent management decisions about dealing with mitigation of impacts to cultural resources in reservoir impoundment zones could only be made in light of increased understanding of the nature of these impacts. The National Reservoir Inundation Study was formally proposed at this meeting, and the project was fully funded and staffed with a core team of archeologists by the spring of 1976. The National Park Service was chosen as the lead agency since the Southwest Cultural Resources Center of the

Park Service had existing expertise and equipment for dealing with submerged sites. The study team eventually became the Division of Submerged Cultural Resources, a branch of the Southwest Cultural Resources Center.

Cal Cummings of the National Park Service's Southwest Regional Office was asked to choose from this staff a project director with underwater archeological background. The Director would organize a study team to research the problems as mandated by the 1975 prospectus. The study group completed a preliminary report in late 1976 which detailed a systematic research design and a series of guidelines for collecting and collating inundation-related data. The research strategy of project personnel was to concentrate for the first two years on evaluating the nature of impacts to archeological values in reservoirs and to conclude with concrete recommendations for mitigating these impacts.

THE MANDATE: PROJECT GOALS

The ultimate goal of the program was to devise guidelines for the use of reservoir managers and archeologists in mitigating impacts of inundation to archeological resources. The Inundation Study core team was charged with several tasks: 1) researching what was already known concerning impacts of flooding on archeological sites (a literature search was published the first year of the study); 2) devising standardized guidelines for collecting comparative data on inundation for use in ongoing salvage programs (a series of guidelines for data collection and site preparation was also prepared by the team in the first year and distributed widely by the agencies); 3) developing a systematic research design for dealing with the inundation question on a nation-wide level (a <u>Preliminary Report</u> published by the team in early 1977 presented a comprehensive research design); 4) acting as a catalyst for dialogue on the subject with archeologists presently working on reservoir mitigation contracts (hundreds of contacts were made, which we personally felt to be one of the most rewarding aspects of the work), and 5) publishing results of the study in a format useful to both reservoir managers and archeologists (the final report of the project, in two volumes).

The core team was expected to use the conservation ethic in archeology as a general philosophic orientation in articulating the problem and presenting insights towards achieving viable solutions. Aside from improving understanding of the nature of impacts that devolve from inundation, the team was asked to scrutinize the general approach to mitigation of reservoir impacts in the country and evaluate the utility of any alternatives to salvage as a standard reaction to a construction project. To what degree could site protection and preservation play a meaningful role in mitigation strategies? Could avoidance of impacts be better orchestrated? Might standard salvage approaches be improved? These were all elements of the Inundation Study's research mandate.

PRELIMINARY RESEARCH DESIGN

The research design of the National Reservoir Inundation Study Preliminary Report was organized around two basic research problems. The first was: What are the effects of freshwater flooding on archeological sites? The second was: What is the best way to mitigate the negative effects of water impoundment on cultural resources?

To answer these questions in organized fashion, categories of archeological data and reservoir processes were defined and placed in a grid (Figure 2.1).

A series of hypotheses and test implications were generated from this chart that addressed:

1. The differential preservation of common cultural materials; i.e., ceramics, bone, lithics, shell, etc.

2. Impacts upon analytical techniques, i.e., soil chemistry analysis, flotation, palynology, source identification techniques, and microwear analysis.

3. Impacts upon standard survey techniques and remote sensing potentials.

4. Impacts upon dating techniques.

5. Impacts upon other archeological resources including loss of qualitative data relating to strata and features (color, texture).

A second series of hypotheses was formulated that used primarily inductive data to support each of the predictive propositional statements. Test implications which were designed to present a testing format for each of the predictions were then added. It should be noted that the hypotheses were not explanative in nature but were low-level propositional statements that were intended to show a causal relationship between a reservoir process and changes in certain archeological resources.

Methodologies used in operationalizing the preliminary research design included field work in sites that had been inundated, comparison of inundated sites to noninundated contemporary sites, and construction of artificial sites in areas about to be inundated. In many cases, principal investigators of ongoing salvage programs cooperated by working Inundation Study test problems into their research. This was sometimes specifically contracted for; at other times, it was totally voluntary.

During the course of the Inundation Study project, many of these emphases changed. In order to more fully understand the final field and laboratory approaches settled on, the reader is referred to Chapter 2 of this volume.

To better standardize the variables involved in retrieving comparative data on Inundation Study problems, a set of "Guidelines for Data Collection and Site Preparation" was published with the research design in the Preliminary Report.

THE FINAL REPORT: HOW TO USE IT

The final report of the National Reservoir Inundation Study is intended to present all of the relevant data and knowledge gleaned by the study during its four-year existence in the briefest, most usable format possible. It supersedes and makes obsolete the first two publications of the study; i.e., all relevant data in those volumes are presented here in finalized form. There are, however, a whole series of reports on particular field and laboratory efforts by core team members and outside institutions which comprise the building blocks of data used to develop this final statement. These frequently have much more detailed information on particular subjects and should be referred to by those with specific interests in those areas.

The first volume of this report contains a brief executive summary, primarily for the use of high-level managers who are interested in an "abstract" capsule that presents the scope of work, methodology, and results of the study in very generalized form.

Aside from this summary, the purpose of Volume I is to inform the concerned archeologists and line managers of: the problem orientation and definition of the study, its developmental history, the research design utilized, a discussion of relevant reservoir dynamics and processes, the methodology employed by the researchers, results of the research, and a discussion of mitigation alternatives.

Volume II is composed of technical reports that discuss particular cular testing programs in detail and speak to certain specialized concerns, e.g., underwater archeology as a tool for mitigation. Reports on much of the laboratory work are presented in detail in Volume II, but the thousands of pages of contracted field reports could only be presented in synoptic form in Technical Report No. 1. Should it become necessary to consult the original documents, the reader may contact the Southwest Regional Office of the National Park Service or the appropriate officials in any of the reservoir construction agencies funding the project. Copies of these reports will be kept on file in all of these places and are also usually available from the contracting institution.

As a general rule, the following procedure is recommended for a principal investigator or reservoir manager wishing to use this report as a guideline for a particular reservoir mitigation situation: First, the section on mitigation (Volume I, Chapter 5) should be consulted for general guidelines and insight into planning and operationalizing a reservoir mitigation strategy.

Next, in order to better understand the reservoir processes that come into play and the interplay between reservoir dynamics and impacts to archeological values, Chapter 3 should be read carefully. Finally, the most complete discussion of study results and the implications for specific archeological values in most reservoir environments will be found in the results section (Chapter 4).

Chapters 1 and 2 of Volume I are primarily designed to explicate the research approach used by the Inundation Study and may be used by the archeologist to better understand the philosophy and methodology used by Inundation Study researchers to address their mandated research problem.

CHAPTER 2: THE RESEARCH DESIGN

Two related problems are addressed in Volume I. The first problem is the prediction of freshwater inundation effects on submerged cultural resources. The second problem is the mitigation of any adverse impacts that might result from freshwater inundation. Since accurate prediction of inundation effects is a precondition to effective mitigation of adverse impacts, there was a logical priority to the problems addressed by the Inundation Study.

The prediction of freshwater inundation effects begins with the identification of potentially destructive reservoir processes and entails measuring the effects of these processes on a representative range of cultural values. In short, the problem of prediction involves filling in the blocks of a two-dimensional matrix (see Figure 2.1) with answers to such questions as: What are the effects of water chemistry variables on the differential preservation of cultural material such as bone, ceramics, etc.? The discussion and answers to questions like the one above will constitute the body of this report. But before proceeding to the answers that fit inside the matrix, we should expand our discussion of the problem by examining the impact categories and cultural values that form, respectively, the rows and columns of the problem matrix.

IMPACT CATEGORIES

Reservoir processes that affect cultural resources begin during the construction of the dam, long before any water is impounded to form a reservoir. The focus of this study, however, is on the less obvious but much more extensive impacts that occur in the watershed upstream and downstream from the dam following water impoundment. The most significant of these impacts occurs either as a direct result of water imersion

Figure 2.1

Archeological Resources Impact Categories	Large-Scale Data: Regional ecological considerations such as geomorphology, settlement patterns, faunal & floral distributions.	Medium-Scale Data: Site contextual data, stratigraphic and spatial relationships within a site.	Small-Scale Data: Differential impacts on common cultural materials including artifacts, features, analytical properties, etc.
Mechanical Impacts	Mechanical (siltation and erosion) and biogeochemical impacts to the reservoir drainage basin, including gross geomorphological changes; impacts to preinundation floral and faunal communities, etc.	Near-shore wave action, erosion and siltation of sites and site deposits.	Mechanical abrasion, freeze-thaw, and wet/dry impacts to artifacts and other cultural materials.
Biochemical Impacts		Biochemical alteration of site soil and contextual relationships.	Differential biochemical deterioration of archeological material categories.
Human and Other Impacts	Dam & barrow pit construction, roads, clear-cutting, etc.	Vandalism, recreational use. Impacts to shoreline by grazing animals; impacts by invader plant species, etc.	Removal of selected artifacts by collectors, etc.

and reservoir erosion and deposition or as the indirect consequences of reservoir use. For analytical purposes, these impacts can be categorized and defined as follows:

1. Mechanical. Perhaps the most important set of reservoir processes affecting the archeological preservation equation are the physical erosion and deposition processes associated with any large body of water. Included in this category are the effects of wave action along a vertically fluctuating shoreline, saturation and slumping of shoreline and submerged geologic strata, and siltation from backshore runoff and stream inflow.

Of these, the most destructive forms of impact occur along the fluctuating shoreline of the reservoir, where the mechanical forces of wave action and nearshore currents within the beach zone can drastically alter shoreline topography and any cultural resources occurring on that topography.

2. Biochemical. The biochemical environment at the submerged mud-water interface of a freshwater reservoir may have a substantial long-term

impact on archeological preservation. A reservoir's unique biochemical environment results from superimposing a riverine aquatic ecosystem on a terrestrial ecosystem. In time, the reservoir stabilizes to form a distinctly new ecosystem whose parameters are in part a complex function of the combination of the two preexisting stable ecosystems and the new hydrologic environment.

Hydrologic processes that influence reservoir chemical processes include inflow and outflow, rates of sedimentation, thermal stratification, density current formation, and frequency and amplitude of the reservoir drawdown cycle. Biological activity is regulated primarily by water temperature, dissolved oxygen concentration, and pH. There are also significant mutual causal influences between biological and chemical processes. For example, microorganisms can alter the concentration of dissolved silica, phosphate, ammonia, kjeldahl, nitrogen, and pH. Such changes can lead to a reduction in the oxidation-reduction potential, which may ultimately lead to anaerobic conditions.

3. Human. From a human impact standpoint, the consequences of building a dam and impounding a reservoir are in many ways comparable to the consequences of building a highway, road, or trail into a remote area: the result is an increase in the accessibility of cultural resources to both intentional and unintentional impacts from human visitation.

As a result of the increased access problem, a major (and often overlooked) implication of human recreational use of a reservoir is that the adverse impacts of reservoir construction on cultural resources may extend far beyond the reservoir shoreline to peripheral areas that are never actually subjected to freshwater inundation. This is in addition to the obvious human impacts at the reservoir shoreline, where induced wave action from boat wakes and recreational impacts only enhance the destructive effects of natural erosion processes in the high-energy beach zone.

4. Miscellaneous. A host of miscellaneous effects of freshwater inundation will be discussed in the body of the report, including floral successional impacts, faunal impacts, loss of access to the cultural resource data base, etc.

We should point out, however, before we leave impact categories and move on to cultural resource categories, that not all inundation effects constitute "adverse impacts." We will also show in the body of the report that the anaerobic environment of a deeply buried or deeply submerged site often proves to be an ideal environment for the preservation of organics and other perishable cultural materials. In fact, all of the above-mentioned facts may actually enhance the preservation of fragile cultural and biological data.

ARCHEOLOGICAL RESOURCE CATEGORIES

It is difficult to classify archeological resources into meaningfully discrete categories, but for analytical purposes it was necessary to do so. In cultural resource management, the traditional unit of research and preservation is the archeological site or historic structure. When addressing specific impacts such as human vandalism, it is often sufficient to focus on the site, but when addressing large-scale, nondiscriminatory impacts such as inundation, the traditional focus on sites may obscure impacts to other, equally significant data bases. Consequently, it was essential in the inundation study to adopt a regional perspective, and from that to adopt a hierarchy of cultural information categories that incorporates all levels of cultural data into a manageable and meaningful framework.

For the Inundation Study, archeological data were organized into a three-level hierarchy of data classes, each level associated with certain analytical techniques that may be affected by inundation.

The first category of archeological resources is defined at the regional level; it includes environmental data such as ecological zones and vegetational communities and physiographic and geomorphic features (soil types, etc.). This macrolevel of cultural material also includes data relating to regional site distribution patterns and other large-scale cultural features, e.g., trails, trade routes, and exploitation zones. All of these large-scale data classes may be adversely impacted by inundation.

The next level down in the hierarchy is the individual site, structure, or activity locus, which is characterized by a certain structure and configuration (architectural remains, artifact distributions, etc.). At the site level, we are not so much concerned with individual artifacts as with the "context" of each artifact in relation to all other artifacts and features within the site.

At the bottom level of the hierarchy are the individual cultural remains or artifacts. Our primary concern at this level is the differential preservation of individual artifacts and whole artifact classes. Some artifact classes (plant and animal remains, for example) are more fragile than others, and a broad-scale impact such as inundation may change (destroy or preserve) entire classes of cultural remains. On the other hand, inundation may leave other classes essentially unmodified.

Finally, the last category of cultural resources includes the various analytical techniques that are performed at each of the data levels outlined above, from the macroscale of the regional environment to the microscale of the individual artifact.

Large-Scale Archeological Resources

Inundation impacts at the regional scale may be expected to affect a wide variety of cultural values. Perhaps the most important of these is the regional environmental data base.

The archeological site, as a locus of human activity in the past, is the traditional focus of archeological research. Within the cultural deposits of a site or historic structure are answers to many traditional questions, such as who occupied the site, when was it occupied and for how long, how were members of the coresident community organized, what resources were extracted from the environment, and what tools were used to extract and process those resources.

But if the answers to many of these questions are contained within the archeological record of a site or group of sites, many problems generated by these answers are not. Such questions as why did people locate sites where they did, why were they organized as they were, why did they use some of the resources and not others, and so on, often require data from outside the boundaries of the site -- from the regional environment.

In the twentieth century, environment is conceived as a crucial and dynamic factor in cultural reconstruction. The sociocultural system is seen as a subsystem within the larger ecosystem, and causal processes must ultimately be viewed in terms of these larger relationships if they are to be understood.

The archeologist interested in the "why" of cultural process, therefore, must look beyond the boundaries of the archeological site in order to collect data relevant to these larger ecosystemic relationships. Even comparatively simple issues, such as the currently popular question, "Why are sites located where they are?", require that the archeologist look beyond the boundaries of the site to identify environmental variables that influenced site location strategies.

The point is that even if every archeological site in a region were preserved and protected from the adverse effects of inundation, inundation adversely affecting the floral, faunal, paleobiological, and geomorphological environment of the sites would cause loss of significant "cultural" information.

Medium-Scale Archeological Resources

Inundation impacts at a site may affect more than just the material contents of the site. An archeological or historical site typically contains assemblages of artifacts, architectural remains, refuse from domestic activities, etc. But from an information standpoint, the site as a whole is much greater than the sum of its parts. If we can assume that people carried out various activities at different locations within a site, then it stands to reason that as activities and groups varied, the material remains associated with those groups varied as well.

Hence, the spatial distribution of artifacts at a site where people performed different tasks constitutes a "fossil" record of the spatial operation of the extinct society. According to Lewis Binford (1964:425):

> The intimate systemic articulation of localities, facilities, and tools with specific tasks performed by social segments results in a structured set of spatial-formal relationships in the archeological record.

Since the structured relationship of artifacts and material remains at a site may reflect significant nonmaterial or organizational aspects of an extinct cultural system (information that could not be derived from the examination of material cultural assemblages removed from their depositional context), the destruction of contextual relationships at a site by mechanical erosive forces such as wave and current action can have a significant impact on the information content of a site. In short, artifacts can be perfectly preserved, but if their spatial and stratigraphic relationships are altered or destroyed, much of their scientific value is irretrievably lost.

Small-Scale Archeological Resources

One of the most important questions addressed by the Inundation Study is the effect of freshwater immersion on the differential deterioration rates of common cultural materials.

When the Inundation Study began in 1975, there already existed an extensive body of data on the deterioration of common industrial materials in a submerged environment. The majority of those studies, however, focused on material preservation in saltwater environments, where marine organisms such as the borer worm are the primary destructive agents. Comparable studies of freshwater deterioration were few and far between. Thus, for the majority of cultural material classes, there was no basis for predicting preservation factors and deterioration rates from the existing literature, although of popular assumptions abound.

One assumption is that the anaerobic environment of a heavily silted site would be an ideal environment for the preservation of organic and other perishable archeological materials. There is no question but that this is the case in many circumstances. However, a number of important questions remained unanswered. For example, what depth of burial is sufficient to preclude aerobic microorganisms? What is the effect of the interplay of intervening variables such as water and soil chemistry, the effects of light penetration and water temperatures, and the potential effects of reservoir dynamic processes such as seasonal drawdowns, turnovers, shoreline mechanical impacts, etc.? In short, what information would we need in order to predict differential preservation of materials in reservoirs?

The question of differential preservation is important from a management standpoint because decisions might have to be made to salvage samples of material classes that would be destroyed by inundation.

Analytical/Dating Techniques

In addition to the problem of differential preservation of materials is the related question of the mechanical and biochemical effects of inundation on the traditional analytical and dating techniques used by archeologists. As a class of analytical techniques, the various chronometric dating methods are indispensable to effective research. An important question being addressed by this study is the effect of biochemical and mechanical reservoir processes on the accuracy of radiocarbon dating, dendrochronological determination, paleomagnetic estimation, etc.

Analytical techniques critical to effective archeological research are performed at each of the data levels discussed above, from the regional level all the way down to the individual artifact, and inundation may either render the techniques impossible or compromise their accuracy or effectiveness.

RESEARCH STRATEGIES

Background Research

A critical aspect of many research endeavors is an understanding of what has gone before in order to determine the foundations upon which new efforts can be built. The major precedent for the National Reservoir Inundation Study was Donald Jewell's classic article (1961), which urged the investigation of reservoir-inundated sites. Following publication of his article in American Antiquity, a few individuals began expressing their concern for the fate of submerged cultural resources within freshwater impoundments.

The first efforts of the National Reservoir Inundation Study in 1976 were directed toward gathering together all available background material dealing specifically with the problem of freshwater inundation of cultural resources. Calvin Cummings compiled a file of letters, memos, and excerpts from written reports documenting inundation effects. They were held in the underwater archeology files of the National Park Service Southwest Regional Office. This information was supplemented by two bibliographies already compiled in the general area of underwater archeology--one by Carol Ruppe and the other by George Fischer. Fischer's work contained some references that were not found through other investigations. Library research by the study team further increased the number of citations which were included.

The initial intent of the background research was to provide source material dealing directly with inundation impacts; however, it was quickly recognized that a number of closely related topics should also be included. Consequently, sections on nonreservoir freshwater immersion, cultural resource management, submerged habitation sites, preservation, underwater archeology, remote sensing, and legal aspects such as vandalism and antiquities violations were added.

Study team personnel also visited Federal research centers specializing in dam-construction sciences. Their goal was to determine whether questions about the physical/chemical nature of impacts had been analyzed at all by these agencies. In addition, the Department of the Interior's Field Services Library was also requested to research the topic. It was quite cooperative; however, it was able to offer only four additional references.

The references compiled were annotated, where possible, and resulted in the first publication of the National Reservoir Inundation Study: The Effects of Freshwater Inundation of Archeological Sites Through Reservoir Construction: A Literature Search. This document contained over 250 references, the majority of which were annotated. It was intended to be exhaustive only in regards to sources which dealt directly with the question of inundation impacts to archeological resources. Sources listed in the sections on related subjects were included as an overview of those areas. They provided the study team a baseline for research and a clearer understanding of the major gaps in the information base concerning the impact of inundation on archeological resources.

The initial literature search, published in 1976, was considered to be a living document. During the past few years, more articles and reports have been generated which deal with inundation impacts. An updated version of the earlier publication has been included in the companion volume to this final report (see Volume II, Technical Report No. 11).

Research by team members into specific areas of interest in other disciplines in order to set the background for inundation study problem formulation has also resulted in a considerable number of additional references being listed in Volume II. Such references are more usually associated with the fields of biology, chemistry, soils science, etc. A prime source for much of this material was the library at the Engineering and Research Center of the Bureau of Reclamation in Denver.

Field Research

Field research conducted by the Inundation Study core team or by university-affiliated professionals under contract to the core team had five distinct purposes. The first, reservoir assessment and familiarization trips, took place early in the project. A number of reservoirs were investigated to determine if the archeological sites known to exist before inundation were intact and accessible to divers and to ascertain what logistic factors would have to be dealt with in returning to them using underwater technology.

The second type of field activity involved returning to sites that had been inundated in the past and attempting to develop comparative data using old site reports as the control for what had been there prior to inundation. In some cases, this was done while the site was dry during a drawdown; in other cases, diving techniques were employed. If prior documentation on the observed site was not available, comparisons were made to archeological data gathered from similar sites from the same time period which were outside of the reservoir pool.

The third class of field work was that of preinundation site preparation and establishment of experimental controls. The objectives in this case were to reach a site or series of sites before water reached the level of the archeological materials contained therein and take steps to ensure that strong control information would be available for comparative purposes after inundation. To ensure as much cross-utilization of data as possible, a standardized format for taking samples for this purpose and for preparing a site for inundation was developed (see Volume II, Technical Report No. 10).

The fourth class of field activity was the logical continuation of the third activity, outlined above. Sites which had been specially prepared for an inundation event were revisited and reexcavated using underwater archeological techniques. In some cases, special containers of various artifact specimens, soil samples, etc., were retrieved after having been left underwater for set periods of time. These materials were brought back for comparative analysis with previously separated portions of the same specimens, which were used as controls.

The fifth and last distinct type of field activity involved visits to sites that were not in reservoirs but were considered as valuable corollaries to the reservoir environment. Included were shipwreck sites in the Great Lakes, submerged sinkholes with early prehistoric remains, and, to a limited extent, saltwater sites. These related environments provided some perspective and insights into the possible longer term effects of reservoir inundation on cultural resources.

The research strategies employed in the field phase of the Inundation Study were influenced by a host of situational and logistic factors, as was the initial selection of sites investigated. In order to glean the largest amount of information from available funding and personnel resources, interface with ongoing mitigation programs would be a critical element of the research strategy. Accordingly, one of the earliest products of the project core team was a document entitled "Guidelines for Data Collection and Site Preparation." It was distributed to many institutional archeologists involved in contract work with the Corps of Engineers, Bureau of Reclamation, Soil Conservation Service, and Tennessee Valley Authority. This document provided a baseline for the collection of standardized data from all aspects of archeological excavation. The guidelines furnished a working handbook that could be used by any archeologist, ensuring that collection, storage, and analysis procedures for samples from different parts of the country were reasonably uniform. In addition to the uniformity of sample collection, the guidelines provided suggestions about how to prepare many sites undergoing salvage excavations so that they could provide the best control information if they were examined later (when dry or wet). This document was distributed to interested parties before the Preliminary Report was written and was also published in that report.

The necessity for interfacing with ongoing salvage programs, however, did affect the nature of the sampling design. The general strategy was to attempt to cover as many geographic and cultural variables as possible while addressing as many of the hypotheses outlined in the research design as feasible. In many instances, however, certain classes of information were deemphasized due to the fact that the principal investigator of a given salvage project could not gather the data. Sometimes the investigator was simply not interested due to his own contractual limitations; more likely, that particular data category was not easily obtainable in any of the direct areas of impact being mitigated by the salvage effort.

Although valuable information on all aspects of the inundation problem was obtained from field work, certain categories of impact consistently seem to be better represented in field research results. We tended to gain our most comprehensive and dramatic returns in the area of mechanical impacts. In those cases where it was felt that returning to actual sites in the field was not producing adequate information, strong efforts were made to emphasize those areas in artifically created field experiments or in the two-year laboratory experiment conducted by the core team in cooperation with the University of New Mexico.

Those phases of field research involving underwater data retrieval were conducted almost exclusively by the Inundation Study core team. Exceptions are the field sessions conducted by the University of Missouri at Table Rock Lake and other sites in Missouri and Arkansas. State-of-the-art underwater data retrieval methods were used in all cases, and new techniques and approaches were devised in several instances. A special Technical Report (No. 9) is included in Volume II which details the data retrieval techniques, research diving procedures, etc., employed by the core team.

The following is a list of all the contracted or cooperative field reports that employed the Inundation Study research design. Data from the report has been integrated into the results section of Volume I, and a special report in Volume II (Technical Report No. 1) summarizes the conclusions on an individual basis.

Table 2.1

CHESBRO RESERVOIR, CALIFORNIA
- Archeological Resources of Chesbro Reservoir (Winter 1977)
- A Baseline Data Study of Three Archaeological Sites at Chesbro Reservoir (Stafford 1980)
- Inundation Effects on Thermoluminescence Response of Archaeological Lithics from Chesbro Reservoir (Rowlett and Bates 1979)
- Results of Testing Inundation Impacts on Site CA-SCL-52 at Chesbro Reservoir (Stafford and Edwards 1980)

FOLSOM RESERVOIR, CALIFORNIA
- The Effects of Inundation on the Pedersen Site, CA-ELD-201, Folsom Lake, California (Foster et al. 1977)
- Archaeology in Solution: Testing Inundation's Effects at Folsom Reservoir, California (Foster and Bingham 1978)

LAKE MENDOCINO RESERVOIR, CALIFORNIA
- Supplementary Investigations into the Effects of Freshwater Immersion on Cultural Resources of the Lake Mendocino Reservoir Basin, Mendocino County, California (Stoddard and Fredrickson 1978)

GRAND COULEE NATIONAL RECREATION AREA, WASHINGTON
- Field Assessment (Carrell 1980)

ABIQUIU RESERVOIR, NEW MEXICO
The Mechanical and Chemical Effects of Inundation at Abiquiu Reservoir (Schaafsma 1978)

NAVAJO RESERVOIR, NEW MEXICO
Effects of Inundation on Archaeological Materials from the Navajo Reservoir (Rowlett and Bates 1979b)

LAKE POWELL, UTAH
Glen Canyon Revisited: The Effects of Reservoir Inundation on Submerged Cultural Resources (Rayl et al. 1978)
Preliminary Experiments in the Structural Preservation of Submerged Anasazi Masonry Units (Nordby 1980)

PALMETTO BEND RESERVOIR, TEXAS
Prehistoric and Historic Archeological Site Magnetometer Surveys in the Palmetto Bend Reservoir Area (Arnold and Prokopetz 1976)

LIBBY RESERVOIR, MONTANA
Field Assessment (Carrell 1980)

SAYLORVILLE RESERVOIR, IOWA
Eyeing the Gathering Waters Whilst Building the Ark: Preparation of Archeological Site 13PK183 Saylorville Reservoir, Iowa, for Post-Inundation Study (Gradwohl and Osborne 1977)

TABLE ROCK RESERVOIR, MISSOURI
A Final Report on the Effects of Inundation on Cultural Resources: Table Rock Reservoir, Missouri (Garrison, May, Marquardt, and Sjoberg 1979)

BLUESTONE RESERVOIR, WEST VIRGINIA
An Inundation Study of Three Sites in the Bluestone Reservoir Summers County, West Virginia (Adovasio et al. 1980)
Inundation Effects on Thermoluminescence Response of Archeological Remains from Bluestone Reservoir, Summers County, West Virginia (Rowlett and Bates 1980)

BLUE MOUNTAIN LAKE, ARKANSAS
Blue Mountain Lake: An Archeological Survey and an Experimental Study of Inundation Impacts (Padgett 1978)

TELLICO RESERVOIR, TENNESSEE
Experiments for Monitoring the Effects of Inundation on the Toqua Site (40MR6), Tellico Reservoir, Monroe County, Tennessee (Schroedl 1977)

OZARK NATIONAL SCENIC RIVERWAYS, MISSOURI
National Reservoir Inundation Study Research at Round Spring and Alley Spring, Ozark National Scenic Riverways, Missouri (Carrell, May, and Garrison 1980)

Laboratory and Field Experiments

A major focus of research in the Inundation Study concerns the question of differential preservation of cultural materials. A two-stage experiment was designed to assess the interaction between various freshwater chemical and biochemical environments and various classes of archeological materials. The function of the experiment was to discriminate between the chemical and biological effects of freshwater inundation.

The first stage, conducted in the laboratory, was designed to isolate and measure the effects of specific chemical ions of known concentrations on various classes of cultural materials over a given period of time. The second stage, conducted in an actual reservoir, was designed to measure the macrobenthic and microbiological impacts to various categories of cultural materials. By isolating the chemical, macrobiological, and microbiological variables, data on rates of deterioration and the composition and distribution of predatory organisms could be compiled and compared with data collected from the laboratory studies.

For both phases of the experiment, seven general categories of cultural materials were selected. These were ceramics, lithics, shell, bone, wood, seeds, and pollen. The selection of representative cultural materials satisfied two goals: 1) to investigate biochemical impacts on a broad range of cultural materials in order to ensure regional diversity and 2) to identify those material states or depositional contexts that influence rates of degradation in an aquatic environment. Toward this end, an attempt was made to control for internal variables of manufacture, design, etc., which might influence deterioration rates and mask the relevant biochemical variables. For example, manufactured ceramics were selected in lieu of prehistoric ceramics so that internal variability resulting from clay type, temper/paste ratio, construction technique, sherd thickness and shape, firing atmosphere, etc., could be held constant, while those variables which directly influence sherd strength such as firing temperature and temper type (Shepard 1956) could be systematically varied. In general, within each of the artifact classes, the selection of those variables which would be allowed to fluctuate were those deemed most significant in terms of material preservation within a reservoir environment.

General Aspects of the Water Chemistry Experimental Design: The subsequent step taken in designing the water chemical experiment was the selection of relevant variables. The water chemistry of a reservoir is determined to a significant extent by the interaction of the geologic, climatic, and biological regimes, as well as by land-use variables. Collectively, these factors influence regional variability. In order to replicate the water chemistry of a "typical" reservoir for experimental purposes, the ionic composition and concentrations of a cross-section of North American reservoirs were determined. An initial list of 28 variables was compiled as a result of contacts with water resources personnel at the U.S. Army Corps of Engineers, the U.S. Bureau of Reclamation, and the U.S. Geological Society. Also, a literature search of water quality data from a variety of reservoirs, published by the U.S. Army Corps of Engineers and Bureau of Reclamation, was subsequently reduced to 10 variables. These included 5 anions--sulfate (SO_4), chloride (Cl), bicarbonate (HCO_3), carbonate (CO_3), and silicate (SiO_3) -- and 5 cations -- calcium (Ca), sodium (Na), potassium (K), magnesium (Mg), and iron (Fe). Although manganese (Mn) was not included as a chemical variable to be monitored, it was selected for analysis since it could be accurately analyzed at low concentrations. Ultimately, the selection of the water chemical variables was based upon the relative ionic concentration in an "average" reservoir and upon the suspected chemical interaction between these ions and various archeological materials.

In order to isolate the effects of a specific cation or anion, ionic concentrations approximating the median value for that compound in a "typical" reservoir were prepared and maintained in covered nalgene containers containing the artifacts. Fourteen such vats were prepared. Each contained a specific ionic combination to permit cross-comparisons between containers in order to isolate impacts attributed to individual ions. Fourteen additional vats containing 20 times the median concentration of at least one of the cations or anions under consideration were prepared in order to simulate the effects of long-term immersion. Since the duration of the experiment was limited to one year, it was hoped that the increased ionic concentrations would accelerate the effects of the ions on submerged archeological materials. Two vats were established as controls. One contained deionized water to serve as a control for the chemical solutions; the other contained five compounds at median concentrations (including $NaHCO_3$, $MgCl_2$, $FeCl_3$, $NaSiO_3$ and $CaSO_4$) to simulate the interactive chemical effects of a reservoir environment.

As the laboratory phase of the experiment was designed to isolate and measure water chemical impacts, an attempt was made to exclude biological activity by changing the chemical solutions at ten-day intervals. An alternative to frequent solution changes, algacide treatment, was discarded early in the planning stages for two reasons: 1) the addition of compounds such as phenol, tincture of merthiolate, or silver nitrate would possibly have a greater effect on the archeological materials than the ions under study, and 2) the addition of the cultural artifacts would possibly add more of the ions under study through leaching than the initial concentrations.

Once prepared, the chemical solutions were permitted to stabilize; samples of each of the cultural materials were immersed; and the containers were sealed, though not hermetically. At four-month intervals following initial immersion, selected categories of materials were removed from solution and subjected to a variety of tests designed to measure chemical, structural, and gross morphological deterioration. Depending upon the category of material, the tests were designed to quantitatively measure changes in shear and tensile strength, wet and dry weight, porosity, and chemical composition as measured by X-ray diffraction, microprobe analysis, and neutron activation. They also tested for qualitative detection of changes in color, textural alterations, etc. Data derived from these interval measurements were formatted for computer analysis, recorded on magnetic tapes, and subjected to simple bivariate statistical analyses to test the significance of change in test parameters between sampling intervals (Ware et al. 1979).

General Aspects of the Biological Experimental Design: Whereas the laboratory water chemical experiment was designed to exclude microbiological impacts, the Brady Reservoir field experiment (Volume II, Technical Report No. 6) was designed to segregate the water chemical from the macrobiological and microbiological components of the reservoir ecosystem and at the same time segregate the micro- and macrobiological components. Brady Reservoir, Texas, was selected as the site for this experiment because its water chemical values approximated the median chemical concentrations established in the laboratory, suggesting it was a "typical" North American reservoir.

In order to systematically collect data on the independent effects of water chemical, macrobenthic, and microbial variables, specially designed containers were utilized for the field phase of the experiment. The cultural materials were placed in five-gallon nalgene containers containing distilled water. The necks of the bottles were fitted with thick rubber stoppers, with a hole drilled in the center to accommodate a millipore filter and rubber stopper, designed to prevent leakage. A 0.2 micron millipore filter was selected to exclude microorganisms, while a larger 2.0 mm filter mesh size was selected to exclude macrobenthic organisms. Smaller containers perforated with 2.5 cm holes permitted interaction at all levels: chemical, micro-, and macrobiological (Benoit and Simmons 1979). Each of the containers was autoclaved for 24 hours in the laboratory to eliminate biological contamination prior to immersion. Duplicate sets of containers (three sets per location) were prepared to facilitate handling and reduce the possibility of contamination between sampling intervals, thus necessitating the removal of only one set of samples (three containers) per station at each sampling interval.

Initially, nine potential sampling stations, each representing a slightly different environmental setting within the reservoir, were selected. However, in order to effectively manage the experiment, this number was reduced to three stations. Station 1, situated nearest the dam and nearest the stream channel, had undergone slight modification during dam construction. Station 2, situated near the mouth of a small cove, exhibited a very rocky substrate consisting of limestone bedrock covered by a thin mantle (< 2.5 cm) of silt. Station 3, situated at the upper end of the reservoir farthest from the dam, was located near the back of a large cove. While this area does receive heavy wave impacts, a deep silt mantle has accumulated. The selection of these three sampling stations was intended to identify differences in the composition and distribution of the various organisms, particularly the "decomposer" population. The procedure for setting up the stations for sampling in reservoirs where visibility is extremely limited follows that designed by Voshell and Simmons (1977).

In October, 1979, following the initial four-month sampling interval, it was discovered that the system employed to exclude microbiological activity from the water chemical (0.2 micron filter size) containers had failed. Evidently the millipore filter and/or seal was unable to withstand the change in water pressure sustained during the initial placement of the containers in the reservoir. The filters on both the water chemical (0.2 micron pore opening) and microbiological (2.0 mm pore opening) containers ruptured, allowing intensive colonization of the containers by microbial organisms. This aspect of the experiment was not a total failure, however, as the microbiological samples provided a good indication of decomposition due to combined chemical and microbiological effects.

In order to deal with this new set of circumstances, an alternate plan was instituted. It involved setting up a three-pronged laboratory experiment in which one set of archeological materials was placed in samplers containing sterilized reservoir water and incubated at 30° C for a period of six months. An identical set of artifacts was placed in containers of sterilized distilled water and incubated at 30°C for six months. A third artifact set was distributed throughout a mud column (under anaerobic conditions) at various depths and incubated at 30° C for six months (Benoit and Simmons 1980). In addition, another attempt was made to place materials in a reservoir. Duplicate cultural materials were put in closed nalgene containers fitted with reinforced filters and placed on the bottom of Claytor Lake, West Virginia, for a period of five months. Claytor Reservoir was selected because of its geographical proximity to the microbiological laboratory at Virginia Polytechnic Institute and State University, Blacksburg, where the analyses were being performed.

At four-month intervals following initial immersion, the artifactual samples retrieved from Brady Reservoir, Texas, were subjected to the same tests and measurements used in the water chemistry laboratory experiment. Following the procedure for the laboratory experimental data, the Brady Reservoir information was formatted for computer analysis and subjected to the same bivariate statistical analyses. The purpose of this procedure was to test the significance of change in test parameters between sampling intervals.

Wet/Dry Cycling Experiment: A final laboratory experiment was initiated in the last year of the Inundation Study to provide controlled data returns on the problem of wetting and drying cycles impacting archeological resources (Volume II, Technical Report No. 8).

A sample of 30 ceramic sherds of each of 15 archeological types and 4 manufactured experimental types were used to determine cyclical saturation and drying impacts. Each sherd was sawn in half, one to be the test population and one to serve as the control. Porosity tests were done before and after the completion of 40 wet/dry cycles. A porosity index derived by dividing the total water absorbed in the sherd by the dry weight of the sherd multiplied by 100 was used for quantitative comparison.

Human osteological material was cycled 35 times. Analysis of impacts was done through comparing complete anthropometric measurements from before and after the completion of the cycles.

Clams (Rangina cuneata) and oysters (Crossostrea virginica) were cycled in the same manner as the ceramics. A porosity index from before and after the cycling was used for analysis of impacts.

Modern pollen and acetylated pollen (representing fossil pollen) of 13 taxa were wet/dry cycled 50 times. Examination of pollen before and after cycling was done through scanning electron microscopy and transmitted light microscopy to determine the specific effects of the cycling on the pollen exine.

Integration of Research Strategies

It had become obvious from the initial literature search that very little substantive information dealing with effects of inundation on archeological resources existed; what little there was in print was based primarily on a limited knowledge of the nature of reservoir environments. The early field assessments of obvious impacts in various reservoirs in association with the later literature search into different aspects of reservoir dynamics and water chemistry served to develop a basic understanding of the reservoir processes that were affecting the cultural resource base.

The subsequent field studies conducted by the core team or by other archeologists through contracts were directed towards retrieving information on specific questions which were outlined in the preliminary report as hypotheses and test implications. The framing of those hypotheses and the actual conceptualization of a systematic approach to dealing with the problems were largely the result of the initial field work and literature search efforts.

As the study progressed, it became obvious that a field orientation coupled with library work was more useful for getting at some areas of the research problem than others. Although it was possible to collect much relevant data on effects deriving from mechanical processes of the reservoir environment, adequate controls were often missing for pursuing the issues of biochemical effects. Although we were able to determine from field efforts the changes that developed from medium-scale biochemical changes (i.e., the level of the whole site, e.g., soil chemistry) the differential preservation of artifacts, or small-scale effects, were more difficult to monitor. Since the critical problem seemed to be tight enough controls it was decided to pursue a laboratory approach to answer these questions; the water chemistry and other experiments outlined above resulted.

Finally, as the project drew to a close, we realized that we had neglected to obtain systematic data on one of the most important dynamics associated with the reservoir environment: wet/dry cycling. Although on the large scale we had noted many impacts related to changes in water level, we had adapted a very "common sense" approach to small-scale effects since they were deemed obviously detrimental in nature. Although it was obvious from the literature and our general observations that recurrence of wet/dry phases was not going to be beneficial to many artifact types, some quantification was needed to offer a degree of predictability as to the nature of the impact in different situations. Consequently, the "wet/dry" experiment was conducted as the last research effort in the study.

It is felt that the integration of the results from these field and laboratory efforts produce a fairly balanced picture of the effects of inundation on different aspects of the archeological record.

CHAPTER 3: RESERVOIR PROCESSES

The goal of this chapter is to describe the reservoir-related processes which affect the preservation and analysis of cultural remains. The impacts of these processes and their implications for cultural resources are addressed in Chapter 4.

MECHANICAL PROCESSES

The erosion, transport, and deposition processes associated with mechanical impacts result from the fluid forces that are generated by water motion. This, in turn, is usually generated by extraterrestrial forces, including solar and lunar gravitational forces, differential heating of water layers by solar radiation, and meteorological forces (Duane et al. 1975). Of these, meteorological forces are by far the most important, especially in small water bodies such as lakes and reservoirs.

Water motion in reservoirs occurs in the form of waves, currents, and tides in descending order of fluid force magnitude. Waves are most often generated by winds flowing over water, although they may also result from tectonic disturbances and boat wakes. (In small recreational lakes, boat wakes may be a significant source of water motion and resulting shoreline erosion.) Currents can be generated by differences in water elevation (resulting in gravitational flow); from density flows resulting from differences in water temperature, salinity or turbidity; from wind blowing over water; and from wave action in the nearshore zone. Tides and tidal currents are caused by the gravitational attractions of the sun and moon on the earth. Water motion generated by tides in small lakes and reservoirs is infinitesimal compared with waves and currents.

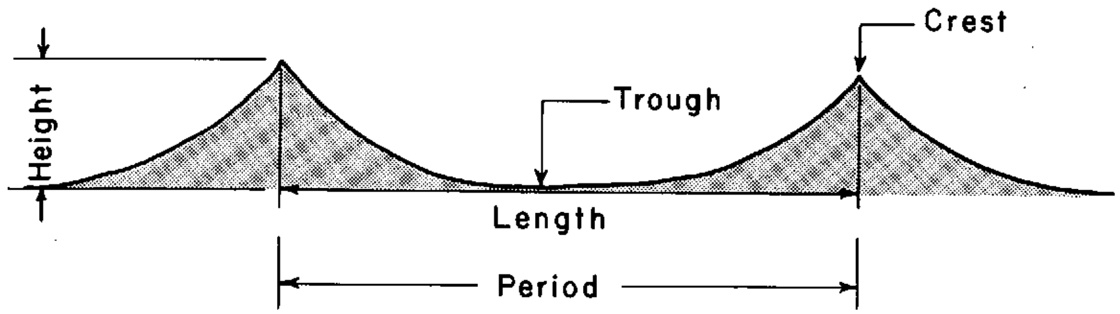
In order to understand and predict transport and deposition and their impact on cultural resources, it is necessary to understand the processes that generate wave and current forces and the variables which affect these processes from one reservoir to the next or in different parts of the same reservoir. The following is a brief summary of the processes that generate waves and currents and the theory relating to the prediction of water motion forces in reservoirs.

Waves

Waves are the single most important fluid force in determining the morphology of a reservoir shoreline. An understanding of the mechanics of wave motion and propagation is essential, therefore, if accurate predictions of shoreline impacts on cultural resources are to be made.

Wind-generated waves are oscillatory and periodic. Wave form and motion is usually defined by the following parameters: length (L), the horizontal distance between successive wave crests; height (H), the vertical distance between the wave trough and wave crest; and period, the time interval separating successive crests as a wave train passes a fixed point (Figure 3.1).

Figure 3.1



With time-oscillatory water waves, energy and momentum are transferred across the water surface, but only a negligible net movement of water occurs. This motion of water particles in a wave train is best described by elliptical orbits that are closed or nearly closed at the end of each wave period (U.S. Army 1977:2-4).

There are a number of theories describing wave-generation mechanisms (Weigel 1964; Komar 1976), but the precise relationships between wind, energy, and surface-water motion are complex and difficult to measure; no current theory has proved entirely satisfactory. Consequently, in the absence of an acceptable theory, wave prediction has been based primarily on empirical studies of wind/wave relationships. These studies have yielded some predictable relationships.

In general, the height and period of wind-generated water waves is a function of wind velocity, wind duration, and the surface-water area over which the wind blows, known as the fetch. In inland lakes and reservoirs, fetch area is particularly significant in limiting wave height and period. Wind intensity and duration being equal, wave period will be determined primarily by fetch size, with long-period waves occurring only when the fetch is large. Since wave period limits wave height (short-period waves become unstable and break at heights lower than long-period waves), fetch area places upper limits on wave height (Komar 1976:77).

Open-water swell profiles approximate sensorial curves. However, when waves enter shallow or shoaling water, they undergo a series of transformations that begin when water depth is approximately one-half of the deep-water wave length. The shoaling process involves a progressive decrease in wave length and wave train velocity, while wave period remains constant. As wave length decreases, wave height increases, until the wave crest becomes unstable and breaks. This transformation is most obvious in large water bodies where larger storm fetches produce long-period sensorial wave swells; the transformation is less pronounced in small fetches where storm waves are initially shorter-period, steep, and less stable than long-period swells (Komar 1976).

When a shoaling wave enters water approximately equal in depth to its height, it becomes unstable and breaks. Instability results from increased wave steepness, and breaking occurs when the orbital velocity of water particles at the wave crest exceeds the velocity of the wave form. The crest eventually becomes unsupported; it then collapses or surges ahead.

Shoaling waves are typically classified according to the way they break. Spilling waves break gradually, while plunging waves curl over at the crest and plunge forward. Surging waves initially set up to plunge forward, but at the last minute, the base of the wave collapses out from under the crest and surges up onto the beach (Weigel 1964). Breaker form is largely a function of beach slope, where spilling waves are most often associated with gradual, nearly horizontal beach profile. Surging waves occur on very steep beach profiles, and plunging waves are most common on beaches of intermediate slope.

Shoaling waves are by far the most significant force for erosion and deposition in the nearshore zone. Although mass transport of silt is of little significance in deep water where the elliptical orbit of water particle circulation is uninterrupted (and, consequently, net transport is negligible) mass transport can be significant for the nearshore. Here the return flow of water is interrupted, and large volumes of water are thrown out of orbit and up onto the beach or shoreline. The forces generated by shoaling waves interact with shoreline geomorphology to determine the location, profile, and configuration of the reservoir shoreline.

Currents

Currents and water circulation systems are a common and complex phenomenon in reservoirs. Although water movement in a reservoir is typically a complex function of meteorological forces such as wind, barometric variation, temperature stratification, tidal forces, basin morphometry, etc., such currents are rarely significant in terms of mechanical impacts on cultural resources (Duane et al. 1975). Nearshore currents are an exception. The strength and sediment entrainment capacity of nearshore currents is closely correlated with wave energy intensity, i.e., when wave energy is high, nearshore current impact on the shoreline can be significant.

Nearshore currents are usually a consequence of either a nearshore circulation system involving wave-induced rip currents and longshore currents or longshore currents resulting from an oblique wave approach to the shoreline. The longshore currents, or currents running parallel to the shoreline that are generated by these phenomena, constitute the primary back-forming mechanisms on the ocean coast. Such currents are capable of substantial sediment entrainment and transport, erosion, and deposition on the shoreline of inland lakes and reservoirs.

One of the most common causes of longshore curents is the nearshore cell circulation system summarized by Komar (1976). Variations in wave set-up due to longshore variations in wave height are sufficient to generate longshore currents. These currents flow from locations of highest breaker height to places of lowest breaker height. Such currents flow in opposite directions and meet to form a rip current which directs the flow of water out beyond the breaker zone. Thus a circulation system within the nearshore zone is formed. Longshore variations in wave height, which generate such systems, are most often associated with variations in offshore bottom topography. This affects the shoaling behavior of incoming waves (Komar 1976).

Another common cause of longshore currents is the breakage of incoming waves at an oblique angle to the shoreline, thus providing a longshore "push" to the mass transport of water parallel to the shoreline. In the case of oblique wave approach, both the direction and speed of the longshore current are determined by the direction and height of the incoming waves.

Regardless of cause, the strength or entrainment capacity of longshore currents is a function of wave height which, in turn, is primarily a function of fetch size and meteorological variables. The potential of nearshore currents to alter shoreline configuration, impacting cultural resources, is significantly less for small reservoirs (or protected shorelines of large reservoirs) than for larger reservoirs where large storm waves are commonplace.

Littoral Processes

Although water throughout a lake or reservoir is in constant and continual motion, the fluid forces generated by that motion are greatest at the reservoir shoreline. Combined effects of shoreline waves and wave-induced currents may pose a substantial threat to cultural resources located in the high-energy nearshore zone. In reservoirs where pool levels and shoreline configuration fluctuate in response to seasonal changes in water use and storage requirements, the problem of nearshore impact is particularly acute. Therefore, it is important to understand how the mechanics of water motion in the nearshore zone interact with the geomorphology of the lake shore to determine shoreline configuration. Such understanding will result in knowledge of the consequences of water and shore interactions on cultural resources.

In general, a shoreline will erode when the total amount of material being transported away from the area by waves and currents exceeds the total amount of material being deposited on the shore. Conversely, a shoreline will accrete when the total amount of material deposited exceeds the total amount eroded. This input/output ratio will vary for any given shoreline segment, depending on the resistance of shore sediments to destructive wave action, the availability of sediments from local sediment sources, and the nature of fluid forces impinging on the shoreline. All of these factors will vary for any given shoreline segment in any given reservoir so that certain segments may be eroding while adjacent segments may be accreting.

If the level of the reservoir pool remains relatively stable, the average reservoir shoreline will tend toward a predictable equilibrium profile. Following stabilization of the reservoir pool level, wind waves will attack and gradually erode the newly formed shoreline. Much of the fine, silty fraction of the winded shore will be carried in suspension beyond the surf zone and redeposited in the reservoir basin or carried by longshore currents and redeposited in adjacent shores, bars, or inlets. The coarser fractions of solid material derived from the erosion of the shore will be deposited as an offshore shoal. The formation of an offshore shoal is a self-limiting process in the erosion of a reservoir shoreline, for the accumulation of shoal sediments tends to impede incoming waves. Consequently, as the size of the offshore shoal increases, wave energy reaching the shore decreases, until a certain limiting form is achieved in which most of the wave energy capable of eroding the shore is dissipated on the offshore shoal (Kondrat'yev and Grig'yeva 1974). This process is complicated, however, when a reservoir pool level is constantly fluctuating. Periodic drops in pool level subject the offshore shoal to periodic erosion which, in turn, interferes with the formation of an equilibrium profile.

Submerged Processes

The discussion of mechanical impacts thus far has focused on the problem of shoreline erosion and its impact on cultural resources in the high-energy nearshore zone. We will now focus on mechanical processes in the reservoir basin, below the zone of active shoreline processes. Whereas erosion processes predominate in the nearshore, deposition rules the offshore region. Two forms of offshore deposition are of particular interest to the cultural resource manager. The first relates to changes in basin morphometry as a result of sediment saturation, slumping, and creep. The second relates to the process of reservoir siltation and its long-term effects on resource preservation and accessibility.

Submarine Slope Failures

The saturation of reservoir slopes during initial submergence often results in dramatic alterations of slope geometry. Resulting slope failures may have a substantial effect on basin morphometry, impacting cultural resources that otherwise withstood the initial impacts of a rising pool level. The shear strength of an unconsolidated slope on a given plane is a function of the effective intergranular pressure on the plane and the effective coefficient of friction. In general, as the pressure of pore water within the sediments increases, the shear strength of the sediments across any plane of failure decreases. The sediments are then subject to gradient shifts until a new angle of repose compatible with the reduced shear strength is achieved (Castro 1966).

A survey of reservoir slope failure by Sherman (1968) indicates that slope failure on initial submergence was most common in unconsolidated talus. Sherman concludes that slope failures due to initial saturation are most common in silty or sandy soils and that more plastic soils tend to be associated with failures due to sudden drawdown (Sherman 1968:5).

Reservoir Sedimentation

When a stream carrying sediment encounters the quiet waters of a reservoir, stream velocity and sediment-carrying capacity are reduced. Silt is then deposited in the form of a delta at the interface of the stream and reservoir. The sediment is sorted as it is deposited, the heavier sediment forming a fan-shaped delta called the foreset bed. The finer silts and other suspended sediments are carried beyond the delta and deposited in the deeper portions of the reservoir basin or along the reservoir shoreline (Stevens 1936).

Unless sediments are periodically flushed or otherwise removed from the reservoir, the gradual accumulation of sediments and growth of foreset beds from all tributary streams (and shoreline erosion) will systematically fill the reservoir basin until only a level floodplain bisected by a meandering stream occurs. While the rates of silt deposition wll gradually diminish as the reservoir fills with sediment (due to the decreasing volume of still water available for sediment entrapment), the process of sedimentation is inexorable. On the silt-laden streams of arid regions, for instance, the process can be extremely rapid.

The role of sedimentation in cultural resources preservation is not entirely understood, due to the lack of first-hand data on the long-term effects of siltation. In general, however, siltation can be expected to enhance preservation by providing a buffer against biochemical, mechanical, and other forms of destructive impacts. With regard to biochemical impacts, the deposition of a silt mantle over a site will eventually reduce significantly the rate of biochemical processes that normally occur at the mud-water interface -- processes that rely on the presence of dissolved oxygen, light, and water-borne nutrients. This same sediment mantle will also serve to buffer the direct impacts of fluid forces at the interface of mud and water. This physical buffering effect would be particularly subjected to nearshore impacts in the event of a reservoir drawdown. A silt mantle may also buffer against human, faunal, and other forms of depredation.

The most serious adverse impact of reservoir sedimentation would appear to be loss of access to cultural resources that are buried under meters of silt, a question that is discussed in greater detail in Chapter 4.

In recent years, a great deal of research has been conducted on the reservoir siltation problem. Such research has led to a greater accuracy of prediction of reservoir siltation rates and the prediction of spatial variability in silt deposition within reservoir basins. One of the most promising approaches has been to construct computer models of reservoirs in an attempt to simulate silt deposition rates and parameters. Two such studies on water impoundments in Kansas (Merrill 1974) have resulted in extremely accurate predictions of sedimentation rates. These studies have demonstrated that the rate of sedimentation deposition is a function primarily of: 1) the amount of sediment supplied per unit of time; 2) the rate of sediment dispersal throughout the reservoir; 3) the nature of sediments supplied, especially in terms of relative silt-sand-clay proportions; 4) the rate at which sediment moves out of the reservoir; 5) the rate and amount of silt compaction, which is primarily a function of the size and nature of the sediments; and 6) the rate of shoreline and bank erosion within the reservoir.

BIOCHEMICAL PROCESSES

The second major category of reservoir processes encompasses the entire complex of hydrologic, chemical, and biological activities which characterize the reservoir ecosystem. In order to determine and predict how biochemical factors will impact submerged cultural resources, one must first identify and define the individual components of each of the interactive systems (chemical, biological, and cultural) and secondly determine the mode of interaction between the structural and functional components of the systems.

CHEMICAL SYSTEM

The principal factors determining the ionic (chemical) composition of freshwater reservoirs include climate, geology, topography, biota, and time. In addition, human activities, animal and human population densities, and land use also affect the chemical makeup of streams and lakes.

Most of the ions that are introduced into fresh waters derive from soils and weathered rocks (Cole 1975:209). However, ions are also injected into surface waters via atmospheric means.

The variations in fresh water are produced through the complex interactions of geologic, biologic, and climatic variables. Those variations notwithstanding, certain general trends characterize all waters throughout the United States. For instance, the salinity of dissolved matter in a river frequently increases from its source to its mouth. Furthermore, rivers contain more concentrated ions during low water stages and more dilute solutions during high water stages (Livingston 1963:4-5). This results from the fact that percolating groundwaters pick up ionic concentrations more readily than do dilute rainwaters washing over weathered soils and rocks.

Knowledge of the geologic conditions can aid in predicting local water chemistry conditions and vice versa. Lowest concentrations of salinity are found in areas underlain by hard metamorphic rocks or igneous granites while high ion contents result from the dissolution of such soluble rocks as limestones or mudstones.

The most up-to-date information on surface water chemistry is available from the United States Geologic Survey (USGS). The USGS now operates a National Stream Quality Accounting Network (NASQAN). Some 345 water-sampling stations located across the country make up the NASQAN network. While this system does not provide extremely accurate information on the total load a stream carries during a year or the complete range in chemical concentrations, it does provide a reasonably accurate estimate of what water quality to expect in a given stream on any given day (Hawkinson, Ficke, and Saindon 1977:15).

Broad-based studies such as Clarke's (1924); Livingston's (1963); and Hawkinson, Ficke, and Saindon's (1977) reveal that only four cations and three anions constitute nearly the total ionic concentrations for most fresh waters. The dominant cations consist of calcium (Ca), sodium (Na), and potassium (K), while the three primary anions include bicarbonate (HCO_3), sulfate (SO_4), and chloride (Cl) (Gorham 1961:797). Hutchinson (1957:556) makes the generalization that the concentrations from highest to lowest in open rivers tend to be Ca, Mg, Na, and K for the cations and HCO_3, SO_4, and Cl for the anions. Because carbonic acid carried in solution by groundwater is the primary mechanism for the chemical weathering of rocks, the cation by-products of this chemical process tend to become tied up as carbonate salts in most freshwater bodies (Clarke 1924:5).

It will be recalled that in an earlier discussion of the water chemistry created for the laboratory experiment (Chapter 2) the chemical factors selected for study include pH, Ca, Mg, Na, silica (Si), iron (Fe), carbonate (CO_3), HCO_3, So_4, and Cl. Therefore, the discussion in this chapter of the sources controlling ionic distribution will be limited to these particular elements.

pH, or the negative logarithm of hydrogen ion activity, usually ranges from 6.0 to 9.0 in surface waters. Its ultimate concentration for a given body of water is intimately connected with the presence of CO_2, since many H ions become tied up as HCO_3 (Hutchinson 1957:685-690).

Ca represents the principal cation in most waters. While abundant in silicates, the chief sources for this ion are lime feldspars, anorthite, hornblende, and pyroxene minerals (Clarke 1924:6).

Mg generally occurs as the second most abundant cation in temperate regions. Its sources include such silicate and nonsilicate minerals as amphiboles, pyroxenes, and olivine. However, the greatest contributor of this ion is the weathering of magnesium limestones and dolomites (Clarke 1924:6).

Na and K derive from the same alkali feldspars of albite and orthoclase. However, K ranks a distant fourth to Na in concentration because it is more active than Na and therefore cannot remain in solution as long (Cole 1975:229).

Si constitutes one of the most significant acidic substances in inland waters. Its sources include clays as well as the extremely abundant feldspar rocks with their silicate minerals (Stumm 1966: 302). The forms that Si takes in inland waters include: 1) true solutions, 2) colloidal particles, and 3) sestonic mineral particles (Hutchinson 1957:788).

CO_3 and HCO_3 are by-products of the chemical weathering of limestones and the decomposition of feldspars. In fact, carbonates as a whole represent nearly 50% of the solid compounds in solution in fresh waters (Clarke 1924:5).

SO_4 ranks second behind CO_3 as the principal anion in water. Clark (1924:5) points out that these sulphate ions derive from the oxidation and partial solution of iron pyrites.

Finally, Cl represents the third most abundant anion. Quite a variety of sources introduce these ions into the water supply. Treated human sewage, runoff from salted streets, volcanic gases, winds carrying Cl inland from the sea, and leaching of salty desert soils are all contributory factors (Cole 1975:220).

These, then, constitute the vast majority of ions found in the surficial water supply. The primary sources supplying these ions to river systems and the general patterns of ionic concentrations vis-a-vis the local geology have also been established. Unfortunately, this preimpoundment river water chemistry does not directly correlate with the conditions present in reservoir waters.

Immediate Effects of a New Reservoir on River Chemistry

How closely will the "pre-dam" water chemistry from the river correlate with later water conditions in the reservoir? In other words, can one use older river chemistry data to predict the water chemistry environment of an archeological site within an impounded body of water?

Most experts agree that "any dam will have some effect on water quality, if only in terms of sediment load, but larger dams with high capacity, long-retention reservoirs are more likely to produce the chemical and biological effects associated with thermal stratification" (Bhutani et al. 1975:43). Despite this agreement, relatively little research (with the exception of oxygen regime studies) has been directed toward the effects of impoundment on major water quality constituents. Certainly, the complexity of the problem defies simple answers. Sylvester and Seabloom (1964:2) argue that the many factors affecting water chemistry in a new reservoir include depth, configuration, position relative to dominant wind patterns, chemistry of inflow water, ratio of volume of inflow to storage capacity, geology, underlying strata, mineralogy of original soil beds, nature of site vegetation, and local climatic conditions. Despite the fact that these many factors all affect the water chemistry of a new reservoir, most investigations which have been conducted focus on only two of the variables. These are soils and climate (essentially, evaporation).

The most elegant case made for the importance of evaporation is a study conducted on the Cheney Reservoir near Wichita, Kansas, by Ward and Karaki (1971). After two years of sampling the water contents from the reservoir and river, these investigators conclude that wherever evaporation excess is positive, dissolved solids will become the principal water quality concern. For those areas where precipitation exceeds evaporation, reservoir waters will dilute the dissolved solids concentrations which are supplied to the impoundment by rivers (Ward and Karaki 1971:66).

Support for this argument can be found in the investigations that Howard (1954) carried out in Lake Mead, Nevada from 1935 to 1949. Howard (1954:182) notes that "significant quantities of water have been lost from the reservoir by evaporation, with a resultant increase in concentration of dissolved solids in the water remaining in the reservoir." Importantly, however, because the zone of water on the lake bottom had a specific conductance and alkalinity higher than the main body of the lake, Howard (1954:180) also felt that the water chemistry had been influenced by the dissolution of material from the bottom strata and sediments. He further concludes that:

1. Potassium and magnesium were slightly more concentrated in the water leaving the reservoir than in the water entering it.
2. Sodium increased 25% while calcium was up to 35% greater in waters leaving the reservoir than in those entering.
3. Silica and bicarbonate decreased significantly in the outflow.
4. Sulfate rose to 50% in concentration (Howard 1954:183).

Additional analyses which supported Howard's conclusions were conducted in various reservoirs throughout the U.S. (See Hoffman and Jones 1973; Cooper, Hestand, and Newton 1971; Bolke and Waddell 1975). In contrast to those studies, Herrmann and Mahan (1977) recorded few gross changes in Pueblo Reservoir, Pueblo, Colorado. Again, these scientists compared a set of river water chemistry data taken just prior to pool formation in 1975 to water conditions for the first year of reservoir operations.

Although these authors appear more interested in describing than explaining the chemical processes at Pueblo, they do hint that the general trend towards a more dilute concentration for several elements may be due to chemical adsorption by the underlying sediments. Furthermore, although not brought out by the authors, Pueblo Reservoir has only a 15-20 inch evaporation excess, far less than for any other reservoir discussed so far. The lack of excessive evaporation certainly helped minimize chemical changes occurring after the river waters had been dammed.

While much of the discussion centers on the effects that particular types of wood have on water, Sylvester and Seabloom's (1964:33) recommendations for preimpoundment studies deserve careful consideration. They ask "Just how would one judge a soil or organic debris beforehand as to its possible future effect on impounded water quality?" (Sylvester and Seabloom 1964:33). The authors offer no definitive answer; however, they do suggest the soil, reservoir, and river water characteristics which should be considered by any investigator concerned with their effects on new impoundment water chemistry. These factors comprise:

1. Organic content of the soil.
2. Stage of decay of organic matter.
3. Relative areas of mineral and organic soils.
4. Amount and type of stumps, logs, grass, and brush to be inundated.
5. Effect this reservoir floor material would have on the physical, chemical, and biological quality of the overlying water.
6. Circulation and rate of water exchange that will be provided.
7. Relative water depths, possibility of stratification, and change in water temperature.
8. Quality of inflowing streams and surface runoff:

a. Silt that will cover organic soil in time.

b. Biochemical oxygen demand.

c. Plant nutrients for algae and bacteria.

d. Temperature and other inflowing water characteristics such as color and turbidity (Sylvester and Seabloom 1964:33).

We have seen how two factors, evaporation and soil leaching, can drastically alter the water chemistry of a river once it becomes impounded by a dam. However, while climatic conditions and evaporation rates will probably remain constant throughout the life of the reservoir, the impacts caused by the underlying soil and strata will not. Sylvester and Seabloom (1964:61) emphasize that:

> The effect of 'new' reservoir soils on overlying water quality will be continually changed with reservoir aging by reason of their being leached and biologically degraded; by their being covered with settleable solids brought in by the supply stream; and by their being covered with sedimented algae cells and other forms of plankton. (Sylvester and Seabloom 1964:61)

Given the fact that the effects of new dams on river water chemistry change over time, one may then ask, "How closely does inflow water chemistry compare to reservoir water chemistry in an older impoundment?" Such a question is relevant for the archeologist working in a drawdown zone who needs to anticipate what chemical conditions the submerged sites have been exposed to.

Effects of Established Reservoirs on Water Chemicals

Unfortunately, while studies on the effects of new reservoirs on water chemistry are fairly numerous, investigations into the long-term modifications of inflow water chemistry are practically nonexistent. Although this investigator feels that the bad effects that take place upon reservoir filling are eventually "aged" out, no definite information for determining what constitutes a normal period for reservoir aging is forthcoming. One is simply left with the proposition that the period of aging will depend upon: 1) the storage ratio of the reservoir,

2) the reservoir's depth and area, and 3) the topography of the drainage area and lands to be flooded (Purcell 1939:1775).

The few reports done on long-term effects (Harris and Silvey 1940; Wilroy and Ingols 1964; Neel 1963) offer little help to the archeologist who needs to know how closely the water chemistry of an established reservoir matches that of the inflow water. Clearly, more research needs to be directed towards the differences that may develop over the long term between impoundments and the rivers feeding them. In the interim, however, one may surmise that, because of the process of siltation, leaching diminishes over time. Therefore, the principal process affecting differences between the chemistry of inflowing water and reservoir lakes is that of evaporation or excess precipitation.

Chemical Variability Within Reservoirs

Archeologists concerned with the chemical impacts to submerged cultural resources must consider one final set of variables: How do vertical, horizontal, and seasonal variability affect the chemical constituents in a reservoir?

Vertical Variability: Vertical variability in water chemistry is important, as sites excavated at different elevations within the reservoir pool will be exposed to different concentrations of water chemicals. Because certain ions are particularly harmful to different types of cultural materials, the depth below the lake's surface at which a site will be submerged may well determine which types of artifacts survive inundation.

The documentation of the vertical variability of water chemistry is fairly extensive. In most instances, the most common pattern observed at increased depth is greater concentration for such constituents as hardness, conductivity, sulfate, iron, sodium, manganese, and zinc (Herrmann and Mahan 1977:22). Confirmation for these trends is provided by Walesh (1967) and Neel, Nicholson, and Hirsch (1963).

In contrast, pH levels often drop in the deeper zones of reservoirs. These trends again were noted by Neel, Nicholson, and Hirsch (1963:98) along the Missouri River and by Hermann and Mahan (1977:23) in the Pueblo Reservoir, Colorado. Apparently, greater pH values near the surface result from photosynthesis in intense light penetration zones (Neel 1963:590).

For many stratified reservoirs, radical changes in water chemistry often occur at depth by the thermocline. Increases in alkalinity, hardness, and conductivity with depth are directly related to bacterial activity in the reservoir. Higgins and Fruh (1968) explain the connection based on their work in Lake Travis, Texas. During warmer months, the pH of the epilimnion (upper layer) increases because of the diminished presence of CO_2 (due to algae photosynthesis). At the same time, the pH of hypolimnion (lower layer) water decreases as CO_2 levels rise (because of the bacterial breakdown of both the organics falling from the epilimnion and the material supplied by the sediments). In contrast, during cooler months, algae activity decreases, which causes a decrease in pH levels in the epilimnion. The pH again decreases in the hypolimnion, though this occurs at lower depths.

As a result of low levels of CO_2 in the epilimnion year-round, the bicarbonate buffer system is altered to yield CO_2 plus carbonate ions. At these temperature and pH levels, calcium carbonate precipitates out of solution, thus decreasing the hardness above the thermocline. In the hypolimnion, however, bacterial generation of CO_2 alters the bicarbonate and carbonate equilibria, thus stimulating the production of these ions (Higgins and Fruh 1968:21-22). (See also King 1973 for a similar analysis of these trends in Table Rock Dam, Missouri.)

Finally, the trend of greater ion concentrations with increased depth can be explained. The vertical distribution of these ions simply reflects the redox potential of the water column (Hutchinson 1957:726).

Horizontal Variability: Horizontal variability in water chemistry is less well documented than that of vertical patterns. Nevertheless, archeologists must be cognizant of lateral differences in water chemistry since these may lead to the loss of certain classes of material from one section of the reservoir basin but not another.

The most common surficial pattern for water chemistry in impoundment is a trend from greater chemical values near dams to lesser concentrations near inflowing rivers (Herrmann and Mahan 1977:9). Both the factors of mineral leaching and evaporation, which have been previously discussed, predict such a pattern. Inflowing rivers deposit most of their load upon entering the impounded lake. Thus, the underlying soils and strata below this juncture would be the first to be sealed off by silt deposits which would inhibit the effective leaching of the underlying soluble minerals. Also, the concentrating effects of evaporation would have had the least time to operate near the inlets. Ward and Karaki (1971:19) discovered how pronounced these lateral differences can be in Cheney Reservoir, Kansas. Horizontal measurements of conductivity increased an average of 10% between sampling transects from the dam to the inlet, although in a few cases it approached 30%.

<u>Seasonal Variability</u>: Seasonal factors should also be considered by archeologists since the pools of many reservoirs rise predictably only during certain months of the year. For those reservoirs, archeological sites located above normal conservation pool levels would normally only be exposed to the water chemistry characteristic of that particular time of year.

Generally, waters feeding reservoirs in the spring and summer contain low ion concentrations. This results from the fact that these waters enter rapidly without having a chance to adsorb many soil ions. In contrast, waters flowing into the pools in the winter contain much higher concentrations of dissolved ions. This runoff from snow soaks into the ground slowly and, therefore, has more time to react with soil minerals. Thus, much of the seasonal chemical variability that occurs in reservoirs simply reflects the relative contribution of surface runoff versus groundwater present for that time of the year (Herrmann and Mahan 1977:21; Livingston 1963:3).

Summary and Conclusions

Obviously, a limited discussion of this nature cannot begin to accurately explain the complex nature of all chemical processes in reservoirs. Two factors have conditioned the sophistication of this study. On the one hand, this presentation has been limited by the scarcity of published literature on the subject itself. On the other hand, this section has been principally directed towards archeologists and not towards limnologists. Therefore, this discussion has focused on the general patterning of water chemistry in reservoirs.

Since the chemical impacts to submerged cultural resources will be greatest where those chemicals are concentrated, it would appear that the areas of highest chemical impacts will be the deepest ones that are also furthest downstream from the inlet location. These deep waters near the dam will have the highest concentrations of chemicals because 1) evaporation has taken place for the longest time there, 2) the bottom soils and strata will be the last to be sealed off by silt, and 3) these deeper waters below thermoclines favor the concentration of most dissolved solids. Areas of least chemical impacts could be expected in more shallow sections nearest the inflowing river. Naturally, those sites continuously inundated by the more concentrated winter pool waters will experience greater chemical destruction than those sites that are only occasionally immersed by the more dilute summer floods.

The reader will have noted that the discussion has focused upon the impacts of water chemistry on submerged cultural resources. However, inundated archeological sites obviously do not exist suspended in a water column. Cultural remains are trapped within geologic sediments. Thus, the true chemical environment of an underwater site (aside from surface remains) will be that of a saturated soil matrix.

Even given this fact, the chemical processes described so far are still relevant when considering the eventual chemical environment of a flooded site. The water chemical patterning in reservoirs will allow one to predict the makeup of the water interacting with the soil layers. Furthermore, actual laboratory tests should be conducted using site soils and actual reservoir water to predetermine what the water-soil chemical mix will eventually produce.

To the extent that this section can be viewed as a "recipe for action," the following steps are recommended so that one might anticipate the eventual water chemistry environment at a site in a reservoir. First, archeologists should obtain the most complete and up-to-date information on the water chemistry of the river to be impounded. In some cases, these data may be available from the dam management agency itself (such as the Army Corps of Engineers, Bureau of Reclamation, Soil Conservation Service, etc.). If complete data are not available, the nation-wide water data exchange network (NAWDEX) should be consulted. Edwards (1978) outlines the operation of NAWDEX and explains how one can obtain its data. These river data, then, constitute a baseline of information which can give an approximate idea of the concentrations to be expected in the reservoir.

Second, the average annual evaporation excess or deficit must be determined for the reservoir. Detailed local information may be procured from the nearest weather station. An evaporation excess or deficit for the area will provide the first clue as to whether or not the river chemistry will become more concentrated or diluted following impoundment.

Third, consideration of the soil matrix surrounding a site must be given. Sylvester and Seabloom (1964) offer several excellent recommendations. One of them in particular should be given serious consideration by archeologists attempting to predict the chemical environment at a submerged site. They recommend:

> That reservoir soils be subjected to water-soil contact studies to predetermine their expected effect

> on overlying water per unit area of soil surface. Some organic soils may have very little detrimental effect on the overlying water because their organic matter has been previously leached or degraded biologically to leaching or to decay-resistant substances. Studies should be conducted under as near actual reservoir conditions as possible, including water temperature and lighting. Indicative water quality analyses would include dissolved oxygen, color, nitrate, ammonia, algal counts, and pH measurements over a period of at least one month, using water to be impounded as the water source.
> (Sylvester and Seabloom 1964:62)

Fourth, the location of each particular site within the pool basin must be taken into account. As has been discussed, a site's vertical and horizontal position vis-a-vis the impoundment's conservation and flood pool levels will modify the concentrations of average water chemicals predicted.

An awareness of the various chemical processes operative in reservoirs plus an understanding of how to obtain accurate local water chemistry data will provide the cultural resource manager with invaluable information concerning those resources he/she is charged to conserve. Were the reservoir environment not complex, one could simply base excavation strategies on the implications of two sets of data: 1) what the effects of specific cations and anions are on classes of archeological material and 2) what is predicted to be the chemical environment at each site within a reservoir. Unfortunately, chemical impacts represent but one facet of the effects of dam and reservoir construction on cultural resources. The projected impacts from mechanical and biological agents will also color decisions concerning which sites to mitigate in the face of inundation. Careful consideration of all these processes will enable the cultural resource manager to utilize these limited resources in the most farsighted manner possible.

BIOLOGICAL SYSTEM

The components of the biological system important to the understanding of biochemical impacts on cultural resources include: chemical parameters (i.e., dissolved oxygen, pH, CO_2, iron, manganese, nitrate-nitrogen, phosphorus, etc.) and physical parameters (i.e., thermal stratification, temperature, turbidity, sedimentation, lake basin configuration, inflow-outflow, depth, etc.). The interrelationship of these factors will determine the distribution and composition of the aquatic biological community and the potential interaction with submerged cultural materials.

The most efficient way to conceptualize the components of the biological system is to place it in the framework of the reservoir ecosystem. Here the entire watershed is recognized as the minimum ecological unit. The ecosystem boundaries include not only the lake area but also the immediately adjoining terrestrial communities, the inflow and catchment areas, and the outflow areas.

The aquatic ecosystem represents a highly dynamic and complex assemblage of biotic and abiotic components in which all of the principal parameters and processes are interdependent. Odum (1971) identifies six structural and six functional components of an ecosystem. The structural members include three abiotic components: 1) inorganic substances (C, N, CO_2, H_2O, etc.), 2) organic compounds (proteins, carbohydrates, lipids, humic acids, etc.), and 3) climatic regime (temperature and other physiochemical factors). Three biotic components are arranged according to a hierarchical trophic scale based on their role in energy flow: 1) producers -- autotrophic organisms capable of manufacturing food from simple organic compounds, 2) macroconsumers or phagotrophs (heterotrophic) -- organisms which ingest other organisms or particulate organic matter, and 3) microconsumers or saprotrophs (heterotrophic) -- organisms, primarily bacteria and fungi, which release enzymes to decompose complex organic compounds and release inorganic nutrients as waste. The six functional components include: 1) energy circuits, 2) food chains, 3) diversity patterns in time and space, 4) nutrient (biogeochemical) cycling, 5) development and evolution, and 6) control or cybernetics. The ultimate goal is to understand and predict the relationships between the structural and functional components and the physiochemical environments of the various aquatic organisms.

Developmental Stages of a Reservoir

During its life, a reservoir will generally proceed through four basic stages of development: 1) planning, design, and construction; 2) initial filling and instability; 3) stabilization; and 4) senescence and death (reverting back to a terrestrial state) (Allanson 1973). During stage 1, the planning phase, the function of a particular dam and reservoir is determined. Intimately linked with its function is the schedule for water release and balance. This schedule is largely predicted from meteorological data collected for the watershed and operates within the constraints imposed by the climatic regime. However, the function of a reservoir can change as the human values affecting land use shift in emphasis. The most immediate and dramatic biochemical impacts occur during the second stage of development, the initial filling.

During this time, the interrelationship between the biological system and the other components of the ecosystem (i.e., hydrologic system) are in rapid transition. The initial impact caused by damming a river to create a lake involves superimposing a riverine (lotic) ecosystem on a terrestrial one, thus creating a new still water (lentic) ecosystem that merges the characteristics of the two parent ecosystems. This results in: 1) mass mortality of the lotic benthos (plants and animals), which will eventually be replaced by lentic organisms, 2) migration of terrestrial organisms to new terrestrial habitats, and 3) development of photoautotrophic plankton populations. Initially, there is a burgeoning of intensive heterotrophic activity sustained by the nutrient release from newly submerged soils, plants, and animal remains (Ackermann et al. 1973).

As the ecosystem gradually adjusts to the new chemical, biological, and hydrologic regimes, it will approach the conditions of a natural lake and stabilize. However, full stability in a reservoir can never be assured, due in large part to the factors of human manipulation and natural climatic conditions (i.e., flooding or drought). Holling (1973) emphasizes that in nature, equilibrium states are seldom if ever achieved. Environmental parameters shift constantly, but at variable rates, magnitudes, and frequencies (Bennett and Chorley 1978). The degree to which a given ecosystem is able to adapt to stress depends upon the degree and frequency of the perturbation and abiotic limitations governing the biological utilization of essential resources (Webster et al. 1975). This is particularly evident in reservoir ecosystems where continuous man-induced stress can affect both the biotic and abiotic components of the ecosystem.

Man-made Versus Natural Lakes

Man-made impoundments differ morphologically and limnologically from natural lakes. The morphological characteristics include reservoir shape, shoreline development, and sedimentation (Cole 1975).

The configuration of a reservoir will conform to the geomorphic features of the drainage basin. For example, a reservoir confined in a deep, narrow valley or canyon may be long, narrow, and steep-sided. Any tributary streams entering the main channel will be incorporated into the reservoir system, producing a dentritic pattern. The reservoir will also exhibit a symmetrical depth pattern as landforms become submerged. Within the submerged stream channel itself, the depth pattern will vary along its longitudinal axis with the deepest portion of the reservoir occurring just upstream from the dam.

Shoreline fluctuation is a characteristic of most reservoirs. It is a result of the alternate storage and release of water. Therefore, the shoreline is constantly subject to modification by mechanical means, such as wave activity and currents. The rate of modification will depend upon the amount of energy available, the configuration of the reservoir and the surrounding terrain, and the resistance of the material.

Sedimentation is linked to shoreline erosion since the material eroded will eventually be deposited within the lake, together with sediment transported from incoming tributaries. Much of the sediment is derived from sheet erosion of the surrounding land or from erosion of the banks of the stream and its tributaries. Where and how the sediment will be deposited will depend upon factors such as lake morphology (i.e., slope) and currents. Heavy sediment loads may encourage the formation of deltas as the sediment-laden stream enters the standing-water reservoir and its flow rate decreases. As the water level fluctuates, the sediments will be eroded anew and redeposited. Consequently, the configuration of the delta will constantly change, making it difficult to predict changes in the sedimentation pattern.

The physical limnology of a man-made lake differs from that of a natural lake in several respects. In many reservoirs, the retention time of water is relatively short, depending upon the schedule for storage and release. Under these conditions, circulation will be dominated by inflow and outflow rather than by thermal circulation and wind-generated currents; although in the larger, deeper reservoirs, all of these conditions will occur.

Discharge (outflow) within a reservoir frequently occurs within the hypolimnion (deepest) zone, whereas discharge in a natural lake occurs at the surface. The result of releasing cold, nutrient-rich water from the bottom of a reservoir affects both the upstream and downstream ecosystems. For example, the heat budget of the impoundment may be altered, resulting in increased evaporative loss and reduced productivity within the reservoir and increased salinity and conditions favoring eutrophication downstream (Odum 1971). The heat budget is controlled by seasonal climatic variables (river inflow rate, temperature, and solar radiation input) and by reservoir design and operation factors (rate of outflow, release schedule, and design of the outlet).

Another property of reservoirs is the formation of density currents that carry silt in suspension and create turbid conditions. Water of a given density will attempt to enter the impoundment at a level where the density (temperature) of the surrounding water is identical to its own. Turbidity currents not only contribute to the sedimentation of reservoirs but also influence the distribution and diversity of the biological communities in much the same manner as thermal stratification, especially as it relates to the vertical distribution of photosensitive phytoplankton.

Man-made lakes may also differ from natural lakes with regard to their chemical limnology. The chemical composition of the impounded water is largely determined by the chemistry of inflows and of precipitation into the drainage basin. However, new impoundments will be subject to the leaching of soluble material from the newly flooded soils. Depending upon the amount of soluble material and the length of retention time, the chemistry of the impounded water may continue to differ from that of the inflow for a long time.

Undoubtedly, each of these physical, chemical, and hydrologic factors will profoundly affect the structure and functioning of the ecosystem; consequently, in most cases, the biological responses must be analyzed for cause and effect on a lake-to-lake basis.

Physical and Hydrologic Processes

The general physical and hydrologic processes which influence the biochemical regime of a reservoir are as follows: 1) thermal stratification and energy; 2) oxygen and other dissolved gases; 3) CO_2, alkalinity, and pH; and 4) redox potential and dissolved solids (i.e., metals, nutrients and organic substances) (Cole 1975).

Thermal Stratification: Thermal stratification in a reservoir is a very stable and predictable phenomenon that occurs as a result of temperature-induced density differences. A stream flow of a given density or temperature entering an impoundment will mix and descend to a depth corresponding to its own density or temperature (Slotta 1973).

The distribution of temperature is governed by two processes: 1) advective heat transfer, and 2) vertical mixing of the water mass. In an operational sense, a reservoir receives heat convectively from stream inflow and solar radiation and loses heat by evaporative loss at the surface and flow through the outlet. Within the reservoir, heat is distributed by molecular and turbulent conduction.

Seasonal variations change the thermal structure and dynamics in a predictable manner (Harleman and Huber 1968). During the fall and winter, the temperature of the water in moderately deep to deep lakes (50°+) is relatively uniform along its vertical axis. During the spring, the higher-angle sun warms the surface waters. As the density of the surface water increases, a temporary stratification develops which sets up convection currents. When assisted by the wind, these currents serve to mix the lake water throughout. Heat transfer is accomplished merely by wind, whereas cooling is accomplished primarily by convective currents. During the summer, solar radiation becomes the principal vector for the onset of thermal stratification, as the surface waters rapidly warm, expand, and become less dense than the lower waters. As the lake waters stratify, three distinct layers are formed: 1) the epilimnion -- uppermost region of warm, homothermal circulating water, 2) the thermocline -- plane of maximum rate of decrease in temperature, and 3) the hypolimnion -- the colder, more viscous, noncirculating zone below the thermocline which receives very little surface heating (Reid and Wood 1976).

Thermal stratification effectively divides the reservoir into two distinct zones where photosynthetic activity is predominant in the epilimnion and bacterial activity is preponderate in the hypolimnion. Thus, temperature regulates the rate of all chemical and biological reactions. Certain organisms are highly sensitive to temperature at critical stages of growth and development. For example, thermal pollution may alter the metabolism and reproduction of various forms of aquatic life. At low temperatures, bacterial decomposition and reproduction are slowed down, consequently reducing the rate of oxygen depletion (Cole 1975). Temperature, therefore, becomes a major limiting factor in the aquatic ecosystem because of the narrow tolerance range of some aquatic organisms (Odum 1971).

Temperature also plays an important role in the solubility of various gases, particularly oxygen (a requirement for respiration for many aquatic organisms). Cold, deep water can hold more gas in solution than warm, shallow water. However, under thermally stratified conditions, where light penetration is severely limited, oxygen is consumed rather than produced due to microbial respiration and decomposition. Thus, thermal stratification affects the rate of destruction of archeological resources because it controls the biological and chemical agents affecting the resources.

Redox Potential: Oxygen produces an oxidation-reduction potential (redox potential) which is influenced by temperature and pH. Generally, oxidation-reduction activities at the mud-water interface will influence the chemistry of the water and sediments in the hypolimnion and the type of organisms present in the sediments.

The differentiation of submerged sediments into two distinct zones, aerobic and anaerobic, as a result of limited oxygen penetration was observed by Mortimer (1941, 1942). The two major factors that determine the thickness of the oxidized surface layer are: 1) the supply of oxygen at the soil surface, and 2) the consumption rate of oxygen. Mortimer found that high oxygen consumption was associated with a thin-oxidized layer and that low oxygen consumption was associated with a thick oxidized layer. By analyzing the distribution of the oxidized and reduced components in each layer, a redox potential profile can be developed that provides information about the processes of oxidation and reduction.

Nutrient Cycles: The balance of supply and demand for important nutrient elements such as carbon, nitrogen, phosphorus, oxygen, and sulphur ultimately regulate the balance of nature. The nutrients serve three main functions: 1) to provide the materials necessary for the synthesis of protoplasm, 2) to supply the energy necessary for cell growth, and 3) to serve as electron acceptors in the reactions that provide energy to the organisms. The growth of organisms which affect archeological resources in a given environmental niche is regulated by specific mineral requirements.

Nitrogen Cycle: The cycling of nitrogen in reservoir ecosystems is extremely complex and is largely a biochemical phenomenon. Nitrogen is an important nutrient which helps regulate the productivity of aquatic ecosystems. The solubility of nitrogen, like oxygen, is related to temperature and pressure, the relationship being an inverse one.

Nitrogen may cycle through five processes: nitrate and ammonia assimilation, ammonification, nitrogen fixation, nitrification, denitrification, and diffusion. All of these affect the chemical decomposition of archeological resources by changing the biochemical agents acting on such resources, causing their eventual destruction or preservation (see Chapter 4).

Phosphorus Cycle: A second major nutrient cycle, the phosphorus cycle, is a sedimentary cycle that involves both microbial mineralization and immobilization reactions.

Phosphorus, an important element required for zooplankton and phytoplankton growth, commonly occurs in soil, sediment, and rock. Other major sources of phosphorus include decaying vegetation, detergents, and agricultural sources. Because phosphorus occurs in both organic and inorganic compounds and in a variety of forms (i.e., dissolved, colloidal, and particulate), it undergoes chemical, biochemical, and geochemical transformations at variable rates, depending upon seasonal temperatures and activities of organisms.

In most hydrologic systems, nutrients such as phosphorus are constantly assimilated by organisms and are recycled through various means such as animal excretion, microbial decomposition, direct recyling, and autolysis (self-decomposition). Therefore, biological availability of any nutrient is determined by the rates of these competitive reactions. Differing rates in an archeological site can be used to determine usage of areas within that site. But phosphorus can be released from the soil through agitation of the mud-water interface. Most studies indicate that greater phosphorus release occurs in agitated sediments than in undisturbed sediments. Diffusion of soluble phosphorus results from the difference in the concentration between the interstitial water of the sediment and the overlying water. The rate of diffusion is governed by the porosity of the mud and by the circulation of the water at the mud-water interface. The incorporation of phosphorus into organisms is one of the primary mechanisms of transfer. Once the phosphorus has diffused out of the sediments, it may be transferred by mechanical means, such as currents.

<u>Carbon Cycle</u>: The carbon cycle is an extremely important nutrient cycle. Autotrophic organisms, the primary producers of the aquatic environment, utilize CO_2 obtained through photosynthesis and provide a source of organic carbon for the growth of animals and bacteria. CO_2, a product of both anaerobic and aerobic metabolism, is important not only in terms of the carbon cycle but also because of its direct influence on growth.

In summary, the amount, type, and availability of organic matter will determine the size and composition of the heterotrophic communities. The nature of the flora will vary with the chemical composition of the substrate, since each organism has a complex of enzymes that only permit it to oxidize a particular, fixed set of chemical compounds.

<u>Sulphur Cycle</u>: Microbial transformations of sulphur involve four basic processes: 1) decomposition of organic sulphur compounds to inorganic compounds; 2) microbial assimilation or immobilization of simple compounds of sulphur and their incorporation into bacterial, fungal, or actinomycete cells; 3) oxidation of inorganic ions and compounds such as sulfide and elemental sulphur; and 4) reduction of sulfate and other ions to sulfide.

<u>Iron Cycle</u>: Iron is another element that readily undergoes transformations by microorganisms. Iron may be precipitated by iron-oxidizing bacteria, heterotrophic activity in decomposing soluble organic iron

salts, and liberation of O_2 by algae. Solubilization may result from acid formation, the synthesis of various organic products, or the creation of reducing conditions.

Corosion of iron and steel materials, particularly in poorly drained saturated soils, may be partially attributed to the activity of anaerobic bacteria. There appears to be a direct correlation between the redox (Eh) potential and the severity of the anaerobic degradation of iron pipes. The optimum conditions for the destruction of buried iron pipes include pH values greater than 5.5, little available O_2, presence of sulfate, and Eh values less than 100 mv.

Biological Zones: Three primary life zones are recognized in lentic habitats: 1) the littoral zone, 2) the limnetic zone, and 3) the profundal zone. The littoral zone is characterized as that portion of the water column which receives light penetration to the bottom of the lake and is occupied by rooted plants. In deep lakes, the littoral zone is influenced by such limiting factors as depth, vertical extent of light penetration, movement of water, and water level fluctuation. The limnetic zone refers to the open water extending from the surface to the compensation level (depth of effective light penetration). The profundal zone includes the bottom and deep water area which is beyond the depth of effective light penetration (Odum 1971).

Within each of these habitat zones, predictable assemblages of organisms may occur that are bounded by local environmental factors or geomorphological features of the habitats. For example, in the limnetic zone, only plankton, nekton (swimming organisms), and neuston (surface swimming organisms) will occur. The composition of the community will vary from lake to lake depending upon such environmental factors as seasonal fluctuations, light, temperature, and dissolved substances and upon biological factors such as competition and growth, and the trophic stage of the lake. Anaerobic bacteria will undoubtedly have the greatest long-term impact on submerged cultural materials. However, the ultimate effect will depend upon the interaction of variables such as chemical environment, soil type and organic content, and depth of burial.

Summary and Conclusions

Although most biochemical processes are complex and do not readily lend themselves to simple formulas of interaction and predictability, general trends and modes of interaction can be examined which are of benefit to archeologists interested in the question of how reservoirs will impact cultural materials. The prediction of how biochemical processes will impact submerged cultural materials requires a knowledge of the cultural values in question and the edaphic, topographic, and climatic characteristics of the impoundment area. The interaction of these cultural and noncultural variables will determine the degree and nature of data preservation.

First, the rate and amount of pollutants and/or sedimentary organic input must be determined in order to assess the biological productivity of the ecosystem. While input of fine, inorganic sediment particles may enhance the preservation of potentially degradable archeological materials by "sealing off" the exposed surface sediments, an influx of organic matter can profoundly affect the productivity of a reservoir and encourage the development of algal blooms and eutrophic conditions adversely affecting cultural materials buried in shallow soil matrices. Reduced anoxic conditions, resulting from oxygen depletion, contribute to conditions of leaching and the diffusion of soluble ions, which are utilized as nutrients by the biotic population. Additionally, as the decomposition of the sedimented organic matter intensifies and the pH is lowered, organic acids accumulate and may contribute to the chemical degradation of the archeological specimens.

Second, the function and water release schedule for the impoundment directly influences biological productivity. The combined factors of nutrient release, dissolved oxygen content, temperature, and pH not only influence the distribution and size of the microbial population but also regulate the rate of deterioration.

Third, the location of the archeological sites relative to the reservoir basin and the depth of the sites within a soil matrix are factors. The most biochemically active is the littoral zone. At the sediment-water interface within this zone, aerobic conditions predominate. Below the soil-water interface and in the benthic (hypolimnion) zone, anaerobic conditions prevail. The effects of chemical degradation may be more pronounced in the hypolimnion due to a combination of accumulated fermentation products of anaerobic decomposition and increased ionic concentrations. Ultimately, the resistance of a particular substrate to microbial and chemical degradation will depend upon the chemical composition of the archeological substrate and the physical and chemical properties of its immediate contextual environment.

OTHER IMPACT PROCESSES

In the proceeding sections the discussion has focused on mechanical and biochemical impact processes. These processes, sometimes visually devastating to cultural remains, sometimes subtle and complex in their net impact are, nonetheless, knowable and eventually predictable in nature. There is no question that a direct frontal assault by waves on a wide variety of cultural remains is destructive. The amount of destruction is measurable; the variables of slope, soil type and compaction, and the nature of the resource can be figured into the overall equation and a rough prediction can be made regarding the potential destruction of the site or feature.

In a reservoir area, however, how can the impacts of human use on cultural resources be measured or predicted? How does flooding of the pool area alter the pattern of wildlife exploitation? How do the processes of human, floral and faunal activity within the reservoir environment change prior to and following impoundment, and what are the implications for cultural resources? The following discussion will focus on these broad impact processes.

Preimpoundment Impact Processes

Prior to construction of a reservoir human, floral and faunal impacts to archeological resources within the impoundment area are limited. Land use is usually disbursed, rather than area intensive along the reservoir margins, and consists mainly of farming, logging, mining and grazing activities. Selected sites or portions of sites within the river drainage may be directly impacted by construction of farm buildings and access roads for logging, mining, fire prevention, and grazing or wallowing by range animals. For the most part, however, large-, medium-, and small-scale resources are not greatly disturbed and their relationships and the potential for site contextual interpretation is not normally compromised.

Recreation activities may impact sites over a wide area in a river drainage; hunting, caving, climbing, and backpacking, for example, appeal to a small percentage of the total population and use of the river basin is usually not concentrated. Camping, unless there are designated campsites, is sporadic in any particular area and impacts to sites from campers are not great. Impacts from canoers or rafters are limited to areas immediately adjacent to, or within a short walk from the river itself. In all cases, impacts to archeological resources are site or artifact specific and sporadic throughout the entire river system.

During the reservoir construction phase human activity constitutes a greater level or degree of impact to archeological resources. Entire sites may be obliterated or severely damaged through road relocation, turning pad construction, barrow pit excavation, clear-cutting and deforestation below the normal pool level, and the removal of buildings, bridges, etc., that may constitute hazards after impoundment. Once again the impacts are site or area specific, the entire complex of sites and their contextual environment (the large-scale data) are not severely compromised.

Postimpoundement Impact Process

Following flooding of a reservoir, land use above the pool level changes dramatically and becomes area intensive due to the constriction of lands formerly available into a narrow band suitable for use. Grazing and range management areas are either reduced or more intensely exploited. Fluctuations in pool level encourages trampling of saturated soils by both domestic grazing and native range animal populations. Sites within the fluctuation zone can be heavily impacted by these activities. As former habitats are eliminated or reduced, new migration trails are established and areas only marginally exploited previously can become denuded as competition for food resources increases. Creation of these new trails encourages erosion both above and below the trail site and loss of vegetative cover or a shift in vegetative species can act together to alter large areas within a river drainage.

Farming and other agricultural use may increase downstream and just outside the reservoir boundary as water supplies become more accessible and reliable and irrigation more practical. Increasing agriculture outside of the reservoir area, although not directly affecting sites, may have indirect impacts. The widespread use of fertilizers, transported into the reservoir by rain, runoff, and percolation, may adversely impact the preservation of small-scale archeological resources as an increase in nutrients accelerates biochemical activity and changes the chemistry of the water. Pollution, resulting from the increased industrial growth potential upstream from a reservoir, may affect the viability of dating and analysis techniques used by archeologists. Pollution by water soluble fissionable materials has been documented in a reservoir area in Oregon (see Chapter 4, this volume), compromising the ability to conduct certain dating analyses.

The most dramatic shift in reservoir area use following flooding may come as a result of recreational activities. As recreational sites are developed and opened to the public, hunting, camping, backpacking, etc., may increase exponentially. Fishing and boating, normally only a small percentage of recreational use prior to impoundment, often becomes the major recreational activity following pool filling, attracting vastly increased numbers of visitors. Associated with an increase in boating is an increase in adverse impacts to sites from casual or purposeful vandalism. Sites accessible only after an arduous climb or hand and toe holds prior to impoundment, become highly visible from a boat and easily exploited as diversions or picnic areas after pool level establishment.

An increase in vacation or retirement home communities often follows reservoir development. Seasonal and year round residents have an unlimited opportunity to walk the reservoir margins and removal of materials from sites denuded of vegetation or stripped of their soil mantle has become a pleasurable pastime for many. Off-road vehicle use and establishment of visitor or resident support facilities accompanies recreational development. Although not directly affecting the archeological resources within the reservoir, the influx of visitors and residents into the area does have an impact; an increase in reservoir visitation is invariably accompanied by an increase in depredation to cultural resources.

The results of management decision regarding pool level fluctuations potentially can impact all sites within the reservoir maximum flood pool area (Zone 3, see Chapter 5, this volume). A decision to raise the water level by as little as 10 feet can constitute a major impact to hundreds of sites either never before inundated or previously inundated for only short periods of time by placing them within the wave action zone and subject to mechanical disturbance by boat wakes.

Postimpoundment impact processes, unlike preimpoundment impacts, do affect the large-scale data base, altering both the floral and faunal communities, and changing the nature of human use throughout the river drainage system.

CHAPTER 4: RESERVOIR IMPACTS TO ARCHEOLOGICAL RESOURCES

ARCHEOLOGICAL RESOURCES

Chapter 3 examined the reservoir and reservoir-related processes that may affect, either adversely or beneficially, the preservation of archeological resources in a reservoir impact zone. Chapter 4 focuses on the other half of the preservation equation: the range of archeological resources that are affected by inundation and the nature of those effects.

Cultural resources have been defined to include "all evidences of past human occupations other than historical documents, which can be used to reconstruct the lifeways of past peoples" (Scovill et al. 1972: 3). In the same article, Scovill, Gordon, and Anderson further delineate the cultural resource base as follows:

> The resource base includes any source of information about the lives of past peoples including, but not limited to, artifacts, architecture, plant and animal remains, local geology, soil composition, topography, and the modern environment....Analysis and interpretation of the data contained in archeological resources requires examination of their total physical and ecological context. (1972:5-6)

Such an inclusive definition of the cultural resource base is particularly appropriate when addressing the effects of freshwater inundation. Inundation constitutes a form of large-scale, nondiscriminatory impact that may adversely affect not only archeological sites and their contents but also the environmental context of entire settlement systems. For this reason, it is necessary to approach inundation impacts from a regional perspective and adopt as broad a definition of archeological resources as possible in order to anticipate the broad range of potentially adverse impacts.

A framework for classifying regional-scale cultural resources was presented in Chapter 2 (Fig. 2.1), and the presentation of data in this chapter will attempt to conform to that scheme. Chapter 2 proposed that archeological resources in a reservoir impact zone should be classified hierarchically to include everything from regionally-scaled environmental data down to the level of the artifact attribute.

The hierarchical scheme proposed for assessing inundation effects encompasses three levels of resource or data scales. The smallest scale includes artifacts and artifact assemblages -- the material remains that comprise a site or activity locus. Assessments of impact at this scale address the important questions of differential preservation of material, data loss at the attribute level, and compromises to analytical techniques.

The next largest scale is the archeological site or activity locus. Assessments of inundation effects at the level of the site focus on soil disturbances which destroy or alter spatial and stratigraphic contextual relationships within the site, mechanical impacts on cultural entities, biogeochemical alterations of the depositional environment of the site, and, of course, compromises to analytical techniques that rely on an undisturbed site context.

The largest scale of archeological resources includes the regional environmental data base, settlement and resource utilization patterns, large-scale cultural features such as trade networks, waterworks, roads, etc., and regional and areal patterns beyond the direct impact zone of a reservoir that may be adversely impacted as a result of data loss within the reservoir proper.

An important consequence of the hierarchical arrangement of cultural resources is that it makes explicit the proposition that cultural values consist not just of discrete entities such as sites and artifacts but also of relationships between such entities; the relationships among, for example, artifacts and features comprising a site, among sites comprising a settlement system, and between a settlement system and its environmental and cultural context. Clearly, the loss of such relational data constitutes as great an impact to the archeological data base as the loss of sites and artifact assemblages.

A hierarchical perspective also encourages the cultural resource manager to view archeological resources not as isolated entities but as component parts of larger functional wholes, a shift in perspective which may cause some to reassess preconceived notions about the implications of information loss resulting from various kinds of impacts. When an artifact is seen as a component of a site, the site a component of a settlement system, and the settlement system a component of a complex ecosystem, it becomes clear that the differential preservation of artifacts has more profound implications than the loss of potential museum exhibits. The loss of data at any level of the cultural resource hierarchy affects the quality of information obtainable from all other levels of the hierarchy.

It is also the case that, when combining components or subsets of a hierarchy, properties inherent in the resource base often emerge that were not evident at the next level below (Moratto and Kelly 1978: 2). This is certainly the case when our perspective shifts from sites to clusters of sites. When we begin to address questions regarding regional settlement systems, site location, and resource utilization patterns, the loss of otherwise insignificant site data may profoundly affect pattern recognition. In this same context, the loss of cultural resource data from a reservoir may have a substantial impact beyond the direct impact zone of the reservoir, if the data lost were essential components of some larger regional pattern.

The presentation of data in this chapter will follow the problem format introduced in Chapter 2 (see Fig. 2.1).

The chapter will discuss, as briefly as possible without being too simplistic, the nature of reservoir impacts to different aspects of the archeological data base.

LARGE-SCALE ARCHEOLOGICAL RESOURCES

When a stream or river is dammed, water impounded, and cultural resources inundated, the most obvious adverse impacts occur to the most visible elements of the cultural resource data base, i.e., the archeological site or historic structure. However, the potential adverse impacts are far greater, for not only are sites and structures lost, but entire historic communities and prehistoric settlement systems may be destroyed. Their geographical and environmental context also may be irreparably altered.

The following discussion focuses on the impact of inundation on the information base that forms the social and environmental context of archeological and historic resources. This information base encompasses three major data categories: 1) the environmental data base of the region; 2) regional intersite and site-environmental patterns; and 3) large-scale cultural features such as roads, trails, agricultural facilities, etc.

Environmental Data Base

In addition to the cultural features and patterns that are superimposed on the modern landscape, significant "cultural" information resides in the landscape itself, especially in the distribution of plants, animals, soils, geomorphologic features, and other data that provide a window on modern environmental conditions or a record of past environmental change.

The environmental data base of any given region is large and extremely varied. Significant environmental data include such things as regional climatic variation, modern distributions of floral and faunal communities, soils, geomorphological features, and so on. In addition, the preserved remains of plants and animals recovered from archeological sites and other contexts and data from buried soil horizons and geomorphological exposures provide direct clues for the reconstruction of past environmental conditions. The spatial and temporal variability of these elements serves as a baseline for reconstructing the paleoenvironment and landscape.

An understanding of the modern ecosystem of a region is essential to the reconstruction of the paleoenvironment and its history of change. According to Butzer (1971:49): "...the ultimate key to paleo-ecology is provided by modern distributions of similar features." Only after a thorough inventory of modern environmental components and an understanding of modern environmental processes is the archeologist able to predict past environemtnal relationships and their variability. The recovery of modern environmental data is, therefore, essential to an understanding of past and present culture - environmental process.

Paleoenvironmental reconstruction is a multidisciplinary task in which independent lines of evidence are supplied by specialists from such diverse fields as botany, zoology, geology, chemistry, astronomy, climatology, etc. It is the task of the archeologist, however, to examine and synthesize these various independent lines of data, determine where they converge, and interpret what these convergent results mean in terms of past environmental conditions and human responses to those conditions. For example, geomorphological evidence may indicate that at the time an archeological site was occupied, the river valley in which it was located was in the process of active erosion. Fossil plant pollen from a contemporaneous soil horizon in the valley may indicate a change in vegetation on the upstream slopes of the river valley, signaling a climatic event that initiated the onset of erosion. Plant and animal remains recovered during the excavation of the site may, in turn, yield evidence of a change in prehistoric subsistence strategies coincident with the onset of erosion.

Such reconstructions constitute critical links in the chains of inference that are the basis of modern archeological research. The closure of a stream channel by a dam initiates a series of complex changes in the ecology and physiography of a drainage basin, thus destroying the data base from which archeological inferences are made. The most dramatic changes occur upstream of the dam where water is impounded to form a lake. The most obvious change and immediate effect of a water impoundment is the destruction of a terrestrial and riverine ecosystem and its replacement by a freshwater aquatic ecosystem.

Most plant and animal communites adapted to a terrestrial and riverine environment cannot be expected to survive in the newly created aquatic environment. Plant communities, because of their lack of mobility, will usually succumb to the effects of flooding, whereas most animal communities can be expected to migrate from their former habitats and establish themselves in adjacent terrestrial zones. Here, competition for territory and resources will almost certainly increase and may eventually alter the faunal composition of surrounding locales. The new aquatic ecosystem of the lake will, in turn, provide habitats for a new assemblage of life forms, both within the waters of the newly formed lake and along its fluctuating shoreline.

Reservoir impacts to modern vegetation are not limited to zones of permanent inundation but extend to the reservoir shoreline, back shore, and downstream zones as well. Most man-made reservoirs experience varying degrees of water-level fluctuation due to seasonal fluctuations in input and output, resulting in seasonal shoreline fluctuations. As the reservoir water level rises during a flood stage, there is an increase in available moisture along the new shoreline. Aided by wave and capillary action, moisture penetrates laterally into the adjacent soils and stimulates plant growth. As the water level recedes during drawdown, the emerging drawdown zone functions as a seedbed for the germination of wind- and water-dispersed seeds. During these initial stages of plant succession, rapidly germinating pioneer species are dominant. Since plant succession is usually a very gradual process, the establishment of a climax vegetation community will depend on the duration of the drawdown and the extent of alteration of the physical and chemical properties of the shoreline soils.

In reservoirs subject to frequent water-level fluctuations, the native vegetation will probably never recover from the impact of initial inundation. In reservoirs subject to infrequent water-level fluctuations, restoration of native vegetation may be inhibited by changes in shoreline edaphic conditions and by competition with invader species. Following the useful life of the reservoir, the vegetation assemblage that ultimately becomes established on the sediments of the reservoir floodplain will probably be similar in composition to the original riparian assemblage of the valley floodplain. However, upland vegetation types may not be represented because of a constriction of their preinundation habitat.

In addition to the biological impacts that occur within a reservoir impoundment, substantial changes in the geomorphology of a drainage basin occur as a result of stream closure and water impoundment. The erosive energy of an advancing reservoir shoreline and the gradual accumulation of sediments in the still waters of the reservoir basin combine to permanently alter the geomorphology of the submerged river valley.

The dominant geological process that occurs within a reservoir is sediment transport and deposition. Sediment is derived primarily from stream inflow and secondarily from shoreline degradation which is accompanied by onshore-offshore sediment transport. Since man-made lakes are essentially closed systems, with sediment input greatly exceeding sediment output, all reservoirs are transitory phenomena; water storage capacity gradually decreases through time as the reservoir basin fills with sediment to the level of the dam spillways. The net long-term result of reservoir sedimentation is the burial of the preinundation landscape under tons of fine-grained sediments.

In spite of the fact that deposition processes predominate in a reservoir basin, erosion processes are far from negligible in any large body of water. The effects of wave action along a vertically fluctuating shoreline are the most visible form of mechanical impact within a reservoir. Another not so visible, but equally destructive, form of impact results from the saturation and slumping of submerged geological strata.

In addition to upstream vegetation impacts, a reservoir impoundment also may have subtle impacts on downstream environmental regimes. A dam typically imposes substantial fluctuations in downstream flow rates.

Because of these inevitable changes in plant and animal communities, the most immediate large-scale impact resulting from inundation is the destruction of the modern environmental data base. The only mitigating factor in the loss of modern environmental data in a reservoir is that species inventories and gross distribution patterns from an impacted drainage system may be partially replicated in an adjacent system. But while similar vegetation zones and animal habitats may exist in adjacent drainages, local differences in soil types, soil depth, slope, topography, moisture, and microclimatic conditions--factors that influence vegetation type and distribution--will almost certainly vary from one drainage system to the next. As a result, inundation always results in the loss of environmental information that is unique to a drainage system.

The loss of this unique data base automatically precludes a broad range of cultural-environmental analyses that require fine-grained environmental analyses data, such as catchment site location and ecological stratification, etc. In many ways typical of modern cultural-environmental studies, Allan and Stuart's (1977) survey of the Fruitland, New Mexico region yielded predictive statements about the location of different types of archeological sites during different cultural periods. By analyzing three environmental variables--slope, potential runoff, and vegetation diversity -- a pattern emerged indicating a correlation between site type, cultural period, and environmental zone which provided insights into changing exploitive technologies. Studies such as this would not be possible in areas subjected to long-term or even periodic inundation.

Intersite and Site-to-Environment Relationships

Archeological sites are components of larger systems which exhibit significant spatial, temporal, and organizational relationships to both the social and natural environment of which they are a part. First, they are components of larger settlement systems. The most obvious physical expression of an extinct settlement system is the spatial and temporal distribution of archeological sites on the landscape.

Analysis of settlement patterns may provide valuable insights into the social and economic behavior of past human populations, insights that would elude the archeologist who adopted a more fragmentary view of the site data base. An underlying assumption of all settlement pattern analyses is that proximity on a spatial dimension is an indication of proximity on social, economic, and other dimensions as well. For example, if archeological sites are clustered with respect to certain nonrandomly distributed environmental variables, the archeologist may reasonably infer that the environmental variables in question may have influenced site location decisions. A corollary of this hypothesis would be that the environmental variables that were attracting sites constituted some critical resource for the prehistoric population. In most cases, this hypothesis could be tested by examining the contents of sites for evidence that a particular resource was indeed being processed and utilized.

In recent years, the study of man-environment relationships in archeology has focused on correlating settlement pattern data with resource extraction strategies in order to develop predictive models of site location and intersite functional relationships (Willey 1953, 1956; Chang 1968; Gumerman 1971; Reher 1977). Other studies employing large-scale settlement pattern data have focused on human interaction with the ecosystem and on changes in adaptive strategies in response to changes in environmental conditions (Struever 1968; Jochim 1976; Yellen 1974). In this latter category of studies are a number of analyses that have examined the relationship of human settlements to potential subsistence and nonsubsistence resources within a hypothetical land-use territory. (Vita-Finzi and Higgs 1970; Coe and Flannery 1964; Flannery 1976; Clarke 1977; Foley 1977). The purpose of most of these studies is to determine the area habitually exploited by a population and the amount of energy required to extract a given resource.

Large-Scale Cultural Features

Perhaps the most obvious elements of the large-scale cultural resource data base are various linear features, such as roads, trails, fences, property boundaries, field markers, walls, fortifications, and waterworks. Large-scale areal features such as hunting, collecting, and other resource extraction zones, agricultural fields, reservoirs, etc., are also included. A common characteristic of such large-scale features is that they often lack the cultural material associations of a habitation or intensive activity locus; therefore, they are often overlooked on ground survey. Even if ground survey succeeds in locating fragments or sections of such features, the total configuration of such features is frequently impossible to detect from a ground-level vantage point because of their scale. As a result, large-scale cultural features are often poorly represented in cultural resource inventories.

With the application of remote sensing techniques to archeology, this picture is rapidly changing. Large-scale features which are difficult or impossible to discern on the ground are now being routinely recorded and mapped with the aid of aerial imagery. The significance of such large-scale features for understanding regional archeological problems, especially problems relating to site location, regional interaction patterns, resource exploitation, etc., are being appreciated for the first time.

One of the best examples of the significance of large-scale cultural features in regional archeological interpretation is the extensive network of prehistoric roadways emanating from Chaco Canyon in northwest New Mexico. The existence of roadways binding archeological sites in Chaco Canyon and outlying areas was reported as early as 1954 (Judd 1954). Navajo Indian informants living in the Chaco Canyon region had reported the existence of such roads even earlier. But it was not until remote sensing and aerial imagery survey techniques were applied to Chaco in the early 1970s that the nature and extent of the Chacoan road system was fully appreciated. The subsequent discovery and mapping of an extensive regional road and communications network is contributing to a major reformulation of prehistoric cultural dynamics in the San Juan Basin of northwest New Mexico and southwest Colorado (Lyons and Ebert 1978).

MEDIUM-SCALE ARCHEOLOGICAL RESOURCES

The medium-scale universe is defined by the archeological site or activity locus. Although operational definitions of archeological sites may vary widely, in the most general terms, a site is any place, large or small, where there are traces of human occupation or activity (Hole and Heizer 1973:59).

The variety of sites studied by the archeologist approaches the variety of past human activities that were associated with the construction of structures and facilities and the use and discard of materials. In describing this variety, archeologists typically classify sites according to criteria that may express a variety of research or management concerns. For example, sites are commonly classified with respect to their location, condition, size, the artifacts or features they contain, the kinds and variety of activities postulated to have occurred on the site, etc.

Different kinds of sites yield different kinds of information, but since our concern in this section is the impact of inundation on the information content of sites in general, there are certain generalizations we can make about that information base that apply to virtually all sites, regardless of their content, condition, or information potential.

In the preceding section, it was emphasized that large-scale cultural resources consist of entities (large-scale cultural features, regional environmental variables, etc.) and relationships between entities (settlement patterns, intersite networks, site-environmental relationships, etc.). Similarly, the information contained in an archeological site consists of entities and their relationships.

Site entities consist of the material remains of past human activity, which may consist of structural features such as architecture and other forms of bounded space; facilities for heating, cooking, storage, and defense; activity and resource areas defined by clusters of artifacts and other forms of nonrandom material distributions; and so on. The relationships among structures, facilities, activity spaces, and artifacts comprising a site are known collectively under the term "archeological context," which is defined as "the environment within which things...are found or within which they operate" (Hole and Heizer 1973: 99). Archeological context is measured on three principal dimensions: time, space, and human behavior. Although the ultimate goal of archeological research is the reconstruction of the behavioral dimension, accurate behavioral reconstruction requires an understanding of temporal and spatial relationships among the material deposits of the site.

Time is one of the most important dimensions in archeological research, and the temporal context of items within and between sites constitutes one of the most important sets of relationships in the archeological record. An understanding of temporal relationships is the basis for constructing archeological chronologies, and accurate chronologies are essential if the archeologist is to observe and measure change. Furthermore, the explanation of culture change requires a degree of temporal precision sufficient to allow the archeologist to isolate relatively discrete units of time, so that contemporaneous events and processes can be analyzed in detail.

The temporal context of an item refers not so much to its absolute age in years as its "relative" age with respect to other items within the site. If every entity within a site could be assigned an absolute age in calendar years, and if these ages could be adjusted to correct for differences in facility use-life and artifact discard rate, the assessment of temporal context would be a fairly straightforward process of correlating the ages of all items recovered from the site. On the basis of such correlations, groups of contemporaneous entities could be identified, and their temporal-spatial associations and behavioral implications could be unambiguously assessed.

In reality, of course, very few items in an archeological assemblage can be dated with the relative certainty necessary to make these kinds of fine-grained assessments. Consequently, temporal context must be determined on the basis of a small fraction of datable items and the "stratigraphic" relationships among items or deposits within a site. Although other means of relative age determination are employed in archeology, stratigraphy is the most important measure of intrasite temporal context.

Stratigraphic interpretation is based on the geological principle of superposition, which states that in an undisturbed profile of sequentially-layered deposits, the deeper the strata, the older the deposit. This simple principle is often extremely complex in its application. The problem lies in the fact that cultural deposits are rarely undisturbed, and only rarely (such as in a cave or other enclosed or circumscribed space) are cultural materials deposited in an orderly, horizontal fashion. In fact, archeological sites often grow by a combined process of lateral expansion and vertical accumulation, so that stratigraphic interpretation must assess temporal trends on a horizontal as well as vertical dimension.

Because the assessment of temporal context depends in large part upon the preservation of undisturbed stratigraphic relationships within a site, temporal interpretations are extremely susceptible to skewing as a result of physical and chemical alterations of archeological deposits. These are the very kind of alterations that often result from the mechanical and biochemical effects of inundation.

The second major dimension of intrasite archeological context is the spatial dimension. The spatial structure of an archeological site is the result of the nonrandom output of human activities which allocate structures, activities, and artifacts to specific loci within a site (Clarke 1977:10). Because of the close relationship between spatial structure and patterned human behavior, a great deal of archeological research is devoted to discovering spatial patterning in the site assemblage and inferring the behavioral correlates of those patterns.

The spatial context of an item refers not so much to its spatial coordinates within the cultural deposits as to its spatial association with other items in the assemblage. The spatial associations of an artifact or feature may provide important clues to a number of questions regarding function. For example, the function of a problematic artifact may often be inferred from the known functions of artifacts or features found in close spatial proximity to the unknown item, and the function of a structure or facility can often be inferred from the various functions attributed to its artifact contents.

The last decade has seen a revolution in spatial analysis theory in archeology. In a recent book devoted entirely to the subject, the late David L. Clarke (1976) defined three levels of spatial structure in archeology, each level with its own set of assumptions, theories, and models. Two of Clarke's spatial levels, the micro and semimicro, involve intrasite spatial relationships. Spatial relationships at the microlevel consist of such things as artifact clusters, activity areas, and any spatial loci or bounded space containing human activities or their consequences; whereas the semi-microlevel consists of the spatial relationships between activity loci and structures comprising the site. Clarke's third or macrolevel of spatial patterning consists of intersite relationships and is analogous, therefore, to the "large-scale" cultural resources discussed above. Clarke goes on to present a number of theories and models that are appropriate for behavioral inference at each of the three levels of spatial patterning, both within and between archeological sites.

The last decade has also seen major advances in methods and techniques for reconstructing intrasite spatial patterns. The goal of spatial pattern analysis is the discovery of subsets of structures, facilities, and artifacts that covary in space. Since the discovery of spatial patterning can rarely be accomplished by intuition alone, recent methodological advances in spatial analysis have involved the application of extremely sophisticated quantitative techniques for spatial pattern recognition. Many of these techniques require precise locational coordinates for artifacts recovered from sites, and these techniques have had a profound influence on data recovery methods, as well as on the cost and time required for site excavation and analysis. Clearly, the application of techniques that requires such precise spatial control over artifact recovery could be severely compromised by inundation processes that alter or destroy the spatial relationships of items within a site.

The third major dimension of intrasite variability is the behavioral dimension. The data of archeology consist of the material remains of extinct cultural systems and the spatial relationships of those remains; the primary goal of archeology is to infer behavior from these data. Behavioral inference in archeology takes place at several different levels. Attributes of material objects can be used to infer behavioral variability, as when the function of a particular artifact is inferred from its size, shape, and evidence of wear or use. On a somewhat higher level, the spatial and stratigraphic relationships between artifacts comprising a site are correlated with certain kinds of patterned organizational and depositional behavior. And at a still higher level, the types and distributions of sites on the landscape can be correlated with environmental variables to infer such things as regional economic and resource exploitation patterns.

According to Lewis Binford (1964:425):

> The loss, breakage, and abandonment of implements and facilities at different locations, where groups of variable structure performed different tasks, leaves a "fossil" record of the actual operation of an extinct society.

Binford's statement suggests that the location of artifacts on a site corresponds to their location of use, and that locations of use correspond with locations of discard. But clearly, this is not always the case. Between the time artifacts are manufactured, used, excavated, and analyzed, they are subjected to a number of cultural and natural processes that alter the systemic context of the remains and produce a blurring in the interpretive processes.

Schiffer and Rathje (1973) distinguish two kinds of "cultural formation processes: C-Transforms and N-Transforms. C-Transforms refer to the processes by which materials are discarded or abandoned by a cultural system, while N-Transforms refer to the" postdepositional changes in site and artifact morphology caused by non-cultural processes, such as wind, water, rodent activity and chemical action" (Schiffer 1976:15). The following discussion focuses on a special kind of N-Transform: freshwater inundation. We hope to show that the direct mechanical and biochemical impacts of inundation, as well as many of the indirect impacts of inundation, are both regular and predictable.

MECHANICAL IMPACTS TO ARCHEOLOGICAL SITES

The fluid forces generated by water motion in a large-water impoundment invariably alter the geomorphology of a reservoir basin. The question we will address in this section is how, and to what extent, reservoir erosion and deposition processes affect archeological sites within the direct impact zone of the reservoir impoundment. The problem is essentially fourfold.

The nature and extent of erosion and deposition impacts to archeological sites will be determined, first of all, by characteristics of the reservoir: its size, depth, and orientation; the size and hydrological characteristics of its watershed; the regional climatic regime; and the operating characteristics of the reservoir, such as fill rate, drawdown frequency, and so on. These characteristics, which may vary widely from one reservoir to the next, are important variables in the cultural resource preservation equation.

Second, and perhaps even more important than specific reservoir charateristics, is the location of sites within the impoundment. Deposition and erosion processes do not occur randomly within a reservoir; rather, they are vertically stratified on the basis of water column depth, with erosion processes predominating in the shallow beach and nearshore zone and deposition processes predominating in the deep offshore zone. As a result, the vertical position of a site within the water column of a reservoir will largely determine the nature and intensity of hydraulic forces impacting the site.

Third, the geological and environmental context of a site will determine, in part, the ability of the site to withstand erosive water impacts. The geological foundation or substrate of a site is particularly important. If the substrate is weak and easily eroded, then erosion impacts to the site almost certainly occur, regardless of the impact resistance of the site deposits themselves. Other factors such as vegetation type and density, slope, and orientation may also have a significant influence on local site preservation conditions in a reservoir.

Finally, characteristics of the archeological site itself will influence its ability to withstand erosive impacts. For example, certain kinds of sites and features within sites are more susceptible than others; a standing wall is more susceptible to wave impacts than a buried floor, for example.

The interaction of these four factors through time will determine the nature and extent of mechanical impacts to archeological sites in reservoirs. Our knowledge of the role that these factors play in site preservation comes from investigations at over 40 man-made reservoirs in the continental United States. The details of these conditions and the nature of their interactions are summarized below:

Reservoir Characteristics

The nature and magnitude of erosion and deposition processes in lakes is determined primarily by the form of the reservoir basin; its size, depth, and orientation; and local meteorological conditions. Meteorological forces are the primary source of energy input into the complex system formed by a reservoir basin and its watershed, and differences in climatic input between reservoirs are a major cause of observed differences in sedimentary processes.

The most important physical inputs in a reservoir dynamic system are wind, river inflow, atmospheric temperature, surface barometric pressure, and gravity (Sly 1978). Of these, wind is by far the most important, followed by river inflow and atmospheric heating, while surface barometric pressure and gravity effects are negligible except on very large lakes (Sly 1978:68).

Wind-generated water waves are primarily responsible for both erosion and transportation of coarse particulates in lakes and reservoirs. Wind shear stress may also generate basin-wide circulation systems and local upwelling, resulting in the transportation and deposition of silt-clay size particles. Variation in wind magnitude from one reservoir to the next may have significant implications for site preservation.

Wind-wave impacts to cultural resources are the most common and most destructive form of impact found in reservoirs, and the strength and direction of prevailing winds is a key variable in the accurate prediction of wind-wave impacts at any given site. Nearly all reservoirs in the study sample contained some evidence of site erosion that could be directly correlated with onshore winds and their effect on wave energy intensity. At Folsom Reservoir in California, wave impacts to some sites are enhanced by seasonal prevailing winds that often exceed 30 m.p.h. (Foster and Bigham 1978). At Table Rock Reservoir in southwest Missouri, Garrison (Garrison et al. 1979:91) was able to account for differences in erosion intensity on different shorelines as a result of differences in wind velocity and fetch area. Furthermore, onshore wind effects are not limited to wave generation. At Libby Reservoir in Montana, where high-intensity seasonal winds accompany 100- to 150-foot seasonal fluctuations in the reservoir pool level, direct wind erosion of unprotected sediments in the drawdown zone is having a major adverse impact on archeological site preservation.

Whereas wind energy is the dominant agent of erosion in a reservoir, depositional processes are regulated primarily by stream inflow, the second major form of physical input in reservoirs. In the still, deep waters of the reservoir basin, sediment transported by stream inflow gradually accumulates. The rate of sedimentation is a function of sediment inflow, the trap efficiency of the reservoir (a measure of the percent of sediment inflow actually deposited: a small percentage nearly always passes through the dam outlet works into the river downstream), and the density of deposited sediments, which provides an estimate of the packed volume of sediment deposits (Koelzer 1969). Of these, sediment inflow is by far the most important variable.

The net effects of river inflow on the sedimentary regime of a reservoir will vary according to basin depth and configuration, river temperature, entrained solids content, rate of discharge, etc. (Sly 1978). Most of the bedload carried by an inflowing stream is normally deposited in a fan-shaped delta or foreset bed as the flowing stream encounters the still waters of the reservoir. In lakes with well-defined density stratification, however, density currents may carry sediments well beyond the major stream deltas and deposit them in the far reaches of the lake.

Perhaps the most important factor influencing sedimentation rates in a reservoir are erosional characteristics of the reservoir watershed. These characteristics will, in turn, be primarily a function of the regional climate. Sedimentation rates from arid watersheds will ordinarily be significantly greater than heavily forested watersheds, with agricultural areas intermediate in sediment yield to these two extremes (Sly 1978). Watersheds with high relief will ordinarily be characterized by extremely variable river inflows with high-volume peaks and coarse particulate loads, whereas a low-relief watershed will be characterized by less variable inflows and finer particulate loads.

The third major form of physical input in lakes is atmospheric temperature, the effects of which are primarily reflected in the thermal-density structure of the lake water column. During the summer months when the warm surface waters (epilimnion) of a lake are somewhat less dense than the cold bottom waters (hypolimnion), a sharp thermal gradient, or thermocline, may exist that effectively separates the shallow from the deep portions of the lake. In the fall, when the surface waters cool to approximately 4° C., vertical mixing of the epilimnion and hypolimnion occurs. Most lakes in temperate zones mix or overturn twice a year, during the fall and spring, whereas high-altitude and mountain lakes, as well as low-altitude lakes (which may never cool to 4°C), may only mix once a year.

The effects of thermal-density stratification in lakes is particularly important with regard to the transportation and deposition of fine-grained sediments (Sly 1978:71). A well-defined density structure in a lake may keep tons of fine silt-clay size sediments in suspension within the water column. During seasonal overturns, these sediments may be transported and redeposited throughout much of the lake basin. If atmospheric conditions are such that ice forms on the lake during the winter, the still-water conditions associated with the ice cover may allow very fine particulates that would otherwise remain in suspension to settle out on the lake bottom (Sly 1978:69).

In addition to the natural forces that affect reservoir sedimentary processes, human use of the reservoir may have a major impact on erosion and deposition processes. Most man-made reservoirs are designed to serve a variety of functions, such as water storage for domestic or agricultural use, flood control, navigation, hydroelectric power generation, recreation, etc. It is common for pool levels in natural lakes to fluctuate somewhat as a result of variation in stream inflow, outflow, evaporation, etc., but the use and management of water in an artificial impoundment, especially in the arid West, typically results in severe pool-level fluctuations. Large-scale seasonal drawdowns often occur in agricultural storage and power generation reservoirs.

The destructive potential of water-wave energy is significantly enhanced when the beach zone retreats during reservoir drawdown. As the reservoir level is lowered, wave energy is applied to the saturated and unconsolidated sediments of the lake bottom. Since these sediments lack a protective vegetation cover, they are easily eroded by waves, nearshore currents, and winds.

During the recent drought-related drawdown at Folsom Reservoir in California, archeologists recorded large areas within the drawdown zone where more than a meter of soil mantle had been eroded away, exposing large expanses of granite bedrock. Archeological sites that were once buried in these deflated soil horizons were either entirely removed or were pedestalled above the less resistant soil matrix. Thus they were exposed to mechanical erosion and transport as well as to biological degradation (Foster et al. 1977; Foster and Bingham 1978).

A common secondary function of many man-made reservoirs is recreation, and adverse impacts associated with the recreational use of reservoirs are well documented and widespread. At Chesbro Reservoir in California, human impacts from boat ramp construction, recreational vehicle use, powerboat wakes, and vandalism are said to be more extensive than at many sites suffering only from natural erosion processes (Winter 1977). Waves induced by powerboat wakes have been singled out as major causes of shoreline erosion at Table Rock Lake, Missouri (Garrison et al. 1979:91) and Lake Powell, Utah (Rayl et al. 1978), to cite only two examples.

In addition to the four kinds of input variables affecting sedimentary processes in reservoirs, the size, shape, depth, and orientation of a reservoir basin are important conditioning variables, for they have a significant influence on erosion and deposition processes. For example, sedimentation patterns in a reservoir cannot be predicted without taking into account the size, shape, and depth of the basin, which control such things as basin-wide circulation systems and the thermal-density structure of the lake.

The size and shape of the reservoir basin also exert a major influence on erosional processes by determining the size of the reservoir fetch and, hence, the size and period of wind-generated waves. Reservoir depth and orientation also influence wave generation and the development of a nearshore current system. High-energy, nearshore systems may never develop in shallow lakes where wave generation is limited by depth and bed effects, and lake orientation relative to dominant wind fields will have a major influence on wind-generated waves, currents, and circulation systems (Sly 1978).

Site Location

Most archeologists who have conducted research on inundation impacts to archeological sites have recognized the importance of site location to accurate impact prediction. (Garrison 1975; Garrison et al. 1977; Mohs 1977; Padgett 1977; Schaafsma 1978; Adovasio et al. 1980). The most destructive forms of erosive impacts in a reservoir are concentrated in a comparatively narrow band, encompassing the fluctuating reservoir beach zone. High-energy water waves, the most destructive form of mechanical impacts in reservoirs, are essentially restricted to this beach-zone band, the width of which is determined by the extent of annual pool-level fluctuation. Beyond the shore fluctuation zone, erosion is usually negligible. In fact, deposition processes in the offshore zone may actually enhance the long-term preservation of sites by providing the site with a silt "blanket"--an excellent buffer against future erosional impacts.

The importance of site location relative to reservoir impact zones (see Chapter 5 for an in-depth discussion of impact zones and mitigation strategies) was recognized at Bluestone Reservoir in West Virginia:

> ...Bluestone Reservoir studies indicate that it is a site's topographic position relative to the impoundment flood pool that ultimately determines or profoundly affects the course of its subsequent preservation history. A site located near the impoundment or reservoir shoreline will be subject to mechanical (sic) erosion...with resultant loss of artifactual materials. In contrast, at sites... well within the flood pool, mechanical erosion does not appear to be a factor. Rather, sedimentation

> occurs thus sealing the site and leaving the cultural component largely intact. (Adovasio et al. 1980:166)

There are some notable exceptions to the above statement, but in general, the vast majority of adverse mechanical processes are concentrated in the shore fluctuation zone of a reservoir, and direct mechanical impacts to sites in the permanently inundated offshore zone are minimal. A similar distinction can be made between the inundated portions of a reservoir and the noninundated backshore and downstream zones, which, although not directly affected by inundation, are nevertheless subject to a broad range of indirect adverse impacts. The location of an archeological site relative to these "impact zones" will largely determine the kinds and intensities of impact processes occurring at the site.

The offshore region of a reservoir is characterized by great water depth, slow-moving water circulation, and a near-uniform deposit of clayey muds, in which clay-size material typically comprises about 40% or more of the total sediment (Sly 1978:77). Although density currents are common in the offshore region, current velocity rarely achieves sufficient magnitude for sediment entrainment. As a result, deposition predominates in the offshore zone, and subaqueous erosion is extremely rare.

To the extent that offshore deposition provides a protective blanket that eventually precludes both mechanical and biochemical impacts to archeological deposits, offshore sedimentary processes may actually enhance archeological site preservation. Nevertheless, there are at least three kinds of adverse impacts that may occur in the deep-water offshore zone. The first and most obvious form of impact is from dam construction activities, such as road building, borrow pit excavation, rock blasting, vegetation clear-cutting, and so on. The other two kinds of offshore impacts involve wave action during the initial inundation episode, subaqueous landslides, and sediment shifts.

The nature and extent of wave impacts during the initial inundation episode will be influenced by a number of factors. In addition to reservoir size and prevailing wind direction and intensity, which combined will determine the size and period of water-wave impacts, reservoir fill rate is perhaps the most important determining factor. The importance of fill rate lies in the speed of shoreline advance up the reservoir slope. The faster the impoundment fills, the shorter the duration of direct wave impact to sites in the offshore region. Extreme fluctuations in the reservoir pool level during initial filling will, of course, intensify wave impacts to offshore sites.

Another factor influencing wave impacts during the initial inundation episode is the slope of the reservoir basin. The effect of reservoir slope is threefold. First, slope steepness will influence fill rate and the rate of shore-front advance. In general, the steeper the slope, the slower the advance and the greater the impact. Second, wave energy will tend to be greater on steep slopes than on shallow slopes where shoaling effects tend to dissipate much of the runup force of the breaking wave. And third, all else being equal, the steeper the slope, the more unstable it will be and the more susceptible it will be to wave and current erosion.

The effect of reservoir slope on shoreline impacts is vividly demonstrated at Lake Powell in southeastern Utah. Many of the sites in Lake Powell occur in alcoves cut into vertical or near-vertical sandstone cliffs. Because of the extreme slope of the reservoir basin, pool-level rise is very gradual. Sites in the drawdown zone may be subjected to direct wave attack for days, and often weeks, as impoundment waters gradually engulf fragile cultural remains. The absence of any nearshore shoal protection in the steep-walled portions of the lake intensifies the destructive power of incoming wind waves and powerboat wakes (Rayl 1978:56).

Reservoir slope has also been cited as an important factor in several Midwestern reservoirs. Padgett (1977) cites wave approach angle and shoreline slope as the most important variables influencing shore erosion at Norfork Lake in the Arkansas Ozarks; Galm (1978) documented extensive sheet erosion at shoreline sites at Wister Lake in southeastern Oklahoma. Based on his survey, Galm feels that the extent of sheet erosion in Wister Lake is primarily dependent on "the angle of the landform adjacent to the shoreline" (1978:263).

A third factor influencing wave impacts during initial inundation is vegetation cover. A dense cover of native vegetation will absorb much of the energy of an advancing shoreline, and it may provide all the site protection necessary during initial reservoir filling. The most effective kind of vegetation cover consists of a dense understory of grasses or shrubs; large trees, on the other hand, provide substantially less protection and may even be detrimental to site preservation. For example, Galm (1978:262) notes that shore erosion and bank slumping at Wister Lake are exacerbated when large trees that are undercut by the advancing shoreline collapse. When this occurs, large quantities of bank material are dislodged with the root systems of the fallen trees, causing extensive bank attrition and accelerating the rate of shoreline erosion.

In summary, a number of factors influence wave impacts on sites during the initial reservoir-filling episode. These factors, which include fill rate, basin slope, and vegetation cover, are highly interrelated. The rate of shoreline advance is a function of river inflow and evaporation/absorption rates, but the speed of advance is also determined by the size and slope of the reservoir basin. Basin slope, which is an important variable in wave impact determination, also conditions vegetation cover. From the standpoint of site preservation, an ideal combination of these variables would include a rapid, nonfluctuating pool rise; sites located on stable, gentle slopes that are rapidly inundated by rising impoundment waters; and a vegetation understory of dense grass to serve as a soil binder during initial inundation. To the extent that real-world conditions vary from this ideal, we may expect a variety of adverse impacts to occur to offshore sites during the period of initial reservoir filling.

Subaqueous slope failures constitute the second kind of adverse impact in the deepwater offshore zone. Another related form of impact is sediment liquefaction and its potential effect on submerged cultural stratigraphy. There are, unfortunately, very little hard data on the effects of either of these processes on submerged archeological site preservation.

According to a survey by Sherman (1968), submarine slope failures are fairly common on initial submergence, especially in unconsolidated talus slopes. Subaqueous talus slumping has apparently occurred on a large scale in Lake Powell, Utah. Since a number of prehistoric sites were recorded on talus-top ledges in Glen Canyon prior to the construction of Glen Canyon Dam, and since they can no longer be found, we may safely conclude that sites have been destroyed as a result of changes in basin morphometry.

The effects of water saturation of submerged archeological deposits are poorly understood, although the future evaluation of several ongoing experiments may bridge this gap in our understanding. The experiments in question consist of linear trenches that are excavated through stratified archeological deposits at sites destined to be inundated. Then a transparent plexiglass sheet is anchored firmly to the prepared trench face, and the visible profile of cultural layers is etched into the plexiglass to serve as a permanent record of the undisturbed deposits. The trench is then carefully backfilled and compacted. After several years of continual inundation, the goal is to reexcavate the trenches, clean the plexiglass facings, and record any change in the stratigraphic profile, such as artifact settling, bed warping, etc.

Experimental trenches were established at Tellico Reservoir in Tennessee (Schroedl 1977), Blue Mountain Reservoir in Arkansas (Padgett 1978), and Saylorville Reservoir in Iowa (Gradwohl and Osborn 1977). To date, reservoir water-level conditions have prevented reexamination of test trenches at Blue Mountain and Saylorville, and the Tellico tests were destroyed by vandals prior to dam closure. Until these or comparable tests are evaluated, the question of adverse impacts from soil liquefaction will be difficult to resolve.

It has been argued that if archeological sites in the deepwater offshore zone of a reservoir can survive the mechanical effects of initial immersion and postimmersion changes in basin morphology, then most offshore sedimentary processes should enhance rather than detract from long-term site preservation. However, the long-term preservation benefits of reservoir siltation may be more imaginary than real. We can only speculate as to the mechanical impacts associated with burying fragile archeological remains under tons of water-deposited sediments. The stresses involved in such burial may, over the long term, have adverse effects on the resource base. There is, in addition, the problem of loss of access to data that is buried somewhere beneath tens of feet of lake sediment. The level floodplain which is the eventual outcome of all man-made reservoirs is not the most efficient archeological data bank. Withdrawals from such a bank could only be made in the rather unlikely event the dam were breached and the impounded sediments flushed downstream by a degrading stream channel. It is by no means clear that archeological sites could survive such a process.

Whereas deposition is the dominant sedimentary process in the offshore region of a reservoir, erosion predominates in the nearshore and littoral zone. Here, water-wave action provides most of the erosive and much of the sediment transport energy (Sly 1978). Under stable water-level conditions, shore erosion is often a self-limiting process in reservoirs. As breaking waves begin to erode a newly formed reservoir shoreline, fine silty fractions of eroded shore material are carried out to deeper portions of the reservoir in the form of suspended load, while coarser fractions are deposited immediately offshore from the breaker zone in the form of an offshore shoal. As the offshore shoal increases in size, it functions as a breakwater against incoming waves, resulting in a reduction of wave energy reaching the shore. Eventually, a relatively stable equilibrium profile is achieved, and shoreline erosion may be significantly reduced (Kondrat'yev and Grign'yeva 1974).

The development of an offshore shoal and stable beach profile is dependent, however, on a number of factors such as beach slope, soil type and gradation, storm-wave frequency and intensity, pool level fluctuation, and so on. To the extent that variation in these factors prevents the establishment of a shoreline equilibrium profile, wave erosion may significantly alter the geomorphology of a reservoir shoreline.

Most waves that reach the shore of a reservoir are generated by shear stresses set up by wind blowing over the water surface of the lake. The height and erosive potential of incoming waves is a function of wind velocity, duration, and the size of the reservoir fetch, or the surface area of water that is subjected to wind shear. In general, the higher the wind velocity and the longer its duration, the larger the wave.

The erosive potential of breaking waves is large but spatially limited. Immediately offshore from the zone of breaking waves, wave turbulence decreases rapidly as water depth increases relative to wave length. At a depth of one-quarter the average wave length, water motion is only 21% of the motion at the surface; at a depth of one-half the average wave length, water motion is only 4% of the surface motion (Sly 1978:73). As a result, nearly all of the energy of a breaking wave is focused on a narrow bank of shoreline known as the beach zone. The width of the beach zone is primarily a function of the maximum height of incoming waves.

Unfortunately, the "effective" beach zone of most reservoirs is significantly increased by seasonal fluctuations in the reservoir pool level, which may significantly enhance the destructive potential of wave action. As the reservoir pool level draws down, breaking waves strike the saturated and unconsolidated sediments of the reservoir basin which have already been deprived of a protective vegetative cover. These fragile sediments are susceptible not only to wave erosion but also to subsequent wind and water runoff erosion within the exposed drawdown zone.

Because shoreline sites are generally more accessible for study and analysis than sites located in the offshore region, comparative data on shoreline erosion processes and adverse impacts far surpass the amount and quality of data on offshore impacts.

Some of the best data available on shoreline impacts comes from central California, where a 1977 drought resulted in large-scale drawdowns at a number of major reservoirs. Two reservoirs, Chesbro and Folsom, received particularly intensive investigation during the drawdown peak, and the results of these studies provide some of the best comparative data on shoreline mechanical impacts.

In 1977, Joseph Winter of San Jose State University conducted an intensive survey of the drawdown zone of Chesbro Reservoir, a Soil Conservation Service reservoir in Santa Clara County, central California (Winter 1977). Chesbro Reservoir, unlike most water-storage impoundments, is periodically filled and drained for groundwater replenishment. As a result, extreme fluctuations in the Chesbro shoreline are common (Winter 1977:4). Winter's survey was conducted at the height of a seasonal drawdown when the impoundment pool level was close to stream-level gradient.

Winter located five sites within the conservation pool of Chesbro; heavy siltation in the lower third of the reservoir basin undoubtedly obscured additional site remains. Four of the sites located were altered to some degree by wave action. Damage was particularly extensive at a large site (4SC152) located along the 25-foot contour line, which corresponds to the average maximum pool level of the impoundment. Wave action along this maximum pool line has resulted in the erosion and redeposition of loosely consolidated soils, charcoal, bone, and other light-weight cultural material and the consolidation of heavier cultural materials that were too heavy to be transported by wave and nearshore current action. As a result of this differential erosion, contextual relationships within the site were severely altered (Winter 1977:46).

Indirect impacts of periodic inundation are also evident at 4SC152. Much of the protective mantle of natural vegetation has been removed from the inundated portions of the site, and the remaining unconsolidated surface soil has become extremely susceptible to postinundation erosion from wind and surface runoff (Winter 1977:46). Winter also noted an increase in ground squirrel activity in the loosely consolidated shoreline sediments. In fact, ground squirrel burrowing was so extensive in the vicinity of one of the sites that a human burial was partially exposed (1977:48).

In the fall of 1977, Jean Stafford and Robert Edwards of Cabrillo College made a followup, detailed study of inundation impacts on three sites in Chesbro (Stafford and Edwards 1979). A major aspect of Stafford and Edwards' work involved setting up controlled experiments at three sites in order to test various impact-related hypotheses. Stafford and Edwards returned to the sites during the fall drawdown of 1979 to evaluate impacts to the experimental tests (Stafford and Edwards 1980).

Of the three sites investigated, the large shoreline site (4SC152) suffered the most extensive mechanical impacts. Detailed contour maps constructed in 1977 were compared with identical maps made in 1979, after two years of periodic inundation. Although portions of the site were actively aggrading due to silt deposition during the two-year interval, the site as a whole exhibited a net overall deflation rate of over 2 cm per year, with the most extensive erosion occurring in the site midden deposits (Stafford and Edwards 1980). Most of this erosion has apparently occurred as a result of direct wave impact, and in most instances, the amount of deflation could be precisely correlated with the duration of inundation.

Another California reservoir affected by the severe 1977 drought was Folsom Reservoir, located on the American River northeast of Sacramento. During the summer and fall of 1976, an archeological team under the direction of John Foster (Foster et al. 1977) conducted salvage excavations at the Pederson site (CA:ELD:201), a large prehistoric habitation site located in the lower portion of the pool fluctuation zone, a zone subjected to perennial inundation for over 20 years (Foster et al. 1977:14).

Wave-generated mechanical impacts to the Pederson site were severe, with very little of the original site matrix remaining intact. On the basis of tree stumps still rooted in the exposed granite substrate, Foster estimated that at least 1 meter of soil had been removed over much of the site area. In addition, two well-developed sand beaches are present on the site, and the site flanks are incised by a series of wave-cut terraces, formed by a succession of pool-level fluctuations.

Only a small portion of the Pederson site has survived the effects of direct wave impact, possibly due to its location on the crest of a low ridge. Postinundation faunal impacts, however, are taking their toll in this portion of the site. According to Foster (1978:37), the dark midden soils in the intact portion of the site support a large population of freshwater burrowing clams. When the site was exposed during the 1976 drawdown, raccoons and other predators moved in to exploit the clams. In the process of digging up the clams, the raccoons destroyed much of what remained of the intact midden, which included three well-preserved semisubterranean house floors.

Supplemental archeological research at the Pederson site in 1977 and 1978 succeeded in quantifying many of the impacts recorded during earlier investigations (Foster and Bingham 1978). With the aid of preinundation aerial photographs of the site, it was determined that from 80 to 95 cm of soil and cultural deposits had been removed from the site by wave and current action. It was also determined that wave impacts were enhanced by onshore prevailing winds whose seasonal maximum coincided with the seasonal inundation of the site. These factors combined to create conditions unusually detrimental to site preservation.

The nature and extent of shoreline impacts documented at Chesbro and Folsom reservoirs in California are the rule, not the exception. Adverse impacts are particularly severe in large reservoirs that experience large annual pool-level fluctuations. In small reservoirs with stable pool levels, shore-related impacts may be much less severe.

Geological and Environmental Context

The geological substrate of a site, its slope, orientation, exposure, and vegetation cover, may be important variables in the mechanical impact equation, depending, to a large extent, on the location of the site within the reservoir impoundment. These factors may be extremely important in the offshore zone where mechanical impacts are transient, but their effect may be negligible in the littoral zone where high-energy beach processes diminish the significance of such intervening variables.

The relationship between geological substrata and reservoir erosion processes is expressed in Table 4.1, which may serve as a general guide to the resistance of various standard soil groups to reservoir erosion processes. The soil groups in Table 4.1 are rank-ordered according to their erosion properties; well-graded gravels and gravel-sand mixtures with little or no fines (VW) are ranked most resistant, while peat and other highly organic soils (PT) are ranked least resistant.

The relative impact predictions in Table 4.1 were provided by hydrologists and engineers from the Engineering and Research Center of the Bureau of Reclamation in Denver. Based on in-field observations, the relative impact chart appears to be a good predictive tool, although it provides somewhat conservative predictions of relative impact. The first systematic application of the model was made at Lake Mendocino, California, where researchers found a fairly high correlation between predicted and observed impacts. Of the 26 kinds of mechanical impacts recorded in the reservoir and employed in the comparison, 14, or just over half of the observed impacts, were in agreement with predicted impacts. Of those not in agreement, 8 observed impacts were greater than predicted, and 4 were less than predicted (Stoddard and Fredrickson 1978:35-36). When similar comparisons were made on 45 mechanical impact categories at Lake Powell, Utah, 26 impacts were found to be in agreement, 13 observed impacts were greater than predicted, and 6 were less than predicted (Rayl et al. 1978:51).

Table 4.1

Environmental Matrix (Soil Types)		EROSION FACTORS								OTHER FACTORS	
	Stream Channel and Reservoir Dynamics	Site located on inside of meander of river	Site located on outside of meander of river	Water velocity in river over site dependent on such factors as slope and nature of water release	Water with high carrying capacity, e.g. in channel just below dam	Periodic drawdown over site	Subject to wave action, boats, wind etc.	Flood plain inside river channel	Flood plain outside river channel	Zone subject to freeze-thaw	Liquefaction
Well-graded gravels, gravel-sand mixtures, little or no fines.	(GW)	*1	1	1	1	1	1	1	1	1	1
Poorly-graded gravels, gravel-sand mixtures, little or no fines.	(GP)	1	2	1	1	1	1	1	1	1	1
Silty gravels, poorly graded gravel-sand-silt mixtures.	(GM)	1	2	2	2	1	1	2	1	2	1
Well-graded sands, gravelly sands, little or no fines.	(SW)	1	2	2	2	2	2	2	1	1	1
Poorly graded sands, gravelly sands, little or no fines.	(SP)	1	2	2	2	2	2	2	1	2	3
Silty sands, poorly-graded sand-silt mixtures.	(SM)	2	3	3	3	2	3	3	2	3	3
Clayey sands, poorly-graded sand-clay mixtures.	(SC)	1	2	2	2	2	2	2	1	2	3
Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity.	(ML)	2	3	3	3	3	3	3	3	3	3
Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.	(CL)	1	2	1	1	2	1	2	1	2	2
Organic silts and organic silt-clays of low plasticity.	(OL)	2	3	3	3	3	3	3	2	3	3
Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.	(MH)	2	3	3	3	3	3	3	2	2	2
Inorganic clays of high plasticity, fat clays.	(CH)	1	1	1	1	2	1	2	1	2	2
Organic clays of medium to high plasticity.	(OH)	1	1	2	1	3	3	2	1	3	3
Peat and other highly organic soils.	(PT)	2	3	3	3	3	3	3	2	3	3

*Numerical weighting predictions in this chart are courtesy of the Bureau of Reclamation Engineering and Research Center. Numeral 1 = minimal impact, numeral 2 = moderate impact, and numeral 3 = maximum impact.

The Archeological Site

The fourth and final variable in the mechanical impact equation is the archeological site; specifically, its ability to withstand the assults of reservoir erosion and deposition processes. As with geological and environmental contexts, the importance of this variable in mechanical impact prediction will depend to a great extent on the kinds and magnitudes of erosive and depositional forces impacting the site. If the magnitude of these forces is large, then the strength of resistance of the resource may have little or no bearing on survival. If, on the other hand, the magnitude of forces is small or of limited duration, then the relative resistance of the resource may be critical to long-term preservation.

It is difficult to characterize in any meaningful way the erosion resistance properties of the wide variety of archeological sites that occur on the North American continent, and we will make no attempt to do so. Instead, we will approach the question of site survivability by examining the kinds of impacts that might be expected to occur to the various categories of information that comprise an archeological site. It will be recalled that the information contained in an archeological site consists of entities (structures, facilities, artifacts, etc.) and their relationships (spatial, temporal, and, by inference, behavioral). An archeological site occupies physical space; that is, it has a measurable length, width, and depth. Various criteria (many of them rather arbitrary) are employed to define the boundaries or limits of these dimensions, but these are of no concern to us here. We are concerned, instead, with the general structure of the matrix, its material contents, and their physical relationships.

When the site matrix is disturbed by mechanical erosion processes, cultural information may be lost in several ways. One alteration may involve the destruction or removal of material remains. This is very often a selective process in which certain kinds of structures or materials are not affected or are only minimally affected. Another kind of impact occurs not so much to the materials themselves but to the relationships between the materials.

Contextual impacts typically involve movement of materials along both the horizontal and vertical planes of the site matrix. Material displacement along the horizontal plane alters the spatial context of materials and the spatial structure of the site, whereas movement on the vertical plane may destroy stratigraphic relationships within the site matrix.

In general, categories of information contained in the various relationships among entities are far more fragile and more susceptible to destruction by mechanical impacts than the entities themselves. We will begin our discussion, however, with impacts to material remains, specifically architecture and other forms of nonportable facilities. (Impacts to artifacts and biological data will be treated in the next section on small-scale archeological resources.)

A wide variety of structure types and house forms occurred prehistorically in North America. One of the most common styles of dwellings consisted of a partially excavated house floor with some form of perishable wood or brush superstructure. In most cases, the only archeological evidence of such structures is a buried floor surface enclosed by a peripheral alignment of post-molds. Several factors combine to make these kinds of architectural remains comparatively resistant to mechanical erosion. First, if they have survived centuries of terrestrial erosion, they have done so because they have been buried under post occupation sediments. These same sediments will ordinarily continue to provide a protective buffer after the structure is inundated. Second, prehistoric house floors are very often composed of native soil that has been highly compacted through use. In many cases, the floors were baked following the firing and collapse of the superstructure. As a result, prehistoric house floors are often somewhat harder and more erosion-resistant than their surrounding soil matrix.

The erosion resistance of buried house floors was demonstrated graphically at the Pederson site in Folsom Reservoir, where three highly compacted house floors were pedestalled when the more loosely consolidated soil surrounding the structures was washed away by reservoir wave action (Foster et al. 1977). Although these structures eventually succumbed to the activity of burrowing animals, they displayed a remarkable ability to absorb the mechanical impacts of inundation.

In the desert Southwest, a variety of architectural forms have survived in the archeological record, including various styles of coursed stone masonry and adobe wall construction. At Lake Powell, Inundation Study archeologists observed several varieties of twelfth-century A.D. sandstone masonry and at least one form of adobe wall construction (jacal) which had been subjected to several short-term inundation episodes (of approximately two to five years each). Several of the masonry walls were remarkably well preserved, even after repeated wave attacks, while other masonry walls were either partially or entirely destroyed. The several examples of adobe jacal construction were obliterated by wave and water action (Rayl 1978).

Several factors contributed to the preservation of masonry structures in Lake Powell. With few exceptions, masonry structures that have survived wave impacts have been partially buried by wind-blown sediments that functioned as a protective blanket against wave and current action. Masonry sites located in high cliff-face alcoves where only a small amount of eolian sand has accumulated over the years were, by and large, poorly preserved. Many of the alcove structures were also constructed on a foundation of leveled trash and sandstone rubble which provided virtually no support for standing masonry walls once saturated by the rising lake waters (Rayl et al. 1978:56).

Some of the best comparative data on architectural impacts come from Abiquiu Reservoir in north central New Mexico (Schaafsma 1977, 1978). Between 1974 and 1978, the School of American Research in Santa Fe conducted investigations at a number of sites within the flood pool of Abiquiu Reservoir that had experienced periodic inundation since 1960. The range of mechanical impacts noted during the investigations was extensive; it included erosion and siltation, artifact redistribution, wall structure collapse, etc. Of particular interest at Abiquiu is the comparatively large variety of architectural and feature types located within the direct impact zone of the impoundment.

Reservoir impacts were observed on no less than four different architectural construction types, including historic rock masonry, jacal, adobe brick, and historic Navajo dry-laid masonry. The historic rock masonry, part of an historic ranch complex, exhibited some evidence of wall slumping, but overall impacts were not extensive. A historic jacal structure was buried in silt to the level of the top of the door frame, and most of the extant walls were essentially intact, with very little evidence of collapse or other adverse impacts. The historic adobe brick structure was also in a comparatively good state of preservation after more than a decade of inundation. Although some adobe bricks appear to have disintegrated, the preinundation condition of the structure is unknown. The most extensive mechanical impacts were recorded at the historic Navajo sites, which consist of dry-laid masonry structures and animal pens. The condition of these sites is attributable, however, to their location within the shore fluctuation zone of the reservoir (Schaafsma 1978).

The excellent condition of historic architecture at Abiquiu is primarily the result of site location within the deepwater offshore zone, where reservoir siltation has provided substantial protection from wave and current erosion. Architectural remains in the nearshore zone of Abiquiu have not fared as well, as evidenced by massive impacts at several Navajo masonry structures (Schaafsma 1978).

In addition to the architectural remains at Abiquiu, Schaafsma recorded impacts to a number of archaic sites containing rock-filled hearths. Several of the hearths exhibited signs of extensive erosion; the rock-filled basin was undercut by breaking waves and the rock fill was pedestalled above the less resistant soil matrix, a process that eventually resulted in the collapse of the pedestalled rock mass. As a result of undercutting and lateral displacement, all or most of the original hearth basin was obliterated.

Site contextual impacts have been documented at a number of reservoirs around the country. For example, a number of archeologists have addressed the problem of lateral artifact displacement which, understandably, is most severe within the fluctuating beach zone of a reservoir. Galm (1978) documented extensive "sheet erosion" along the shoreline of Wister Lake in southeastern Oklahoma, where the degree of artifact displacement appears to be dependent primarily on the angle of the landform adjacent to the shoreline (1978:263). Winter (1977) and Schaafsma (1977, 1978) documented comparable examples of sheet erosion and differential displacement at Chesbro and Abiquiu Reservoirs, respectively.

One of the first attempts to quantify surface artifact displacement in the beach zone of a reservoir was made at the Pederson site in Folsom Reservoir, California (Foster and Bingham 1978). During initial surface collections in 1976, Foster and Bingham noticed what appeared to be an overabundance of large, dense artifacts (e.g., groundstone) and a paucity of small, lightweight materials. To test the hypothesis that surface artifacts had been differentially sorted by wave and current action, Foster and Bingham compared artifact frequencies from surface and subsurface excavation units; they found significant differences in several artifact categories.

The most significant differences were in the small lithic flake category. Whereas lithic flakes accounted for 27-73% of the total artifact frequencies from the excavated units, the relative frequency of lithic flakes dropped to 12-56% on the surface. Conversely, large pieces of groundstone were significantly overrepresented in the surface collection units (Foster and Bingham 1978:25).

A different approach to studying surface artifact impacts was employed in the same year at Chesbro Reservoir (Stafford and Edwards 1980). One of several experiments established at site 4SC152 was designed to test the effects of seasonal inundation on surface artifact distributions. Instead of comparing surface and subsurface artifact frequencies, Stafford and Edwards approached the same problem by constructing detailed maps of test grids, showing the precise locations of all artifacts within the grids. Two years later, Stafford and Edwards returned to the site and remapped all of the grid units, noting precise changes in artifact position from one unit to the next and noting also the addition and deletion of items from the test grids. Unfortunately, the frequency of plotted items from the control grids was so small as to preclude statistical tests of significance. Over the two-year period, however, 70-90% of the items from the combined test units were either removed or changed provenience within the grid. In addition, Stafford and Edwards recorded a number of items in the grids in 1979 that were not present in 1977, demonstrating not only that material was removed and displaced but that new items were transported in as well.

Based on these and other studies of lateral artifact displacement, it appears that the process is controlled by the magnitude of the erosion process, the slope of the shoreline, the erosion resistance of the substrate, and the size and density of the artifacts on the erosion surface. Of these four variables, the first is probably the most important. In the offshore zone of a reservoir, water motion rarely approaches magnitudes sufficient for sediment entrainment and transport. But in the littoral zone of a reservoir, the high energies associated with repeated wave impacts may transport material of considerable weight and density.

Based on laboratory wave tank experiments, Komar and Miller (1973) developed equations for predicting sediment entrainment thresholds in the nearshore zone. The crucial variables in the equations were oscillatory water-wave velocity and sediment grain diameter. These equations might be useful in predicting the amount of lateral artifact displacement of prehistoric occupation surfaces exposed within the fluctuating beach zone of a reservoir.

Inundation impacts to site stratigraphy--the vertical dimension of intrasite contextual relationships--are not as well documented as spatial impacts. Nevertheless, many of the factors responsible for the lateral displacement of artifacts on an occupation surface appear to be important variables in the degradation of cultural deposits and the vertical mixing of artifacts and other cultural materials.

Erosion intensity is the primary determining variable in impacts to stratigraphy. In Table Rock Reservoir, Missouri, where A and B soil horizons are entirely missing at several shoreline site localities, wind-waves and boat wakes are cited as the major causes of site erosion (Garrison et al. 1979:87). Differences in erosion intensity between sites in Table Rock can be accounted for on the basis of variation in exposure, storm fetch, and powerboat activity (Garrison et al. 1979:91). At Norfork Lake in Arkansas, the approach angle of shoaling waves is cited as another important variable in shoreline site erosion (Padgett 1977:44), and the intensity of prevailing winds is apparently a major factor in wind-wave erosion at the Pederson Site in Folsom Reservoir (Foster and Bingham 1978). Another frequently cited factor in erosion intensity and poor stratigraphic preservation is the frequency and intensity of seasonal drawdowns (Chance et al. 1977; Foster et al. 1977).

A second important variable in stratigraphic impacts is the stability of the substrate soil. Some substrate materials, such as the loess deposits flanking Oahe Reservoir in South Dakota, are extremely susceptible to wave erosion and cutbank formation, and shoreline impacts are correspondingly severe (Weston et al. 1979:28). An important factor in substrate stability is vegetation cover. At the endangered Travis II site on the shore of Oahe Reservoir, preliminary attempts to stabilize the site by means of a protective blanket of polyetheline sheeting anchored with snow fence involved the removal of a large stand of shrub willow. Unfortunately, the artificial protection proved to be of minimal value, and it was concluded that leaving the native vegetation in place would probably have provided more effective short-term protection (Weston et al. 1979:27).

In terms of stratigraphic information potential, some of the most important archeological "soils" are refuse middens. A refuse midden is not only a detailed record of what was used, manufactured, eaten, and eventually discarded at a site, but stratigraphic profiles of refuse middens are often the archeologist's most direct windows on culture change. Unfortunately, due to their poor consolidation and frequent high organic content, refuse middens are often extremely fragile and easily eroded. At all three sites investigated by Stafford and Edwards at Chesbro Reservoir, the midden areas were the most profoundly affected by wave and current action (Stafford and Edwards 1980). Similar results have been reported elsewhere. Galm recorded substantial impacts to prehistoric midden mounds at Wister Lake in Oklahoma. Under direct wave impact, mounded midden deposits were totally leveled at several sites along the shoreline. Impacts to other mounds were more subtle but no less severe in terms of the loss of stratigraphic information:

> Mixing at midden mound sites was identified by buried lenses (often in the form of fine liminations) of organic litter (e.g., leaves, grass), the presence of modern debris (e.g., glass, metal) incorporated in the midden fill, and the loose or unconsolidated nature of the deposits. (Galm 1978: 263.

A third important variable in stratigraphic impacts is the slope of the reservoir shoreline. On flat to gentle slopes, sheet erosion is common. Successive intervals of sheet erosion may gradually erode down through the more poorly consolidated site deposits, dislodging and carrying away small, light artifacts and organic materials. These may be redeposited in a series of bands just beyond the breaker zone (Winter 1977). Whereas low-density materials are often carried away and redeposited elsewhere within the lake, materials too heavy to be transported will tend to accumulate in the lower levels of the site. Examples of this process of differential sorting and artifact concentration have been recorded at a number of reservoirs throughout the country.

On steep to near-vertical reservoir slopes, an erosional "cutbank" may form. The process of cutbank degradation involves the gradual undercutting of a vertical face followed by slumping of unsupported blocks of soil. In Oahe and other reservoirs on the Missouri mainstream in South Dakota, shoreline cutbank erosion is so severe that entire sites are slumping into the reservoirs. Padgett (1977) documented the same general pattern of shoreline erosion at Norfork Reservoir in Arkansas. He found that in areas where the shoreline is steep to near-vertical, bank-cutting predominates; on flatter slopes, sheet erosion is most common; and sites located on nearly flat terrace slopes are least affected by erosion since "...the level terrain minimizes gravity flow and artifact displacement" (1977:48).

BIOCHEMICAL IMPACTS TO ARCHEOLOGICAL SITES

At the medium scale of archeological resources, biochemical processes contribute to the systematic destruction of various classes of contextual data such as perishable remains and subtle chemical characteristics of the soil profile. The elimination from the archeological record affects the representativeness of the cultural assemblage and the relative frequencies within the various data classes. An important distinction should be made between mechanical and biochemical impacts with regard to contextual data. For the most part, mechanical impacts are nondiscriminatory in nature, whereas most biochemical impacts are selective. This is not to say that any one of these processes is more or less destructive than the other. What is important is determining the potential nature of the interaction between these processes and the site and then assessing a proper mitigation plan addressed to these kinds of problems. The discussion of biochemical impacts to medium-scale archeological resources will focus on impacts to soil chemistry and stratigraphic data.

Soil Chemistry

What distinguishes most cultural soils from natural soils is the concentrated accumulation of organic habitation residues of vegetable and animal origin. The amount and composition of the residues will vary according to the conditions of preservation, the population density, the duration and intensity of occupation, and the behavioral activities of the resident population (regarding both use and discard behavior). Depending upon the conditions of preservation, these residues may exist in a variety of forms: 1) as identifiable organic or inorganic remains such as bone, macrobotanical specimens, and shell; 2) as organic stains, or 3) as chemical residues. The first category is discussed in the section dealing with small-scale archeological values. Organic stains will be referred to in the section on stratigraphy. The present discussion will focus on impacts to chemical residues.

The ability to detect and interpret chemical patterns within the site is becoming an increasingly important aspect of data recovery (Eddy and Dregne 1964; Cook and Heizer 1965; and Eidt 1974). By performing various chemical and physical tests, the archeologist can learn more about the processes of cultural and noncultural deposition within the site and detect features which may otherwise go undetected (i.e., hearths, refuse areas, burials, etc.).

The elements of chief interest to the archeologist are the same as those that interest biologists, namely carbon, nitrogen, phosphorus, sulfur, and calcium. These are the primary elements released during decomposition. It is important to note that the nutrients released from the decomposition of organic materials associated with archeological sites enter the nutrient cycles indistinguishably from those of adjacent areas (Cook and Heizer 1965). Therefore, any cultural interpretations must be based on a knowledge of the native chemical distributions and of the postdepositional alterations (i.e., erosion) which may have occurred onsite.

Phosphorus: An important element which may be preserved in archeological contexts is phosphorus. This is primarily attributed to the fact that phosphorus tends to form insoluble compounds with various soil constituents, such as iron, aluminum, and calcium (Cook and Heizer 1965). Important sources for phosphorus include weathered parent material, the decomposition of plant and animal tissues, urine, excreta, bone, and other organic detritus (Cook and Heizer 1965). Uptake of phosphorus by vegetation and microorganisms accounts for the relatively low percentage of available soluble phosphorus at any one time.

Phosphorus occurs naturally in several forms: 1) soluble phosphate phosphorus, 2) soluble organic phosphorus, and 3) particulate organic phosphorus (Reid and Wood 1976). Soil pH largely determines the nature of the phosphate compounds. In slightly to moderately alkaline soils (pH values 7.0), phosphate ions combine with calcium to form insoluble calcium phosphate. Conversely, in acidic soils (pH values 6 or 5.5) phosphates are precipitated as either soluble iron or aluminum phosphates (Buckman and Brady 1969). Soil pH therefore is an extremely important factor in determining the availability of inorganic phosphorus, since it is only soluble within a very limited range of pH (pH values 6.0 - 7.0). Above pH 7.0 and below 6.0, inorganic phosphates are fixed in insoluble compounds.

Because of the relatively insoluble state of phosphorus in the soil (as compared with carbon or nitrogen), it is not subject to rapid change; therefore, it tends to remain in the soil profile at the same level for a considerable period of time, provided that environmental changes do not interrupt the delicate pH balance. The feature of stability makes phosphorus an important element of study in archeological contexts.

Generally, the highest concentration of phosphorus occurs at the surface where it is constantly being recycled by vegetation. In most instances, the concentration of phosphorus tends to decrease with depth. Soil particle size and pH are apparently significant factors in determining the amount of phosphorus retained in the profile (Cook and Heizer 1965).

Leaching, erosion, and crop removal are the principal mechanisms by which phosphorus may be lost from the soil profile. The rate and degree of leaching (the removal of materials in solution from the soil) is determined by the amount of moisture passing through the soil, the chemical nature of a mineral and its solubility, and pH. As noted previously, phosphorus is released very slowly at pH values below 6.0 and above 7.0. This is because the phosphorus is locked in insoluble compounds with calcium, iron, and aluminum. Moisture is an important factor in the release process since the depth of moisture penetration influences the depth to which the solute will be transported. At pH values between 6.0 and 7.0, phosphorus is rapidly released due to its mobile ionic state.

Erosional processes, particularly sheet erosion, effectively remove phosphorus from the soil profile by stripping the surficial soil layers (which contain the highest concentrations of phosphorus) and, to varying degrees, the subsurficial layers, and redepositing them elsewhere.

The third mechanism for phosphate depletion is crop removal. During their life cycle, plants take up phosphorus through their roots and store it in their tissues. Upon death, the phosphorus returns to the soil. The removal of vegetation (e.g., through harvesting) permanently removes the phosphorus source, and it will not be replenished until the vegetation is restored.

These mechanisms operant to release phosphorus on land from the soil are accelerated in a reservoir. The effect that each of these processes will have on inundated soil matrices is outlined below.

One of the most important movements of phosphorus in the lake system is its exchange between the sediment and water. The clay and colloidal components of the sediment tend to adsorb phosphorus rapidly. The important chemical variables determining adsorption and release of phosphorus from the sediment include the pH values, oxidation-reduction (redox) potential, calcium concentration, and the degree of agitation at the mud-water interface (Kramer et al. 1972).

As mentioned previously, pH is perhaps the most important factor regulating the solubility of phosphorus. In the soil, the principal cations responsible for acidity are hydrogen and aluminum. The principal base-forming cations are calcium, magnesium, potassium, and sodium (Buckman and Brady 1969). Conditions which permit the basic cations to persist in the soil will encourage high pH values. Conversely, the accumulation of decomposed organic matter, such as organic and inorganic acids, will cause dissolution and leaching of the exhangeable bases and encourage acidity.

The redox potential defines the ferric/ferrous iron ratio. When an impoundment stratifies and the hypolimnion becomes anaerobic, the redox potential falls. Then the ferric iron adsorbed in the mud is reduced to the soluble ferrous form. The reduction probably occurs as a result of anaerobic decomposition processes taking place in the mud. At dissolved oxygen levels below 1 ppm, the iron oxide-phosphate complex becomes unstable and dissolves. When the reservoir stratification is destroyed, the soluble ferrous iron is oxidized and precipitated as ferric hydroxide, $Fe(OH)_3$. At pH 6.0, phosphate ions either precipitate as iron phosphate, $FePO_4$, or are adsorbed to $FE(OH)_3$. Adsorbed phosphorus is more readily exchangeable than the phosphorus in $FePO_4$ (Golterman 1967). The concentration of totally exchangeable phosphorus in natural waters is determined by four factors: 1) basin morphometry as it relates to volume and dilution and to stratification of water movement, 2) chemical composition of the geological formations that contribute dissolved phosphate, 3) drainage area features as they relate to the input of organic matter, and 4) organic metabolism and the rate of phosphorus loss to the sediments (Kramer et al. 1972).

Apparently most of the phosphorus adsorbed by the mud is confined within an oxidized layer a few millimeters thick. This oxidation-reduction boundary (boundary potential) between the free-oxygen layer and the lower anaerobic layer is an extremely important one in that it represents a balance between rates of oxygen supply and consumption (Mortimer 1949). The boundary potential is also critical when the soluble ions are free to migrate through the soil profile and diffuse between the sediment-water interface. As long as the mud surface and water are anoxic (i.e., oxygen concentration below 2 mg/1 and the pH values remain betwen 6.0 to 7.0), the phosphorus will freely diffuse and remain in solution--unless assimilated by microorganisms. Once oxidized conditions are reestablished, the phosphorus will again form insoluble compounds and become distributed throughout the lake in the sediments. The seasonal release and redeposition of phosphorus as reduced and oxidized conditions prevail are perhaps the most significant biochemical impacts that can affect native prehistoric phosphate compounds. It is anticipated that these impacts will be most severe in reservoirs that stratify and/or eutrophy. The degree to which leaching will occur in oligotrophic lakes will largely be dependent upon redox potential and pH.

Calcium concentration influences the solubility of phosphorus due to its role in the pH balance. When combined with calcium, most phosphorus occurs as apatite, a very stable compound in alkaline sediments above pH values of 7.0. Since the pH values of most reservoirs range between 6.0 and 9.0 (Cole 1975), it is anticipated that most inorganic phosphorus in the form of apatite will persist. However, depending upon the pH of the soil matrix, other forms of sorbed phosphorus (i.e., iron phospate) may be reprecipitated as apatite, depending upon the pH of the soil matrix (Williams and Mayer 1972). A possible result in terms of impacts to prehistoric phosphorus is the indiscriminate increase of inorganic phosphorus in the archeological soil profile. This may skew the phosphate pattern of the site . This is a typical chemical response whereby compounds may be precipitated in those areas of low concentration.

The transfer of phosphorus between the sediment-water interface and within the sediment profile may also affect a sites phosphate pattern. The primary mechanisms of transfer include: 1) sediment disturbances mediated by mechanical factors (wave action and currents) and biological factors (burrowing organisms) and 2) diffusion as a result of the difference in concentration of the solute between the interstitial water of the sediments and the overlying water (Williams and Mayer 1972; Lerman 1978).

Mechanical impacts will significantly alter the distribution of archeologically deposited phosphorus since the host sediment is subject to mechanical transport and redeposition. The depth and extent to which mechanical forces will impact the soils will depend upon factors such as the nature and intensity of the disturbance, the susceptibility of the sediment to disturbance, and the physical geomorphology of the reservoir basin. The predominant shoreline processes (which include sheet erosion, bank undercutting, and slumping) effectively remove large quantities of soil, vegetation, organic matter, and mineral components and redeposit them elsewhere. In the drawdown and shoreline zones of the reservoir, mechanical processes such as erosion will probably be more active in removing phosphorus than biochemical processes. Concomitantly, archeological sites located in those reservoir zones that are subject to mechanical processes are vulnerable to erosion and related impacts which can seriously disturb the cultural context. Thus any interpretations based on contextual relationships may be skewed.

Burrowing zoobenthic organisms also contribute to sediment disturbance. Depending upon the species of organisms and their feeding activities, sediments may be disturbed to a depth of 30 cm (Jones and Bowser 1978). Since feeding activity is governed by nutrient and carbon sources, one would expect greater rates of mixing and depth penetration in more productive areas (i.e., eutrophic lakes).

A third method of transfer--diffusion--is an important though somewhat slow mechanism for nutrient exchange. The major factors governing rates of diffusion include: 1) grain size and 2) pore fluid processes. Grain size is an important factor in determining the rates of diffusion of soluble elements. Because of the importance of surface reactions in regulating the aquatic chemistry of trace metals, organic compounds, and nutrients, fine-grained materials such as clays and silts have the most potential for interaction with the lake water (Jones and Bowser 1978). Grain size also influences porosity and compaction, factors which are important in pore fluid processes. Lake muds typically have a higher porosity (70-95%) than sandy substrates (40%) and therefore will tend towards greater pore fluid concentrations. Compaction of fine-grained sediments may encourage an increase in total advective transport of solutes due to the "squeezing" effect of sediment deposition.

The critical zone for the transfer of solutes between the sediment-water interface is the upper 10 to 20 cm of the sediment (Jones and Bowser 1978). Below this depth, the rate of migration of phosphorus upward through the lower layers is much less because the rate of release of soluble phosphorus from sorbed combinations is slower (Williams and Mayer 1972). However, chemical and biochemical reactions will continue to take place in the deeper sedimentary layers. And as long as a column of the interstitial water is open to the overlying lake water, dissolved solutes will migrate up or down across the sediment-water interface in response to the existing concentration gradients (Imboden and Lerman 1978).

With regard to the aforementioned processes, additional research should be conducted to determine: 1) what happens to the sorbed phosphate when the oxidized layer is reduced due to the anaerobic properties of the overlying water or because the mud below the newly sedimented layer has become anaerobic; and 2) how far the oxidized layer inhibits all chemical and physical movements of molecules and ions upwards and downwards (Golterman 1967).

On the basis of the theoretical and observed relationships of phosphorus activities in various lakes and reservoirs, it appears that the processes discussed above will have a significant impact on the interpretive potential of phosphorus deposited prehistorically. The fate of the archeological phosphorus in the aquatic ecosystem will depend upon factors such as the depth and nature of the overburden protecting the habitation surface; the location of the site within the reservoir; and the hydrologic, biological, and chemical regime of the reservoir as it relates to the biogeochemical cycling of phosphorus.

<u>Nitrogen</u>: Much of the nitrogen encountered in archeological contexts is derived from the decomposition of habitation refuse, including plant and animal tissues, urine, and fecal matter. Since the four principal elements of organic decomposition (phosphorus, nitrogen, carbon, and calcium) generally occur in archeological sites, certain assumptions may be made regarding their value in cultural interpretations. The first assumption is that because all four are deposited simultaneously, their concentration should essentially follow the same trend toward increase

or decrease. The second assumption is that knowledge of the correlations between these elements (i.e., the C:N ratio) should enhance the archeologist's understanding of the depositional and postdepositional processes of a site area (Eddy and Dregne 1964).

As in the case of phosphorus and carbon, most nitrogen enters the soil at the surface. The eventual depth of accumulation of nitrogen will depend upon the depth of organic matter accumulation and the depth of water penetration (Black 1957). Rapid leaching accounts for most of the nitrogen loss from a soil profile and for the characteristic concentration gradient which shows a decrease in nitrogen with depth.

There are three major forms of nitrogen in mineral soils: 1) organic nitrogen, 2) ammonium nitrogen (clay-fixed), and 3) soluble inorganic ammonium and nitrate compounds (Buckman and Brady 1969). At any one time, most nitrogen occurring in a soil is the organic form. During the process of microbial decomposition of plant and animal residues, a large amount of the inorganic nitrogen is converted to organic forms and immobilized. Gradually, at a rate of about 2-3% per year, the immobilized nitrogen will be mineralized, and ammonium and nitrate ions will be released (Buckman and Brady 1969).

Some clay minerals (i.e., vermiculite, illite, and montmorilonite) have the capability to fix ammonium nitrogen (NH_4) ions in an essentially nonexchangeable form. Statistics indicate that up to 8% of the total nitrogen in surface soils and 40% of the nitrogen in subsoils is in the clay-fixed form (Buckman and Brady 1969). In most soils, nitrogen in the form of soluble ammonium and nitrate compounds seldom exceeds 1-2% of the total nitrogen, since it is rapidly lost through leaching or volatilization (gaseous loss).

The concentration and forms of nitrogen in lakes and reservoirs is largely determined by external variables such as: 1) input rates; 2) transformation reactions occurring within the lake; and 3) the rates of loss through outflow, denitrification, and sedimentation

(Brezonik 1972). Superimposed on these are factors of basin geomorphology and geochemistry. The depth of a lake or reservoir is an important variable in determining nutrient loading and assimilation capabilities (Brezonik 1972).

Various internal mechanisms also influence the nitrogen content in lakes and reservoirs. As in the case of phosphorus, the nitrogen exchange system at the sediment-water interface is influenced by various chemical and biological factors. Nitrogen is added to the system by the sedimentation of silt and organic material, and by the sorption of ammonia into clays within the sediments. Nitrogen can be released by the activities of burrowing animals, the decomposition and subsequent diffusion of organic nitrogen to ammonia, and the release of ammonia from clays and organic colloids in the sediment (Brezonik 1972). The principal factor controlling the release and adsorption of the nitrogenous compounds is redox potential. In oxidized sediments, nitrates are released as a result of nitrification. In reduced sediments, the iron-containing floc is broken up, and nutrients, including ammonia, are released (Mortimer 1941, 1942). Once these products have been released, rapid microbial assimilation occurs via the four nitrogen transformation reactions: 1) nitrate and ammonia assimilation, 2) ammonification, 3) nitrification, and 4) nitrogen fixation.

The impact of these biochemical processes on nitrogen in inundated soils is similar to that of phosphorus, large quantities of nitrogen will be leached from the soil matrix of the archeological site and will diffuse into the overlying water. Then they will be biologically assimilated or deposited at random in the reservoir sediments, which adversely affects the ability to interpret the archeological record.

Carbon: Carbon is a universal element associated with organic residues. During the initial stages of decomposition, the more soluble carbon compounds such as sugar or acid are rapidly leached. Insoluble compounds such as cellulose and lignin will remain in the soil matrix until chemically or biologically altered. The subsequent degradation of these carbonaceous materials results in a net loss of total organic carbon.

Organic carbon is removed from the environment primarily through biooxidation. In an aerobic environment, aerobes participate in energy-yielding oxidation reactions. The microbial end products of aerobic decomposition of organic matter are CO_2, water, and humic components. These are, in turn, lost to the environment, assimilated by organisms, or may form inorganic compounds such as carbonates. In the absence of oxygen, organic carbon is incompletely oxidized, and anaerobic end products, including methane (CH_4), CO_2, organic acids, and alcohol, accumulate.

The greatest rate of CO_2 evolution occurs near the surface of the profile and diminishes with depth. Below 50 cm, little gas is volatilized. This parallels the concentration gradient of carbon in which the organic carbon level decreases with depth.

The rate at which a given organic substrate is oxidized will depend upon its chemical composition and the physical and chemical conditions of the environment. These include factors such as temperature, oxygen supply, moisture, pH, inorganic nutrients, and the C:N ratio of the plant residues (Alexander 1961).

Generally, the decomposition of organic matter is undertaken by a limited number of microorganism species which are particularly adapted to the soil conditions. For example, in a mineral soil such as sand, a definite flora of microorganisms will develop in response to the particular substrate present (i.e., carbohydrate vs. protein). Coryneforme bacteria such as Arthrobacter, Cellumonas, Micrococcus, and to a limited extent Flavobacterium are active in the presence of carbohydrate polymers such as glucose and cellulose. Bacillus and Pseudomonas require a protein source such as peptone to initiate protein and carbohydrate degradation. In an organic soil, each of the above-mentioned bacterial genera proliferate, particularly in the presence of both a carbohydrate and protein nutrient source. The addition of fresh organic material, therefore, stimulates microbial activity.

The field experiment undertaken at Brady Reservoir, Texas (discussed in Chapter 3), was designed to examine the micro- and macrobiological impacts to various classes of submerged cultural materials. Degradable materials such as seeds, wood, bone, and pollen were included in the experiment, together with more durable materials such as shell, stone, and ceramics. The perishable organic materials in the aqueous environment sustained an active microbial population represented by the genera Pseudomonas, Flavobacterium, Archromobacter, and Arthrobacter. Anaerobic, facultative, and gram-positive bacteria were represented in the sediment samples recovered from Brady Reservoir. The results of the analysis indicate that micro- and macrobiological predation are both significant factors in organic matter decomposition. Other factors affecting decomposition include nutrient concentrations, temperature, and the dynamic condition of the environment. In the seed study (Volume II, Technical Report No. 5), the number of surviving seeds was directly proportional to the sampler mesh size. Predictably, the greatest amount of seed deterioration occurred in the samplers with the largest size openings (2.5 cm), and the least amount of deterioration occurred in the samplers with the smallest openings (0.2 micron).

In the pollen study (Volume II, Technical Report No. 4), the two most significant variables affecting pollen degradation were time and location. Most exine deterioration occurred within the first five days after immersion. Following the initial flurry of biological activity, the rate of deterioration slowed down. Location was also an important factor in pollen degradation, since local differences in pH and substrate could account for different microbial and macroinvertebrate communities capable of degrading different pollen taxa at differential rates.

The previous discussion of biochemical impacts to soil chemistry has largely been derived from the literature. General trends observed from chemical analyses performed on soil samples that were collected from inundated contexts are summarized in a subsequent section specifically addressing impacts to soil chemistry analysis.

Summary

The most dramatic impacts to sites will result from mechanical processes such as erosion, bank cutting, and liquefaction. Biochemical impacts will generally be more subtle in appearance but not necessarily in effect. For example, biochemical impacts may obscure or alter discrete chemical patterns within a site. The implications of these kinds of impacts to the interpretive value of the soils data are significant. Depending upon the chemical contributions from the reservoir system, it may no longer be possible to discern discrete cultural entities which are sometimes preserved solely as chemical entities (i.e., hearths, burials, etc.). The loss of these kinds of data in essence eliminates chemical patterning from the contextual sphere.

Other examples relate to the ability to reconstruct human behavior through artifactual analyses. The selective destruction of certain archeological resources, especially organic remains, affects archeological interpretation at a variety of levels. Differential preservation restricts the interpretation of cultural behavior by systematically eliminating from the archeological record the kinds of data which are necessary for making inferences about various aspects of behavior. The selective destruction of bone would preclude making inferences about dietary preferences, seasonality, butchering practices, and other aspects of animal usage such as domestication and utilitarian purposes (i.e., tools). The inferences one can make about a particular aspect of the cultural system are limited if the tangible remains relating to that behavior are not present.

Inferences which are based on existing data are skewed by the fact that only a portion of the record is preserved, and that portion which is preserved is not necessarily reflective of the cultural behavior for the group as a whole. The contextual relationships between objects and features and the soil matrix within a site are perhaps the most important tools in interpreting functional and behavioral relationships. When these contextual relationships are destroyed through mechanical or biochemical means, such as differential preservation, the quality of interpretation is severely affected.

OTHER IMPACTS TO ARCHEOLOGICAL SITES

Human, floral, and faunal impacts are addressed specifically in this section. The impacts resulting from these forces acting alone or together upon medium-scale archeological resources, (i.e., the site) may be the most difficult to reduce or control. It may be a useful conceptual tool to view the interaction of these destructive forces from three major categories: vandalism, land use, and management decisions. The complete interplay of each should become clear as we address each category in turn.

Vandalism

Through the raising of water levels in an impoundment, many archeological sites which were remote and comparatively inaccessible become subject to impact by even the most casual weekend boaters and campers. The attitudes and activities of humans when relating to the environment, both natural and cultural, while on vacation in remote areas are very difficult to control. If an individual chooses to remove cultural materials from a site, there is often no practical method of preventing this action. Vandalism of archeological sites is, without doubt, one of the most destructive and uncontrollable sources of impact to cultural remains in reservoir areas. For the purposes of this discussion, vandalism is defined as the result of any act, intentional or unintentional, which damages either the natural or man-made features of the environment.

Generally speaking, vandalism of archeological resources may be classified into three categories. The first is the casual or unknowing vandal. This individual is often not considered to be a vandal in the strictest sense of the word; the act involves casually picking up an "arrowhead" or a bit of pottery while out hiking, camping, or fishing. Such persons often do not realize that removal or disturbance of the artifact in question is a form of vandalism and, indeed, is illegal on Federal lands. There are numerous examples of this type of activity, particularly within reservoir recreation areas. The destruction of prehistoric wall alignments at Lake Roosevelt, Arizona, or the removal of other large artifacts to build a campfire hearth, is common throughout the United States (Foster and Bingham 1978; Rayl et al. 1978; Winter 1977; Stafford and Edwards 1979; etc).

The second category is the indiscriminate vandal. This individual has little regard for the environment and is equally ready to throw an axe into a tree as to carve initials into historic wooden beams or spray-paint graffiti onto rock art. The target of the vandalism is not exclusively limited to cultural remains; these features simply become available for depreciative behavior because they are there. A recent attempt at preservation of an Anasazi masonry wall in Glen Canyon (Nordby 1980) met with failure most probably due to this type of vandalism. There was no intrinsic value to the wall remains, nor was there anything desirable about them from an aesthetic standpoint. Their destruction was, presumably, done for the sheer joy of destruction.

The third, and most directly damaging, type is the purposeful vandal whose targets are specifically cultural resources. Members of this group include the "weekend citizen" or collector

> ...who finds it restful to wander about...seeking projectile points, pottery, and skeletal material. Such individuals operate in family settings with some vague ignorance and resentment of professional and legal constraints and collect artifacts as curios. (Rippeteau 1979:85-86)

This group views their activities as an inalienable right or harmless recreation and are quite proud of their collections. Some will even "share" their finds with archeologists working in an area. An example of this latter behavior can be found at a U.S. Army Corps of Engineers Reservoir in Missouri. During reservoir pool level drawdown, the local residents walk the shoreline collecting artifacts. A team of archeologists undertaking a study of reservoir impacts on cultural remains were befriended by one couple and were shown their extensive collection (Garrison et al. 1979). Artifact collecting at this same reservoir was advertized in a 1976 issue of a popular magazine, Skin Diver, in which divers were encouraged to come and collect artifacts while diving in the clear lake waters. These activities were carried on with the full knowledge that removal of the prehistoric remains was illegal.

The above are merely a few examples of literally hundreds of instances where cultural resources are damaged as a result of directed, purposeful human action. An experiment to monitor inundation impacts in Tellico Reservoir, Tennessee, was completely ruined prior to pool filling (Schroedl 1977:24). The vandals were so determined they used dynamite to destroy some of the tests. This activity is by no means confined to the United States; relic collectors around reservoirs in Canada have amassed collections numbering as many as 2,000 pieces (Mohs 1977: 27-32).

The selective nature of artifact collecting and other associated forms of depreciative behavior can quickly obliterate an entire site or remove a whole class of cultural remains from the archeological record.

Land Use

Grazing, range management, and agricultural activities are common uses of lands both up and downstream from a dam. A change in the patterns of land use can directly impact archeological sites. Schaafsma observed:

> A special condition found at Abiquiu...is the presence of stock.... As the water in a fluctuating reservoir...goes up and down, it forms a varying zone that is trampled by stock as they come to the water to drink. Their feet in the muddy soil can do extensive damage to archaeological remains in the upper foot or so. Because of the fluctuating water level, this zone passes back and forth over the landscape many times, affecting any sites that happen to be in the way. (Schaafsma 1978:28-29)

In this manner, the upper stratigraphy of a site can become hopelessly jumbled. If it is a shallow site or if the cultural remains consist solely of surface artifacts, the site could easily be obliterated.

Another type of faunal impact associated with grazing is the use of rock shelters as cattle shades or middens as wallows. Deposition and mixing of fecal material on a site, coupled with leaching, can severely impact the ability to conduct soils analysis for cultural features (Garrison et al. 1979; Stafford and Edwards 1979); wallowing can disrupt a meter or more of midden (Foster and Bingham 1978:38). Yet these friable soils appear to be particularly attractive to cattle.

The introduction of anomalous fish or shellfish species into a river basin, as a result of stocking or accident, is a less obvious faunal impact associated with the shifting land use patterns. Where there was once a meandering stream, a large, still body of water may now exist.

The introduction of a nonnative burrowing clam, *Corbicula fluminea*, into the American River valley and reservoir system has, at least in Folsom Reservoir, California, adversely impacted one archeological site. The midden remnants at CA-ELD-201 have been riddled by these clams (Foster et al. 1977:24). Excavation confirmed that penetration was confined to the upper 10 cm of midden; however, the remaining intact midden did not exceed 30 cm (Foster and Bingham 1978:38). Therefore a major impact on the midden occurred.

Compounding the burrowing activity of these clams, raccoons have found them to be an easily obtainable and abundant food source. As the lake waters fluctuate and the clam-laden midden is exposed, raccoons have moved in and begun excavation. The result of the clam/raccoon attack on CA-ELD-201 has been widespread destruction of the remaining midden (Foster and Bingham 1978). Burrowing clam activity has not been restricted to the Western states' reservoirs. Another species, *Corbicula manilensis*, has been documented in Bluestone Reservoir, West Virginia. Found in the upper strata of site 46Su3, this clam has contributed to the mixing of cultural materials at the site. This "may have created some serious problems for the interpretation of recovered archaeological data" (Adovasio et al. 1980:41).

The National Reservoir Inundation Study has hypothesized that faunal impacts would be greater at sites in shallow water (Lenihan et al. 1977:110). Data gathered from seven transects sampled over a 23-month period at Table Rock Lake, Missouri indicates that "95% of the mussel disturbances occur [at water depths] between 1 and 3 meters" (Garrison et al. 1979:105). There was a noticeable lack of mussel disturbance in less than 1 meter of water and greater than 6.5 meters of water (Garrison et al. 1979:106).

Further examination of the data revealed some interesting general trends relating to bottom matrix and mussel activity. Those soils which are predominantly medium/fine silt over clay exhibited the greatest total number of mussels; gravel and silt over clay had fewer mussels; and a bottom matrix of gravel/pebbles over clay exhibited no mussel activity (Garrison et al. 1979:102). This strongly suggests that, in addition to the shallow depths (1 to 3 meters), bottom matrix plays a role in determining where mussel activity will occur. Shallow sites on deflated rocky soils could be expected to be impacted to a lesser degree than a site with a more humic soil matrix.

The deposition of fish remains on archeological sites is another subtle impact that can contribute to misinterpretation of a site. One instance at Abiquiu Reservoir, New Mexico, where anomalous fish scales were present in the site, caused some consternation among the researchers until it was determined the scales were intrusive (Schaafsma, personal communication).

An increase in ground squirrel activity in the periodically inundated areas of 4SC152 in Chesbro Reservoir, California was noted by Winter (1977:48). Stafford and Edwards, during follow-up investigations at the site, developed a specific hypothesis regarding the impacts of rodent activity on archeological sites in Chesbro. They suggested that:

> In a reservoir context, seasonally exposed sites on the border of reservoirs will experience a severe negative impact to stratigraphy from increased rodent activity in the zone just below the high water line.... (Stafford and Edwards 1980:54)

This hypothesis was not confirmed; rather, it appears that the seasonal inundation of the reservoir margins may have had an inhibiting effect on rodent activity. It now appears that the increased rodent activity observed in 1977 just below the normal pool level may have been due to the prolonged drought and reexposure of previously unavailable areas. Further, it may be that unusually high water levels in a reservoir, once passed, may be similar to a drought situation in reverse; the drop contributes to an increase in burrowing animal activity.

A change in land use, from a recreation standpoint, also poses some problems for the preservation of medium-scale archeological resources. The establishment of a reservoir, in many cases, signals the development of the reservoir margins for vacation or retirement home sites, picnic or camping area development, hiking or riding trails, and off-road vehicle use, as well as boating ramps and other support facilities.

As a result of nearby boat landings, or areas generally suitable for landing a boat, numerous sites across the United States have been destroyed (Winter 1977:49; Foster and Bingham 1978:38; Nordby 1980:26; Adovasio et al. 1980:47; among others). Following establishment of a reservoir, sites accessible only by hand- and toe-holds prior to flooding become available for examination and camping to anyone with a boat. Numerous sites in Glen Canyon have been so severely impacted by picnickers that they can be considered a total loss. A popular swim area near a large pictograph panel in Glen Canyon Reservoir has been found to have unusually high concentrations of uric acid in solution in the water (Anderson, personal communication); the short- or long-term effects are as yet unknown. Prehistoric wall alignments were dismantled and used to make campfire hearths by boaters and campers in Lake Roosevelt, Arizona. Similar activities have been noted nation-wide (Rayl et al. 1978; Schaafsma 1978; Foster and Bingham 1979; and others).

During the 1975-77 drought in the western states, numerous reservoirs experienced unusually low water levels. Heavily silted flood plains provided ideal locations for off-road vehicles, and numerous sites were severely impacted (Winter 1977:49; and others).

Clearly, as use of a reservoir increases in a general way, the potential for impacts to cultural remains increases exponentially. Residents in the area of one reservoir in California totally dismantled an historic vineyard for firewood during a drawdown (Fredrickson, personal communication). An historic mining camp in Lake Shasta Reservoir, California, once a six-mile walk from the nearest road, was only a ten-minute walk after the reservoir flooded. In an excellent state of preservation prior to pool filling, the site was completely destroyed within two years by individuals who removed the bricks and wood from the historic structures.

Widespread changes in native vegetation as a result of the creation of a lake are classified in this report as having large-scale impact generally; however, there are definite implications for impacts to medium-scale materials. The invasion of anomalous floral species into site areas was documented by Foster and Bingham (1978) in California and the National Reservoir Inundation Study team in Arizona:

> Plant growth in the midden areas was seen to accelerate the general rate of soil erosion. The process of soil desiccation combined with root penetration opened numerous fissures (in the midden)...and root action became more damaging as the season progressed.... (Foster and Bingham 1978:38)

Salt cedar in Painted Rocks Reservoir, Arizona has totally obliterated several site areas in shallow water and has formed an impenetrable salt cedar marsh.

The loss of vegetative cover on periodically inundated sites can contribute to increased erosion and loss of provenience data from archeological sites. The thick grasses and root matt found on the undisturbed areas of site 4SC152 in Chesbro Reservoir did not become reestablished adequately for site protection during periods of fluctuating water levels; the erosion of the periodically inundated areas increased as a result of limited groundcover (Winter 1977:46). Erosion redeposition and mixing of site soils are the primary factors affecting the Chesbro sites, particularly in the wave-action zone. Similar impacts could be expected nation-wide.

Management Decisions

The impact of management decisions on medium-scale archeological resources should not be underestimated. Protection of archeological remains from vandalism and eventual destruction is directly proportional to the amount of effort expended by the managing authority in establishing priorities for and personnel to patrol accessible site areas. Adovasio et al. note that:

> the determined efforts of a park ranger have played the major role in keeping the amount of vandalism that has occurred from 1948 to 1977 at a minimum. (1980:47)

Further support for a program that provides an effective deterrent to vandalism comes from California. Visitor impact to CA-ELD-201, the Pederson site, was minimal due to "the vigilance of the Folsom Park ranger staff in protecting [it]..." (Foster and Bingham 1978:38).

Whether or not to enforce site protection and the use of area patrols is clearly a management decision. Increased detection and enforcement of the law has been shown to decrease vandalism in park areas (Hoots 1976:21; and others). It has been pointed out, however, that in order to be an effective deterrent, the vandal must feel that there is a high <u>probability</u> of being seen, caught, and punished (Clark 1976; Campbell et al. 1968; Christensen and Clark 1978; and others).

Management decisions also directly affect fluctuations in reservoir pool levels. For example, in Lake Powell, Utah, a major pool level raising in 1979 resulted in the initial flooding of numerous sites which had otherwise been accessible only by hand- and toe-holds. These sites, in an excellent state of preservation prior to flooding, had minimal pre-impoundment documentation and only a few were able to be stabilized or otherwise prepared for inundation. As a result of the decision to test certain of the dam's facilities and raise the existing pool level, many of these sites were destroyed either from vandalism or from a frontal assault consisting of wind and wave action that toppled walls and undercut site matrices.

The length of time that the pool level is held at any given elevation is, for the most part, a management decision. It has been clearly documented (Rayl et al. 1978; Schaafsma 1978; Adovasio et al. 1980; Stafford and Edwards 1979; among others) that the longer a site is subjected to wind-driven waves or boat wakes, the greater is the potential for site destruction. Preplanning and thoughtful management of water-level fluctuations, coupled with knowledge of the elevations of major site concentrations, could reduce many of the most severe impacts resulting from seasonal fluctuations in water level. Preplanning should influence management decisions concerning major changes in the reservoir pool.

Conclusion

The effects of human use and floral and faunal impacts on medium-scale archeological values are complex and difficult to quantify. Yet they may, ultimately, be the most destructive. Only those sites that are above the flood pool or are shallowly flooded are going to be readily and easily accessible to future researchers, and such sites are most heavily impacted by human, floral, and faunal activities in a reservoir.

SMALL-SCALE ARCHEOLOGICAL RESOURCES

In preceeding sections we emphasized the fact that archeological information consists not only of entities but of relationships between entities. Clearly, however, the relationships between entities cannot be assessed unless the entities themselves have been preserved.

> What we have at our disposal, as prehistorians, is the accidentally surviving durable remnants of material culture, which we interpret as best we may, and inevitably the peculiar quality of this evidence dictates the sort of information we can obtain from it. (Piggott 1965:5)

Although modern archeology has largely abandoned Piggott's negativistic obsession with data limitations, the differential preservation of cultural materials remains one of the major limitations on archeological inference. The significance of this problem can be appreciated when one compares the material assemblages from open or exposed sites with contemporaneous assemblages recovered from the sheltered deposits of dry caves or other protected environments. Even in areas such as the arid American Southwest, where conditions are assumed to be ideal for preservation, such a comparison often yields scores of material items that are poorly represented or entirely lacking in the material assemblages of open sites.

The differential preservation of archeological materials affects information potential at every level of the cultural resource hierarchy. At the small scale, every material item in the archeological record, including manufactured items and unmodified material remains, possesses potential behavioral information in the form of attributes. Attributes are defined as the observable or measurable characteristics of a material item and include such things as the decoration or surface modification of a ceramic sherd, the pattern or retouch on a stone implement, the butchering scars on an animal bone, etc. Each attribute, therefore, is equivalent to some aspect of human behavior. The end product is an artifact that embodies two sets of behavior--one for manufacture and another for usage. As long as the artifact remains intact, these complexes of attributes will persist. When these attributes are altered or destroyed as a result of biochemical and mechanical weathering processes, or the artifact is destroyed, altered, or removed by other impacts, important cultural and behavioral information may be lost.

The artifactual and nonartifactual material remains of past human activity often provide the archeologist's most direct clues to human behavior. It would be impossible to review even a small fraction of the behavioral inferences that are routinely made on the basis of artifact analysis, but an example will demonstrate the broad range of behavioral inferences that are possible from just a single category of material data.

Before the advent of metallurgy, stone provided the raw material for many of the implements that comprised the human tool kit. (The resistance of stone to natural weathering processes accounts for the fact that stone tools often comprise the bulk of the surviving artifact assemblages.) The largest category of stone tools are manufactured from crystalline or cryptocrystalline rocks (chert, flint, obsidian, etc.) by the application of a directed force onto an edge or face of a rock nodule. When the force is directed properly, a flake or spall is produced, which can be further modified by additional force. Knowledge of the brittle fracture properties of cryptocrystalline rocks enables the investigator to reconstruct the various technological steps employed by the prehistoric knapper to reduce a core of parent rock to a finished artifact form. Since each technological step in the core reduction process involves a characteristic type of flake waste material, the archeologist can often identify areas on the site where certain lithic manufacturing activities took place by identifying concentrations of flakes.

In addition to technological analyses, lithic artifacts and their waste by-products are often subjected to highly sophisticated functional analyses. When lithic tools are used to cut or scrape resistant materials such as bone, animal hide, or plant fibers, they often develop evidence of wear on the cutting edge in the form of polish, edge attrition, certain forms of edge fracturing, and, in some instances, linear striations. The kinds of wear patterns displayed by a stone tool may provide clues to the class of raw materials the tool was employed to modify. These interpretations may, in turn, provide a basis for inferring the function of artifacts and artifact tool kits. The archeologist also may gain important insights into the kinds of raw materials that were utilized by a population and how these materials were processed for consumption.

Another kind of information routinely derived from the analysis of stone artifacts are the types of lithic materials employed. This information may lead to inferences about quarry or source locations and, in turn, may provide information about regional trade and interaction patterns. In addition, studies of technological or stylistic attributes that may be diagnostic of a certain temporal period or cultural affiliation may follow.

From these examples, it should be clear that the loss of artifacts or artifact attribute data may compromise medium- and large-scale archeological data bases as well. At the medium scale of the site or activity locus, the differential preservation of artifacts and nonartifactual material data may significantly compromise the interpretation of the contextual data base. If, for example, a prehistoric tool kit, identified on the basis of the spatial context of its component implements, is missing one or more categories of items due to differential preservation, is missing functional attributes due to selective weathering processes, or is missing stylistic components due to casual removal by visitors to the site, interpreting the behavioral implications of the tool kit might be severely compromised. Similarly, at the small scale, the systematic elimination, by whatever process, of entire artifact classes or analytical attributes will alter the relative frequencies of the artifactual assemblage and will, therefore, skew the cultural interpretation based on these data.

The preservation of contextual and attribute data depends upon the interaction of both cultural and natural processes. One of the first steps to be taken in evaluating the problem of differential preservation involves identifying the potential physical and biological agents that are acting on a given archeological substrate and/or site. The next step is to predict the susceptibility of the substrate to attack within a set of known environmental conditions. Of primary concern to the archeologist are the physical, chemical, and microbial factors that operate during deposition and within the first meter of burial. Ethnoarcheological and experimental research are focusing on some of these problems in order to identify the various processes causing differential destruction of cultural materials and to describe the manner in which the cultural assemblages are affected (Jewell and Dimbleby 1966; Gifford 1978).

Dowman (1970) has observed that any material has a potentially stable form relative to any environment. Upon burial, an artifact will undergo modification until an equilibrium is reached between the artifact and its depositional environment. At that point the rate of alteration of an object will depend upon the composition of the material and the physical/biochemical conditions the object has been subjected to since deposition (e.g., the dynamic aspects of the environment). To evaluate the impacts resulting from inundation, the survival potential of the various data categories under a variety of burial contexts, must be detemined. Such studies are currently being undertaken and should contribute greatly to our knowledge and understanding of the processes involved in differential preservation (Dowman 1970; Gifford 1978).

MECHANICAL IMPACTS TO ARCHEOLOGICAL RESOURCES

Mechanical impacts can alter or eliminate certain analytical attributes of small-scale archeological resources and contribute to the differential preservation of their remains. It has been recognized that materials have a potentially stable form after equilibration with the depositional environment, but mechanical impacts are often an ongoing process which can detrimentally affect the stability of small-scale archeological materials.

A principal mechnical impact within reservoirs is wet/dry cycling within the maximum flood pool zone. This zone is the area subjected to periodic inundation at higher pool levels and is dry at the lower pool stands. The fluctuations in the pool level cyclically saturate and dry archeological materials within the zone. This process is qualitatively different than the wet/dry cycling imposed by rain as material rarely becomes fully saturated during rainfall and subsequent draining.

To gain insight into the nature of wet (saturation)/dry cycling on certain common archeological materials a laboratory experiment was set up. This discussion of wet/dry cycle machanical impacts results from that experiment.

Ceramics exposed to wet/dry cycles become more porous and presumably weaker, probably eventually resulting in loss of the sherd. Paint, whether organic or mineral, was affected little, though some cracks in heavy slip tended to open.

During the experiment it was noted that potassium, sodium and magnesium were the priniciple leachates, in that order of decreasing amounts. The first few cycles represent the major loss of these elements which may indicate significant changes in ceramic porosity and strength after a few exposures to saturation and drying. The experiment consisted of 40 wet/dry cycles and the trend produced indicated potential loss of data from ceramics in the fluctuation zone during the operational life of the reservoir.

All osteological materials showed some form of degradation resulting from exposure to 30 wet/dry cycles. Cortical lifting was on common all bone material. The thinner sections of bones, such as found in the scapula, were subject to cracking and the innominates were noticeably distorted. Anthropometric measurements taken before and after the cycles showed an overall shrinkage of approximately 1%. Teeth were seriously affected and tended to crack throughout with the enamel spalling off in large sections. Calcium, sodium and potassium were the priniciple leachates, in that decreasing order of concentration. As found in the ceramics, the concentration of the leached elements diminished rapidly after the first few cycles, but were detectable throughout the experiment.

It is clear that wet/dry cycling seriously affects osteological materials and the probability of archeological data loss is high for these materials in the reservoir pool fluctuation zone. The potential for the understanding of prehistoric populations can be significantly diminished by the loss of osteological materials in the wet/dry zone of reservoirs.

Oyster and clam shells were subjected to 40 wet/dry cycles. Leaching did occur in both species. Other than a dulling of the surface of the shells, little change was noted; however, the test specimens did become more porous than the controls. Long term analysis of shell in this zone may be impaired, e.g., the growth rings which denote seasonal conditions in oysters may become undistinguishable over time from the impacts which led to the dulling of the surface.

Pollen, the principal analytic tool for environmental reconstruction, is impacted by wet/dry cycling. After 50 changes in moisture 69.8% of the unacetylated and 83.2% of the acetylated (representing the fossil condition) pollen were degraded. The experiment demonstrated that wet/dry cycling plays an extremely important role in the eventual preservation of the pollen exine and again, increased data loss from small-scale archeological resources is high in the pool fluctuation zone. Comparatively, this zone has the highest potential loss of data from pollen degradation. Studies of the impact of freeze/thaw on pollen exine (Holloway 1981) and continual inundation (Vol. 2, Technical Report No. 4) indicate these affects are minimal when compared to the impact of wet/dry cycling. Pollen will be better preserved in an inundated area than in the zone of pool fluctuation. It can be concluded from the study of wet/dry impacts on pollen that within sites in the area between maximum and minimum reservoir pool area the preservation of palynological and perhaps other organic material will be minimal.

The wet/dry cycle experiment has demonstrated that the area within the maximum flood pool zone will be subjected to mechanical impacts seriously affecting small-scale archeological resources resulting in loss of cultural data. It is also apparent that the mechanical impact of cyclical saturation and drying periods affect the archeological materials in a relatively short time as major changes occur during the first few cycles and significant data loss will occur over the life of the reservoir.

BIOCHEMICAL IMPACTS TO ARCHEOLOGICAL RESOURCES

Microorganisms, particularly the bacteria and algae, are the most active biochemical agents in the aquatic habitat. Microbial activity is particularly intensive at the mud-water interface, largely due to the sedimentation and diffusion of assimilable nutrients. In fact, most microbial decomposition is caused by the attack of enzymes produced by the microorganism for the purpose of obtaining food. Since no one organism is capable of producing all of the enzymes necessary for degradation, complex chemical compounds are sequentially degraded by a variety of organisms. Usually enzymatic attack is highly localized and is regulated by the accessibility of the enzyme to the substrate. Logically, it can be assumed that any factor that inhibits the growth of the decomposers (e.g., suboptimal environmental conditions of temperature, pH, aeration, and nutrient availability) will reduce the rate of decomposition. For example, the excellent preservation of the "bog people" interred in peat bogs in Europe is attributed to the antiseptic qualities of humic acid complexes, associated acidity, and low redox potential. When combined, these factors effectively inhibit bacterial fermentation and fungal activity (Glob 1969).

Other factors which influence preservation include soil type, depth of burial, and chemical and biological regime of the reservoir. Soil type is an important variable in differential preservation. Many clays (e.g., montmorillonite and bentonite) have the capacity to adsorb organic substrates, microbially produced enzymes, and bacterial cells. This carbon-retaining property of some clays tends to suppress decomposition by making a substrate unavailable. Likewise, sand and silt-sized particles may function as mechanical barriers to inhibit microbial movement or prevent contact between the microbe and its enzymes and a potentially degradable substrate (Alexander 1961).

A second factor influencing preservation is the depth of burial within a soil matrix. Although microbiologists have not as yet determined the depth at which microbial activity ceases (Eglinton and Barnes 1978), at least one source (Alexander 1961) indicates that vertical migration of microbes in a homogeneous soil rarely exceeds a depth greater than 1 meter. This is largely because the sand and silt particles represent a formidable barrier to all but a small number of organisms. Furthermore, in the deeper sediments, microbial activity diminishes and eventually ceases as the sediments are compressed. Data pertaining to the depth of microbial activity would be of considerable importance to geochemists and archeologists alike in determining the diagenetic fate of various organic and inorganic substances.

A third factor, the dynamic aspect of the reservoir environment, is critical to the understanding of the biochemical impacts of inundation of submerged cultural resources. For example, in the littoral zone of the reservoir, aerobic organisms predominate at the mud-water interface. Among these are burrowing organisms, some of which are capable of burrowing to depths of 30 cm. These organisms assist in the decomposition of organic material through their feeding strategies and their ability to effectively aerate the bottom sediments and create habitable niches for various aerobes which are enzymatically equipped to attack certain organic substrates. Therefore, organic materials preserved in sites situated in the littoral zone, and which are not deeply buried under sediment or silt, are potentially vulnerable to aerobic decomposition.

Below the mud-water interface, anaerobic activity predominates, though generally at a much slower rate than aerobic activity. The reductive nature of the reactions and the greater metabolic inefficiency of the anaerobes causes anaerobic domination. Therefore, higher quantities of preserved organic materials are to be expected in poorly drained anaerobic soil matrices than in aerobic soil. Since the decomposition rate of organic substances is determined by their solubility, preservation will be greatest for those organic compounds or materials that occur in environmental concentrations exceeding the saturation level in the surrounding water. This same phenomenon was discussed with regard to the biochemical impacts to phosphorus, where certain conditions favored the precipitation of phosphates in areas low in phosphates. Additionally, since the degradation rate of soluble organic compounds varies, sedimentation is prerequisite to preservation.

Under anaerobic conditions, the rate of degradation is slow due to the rapid accumulation of fermentation products which lower the pH sufficiently to inhibit bacterial metabolism. Additionally, the lower temperatures of aquatic sediments tend to retard microbial metabolism and may, therefore, enhance preservation (Wetzel 1975).

In summary, the interrelated physical, chemical, and biological components of a reservoir ecosystem exert a profound influence on the composition of the aquatic biocommunity. The ecological relationship between a particular organism and its environment is in part regulated by factors such as temperature, pH, dissolved solids (nutrients), thermal stratification, dissolved oxygen content, etc. On a macroscale, these factors are affected by edaphic, topographic, and climatic determinants. On a microscale, the environment can be altered by the activities of microorganisms. Local accumulations of organic matter from allocthonous (external) sources and autochthonous (internal) sources and decomposition end products (such as ammonia, carbon dioxide, and organic acids) not only affect pH but can also reduce the oxidation-reduction potential of the environment and affect the concentration and ionic state of various compounds.

Just how these environmental factors -- soil type, temperature, moisture, aeration, pH, and the nature and condition of the cultural materials -- will influence the rate and degree of degradation will be discussed in the context of their effect on the differential preservation of a particular data category.

Bone

Bone, including human, artifactual, and nonartifactual types, is frequently preserved in archeological contexts. It represents an important constituent of the cultural assemblage. Human skeletal remains may reveal information about mortuary practices, physical type, genetic traits, nutritional status, morbidity, and mortality. Faunal remains are used to infer paleoecological and paleoeconomic information about dietary preferences, seasonality, butchering practices, domestication, culinary practices, and tool usage. The loss of osteological material from archeological contexts as a result of differential preservation may alter the relative frequencies of species and/or skeletal components, thus skewing cultural or ecological interpretations based on this evidence.

The principal factors influencing the rate and nature of degradation include environmental factors such as soil type, temperature, pH, and the nature and condition of the osteological material. The nature and extent of biochemical degradation to bone will therefore depend upon the rate and magnitude of the various chemical reactions. The effects may vary from alteration of the chemical structure, which affects the dating potential, to complete deterioration of the bone, which eliminates it from the archeological record. An important aspect of preservation, therefore, is the microenvironment of deposition and the resistance of the substrate to biochemical weathering.

Generally, bone is best preserved in an alkaline environment. Bone is largely comprised of calcium phosphate, a very stable compound that resists leaching under alkaline conditions, pH 7.0 (see section on soil chemistry, this volume). However, under acidic conditions, such as may occur within the anaerobic zone of a reservoir (e.g., the sediment zone beneath the soil-water interface), the bone minerals may be dissolved or leached, thus accelerating the rate of deterioration. The nature and extent of deterioration will depend upon the condition of the bone and the micro- and macroenvironmental conditions to which the bone is subjected.

The chemical effects of the interaction between groundwater, the ions transported by water, and the chemical constituents of bone have been investigated by Von Endt and Ortner (1977). They postulate that bone buried for archeologically significant periods of time may undergo chemical changes resulting from the hydrolysis of protein constituents of the bone. Such hydrolysis would weaken or alter the bonding between the mineral and protein phases and promote degradation. The microenvironment surrounding the bone would contribute water and exchangeable ions. The latter would then diffuse into the bone and induce the protein and mineral phase changes, thus affecting the chemical integrity of the bone. Consequently, bones that have the greatest surface area and porosity (e.g., cranial bones and ribs) will exhibit greater rates of internal change than bones of lesser surface area and greater density (Von Endt and Ortner 1977).

To test their hypotheses, two experiments were conducted. The first experiment was designed to measure the relationship between temperature and the rate of bone dissolution. The results of the experiment indicated that nitrogen loss from the bone is dependent on protein content and that the rate of nitrogen loss is dependent upon temperature. The second experiment was designed to measure the relationship between bone size and deterioration. In this experiment, temperature and water volume were held constant, while the size of the bone was varied. The results indicate that when bone of differing sizes is saturated at a constant temperature, the rate of nitrogen release is inversely proportional to bone size. This implies that bone size, surface area, and porosity are important factors in deterioration.

The implications of these results for archeological bone specimens subjected to reservoir inundation are significant. One would expect a greater diffusion of soluble ions with a resultant weakening of the protein-mineral bone and an accelerated rate of hydrolysis of protein constituents of bone in inundated osteological materials. The solubility of the ions, however, would be dependent upon pH, temperature, and the concentration gradient of the ions in solution.

During the course of the Inundation Study, an attempt was made to determine the change in chemical and physical properties of bone resulting from saturation and exposure to various chemical solutions. Samples of charred deer and cow bone and uncharred rabbit bone were submerged for one year in 30 chemical environments (see Volume II, Technical Report No. 3). The experiment was designed to measure the effects of the various chemical solutions on selected artifact classes and, conversely, to measure the effects of the artifacts on the solutions by determining the amount of a particular leached ion present in the solution. Unfortunately, the experimental design did not permit a systematic study of chemical impacts on the individual artifact categories. Consequently, it is impossible to evaluate the direct chemical interaction with bone. A second problem was the inadequate sample size. Only five specimens of charred deer and cow bone and two specimens of rabbit bone were immersed in each chemical environment. The sample size is clearly inadequate for evaluating statistical significance of change or measuring intraspecies physical and morphological variability.

However, despite these problems, the data do suggest certain trends that may be attributed to the chemical exposure. Atomic absorption analysis of the chemical solutions indicated some leaching of calcium, sodium, potassium, and magnesium following the initial immersion of the bone samples (Volume II, Technical Report No. 3). Predictably, bone immersed in concentrated (20 x) hydrochloric (HCl) and sulfuric (H_2SO_4) acid solutions was affected to the greatest extent. The degree of degradation was proportional to the density, amount of exposed surface area, and condition (charred or uncharred) of the bone. In general, charred deer bone withstood the chemical immersion better than either charred cow or uncharred rabbit bone. By the end of the year-long immersion period, the rabbit bone had completely dissolved in the concentrated acid solutions.

Although the results of the laboratory water chemical experiment demonstrate that chemical interaction is an important variable in the differential preservation of bone, soil type and grain size are important intervening variables in terms of chemical interactions, in an archeological site, for cultural materials are commonly deposited in some sort of soil matrix. In general, leaching and ionic exchange occur more rapidly in porous, sandy soils than in clay or silty matrices, suggesting that materials interred in undisturbed, compacted, fine-grained matrices will generally be better preserved than those buried in sandy matrices. There are data to corroborate this inference (Dowman 1970; Gifford 1978; Fisken, personal communication; Adovasio et al. 1980).

Observations on bone preservation in submerged contexts from various reservoirs in the eastern and western United States vary from no adverse effect (Adovasio et al. 1980) to possible adverse effect (Foster et al. 1977; Volume II, Technical Report No. 6). Since a myriad of factors influence preservation, systematic research is necessary to evaluate those factors that are responsible for the preservation and/or destruction of osteological materials and to determine the rates of destruction.

Shell

Shell is another category of material frequently encountered in archeological sites. Shellfish was an important dietary element as evidenced by the archeological remains of extensive shell middens along seacoasts and riverbanks. The discarded shell was utilized extensively for utilitarian and ornamental purposes; it was also an important trade item.

The chief chemical constituent of shell is calcium carbonate, represented either as the polymorph calcite (oyster shell) or aragonite (clam shell). Other elements such as phosphates, silicates, and gypsum may also be present in trace amounts, but they are quantitatively insignificant when compared to the calcium carbonate content (Register 1980). Generally, calcium carbonate ($CaCO_3$), an insoluble compound, is not very reactive. However, in the presence of water and carbon dioxide, calcium carbonate reacts to produce carbonic acid and its soluble bicarbonate, $Ca(HCO_3)_2$. Chemically, this is the reaction that creates limestone-solution caves. In a reservoir, the reaction of calcium carbonate with water and carbon dioxide evolved from microbial respiration and/or decomposition would produce a similar result. The rate of the reaction would depend upon environmental factors such as depth of burial, pH, temperature, and the concentration gradient of the ion in the soil-water solution.

Results from the water chemical experiment conducted by the Inundation Study indicate that maximum leaching of calcium carbonate occurred during the first few days following initial immersion, then subsided as the solutions approached neutrality (Volume II, Technical Report No. 3). Predictably, shell dissolution was greatest in the concentrated acidic solutions, HCl and H_2SO_4, although advanced degradation was also noted in the concentrated sodium chloride (NaCl) solution.

In a reservoir, the rate of leaching would be further affected by the reservoir's seasonal properties, such as periodic exposure during drawdown or thermal stratification. In the field experiment conducted at Brady Reservoir, calcium leaching was the most significant impact to shell. This was determined through atomic absorption analysis of the water contained in the samplers and through dry-weight measurements. Time was a highly significant factor in weight loss, suggesting that prolonged inundation may adversely affect shell preservation. An indirect effect of inundation is the possibility that the variety of shells may increase on a site due to colonization by indigenous freshwater reservoir species. However, this should not present a serious problem if the investigator is alert to this possibility.

Wood

Wood, an important material historically and prehistorically, is rarely preserved in archeological contexts, largely because it is susceptible to fungal and bacterial attack. In the American Southwest, preserved wood and other organic materials are occasionally encountered in dry caves and alcoves where moisture, a prerequisite to microbial growth, is excluded. In the Pacific Northwest and northern Europe, wood has sometimes been recovered from waterlogged contexts. The preservation of these materials is generally attributed to microenvironmental conditions which are inhibitory to microbial growth, such as the accumulation of organic acids and anaerobiosis.

The preservation of wooden artifacts and architectural elements such as jacal (brush superstructures), roof beams, and support posts imparts valuable information regarding tool use, techniques of manufacture, and construction. It also provides the kind of data useful for making inferences about resource availability and material preferences. The loss and/or differential preservation of wood resulting from inundation impacts would preclude these kinds of inferences.

Wood is also crucial to archeological analysis because of its dating potential. The technique of dendrochronology (tree-ring dating) has been used to date many prehistoric Southwestern sites that are too recent for radiocarbon dating.

Bannister and Smiley (1955) outline four conditions that must be met before the techniques can yield a satisfactory tree-ring chronology, enabling the dating of prehistoric artifacts and sites.

1. The trees must produce defined annual rings as a result of a defined growing season.
2. Tree growth must be primarily dependent upon a single controlling factor such as soil moisture.
3. The indigenous population under study must have made extensive use of wood.
4. The wood must be well enough preserved so that it still retains its cellular structure.

Dendrochronology is a useful technique for dating occupation and construction phases of archeological sites and for establishing cultural chronologies. Charcoal, a wood derivative, is one of the most reliable materials used for radiocarbon dating. Fortunately, it is little affected by chemical reagents and, therefore, should continue to yield reliable dates, even after inundation.

The preservation of wood in submerged contexts is well documented (Greaves and Levy 1968; Croes 1976). However, despite the outward appearance of being preserved, varying degrees of chemical and biological degradation have been reported, depending upon the type of wood and the condition of burial. Micromorphological analyses conducted on various wooden artifacts indicate that waterlogged wood may undergo chemical, physical, and morphological changes. These changes are generally reflected in the relative compositions and quantities of the vegetal and mineral components of the wood. For example, losses of cellulose and hemicellulose are reported (Florian, n.d.; Greaves and Levy 1968). In some cases, the residual cellulose may be converted to noncrystalline oxycellulose. This form of decomposition is well documented in those instances where wood comes into contact with ferrous metals. Ferric salts produced by the interaction of the mineral components of the wood with iron can function as an oxidizing catalyst for the conversion of cellulose into oxycellulose (Campbell 1952). This reaction, however, cannot proceed under reducing conditions, such as would occur in the anaerobic soil zones beneath the sediment-water interface.

Cellulose, a primary constituent of wood, is more resistant to degradation than many other polysaccharides because of its beta 1-4 molecular linkage. Lignin, the second most abundant constituent of wood, is even more resistant than cellulose to degradation. Chemically, it is an insoluble high molecular-weight phenolic substance bound by an aromatic linkage. This molecular arrangement ensures the very high resistance of lignin to deterioration (Alexander 1961).

Despite their apparent immunity to degradation, cellulose and lignin are subject to chemical and biochemical deterioration via hydrolytic reactions. Biochemical hydrolysis of cellulose precipitated by organically produced enzymes can proceed both in aerobic and anaerobic environments. The process of degradation in wood is essentially the same as that for most cellulose-containing organic materials. Under aerobic conditions, the wood will undergo attack by organisms able to cause the decomposition of cellulose and lignin. Under anaerobic conditions, anaerobic bacteria participate in the degradation process. However, given sufficient time, chemical degradation may be more destructive than biological deterioration under anaerobic conditions (Croes 1976). For example, anaerobically produced hydrogen sulfide (H_2S) and its aqueous solution, sulfuric acid (H_2SO_4), can degrade cellulose (Barghoorn 1949).

Chemicals other than those causing hydrolytic reactions can produce similar results. Several experiments have been conducted to determine the chemical resistance of various types of woods used for industrial chemical storage (Stewart 1938; Hauser and Bahlman 1923). The results of these experiments may prove useful in predicting and understanding the interactions between the various ions and/or chemical compounds and the archeological specimens of wood that are submerged in reservoirs.

The results of these chemical experiments are summarized in general terms. For the most part, hardwoods exhibit more decay than softwoods. Though oak appears to be more durable than other hardwoods with respect to biodeterioration (because of its bacteriostatic tannin content), it is nonetheless susceptible to chemical degradation. Softwoods such as pine are less susceptible than hardwoods to biological deterioration, primarily because the lignin serves to protect the cellulose against biological attack. As with hardwoods, softwoods are also subject to chemical degradation. The nature of the chemical reactivity is summarized as follows.

In general, wood exhibits considerable resistance to hydrolysis by dilute acids since most woods are chemically acidic in nature. However, exposure to concentrated acids (e.g., 60% sulfuric or 37% hydrochloric acid) will result in more rapid hydrolysis of the polysaccharides. Likewise, strong alkaline solutions will degrade wood rapidly by dissolving the carbohydrate and lignin fractions. Weak alkaline solutions, however, have little effect on wood. Similarly, aqueous solutions of neutral salts also have little effect on wood, but acid salts such as calcium chloride and basic salts such as sodium carbonate may produce hydrolytic effects (Browning 1963).

The results of the water chemical experiment conducted by the Inundation Study show a few changes which can be attributed to chemical exposure. In general, the results corroborate the findings of Browning (1963). The most notable change occurred in the oak samples immersed in the concentrated sodium silicate solution. After a year's immersion, the oak exhibited linear splits along the end grain; the pine, however, did not appear to be adversely affected. None of the other solutions produced this kind of degradation.

Measurements of weight loss from T_1 to T_3 (eight months) indicated significant changes in the majority of samples immersed in the concentrated solutions. Of these, three basic salt solutions ($MgCl_2$, $CaCl_2$, and $MgSO_4$) accounted for weight losses that were significantly greater than those observed for the deionized water control (Volume II, Technical Report No. 3).

Weight loss and compression strength data from the Brady and Claytor Lake Reservoir experiments also indicate that some destruction of internal wood structure occurred as a result of inundation. Presumably, the structural weakening was caused by solubilization of the extractive portion of the wood and/or by the drying process. Since immersion time and environment were significant factors in loss of compression strength, we may conclude that long-term immersion in an intensely anaerobic or aerobic environment may cause some deterioration of wood. The rate of degradation will depend upon the type of wood, the condition of the wood, and the edaphic, chemical, and biological components of the environment.

Seeds, Pollen, and Organic Remains

The preservation of pollen, seeds, and vegetal remains in archeological contexts can yield valuable information about the previous climate and environment of a region and about the types of plants utilized for food and no-food purposes. However, due to their perishable nature, many categories of organic remains are not preserved, leaving gaps in the record which skew archeological interpretation. Thus, it is important to understand how the process of differential preservation operates and why some plant and pollen taxa are more susceptible to deterioration than others.

The differential preservation of pollen and macrobotanical remains is influenced by several factors. Included are the rate and environment of deposition, soil type, pH, Eh, drainage characteristics, type and condition of the vegetal material, and the number and kinds of macro- and microfaunal and floral organisms present.

During the past 20 years, the differential preservation of pollen has been studied by a number of investigators (Bryant 1978; Faegri and Iversen 1964; Holloway 1979; Sangster and Dale 1961, 1964; and Tschudy 1969). Pollen deterioration (corrosion) is a very complex process that involves the interaction between external factors such as microbial attack, oxidation, mechanical forces, and internal factors (such as sporopollenin content and the chemical/physical composition of the pollen wall). Through experimentation, Sangster and Dale (1961) demonstrated that the more susceptible the pollen is to oxidation, the more rapidly it is destroyed.

Havinga (1964) observed a similar correlation between the percentage of sporopollenin and the susceptibility of pollen grains to processes of oxidation. He concluded that the higher the percentage of sporopollenin, the more likely a pollen grain will be preserved and the less likely it will be affected by oxidation. The experimental results suggest that varying proportions of sporopollenin in exines of different species may result in differences in the percentage frequency of species in the modern and fossil pollen spectra.

Oxidation of sediments under aerobic conditions is a major factor in organic losses. Consequently, the preservation of botanical remains will be greatest in those sediments of acid pH (1-6) and negative oxidation-reduction (Eh) potential (e.g., in an acidic, reducing environment such as the anaerobic bottom sediments of many lakes and reservoirs). In addition, the accumulation of humic acid products such as phenols have bacteriostatic properties which may enhance the preservation of various organic materials, including pollen exines.

The variable physical condition of organic remains recovered from similar contexts within the same archeological site further demonstrates the complex nature of differential preservation. Before the archeological data can be reliably interpreted, it is necessary to evaluate the cultural and noncultural processes of deposition. The archeologist must consider the local mechanical, chemical, biological, climatic, and edaphic processes that influence differential preservation and determine the susceptibility of a particular assemblage to decay. Misinterpretations of the data can occur without the prerequisite knowledge of the regional plant ecology, plant succession, mechanisms of differential pollen and seed production and preservation, transport mechanisms, and seasonality.

One purpose of the laboratory and field (reservoir) experiments conducted by the Inundation Study was to investigate the rates of deterioration of various seed and pollen taxa subjected to chemical and biological stimuli. The research designs and results are briefly summarized as follows:

Seed experiment: Charred and uncharred seeds of seven plant taxa; (kidney, pinto, and navy beans; popcorn; blue corn; wheat; and rye) were immersed in 30 chemical environments, which consisted of a single cation and anion, for a period of one year (see Volume II, Technical Report No. 5). The chemical environments selected were representative of typical ionic species and concentrations found in freshwater reservoirs. Fourteen concentrated solutions were included to simulate conditions of long-term immersion. In addition, duplicate seeds were immersed for 8 months in an actual reservoir in central Texas. The purposes of these experiments were to describe and quantify morphological change in specific seed taxa resulting from exposure to different known chemical environments and to isolate the specific factors that relate to the rate and type of biological degradation.

Quantitative measurements of seed length, width, and thickness were made to determine changes in seed size and shape. Dry and wet weights were measured to determine the loss of seed attributes that are not visible (e.g., internal breakdown of cell structure, dissolution of soluble cell components, etc.). A series of visual observations was also conducted to determine the extent of superficial damage to the seed coat, endosperm, and cotyledons.

In the laboratory water-chemical experiment, it was observed that the charred seeds deteriorated at a faster rate than the uncharred seeds. In almost all cases, the charred seeds exhibited varying degrees of seed coat damage, cracked endosperm, and cotyledon splitting, while the uncharred seeds were only minimally affected. It is apparent from the noninundated control samples that the charring process was responsible for the initial seed coat damage, cotyledon separation, and endosperm cracking; however, inundation exacerbated these conditions. The frequency of occurrence of the damage attributes varied significantly within each taxonomic group, but not between chemical environments, as was expected. The seed category most affected was beans, followed by corn, wheat, and rye.

The relationship between moisture content and differential preservation of different seed taxa was recently addressed in an independent experiment conducted by Gasser and Adams (in press) at the Museum of Northern Arizona, Flagstaff. The experiment was designed to examine the effects of moisture, temperature, moisture and temperature periodicity, and acidity on seed preservation. Seeds of five plant genera found at Walpi, a Hopi pueblo continuously occupied since A.D. 1690, were examined: Hopi corn; pumpkin seeds; pinon nuts; red, white, and kidney beans; and sunflower seeds. The seeds were subjected to varying conditions of temperature, moisture, and acidity for varying periods of time. Although their results are not directly comparable to those from the Inundation Study laboratory experiment, some similarities can be noted:

1. Beans were the most susceptible of all taxa to deterioration. Toll, Gasser, and Adams all attribute this to the fragile seed coat which is easily broken, thus leaving the seed interior vulnerable to chemical and biological agents of deterioration.

2. Weight loss was greatest in the seeds subjected to saturated conditions. In seeds subjected to slightly moist or dry conditions, weight loss was not as great (Gasser and Adams, in press).

3. Under aerobic conditions, moisture was the most important factor causing seed deterioration.

4. Saturated conditions and stable temperatures promoted biological deterioration; however, deterioration also occurred under saturated conditions subjected to temperature variation. Both conditions occur in reservoirs.

5. Acidity helped retard microbial growth.

The reservoir field study more closely approximates the chemical and biological conditions to which submerged archeological sites and artifactual materials are subjected. In contrast to the laboratory experiment which emphasized chemical agents of deterioration, the field phase emphasized the interaction of chemical and biological agents at the mud-water interface. Toll (Volume II, Technical Report No. 5) notes that the most obvious difference between the data from the field and laboratory is the number of surviving seeds. In the laboratory experiment, biological predation was an insignificant factor in seed degradation since the pH of the chemical solutions was sufficient, in most cases, to retard microbial growth. In the field experiment, biological predation was a very significant factor in seed degradation. Predictably, the number of surviving seeds was directly proportional to the mesh size used for the samplers.

Three different mesh sizes, designed to exclude certain classes of organisms, were utilized in order to determine the relative contribution of each category of organism to seed degradation. Mesh size 0.2 micron excluded all microorganisms; mesh size 2 excluded macroinvertebrates; and mesh size 2.5 cm permitted the interaction of both microorganisms and macroinvertebrates. As expected, the greatest amount of seed deterioration occurred in the samplers with the largest size openings (2.5 cm). Predictably, uncharred seeds were more susceptible to biological attack than charred simply because they contain easily assimilable nutrients.

Unfortunately, the experimental design did not allow for frequent collection and measurement intervals to determine rates of degradation. However, based on the results of the pollen study in which Holloway (Volume II, Technical Report No. 4) demonstrates that most pollen degradation occurred during the first five days after initial immersion, and based upon information in the literature regarding decomposition of organic matter, it is assumed that the greatest amount of seed degradation also occurred within the first few days following immersion. The initial microbial activity was probably aerobic in nature. As decomposition proceeded, biochemical reactions initiated by microorganisms removed the available oxygen and replaced it with carbon dioxide and hydrogen sulfide. This resulted in a lowering of the pH and the replacement of aerobic organisms with anaerobic ones. The presence of hydrogen sulfide and methane gas in the samplers and low redox (Eh) readings during the sampling intervals confirm the activity of anaerobes. Future studies should address the problems of determining rates of degradation and quantifying aerobic versus anaerobic decomposition.

Pollen experiment: A correlate to the seed study was the pollen experiment. This experiment attempted to identify the factors influencing pollen preservation in freshwater reservoirs. It also tested cause-and-effect relationships in pollen preservation (Volume II, Technical Report No. 4). As in the seed experiment, pollen was placed in 30 water chemical environments in the laboratory, as well as in an actual reservoir.

Thirteen pollen taxa were selected on the basis of the following criteria: 1) represent economic plants used prehistorically, 2) include common plants used to interpret fossil vegetation communities, 3) contain known conditions of preservation based on previous experimentation, and 4) maintain ease of recognition once degradation is underway.

Four parameters were isolated for study in the reservoir experiment: location, time, position, and treatment (fresh versus fossil) effect. The percentage of pollen deterioration in the reservoir varied directly with the four parameters. Of these, time was the most significant factor affecting degradation. Samples were extracted after 5, 10, 20, 90, 180, and 358 days of immersion to measure the rate of degradation. After the initial flurry of attack immediately following deposition, the rate of pollen deterioration slowed down. This corroborates the findings of Sangster and Dale (1961, 1964).

The location variable was of secondary importance in pollen degradation. This may be due to the different microfloral and microfaunal communities present at each sampling locus. Local differences in pH and substrate may account for the different microbial communities. The highest overall deterioration occurred at Station 2 (limestone substrate with little sediment cover).

The position of the pollen (sediment versus water column) had less of an effect on pollen preservation than the other parameters. The variable treatment effect (acetylated versus unacetylated) also had little effect on the rate of deterioration. In general, acetylated pollen suffered less biological attack than untreated (fresh) pollen. This is consistent with the seed study results (charred versus uncharred).

As in the field experiment, the laboratory experiment consistently showed less deterioration in acetylated than in unacetylated pollen. Again, the variable of time was probably the dominant factor contributing to the exine deterioration. Of the 30 chemical solutions tested, pollen degradation was greatest in the sodium silicate (Na_2SiO_3) and chloride ($MgCl_2$, $FeCl_2$, and NaCl) solutions, with Na_2SiO_3 and $MgCl_2$ showing 40% unacetylated pollen deterioration.

In both the laboratory and field experiments, thin-walled exines were the most susceptible to degradation. Among these are many of the economic plants, such as Amaranthus, which are of archeological importance. Consequently, the systematic, selective elimination of thin-walled pollen types will significantly skew the pollen record that is preserved within an archeological site.

These experimental data support the observations of other investigators that pollen degradation affects different pollen taxa at different rates. The two principal factors controlling the rate of degradation are time and the condition of the substrate. The results demonstrate the selective nature of pollen preservation and indicate some of the factors responsible for degradation.

Reservoir inundation can affect pollen preservation at each of the scales outlined in this chapter. At the large scale, the initial episode of flooding destroys modern vegetation and destroys and/or mixes modern pollen. Both are essential for interpreting the fossil pollen record. At the medium scale, pollen preservation may be academic if contextual data are lost through mechanical processes such as slumpage, sediment mixing, etc. Tight stratigraphic control is essential for proper data evaluation since pollen preservation is influenced both by random and nonrandom events. Differential pollen preservation also affects archeological interpretation at the medium scale in that the selective destruction of certain pollen taxa eliminates from the record various pollen types that relate to the cultural occupation of the site. At the small scale, loss of attribute data resulting from degradation processes may corrode or alter the exine beyond the point of recognition.

In summary, the experimental results demonstrate that Eh and pH conditions and changes and microbiological activities are highly significant factors in the preservation or destruction of palynomorphs and other sedimentary organic matter. Thus, the survival of pollen, seeds, and organic matter in a reservoir will largely depend upon the initial depositional episode, subsequent environmental events, and the physical and chemical properties of the inundated soil matrix. Deeply buried (e.g., greater than 40 cm) materials will probably show few adverse effects resulting from inundation, since microbiological activity is considerably reduced and the soils tend to exhibit low redox potential. Materials deposited on or near the surface (less than 10 cm) are more susceptible to oxidation processes and microbiological activities. Consequently, preservation of these materials will depend upon the local reservoir conditions.

Ceramics

Pottery is an important constituent of many archeological sites for several reasons. It is widely distributed both in time and space; it is generally resistant to weathering; and it is characterized by a number of cultural traits that permit the archeologist to separate the potsherds into types for purposes of analysis and chronological ordering (Colton 1953). Because ceramics possess attributes that change through time (e.g., vessel form; design elements or motifs; surface treatment such as slipping, corrugation, etc.; temper type; and so on), they have been widely used as a tool for relative and absolute dating.

Sequence or seriation dating depends upon change that is nonreversible and continuous (Hole and Heizer 1973). Dating by seriation depends on the fact that artifacts change stylistically and in their relative frequency (Hole and Heizer 1973).

With the development of dendrochronology (tree-ring dating) by A. E. Douglass in the 1910s and 1920s, it was possible to assign a date to the various pottery types found in the prehistoric Southwest. Once the cutting dates had been established, the ceramics found in Southwest sites could be dated on the basis of their relative stratigraphic positions. Predictably, small pithouse and Puebloan sites of brief occupation contributed more to the dating of pottery types than the large pueblos. This is because the smaller sites offered tighter stratigraphic and chronological controls.

In addition to its archeological value as a dating tool, pottery can also be used to infer aspects of social organization based on the contextual relationships of various artifact classes within a provenience (Hill 1970). However, the ability to utilize ceramics in this capacity or as a dating tool depends upon the preservation of the contextual and attribute data. In general, ceramics are very resistant to weathering. Still, Colton (1953:41-42) lists several environmental agents which can deteriorate pottery. The agents of deterioration -- heat, cold, moisture, dryness, freezing, and thawing -- can produce the following weathering patterns: natural abrasion, artificial abrasion, peeling, spalling, pitting, fragmentation, false oxidation, and lichen growth. Obviously, any weathering process that obliterates the design elements or alters the surface of a potsherd will severely compromise the interpretations based on those attributes. For example, peeling or spalling of the slip or ceramic surface will eliminate design elements that are used to identify ceramic types and determine the period of occupation of a particular site or portion of a site. Frequently, typological differences between ceramic groups are assigned on the basis of pigment type (e.g., organic versus inorganic) or general surface treatment (e.g., slipped versus unslipped, polished versus rough). Any alteration of the surface will also affect the relative frequency of ceramic types within a given assemblage. Potsherds that are ordinarily identified on the basis of stylistic attributes and surface treatment will be lumped into general ware or indeterminate categories. This not only reduces the variability of the assemblage but also limits the potential for fine-grained seriation dating.

In order to determine the kinds of impacts that may result from inundation, four ceramic types, manufactured to prescribed specifications, were immersed in the 30 water chemical environments and in the test reservoir. Since prehistoric variables of source material, manufacture, firing temperature and atmosphere, tempering material, etc., could not be strictly controlled for experimental purposes, a ceramist was contracted to produce the desired set of attributes. Four categories of ceramics reflecting variability in firing temperature and tempering material were produced (Volume II, Technical Report No. 3). At four-month intervals, samples of each ceramic type were removed from the chemical solutions and from the reservoir; they were measured, weighed, and subjected to tensile strength tests. At the end of 12 months, samples of each type were selected at random for X-ray diffraction, electron microprobe, and atomic absorption analysis. In addition, visual observations were made in order to assess the effects of immersion on ceramic attribute data. The variables of firing temperature, temper type, and pigment type were systematically altered in order to determine whether these factors are differentially affected by inundation. The results are briefly summarized as follows:

1. Few visible changes were observed between samples submerged in different chemical environments, with the exception of samples submerged in the sulfuric acid (HiSO) solution. The extent and nature of degradation varied directly with the firing temperature. Those samples fired at the higher temperature (1050°C) were affected to a lesser degree than those fired at a lower temperature (600°C).

2. The most notable effect of inundation was the consistency of change between ceramics of the same group regardless of the chemical environment. Group IA (750°C, mineral paint, organic temper) ceramics exhibited a high incidence of surface pitting probably attributable to the greater porosity of the ceramics after firing. The mineral paint was faded but remained intact. Also, the clay body was softer and lighter in color than the noninundated control samples. The group IIA (600°C, organic paint, sandstone temper) ceramics were the most affected by immersion. Very few samples survived the year-long immersion intact. Those that did were extremely soft and friable and were generally poorly preserved. The organic pigment failed to adhere in most cases and where present, it was extremely faded. Group IB (900°C, organic paint, sandstone temper) ceramics were generally in worse condition than the IA ceramics, despite having been fired at a higher temperature. The organic pigment was faded, though less than the mineral paint, and tended to exfoliate. The clay body was also softer than the control samples. Group IIB (1050°C, mineral paint, sandstone temper) ceramics were the least affected by inundation. This is undoubtedly attributed to the higher firing temperature and apparent vitrification or sintering of some of the clay minerals. The mineral paint faded but not as much as the IA group. Nor was the clay color fading as pronounced within the IIB group as within the other ceramic groups.

3. In general, the mineral pigment faded more consistently than the organic pigment. However, for the most part, the design elements were still discernible even after fading. The organic pigments tended to fade differentially within the same bucket and even within the same sherd.

4. Ceramic firing temperature was the single most important factor in determining ceramic breakstrengths among the experimental ceramic groups. High firing temperatures not only increased ceramic tensile strength but also reduced the variability in tensile strength change across different water chemical environments.

5. Immersion time was also a significant factor in ceramic deterioration. Apparently, the most significant change in ceramic breakstrength across all four ceramic categories occurred during the first four months of immersion and gradually decreased afterwards.

This change can probably be correlated with the rate of calcium leaching, which was greatest immediately after inundation and slowed down with time.

6. Atomic absorption analysis of the chemical solutions and powdered ceramic samples indicated a significant amount of calcium release, with trace amounts of potassium, magnesium, silica, and sodium also released. The results of an analysis of variance indicated that chemical environment, firing temperature, and the interaction between the two are all significant factors affecting the rate of calcium leaching.

Some of the implications of these results for prehistoric ceramics have already been addressed. One which has not yet been mentioned is the effect of the dissolution of calcareous clay and temper minerals. The water-chemical and reservoir inundation experiments demonstrated that significant amounts of calcium are leached from ceramics, resulting in a general weakening of the clay body and increased porosity. The preservation of shell or limestone-tempered ceramics will depend upon the relative amounts of these constituents, the condition of the clay, and the environmental conditions. In some instances, the entire ceramic may deteriorate. This phenomenon was reserved in shell-tempered ceramics from the Kinzua Valley/Allegheny Reservoir, where the only trace of the ceramic was a "tell-tale off-color smear in the subsoil matrix" (Adovasio et al. 1980:164). Even the grit-tempered wares were in a poor state of preservation. They had to be "refired" with a propane torch before they could be removed from their archeological proveniences (Adovasio et al. 1980:164). Adovasio et al. (1980) also observed leaching of the shell temper from sherds that were lying exposed on the ground surface and subjected to continuous inundation since the impoundment of Bluestone Lake. Cursory visual analysis revealed that the shell temper from the ceramic surface that was in contact with the reservoir water had completely dissolved. At the time of this writing, the extent of leaching had not been determined either by physical or chemical tests. The results, however, are equivocal since comparative preinundation data are lacking. Colton (1953:42) observed that rainwater can cause similar pitting and leaching, especially in ceramics that are exposed on the ground surface; ceramics that are buried are less likely to exhibit this kind of weathering pattern.

Regardless of the cause of leaching in this particular case, the experimental and field data suggest that differential preservation can occur within certain ceramic groups and that immersion is clearly a factor in ceramic deterioration. The nature and extent of the impacts will depend upon factors such as artifact condition, variables of manufacture, firing temperature, and the chemical and physical environmental variables.

Lithics

Because of their durability and general resistance to weathering, lithics are commonly preserved in archeological contexts. The majority of stone tools are manufactured from fine-grained cryptocrystalline rocks such as flint, chert, and obsidian. They are qualitatively selected on the basis of their fracturing properties, ability to maintain a sharp working edge, and aesthetic qualities. Of course, raw material selection depends, in part, upon availability; consequently, other materials such as basalt, quartzite, and silicified wood were also utilized for tool manufacture.

Lithics can provide useful information about various aspects of cultural behavior. For example, by identifying the types of raw materials selected for tool manufacture, the archeologist may be able to determine the location of likely quarry sources or whether a particular type of material or artifact was traded into the area. In addition, the variability (or lack of variability), expressed in terms of the relative frequencies of certain kinds of raw materials, may suggest a cultural preference (either stylistic or functional) for a particular type of stone.

Furthermore, by studying the spatial patterning of lithic debitage and finished artifacts, the archeologist can often identify specific areas within a site where certain tool manufacturing or modifying activities took place. The individual tools and flakes can be subjected to various functional analyses to determine how the tools may have been used and what kinds of materials they may have been used to modify.

Much of the data regarding tool use is derived from experimental studies, ethnological observations, and published ethnographies. Jelinek (1976:32) has suggested that it may be possible to test tool use inference, based on experimental observations, in the prehistoric record by isolating traces of particular amino acids or other chemical substances that penetrated the edges of the tools during use. Under exceptional conditions of preservation, the actual organic residues resulting from these activities may adhere to the stone tool faces and edges and be preserved (Shafer and Holloway 1979).

Data pertaining to this particular aspect of lithic analysis were not collected during this study; however, general information pertaining to chemical, biochemical, and mechanical impacts was compiled. Chert and obsidian flakes were immersed in the 30 water-chemical environments to evaluate water-chemical effects; chert flakes were also immersed in Brady Reservoir, Texas to evaluate combined water-chemical and biochemical impacts. After 12 months of immersion (8 months for the reservoir samples), the flakes were removed from the solutions and visually analyzed to assess qualitative changes in attribute states. The materials were also subjected to electron microprobe, atomic absorption, and neutron activation analyses to measure quantitative changes in lithic composition.

The results of these analyses indicate that chemical and biochemical processes occurring in a reservoir will not adversely impact chert and obsidian artifacts immersed for short periods of time. Although the long-term effects are not known, visual examination of chert and quartzite flakes immersed for 20 years in Table Rock Reservoir, Missouri revealed no apparent differences in the rate of deterioration between inundated and noninundated materials. The three variables selected for study were wear patterns, patination, and mechanical impacts. The results are summarized as follows (Garrison et al. 1979):

1. There were no observable differences in the rate of wear pattern deterioration between inundated and noninundated samples.
2. Although quantitative differences in patination were difficult to measure due to color differences and the presence of banding in

some artifacts, there were no obvious differences between inundated and noninundated materials. However, dull patination was more prevalent in artifacts collected from the beach zone. Mechanical impacts and/or exposure to ultraviolet light may be causal factors.

3. Mechanical impacts on chert artifacts in the beach zone were not as great as expected. Within the limits of the analysis, no major differences could be detected between inundated and noninundated samples.

Unfortunately, since no chemical tests were performed on these samples, it is not known whether inundation affected the trace element composition of the artifacts. Alterations in the chemical composition of lithics can affect both the dating potential (e.g., fission-track and obsidian hydration dating) and the ability to determine the material source. Future research should address these questions.

Summary and Implications

The data presented in this section suggest that reservoir processes do influence the rate of deterioration of common cultural materials. The mere fact that an object or chemical residue is preserved implies that a balanced relationship exists between that object or cultural material and its contextual, geomorphological, chemical, and biochemical environment. However, environmental systems are not static. Environmental parameters are subject to random and nonrandom fluctuations that vary both in magnitude and frequency. The creation of a reservoir imposes a new set of physical and chemical environmental variables and alters previously existing ones.

One purpose of this study has been to examine and evaluate the effects of typical biochemical reservoir processes on artifacts commonly preserved in archeological sites. The study's goal has been to determine under what conditions artifacts may continue to be preserved and/or to predict rates of deterioration. In order to meet this objective and make the results meaningful and relevant for archeologists confronted with these kinds of problems and situations, a two-stage strategy for data collection was employed: the first involved carefully controlled scientific experimentation in field and laboratory settings; the second involved the real world of complex, fragmentary archeological data. In designing the experiments, it was necessary to reduce the complexity and variability of the depositional environment and the material properties so that direct causal relationships between select environmental variables and a particular set of attributes could be examined. This was accomplished by selecting "fresh" materials of comparable quality and controlling the number and kinds of attributes to be studied. It is difficult enough to control the amount of variability in samples selected for experimental purposes, since external factors affecting growth, nutrition, etc., may not be known. It is even harder to control the variability exhibited in archeological materials.

However, without the empirical baseline data provided by the archeological remains, the experimental results are little more than testable, hypothetical statements and inferences generated from a particular data set. Conversely, without controlled experimentation, rates of deterioration and subtle aspects of selective preservation or destruction cannot be determined. Various factors account for the presence or absence of certain kinds of archeological data that are contained within sites. Included are cultural factors -- such as discard behavior, abandonment procedures, and scavenging practices -- and noncultural factors -- such as differential preservation and postdepositional conditions. The archeologist must be aware of both the cultural and noncultural factors and recognize the limitations they impose before he can meaningfully and accurately interpret the archeological data that are preserved in an archeological site.

In this discussion, we focused on the question of differential preservation, which can be summarized as follows:

1. In general, all material categories, with the single exception of lithics, analyzed in the laboratory exhibited some degree of deterioration after exposure to normal and concentrated chemical solutions. The extent of deterioration depended upon length of immersion, specific chemical environment, and type of material. Considerable variability within material classes was also observed. This is partially attributed to morphological and compositional differences between samples. These same factors are, presumably, responsible for differential preservation between related materials such as pine versus oak and the different seed and pollen taxa, etc.

2. Likewise, those samples immersed in Brady Creek Reservoir also exhibited varying degrees of degradation, depending upon the length of immersion, the environmental conditions, and the type of material. For the most part, the materials in contact with the sediments were more degraded than those in the microbiological samplers. Time is a crucial factor in assessing the rate of degradation; most deterioration occurred within the first four months after immersion and tended to slow down thereafter.

3. Archeological data from the field were largely inconclusive because comparable preinundation data were lacking. Many of the sites had been inundated for nearly 20 years, and little or no work had been conducted prior to their submersion. Conversely, some sites that were excavated and set up for experimental purposes had not been flooded by the end of the project due to various economic, political, and/or environmental factors. Consequently, the data collected from submerged archeological sites is both sparse and somewhat problematical. It is hoped that future researchers will return to some of these sites, especially those set up for experimental purposes, collect and analyze the data, and report the findings so that some of the questions may begin to be resolved.

The problem of differential preservation is far from resolved. It involves understanding the complex interaction between the edaphic, geologic, chemical, and biological components of the environment. This interaction results in the selective preservation and/or destruction of various archeological materials deposited in similar archeological and environmental contexts. In this study, we succeeded in identifying some of the factors which might influence differential preservation of archeological materials submerged in freshwater environments. The most important of these are environmental factors such as soil type, temperature, moisture, aeration, pH, Eh, composition and distribution of freshwater macroinvertebrate and microorganism populations, chemical composition of the water and soil, etc.; mechanical factors such as erosion, slumpage, wave action, abrasion, and so on; and physical factors such as the nature, composition, and condition of the cultural materials, depth of burial, length of inundation, etc.

In spite of the quantity of data collected, we have gained only a peripheral understanding of the complex nature of differential preservation. Future research should focus on quantifying the rates of degradation and measuring the relative contribution of each causal factor so that more reliable prediction can be made regarding the loss and/or preservation of our nonrenewable archeological resources.

OTHER IMPACTS TO ARCHEOLOGICAL RESOURCES

The results of human, floral, and faunal impacts to small-scale archeological resources (i.e., the artifacts, features, soil profiles, etc.) are often deceptive in their destructiveness to the resource base. In this section each of these impact processes will be examined in turn.

Human Impacts

As discussed in the medium-scale impact processes section of this chapter, vandalism may be the single most destructive force to sites which are periodically flooded or just above the pool level. The increased access to remote sites after inundation can be directly correlated to an increase in destruction. Not only do vandals or collectors destroy specific large cultural remains (e.g., historic buildings dismantled) but they also disturb the original context and remove smaller artifacts with even greater frequency.

The collection of lithics, groundstone, potsherds, historic bottles, burials, and associated grave goods, all of the "goodies" that make up the vast majority of private collections, is devastating to the archeological record. Widespread and sometimes well-organized collection of artifacts has been documented throughout the United States and Canada (Stafford and Edwards 1980; Garrison et al. 1979; Mohs 1977; Schroedl 1977; and many others). In their efforts to get at prehistoric remains, collectors will dismantle wall alignments (Rayl 1979), dig up and scatter human remains (Collins and Green 1978), use dynamite to lay open mounds and trenches (Schroedl, personal communication), and use backhoes and bulldozers to remove dirt quickly (Collins and Green 1978; Rippeateau 1979), to cite but a few examples. The destruction of artifacts and features themselves and, equally important to the archeologist, the alteration of context severely compromise, and in some cases completely eliminate, the possibility for site interpretation.

Another indirect form of human impact to small-scale archeological resources results from industrial or agricultural pollution. As a result of contamination from a nearby plant in Oregon, site soils up to a depth of 4 meters were found to contain quantities of Cesium 137, a radioactive isotope (Cole, personal communication). The presence of this fissionable material can affect dating techniques, causing unreliable returns.

Agricultural pollution, chemicals and fertilizers used in crop production, can impact site soils through discoloration and shifting of soil chemistry values. In the same area of Oregon, Cole has noted a homogenizing of soil chemistry values (personal communication).

Faunal Impacts

Impacts to specific features can result from a combination of stock grazing and pool-level fluctuations. For example, Schaafsma observed a cow stepping into a partially flooded, but well saturated, prehistoric hearth in Abiquiu Reservoir (1978:28-29). The end result was the destruction of the feature. Stock or other wildlife grazing, trampling, or wallowing in saturated site soils can break, damage, or destroy artifacts and features buried up to a depth of 30-50 cm. As the water level fluctuates, this zone of impact may move across the site several times in a single year. The resulting impacts may be quite significant.

Burrowing animals along the reservoir margins also seem to prefer site soils to sterile areas when available (Stafford and Edwards 1980). The loose, friable middens of California are often riddled with gopher or ground squirrel activity. Disruption of artifact context, "mounding" of lithics and sherds outside burrows, destruction of soil profiles, and damage to the artifacts themselves are common.

Floral Impacts

The impacts of vegetation to small-scale archeological resources are generally of two types: loss of plant cover and growth of intrusive species on a site.

The thick grasses and root matt found on many sites, under normal conditions, inhibit erosion and disturbance of the site surface. Once flooded, these grasses die back and, during periods of fluctuating water levels, they do not become adequately reestablished for site protection. An increase in erosion of the periodically inundated areas of site 4SC152 (Chesbro Reservoir), noted by Winter (1977:46) and Stafford and Edwards (1980), was directly attributable to limited ground cover. Other scientists (Foster and Bingham 1978; Adovasio et al. 1980; Schaafsma 1978; among others) have noted similar problems in reservoir areas across the United States. As grass cover is depleted and erosion increases, features and artifacts are moved and damaged.

> Plant growth in the midden areas was seen to accelerate the general rate of soil erosion. The process of soil dessication combined with root penetration opened numerous fissures [in the midden].... (Foster and Bingham 1978:38)

Intrusive vegetation can create problems of a different nature. As root systems become developed in site areas, they can contaminate or otherwise alter soil profiles and features. If the site has undergone erosion of topsoil, freshly exposed site areas become available for plant growth. At Folsom Reservoir, over a meter of soil had been removed from the Pedersen site as a result of inundation. During the drought episode of 1977-78,

> an astounding array of intrusive plants colonized the site as the lake waters receded. They include grasses, vines, tomato and watermelon plants ...weeds and tree saplings. Prominent among the latter were cottonwood and willow sprouts with many specimens exhibiting trunk diameters of 1 inch or more. (Foster and Bingham 1978:37-38)

The intact housepit floors, all that remained of the Pedersen site, were quickly damaged by root penetration, cracking, and heaving. Artifacts within the midden were exposed to alternate periods of wetting and drying without the benefit of a soil buffer to mitigate the extremes in temperature and moisture. Provenience data were lost, groundstone artifacts were further damaged, and soil profiles were altered.

Conclusion

Impacts to small-scale archeological resources from human, floral, and faunal processes, while not as dramatic or as obvious as some other impact processes, are nonetheless potentially just as destructive to the resource base.

IMPACTS TO DATING AND ANALYSIS TECHNIQUES

In the last four decades, impacts to archeological sites by reservoir construction activities have achieved immense proportions. The archeologist's recommendations in response to the threat of inundation has been to "salvage" as much of the data base as possible before flooding occurs. This has often resulted, unfortunately, in abortive attempts at total excavation without due attention being paid to differences in site type, extent, importance, or location within the reservoir pool. With the development of the conservation ethic in archeology, members of the profession are devoting more of their efforts toward improving the quality of research designs and their data-gathering tools. The conscientious archeologist or manager is faced with a dilemma: how to preserve as much of the resource as possible when it will be flooded. Where should our research efforts be placed and how do we prioritize our data gathering?

In a reservoir, the concept of a data bank depends on the preservation of archeological resources from any detrimental impacts which may be caused by freshwater flooding. The National Reservoir Inundation Study has focused on the acquisition of information that could be used to reasonably determine which reservoir variables would be destructive to specific archeological values. In this section, the following questions are addressed:

> Will the effects of immersion, permanent or periodic in nature, skew or make less valid the results obtained from specific dating and analytic techniques? Will inundation adversely impact the potential a drainage area has for preliminary cultural resources inventory efforts, including standard survey techniques and remote sensing? Will inundation impact those qualitative elements of archeological sites that are often used as indicators of natural and cultural features, such as soil color and texture? (Lenihan et al. 1977:11)

IMPACTS UPON DATING TECHNIQUES

The degree to which freshwater immersion will affect the application of various dating techniques to different artifacts is a major concern to many researchers. This section does not address questions of the basic viability or reliability of any particular dating technique. Rather, the emphasis here is on whether similar results can be expected from samples analyzed prior to and following an inundation episode. Research results from field work undertaken under the auspices of or in coordination with the National Reservoir Inundation Study are the data sources used below.

Carbon-14 Dating

Carbon-14 (C-14) dating has, for many years, been one of the most important absolute dating techniques available to archeologists. Theoretically, any organic substance should be datable by this method because all organic matter is composed of carbon compounds. A review of the literature on C-14 techniques suggested that freshwater immersion should not alter the potential of samples to yield usable dates, with the possible exception of freshwater shell. Some already existing natural agents that decrease C-14 sample recovery may be magnified as a result of flooding, but the principle problem is the degree of preservation of suitable materials. In bulk sampling situations, or where individual sample weight or volume is marginal, samples taken after inundation may be adversely impacted.

Carbon-14 samples were collected from three sites in Chesbro Reservoir, California. The sites had been roughly dated, based upon analysis of material collected, to an occupation period between 1500 B.C. and 1800 A.D. Results of the analysis dated the three sites as follows (Winter, personal communication):

4SC152 - AD 1320± 100
4SC152 - AD 1520± 100
4SC152 - AD 375± 100

All of the dates were well within the estimated occupation period given for the sites. It should be noted that 4SC152 has undergone periodic inundation; 4SC1223 had been continuously inundated for over 20 years; and 4SC1224 had never been flooded.

At Folsom Reservoir, California, two desert side-notched points were found in association with a hearth, permitting a reasonable test of the reliability of C-14 at a periodically inundated site (Foster and Bingham 1978:31). Desert side-notched points are reliable time markers for the late horizon in central California, which occurs from about 1500 to 1700 AD; analysis of the hearth sample by Dicarb Laboratory resulted in a date of 1320-1770 AD (DIC 975). The carbonized material in this sample does not appear to have been adversely impacted by inundation, arguing strongly for the usefulness of C-14 dating after inundation.

Two charcoal samples from Lake Mendocino, in northern California, were submitted for C-14 dating and, although the date from one site was earlier than anticipated, Fredrickson felt that there was no reason to reject the date. He stated that "all data were consistent with expectations and there was no reason to believe that results were skewed by the effects of inundation" (Stoddard and Fredrickson Appendix B 1977:6).

Samples from the Kettle Falls area in Washington were found to be in accord with dates based on artifactual material (Chance et al. 1977: 143). Nine samples from Bluestone Reservoir, West Virginia were submitted for analysis; four from a continuously inundated site, two from a site never inundated, and three from a periodically inundated site.

> It should be stressed that, according to Stuckenrath [Smithsonian Institute] and Stehli [Dicarb Labs], the radiocarbon samples from Bluestone were essentially 'similar' in laboratory 'behavior'; that is, there were no apparent differences in the physio-chemical attributes of the samples from any of the Bluestone Lake sites. (Adovasio et al. 1980:75-77)

The dates provided by C-14 analysis appeared to accurately reflect chronological and cultural factors at each site under investigation and, therefore, were not adversely impacted by either continuous or periodic inundation.

Results from this limited sample argue strongly for the continued viability of C-14 as a dating technique in reservoir areas.

Obsidian Hydration Dating

The use of obsidian by native populations for fashioning various tools has long been acknowledged by archeologists. The dating of these tools was determined by typology and contextual association until 1960, when the obsidian hydration dating technique was developed (Friedman and Smith 1960). This method was based upon the fact that obsidian absorbs water from the atmosphere to form a hydrated layer which thickens through time. When a tool is fashioned from obsidian, fresh faces are exposed to the atmosphere, and the process of hydration begins again. The reliability factor of obsidian hydration should be within "...±10 percent of the true age over periods as short as several years and as long as millions of years..." (Friedman and Long 1976). The variation of the hydration rates among rhyolitic obsidian (Ericson and Kimberlin 1976) and basaltic glass flows (Norganstein and Riley 1971) is appreciable, making source-specific determinations necessary.

Hydration rim readings for 17 samples submitted from Lake Mendocino, California yielded dates which fell within the range of site ages estimated by the Sonoma researchers. Hydration rim development, and therefore dating results, were not adversely affected by inundation. This may be due, in part, to the relatively short period of inundation, ca. 20 years. It may also indicate that hydration dating of obsidian is viable following inundation because of the stone's high resistance to deterioration.

Additional support for the usefulness of obsidian hydration dating comes from the Kettle Falls area in Washington. The results of hydration analysis were, for the most part, consistent and useful for general comparisons within and between sites. "Specimens from 45Fe45, a deep midden suggesting a long occupation, showed a general progression through time in the widths of hydration bands" (Chance et al. 1977: 144).

Data returns from this limited sample suggest that obsidian hydration dating will not be affected by periodic or continuous inundation; its use as a dating tool in reservoir areas is recommended.

Archeomagnetic Dating

Archeomagnetic dating operates on the principle that the intensity and direction of the earth's magnetic field, expressed in terms of angles of dip and declination, change over time. The best results in archeomagnetic dating are obtained from well-fired clay samples (fired clay floors and walls, kilns, and ovens) and well-built hearths. It is assumed that the remnant magnetization of a sample represents the orientation of the earth's magnetic field as it existed when the archeological feature was heated to the Curie point (675°) and cooled for the last time. During cooling, the alignment of the ferromagnetic particles in the clays are "frozen" and can be recorded as long as the clay is preserved intact. The sample's remnant magnetic orientation is then compared to variation curves for the region.

It has been hypothesized by the National Reservoir Inundation Study that archeomagnetic samples removed from reservoir contexts will not exhibit adverse effects from inundation, except when exposed to periodic drawdown conditions (Lenihan et al. 1977:93).

A series of nine individually oriented samples were collected from the central hearth at AR-9 in Abiquiu Reservoir, New Mexico to test the effects of inundation on this dating technique (Wolfman 1977:1). This site was inundated in the spring of 1973 and 1975 and may have been inundated briefly at other times as well. Seven of the nine samples collected produced statistically reliable results, indicating that "there is a 95% chance that the hearth dates between ca. AD 1800 and the present" (Wolfman 1977:3). AR-9, a Ute ramada structure, was also tentatively dated by other means as ca. 1810-1878 AD (Schaafsma 1978:75). The fact that AR-9 has been periodically inundated for 17 years would suggest that the physical integrity of the feature, rather than periodic inundation, is the critical factor in the usefulness of archeomagnetic dating. Although there were no strong independent controls to check against the AR-9 dates, their very consistency argues against an impact.

Fission-Track and Alpha-Recoil Track Dating

Fission-track and the recently associated developments in alpha-recoil dating are two promising techniques that archeologists are beginning to adapt to their needs. The techniques date the time of formation of certain minerals, particularly those with glass-like properties such as obsidian and mica. In fission-track dating, the radioactive decay of the uranium content in these minerals is what is actually being monitored, while in the alpha-recoil track dating process, the alpha decay of uranium, thorium, and samarium-147 are monitored. Both fission-track and alpha-recoil dating may be skewed as a result of dilution of the uranium content of the samples, as uranium is water soluble.

It was suggested by Lenihan et al. (1977:105-106) that fission-track and alpha-recoil dating would not be adversely affected by inundation. In order to test this hypothesis, a series of periodically inundated sherds from Abiquiu Reservoir, New Mexico was submitted to the Arkansas Archeological Survey for analysis. The sherds selected for analysis were from sites AR-513 and AR-3. They had been inundated for 38 days and 893 days, respectively (Wolfman and Rolniak 1977:3). Schaafsma assigned both sites to the Navajo occupation dating between AD 1650 and 1720 and classified the samples as Penasco micaceous (Wolfman and Rolniak 1977:3).

The two researchers found that the sample from AR-3 had an unusually high uranium content:

> It should be noted that the Chama Valley cuts through portions of the Morrison and Chinle formations in which uranium deposits have been discovered ...the sediments of sites which have been covered by the Chama River water probably have higher than normal uranium concentrations. The shallowly buried sample [from AR-3 collected just below the surface] with longer inundation in deep water seems to have been contaminated while the more deeply buried sample [from AR-513 collected at 8 inches below the surface] with shorter inundation in shallow water does not appear to have been affected. (Wolfman and Rolniak 1977:4)

The two researchers concluded, based upon this limited test, that samples will be subject to uranium contamination in those situations where long inundation and shallow burial in enriched soils occur, rendering analysis results unusable (Wolfmam and Rolniak 1977:5).

Thermoluminescent Dating

Thermoluminescent dating operates on the assumption that radioactive elements within the material to be dated will cause ionization, electrons, and other charge-carriers to form during initial heating. The technique is used primarily to date ceramic materials, but heat-treated lithics and fire-cracked rock may also be dated by this method. The charge-carriers remain trapped within the material at normal ambient temperatures. Upon laboratory reheating to 400°C or higher, the charge-carriers are released; a reaction takes place that restores them to their stable state; and the excess voltage produced by the reaction is emitted in the form of photons of light. The light is measured by a photomultiplier tube or by a predetermined dose of ionizing radioactivity (Cairns 1976). The data is then plugged into a formula, and the age of the material since the time of initial firing can be determined.

Samples collected from three reservoirs across the country were submitted for thermoluminescent dating. Two sites in Chesbro Reservoir, California, which had undergone continuous and periodic inundation for a period of 20 years, were tested. A third site, which had never been flooded, was also sampled. Six archeological structures at the Albino Village site in Navajo Reservoir, New Mexico, which had undergone continuous inundation for a period of 20 years, were sampled. A total of 19 samples were collected from the inundated areas; 10 additional samples of materials excavated from the same structures prior to flooding were submitted for comparison. Samples submitted from Bluestone Reservoir, West Virginia were selected from three sites which had experienced varying amounts of inundation since 1949. Samples from site 46Su22 were used as the baseline for the study since it had suffered only rare inundation from 1949 to 1979. Site 46Su9 had an intermittent inundation history, and 46Su3 had been annually inundated each summer for the past 30 years.

Rowlett and Bates found that the samples from each of the continuously inundated sites from all three reservoirs produced the greatest variation in TL response:

> Results of the TL response of the non-inundated and the samples inundated for 20 years did show differences in the TL response of such samples... (Rowlett and Bates 1979b:7)
>
> Like most other flooded sites, the date comes out too young, i.e., there is a decreased thermoluminescence response. (Rowlett and Bates 1980:7)

The periodically inundated sites fared only slightly better. The periodically inundated samples from Chesbro Reservoir did not appear to be affected adversely. At the same time the periodically flooded site at Bluestone produced less reliable results; "...the apparent younger age for site 9 would be consistent with other inundation studies we have done; inundation reduces TL response, creating thus the illusion of reduced age ..."(Rowlett and Bates 1980:6).

The rarely or never-inundated sites produced the most reliable results from TL analysis. The Bluestone site dates fell squarely within the age estimated by C-14 for the site; the Navajo samples showed "responses more consistent from the inundated samples" (Rowlett and Bates 1979b:7), and the Chesbro samples were not adversely affected (Rowlett and Bates 1979a:5).

Therefore, it does appear that continuous inundation has a deleterious effect on TL response, "making it both less consistent as well as generally diminishing the amount of response. This interferes drastically with TL dating and makes interpretive assays less definite" (Rowlett and Bates 1979b:9). Further, the progressively more flooded materials from all of the sites exhibited reduced TL response.

> This is true of the shell temper dates, as well as for the grey-black [ceramic] temper. This joins other evidence from the West that TL response of burnt limestone, flint, chert and even basalt... is distorted if the rocks are heavily inundated. While this distortion is quite severe and would render the absolute TL dating of flooded sites extremly difficult, seriation of responses would still be possible. (Rowlett and Bates 1980:11)

IMPACTS UPON ANALYTIC TECHNIQUES

This section specifically addresses the impacts of inundation upon certain analytic techniques used by archeologists to determine such factors as site boundaries, environmental parameters, and/or special use.

Soil Chemistry Analysis

Human activity will alter many of the chemical properties of the soil at a site. Archeologists use chemical analysis to locate human activity areas and also to differentiate between and interpret functional loci within a site (Sjoberg 1976; Eddy and Dregne 1964). There is an emphasis in archeology today upon the collection of many types of non-artifactual data (Watson et al. 1971). Within this framework soil analysis has become a very important technical and methodological tool. A variety of different chemicals have been tested at archeological sites with varying degrees of success.

The National Reservoir Inundation Study personnel selected several chemical tests that offered a fairly wide application to archeological interpretation and explanation; these were pH, nitrates, potassium, phosphate, and organic matter. Although not specifically addressed by the National Reservoir Inundation Study calcium, magnesium, and sodium concentrations in anthropic soils were also examined by some of the Inundation Study researchers.

Soil chemical analyses were undertaken in a number of reservoir areas as part of the Inundation Study. It was suggested (Lenihan et al. 1977:58) that inundation would alter the natural long-term effects of climate on soil and should, therefore, affect the chemical nature of the soil's organic content. Potassium, phosphates, and pH are affected most by leaching; while nitrates are affected primarily by percolation.

pH of Soils: Lenihan et al. (1977:58) hypothesized that at a specific site, absolute pH values would be altered by the effects of inundation but should still yield relative pH values that are useful for archeological interpretation.

Preliminary analysis of soil at Chesbro Reservoir by Winter (1977: 52) suggested that the pH values in the noninundated areas of 4SC152, were higher than the inundated areas of the site. Winter suggested that inundation was the causal agent in the lowered values. Confirmation of this hypothesis was provided by Stafford and Edwards:

> Siltation over portions of the site, and redeposition of midden particles, are causing misleading surface representations of true subsurface pH values rendering surface pH ineffective in determining subsurface areas...of cultural activity. (Stafford and Edwards 1979:91)

Further, it appears at this site that pH is being reduced in the soil to depths of at least 1 meter in areas where wave action has occurred (Stafford and Edwards 1979:91). A continuously inundated site in the same reservoir also exhibited a loss of pH content (Stafford and Edwards 1979:89).

In Abiquiu Reservoir, New Mexico, pH analysis of inundated sites revealed nearly homogenous values (Schaafsma 1978:83). However, the control site (noninundated) of the same type and temporal affiliation exhibited clear intrasite patterning of pH values with differences well in excess of .5, which is considered to be of archeological interpretive significance according to Eddy and Dregne (1964:12). Presumably cultural variables at the three sites were similar and, therefore, pH results should be similar. The inundated sites, whose range of pH values barely exceeded .5, appear to have been adversely impacted as a result of inundation.

An overall comparison of pH from the inundated and noninundated sites in Bluestone Reservoir, West Virginia revealed a general trend toward a more acidic soil, that is, a lowered pH value. The mean values of the test units at site 46Su3, which exhibited a gradient of inundation episodes from continuously to rarely inundated, were similar to those found at Chesbro and Abiquiu. The continuously inundated unit had a pH value of 6.9; the moderately inundated unit had a pH value of 7.34; and the rarely inundated unit had a pH value of 8.4 . Site 46Su22, only intermittently inundated, had a pH value of 7.92; while 7.96 was the mean pH value of the never-inundated site (Adovasio et al. 1980: 112-116).

Clearly, these data strongly suggest that inundation has a deleterious effect on pH analysis of inundated site soils; and they confirm the National Reservoir Inundation Study hypothesis of overall adverse effect. Adovasio and his colleagues suggested that although inundation had moderately affected the pH at Bluestone, the intra- and intersite patterning had not been adversely impacted; relative results were still useful for interpretive purposes at those sites.

Phosphate Analysis of Soils: The loss of phosphate as a result of inundation was hypothesized by the National Reservoir Inundation Study (Lenihan et al. 1977:59). The phosphate values at the Chesbro Reservoir site (4SC152) did exhibit great differences between the inundated and noninundated portions. The noninundated sample values were twice that of the inundated ones (Winter 1977:51). Stafford's data were somewhat contradictory at this site. She found that phosphate values were altered in those areas where there was no silt overburden, while it appeared that the presence of silt retarded the surface alteration of this chemical. The continuously inundated site in Chesbro did exhibit slightly lowered values. It is possible that "inundation ...[may have] an effect on decreasing values of phosphorous... in midden soils that are well aerated after long periods of inundation..." (Stafford and Edwards 1979: 101)

Schaafsma found that although internal variability of phosphate values at the inundated sites in Abiquiu Reservoir, New Mexico had not been affected, the patterning of concentrations was not as clear at either of the inundated sites as it was at the control site (Schaafsma 1978:80). He suggested a homogenizing effect on phosphorous values as a result of inundation. The continuously inundated site in Bluestone Reservoir, West Virginia also exhibited lowered phosphate values (Adovasio et al. 1980:118).

Garrison and his colleagues took the basic hypothesis of the Inundation Study a step further at Table Rock Reservoir, Missouri, and suggested:

> 1) sites located in relatively shallow water, where wind generated processes occur constantly will ...decrease in phosphate content due to leaching and erosion...
>
> 2) sites located on beaches are affected by erosional movement of soil particles, but also by leaching of chemical compounds such as phosphate ....The repeated but not permanent presence of water... increases the possibilities of leaching.
>
> 3) sites deeply buried below the water surface and located where wind generated processes seldom occur and soil transport or erosion is minimal will show little or no chemical alteration. (Garrison et al. 1979:44)

Results tended to support all of the above hypotheses with the exception of the last. A statistically significant difference was found between the inundated and noninundated areas tested (Garrison et al. 1979:62-66).

The permanently inundated site, at Table Rock, 23BY8, exhibited phosphate values significantly higher than those obtained in shallow water contexts by the researchers. On the surface this would tend to support the third hypothesis; however, this rock shelter site was used as a cattle shade prior to inundation (Garrison et al. 1979:62), which may have a direct bearing on the high phosphate values. Further, when these data are compared with that from Chesbro, Bluestone, and Abiquiu, the higher phosphate values at the Table Rock site that was continuously inundated appear anomalous. Verification of Garrison's third hypothesis must remain tentative.

It generally appears that continuous inundation will adversely affect phosphate values, although intrasite patterning may still be discernible.

Nitrate Concentration in Soils: Winter (1977:51) found that nitrate levels between the flooded and unflooded areas of site 4SC152 in Chesbro were not noticeably altered by inundation; both areas exhibited similar concentrations. Stoddard and Fredrickson, however, found low nitrate concentrations in the soil samples tested from the Lake Mendocino sites, which had been continuously inundated for nearly 20 years. Further, the striking differences in total nitrate content of the inundated versus noninundated sites in Bluestone Reservoir, Virginia (Adovasio et al. 1980:121) tend to support Stoddard and Fredrickson's findings. It was tentatively hypothesized by the National Reservoir Inundation Study that the potential for nitrate analysis would be adversely affected in direct proportion to the temporal length of inundation (Lenihan et al. 1977:59). Both the Lake Mendocino and Bluestone Reservoir sites have been inundated for more than 20 years; in contrast the Chesbro site has only received seasonal inundation for less than 10 years. These data, although only preliminary, argue strongly for confirmation of the National Reservoir Inundation Study hypothesis of adverse impacts to nitrate concentration in inundated soils.

Potassium Concentration in Soils: The National Reservoir Inundation Study has hypothesized that inundation would adversely affect potassium concentrations in the upper strata of a site but would not affect concentrations of potassium below the soil-water saturation levels. Because samples were collected from the upper strata of CA-SCl-52 (Chesbro Reservoir), only the first half of the National Resorvoir Inundation Study hypothesis could be tested by these data. The potassium values in the unflooded areas of the site were found to be twice those of the flooded areas (Winter 1977:53). The potassium values in the periodically flooded areas appeared to be dissolving at a rapid rate, adversely affecting potential data returns, at least at this site.

Lowered potassium values were also found in the inundated sites in Bluestone Reservoir, West Virginia. "The difference in potassium values between the inundated and exposed sites is not great, but may be due to leaching caused by submergence..." (Adovasio et al. 1980:117).

This limited sample points weakly toward confirmation of the National Reservoir Inundation Study hypothesis that potassium values will be adversely impacted as a result of inundation.

Organic Content of Soils: Both sites which had undergone either continuous or periodic inundation in Bluestone Reservoir exhibited reduced total organic matter. "The inundated loci have lower values ...generally ranging from .05 to 1.5% below the non-inundated loci" (Adovasio et al. 1980:117). Soils deposited on the sites during flooding appear to have an increased organic content. These sediments, deposited during quiet water conditions, may contain increased organic matter resulting from soil erosion and upstream runoff.

A loss of organic matter may have occurred at the continuously inundated Lake Mendocino sites.

> The generally low percentage of organic matter found in the soil samples from Lake Mendocino in both near-surface and subsurface samples suggests loss of organic matter may have occurred.... Lacking pre-inundation data, the possibility must be left open that the organic content of the sites was never high during the pre-inundation period. (Stoddard and Fredrickson 1978:40)

The data from both of these areas are inconclusive as the reduced organic content at the sites may have been related to cultural variables at the sampling locales. The National Reservoir Inundation Study hypothesized that flooding would not affect the percentage of organic matter in subsurface samples; however, surface soil would have reduced organic content (Lenihan et al. 1977:60). Without further testing, this hypothesis cannot be confirmed or denied.

Calcium and Magnesium: The overlapping pattern of three independent chemicals (calcium, magnesium, and phosphate) at a never inundated site (AR-512) in Abiquiu Reservoir, New Mexico strongly suggested definable activity and disposal areas. The concentrations also closely corresponded to a lithic scatter (Schaafsma 1978:77). The chemicals did not correspond as clearly at the two inundated sites, AR-8 and AR-23; calcium values were less at the inundated sites, presumably as a result of flooding (Schaafsma 1978:81). In Bluestone Reservoir, West Virginia, calcium values were significantly less at the periodically and continuously flooded loci than at the rarely flooded area (Adovasio et al. 1980:117).

The Lake Mendocino, California results are equivocal; samples were collected from two sites which had been flooded for 20 years and no preinundation baseline data were available for comparison. Calcium values ranged from 4400 to 8460 ppm (Stoddard and Fredrickson 1978: Appendix A), low when compared to another similar site in northern California which exhibited calcium values ranging from 46,000 to 15,000 ppm in an area which has never been inundated (Sjoberg 1978:43). This same site shows a significant impact to calcium values in the seasonally flooded zones, with ranges from 3000 to 1800 ppm (Sjoberg 1978:42-43). Together these data suggest that calcium concentrations are adversely impacted by continuous or periodic flooding.

Magnesium values at the inundated sites (AR-8 and AR-23) in Abiquiu Reservoir continued to form clear intrasite patterns (Schaafsma 1978:81). Adovasio found slightly higher magnesium values at the inundated loci when compared to the noninundated loci at the same site in Bluestone. He suggested that sedimentation may be adding that chemical to the site (Adovasio 1980:118). There is some indication, based upon this limited test, that magnesium might be a stable chemical after inundation and continue to reflect preinundation values.

Sodium: Sodium concentrations were relatively consistent between the sediment columns at each test locale in Bluestone Reservoir. "Values are slightly higher at the inundated loci, suggesting that sodium actually may be added to the sediments with submergence" (Adovasio et al. 1980:117). Sjoberg found little variability in sodium values between the inundated and noninundated sites both in Abiquiu and in Chesbro Reservoir (1978:40-45). Sodium concentrations may be stable enough to prove useful in delineating certain activity areas or features even after flooding.

Source Identification Analysis

The essential purpose of the chemical analysis of minerals or artifacts is to discover the components from which they are made so that their origins may be determined. From this source identification process, inferences can be made about cultural patterns, trade relations, and trade routes.

Neutron-activation analysis, optical emission spectroscopy, X-ray fluorescence, and X-ray diffraction are four analytic techniques from which identification of the constituent elements of artifacts can be made. These techniques have been applied successfully to metal, glass, obsidian, turquoise, jade, steatite, and pottery. It was hypothesized by the National Reservoir Inundation Study that inundation would not affect the analytical characteristics of silicates on those metal artifacts which can be analyzed by neutron activation analysis, optical emission spectroscopy, X-ray fluorescence, and X-ray diffraction analyses.

Retrieval of data through trace element analysis is an essential step in obsidian hydration dating. Potential problems in analytical results could stem from leaching or contamination through absorption of elements present in the water. In order to test for the effects of inundation on trace element analysis, studies were conducted on obsidian artifacts collected from 1) a site that was never inundated near Abiquiu Reservoir, 2) a prehistoric source quarry, and 3) two seasonally inundated sites. All obsidian samples used were originally from the Polvadera Peak quarry.

> The assumption underlying the test is that samples from the same quarry are chemically similar. Significant differences between the quarry samples (and presumably the uninundated samples) and the inundated samples could be the result of immersion. (Schaafsma 1978:50)

David Laing, a geologist, was contracted to perform the analysis. The conclusion reached was that inundation had no effect on trace element analysis. "Within the limitations of the present sample and experimental design, no significant difference can be demonstrated between the element composition of inundated and non-inundated obsidian artifacts" (Laing 1978:6). Schaafsma points out, however, that Laing's findings must remain tentative due to procedural errors (Schaafsma 1978: 53-56).

A total of 20 samples, however, were collected from sites within Lake Mendocino for source identification analysis. Seventeen of those specimens submitted were identified through the X-ray fluorescent technique. The source analysis was successful enough to permit obsidian hydration dating of the samples. It appears that in this case, the ability to successfully employ X-ray fluorescence as a source identification technique was not compromised by inundation.

Microscopic Analysis of Artifacts

A comparison of materials from both an inundated and noninundated context was undertaken to test the effects of inundation on microscopic analysis results of stone from Table Rock Reservoir, Missouri.

> The microscopic analysis of selected stone artifacts from inundated and uninundated contexts were ...inconclusive... Only sandstone was seen to be altered enough by mechanical action, scoring and abrasion to obscure edge wear. (Garrison et al. 1979:41)

The authors suggest that the lack of results may be due to a relatively short period of immersion (ca. 20 years). Furthermore, the effects of inundation on chert may not be as great as initially hypothesized; the microscope used may have been inadequate to detect changes; or the researchers may have been unable to discriminate between natural weathering and inundation (Garrison et al. 1979:41).

Neither plant nor animal residues could be detected for either group of artifacts examined under low to medium magnification. Inundation may not affect this category of analysis either, however, since poor preservation of organic materials is common in these sites (Garrison et al. 1979:41).

Analysis of bone fragments recovered from excavation at Folsom Reservoir, California revealed the presence of butchering scars after 20 years of periodic inundation (Foster and Bingham 1978:31). It appears that, at least in this circumstance, buried bone was not adversely affected.

Standard Survey Techniques and Remote Sensing Potential

In an era where much of the archeology is conducted under the auspices of contract or salvage programs, it has become increasingly important to combine standard survey procedures and remote sensing for site and feature detection, site location prediction, recognition and differentiation of ecological resources, and photogrammetric and digitized mapping. Remote sensing is especially valuable in situations in which a large tract of land must be surveyed or inventoried. Lenihan et al. (1977:74) hypothesized that the two factors

> that will pose the greatest limitation in post-inundation survey are siltation and mechanical disturbances ...Sites that are buried beneath deep accumulations of silt will be virtually impossible to detect or relocate by the use of standard survey procedures....Survey procedures conducted to relocate sites... will not yield comparable pre- and post-inundation results.

Resurvey potential was severely limited in the lower areas of Chesbro Reservoir due to heavy siltation. Areas of site 4SC152 were buried by up to 1 meter of silt in some areas (Winter 1977:13-17).

During the 1977 investigations at Lake Mendocino, it was found that standard survey techniques had to be "augmented by extensive augering and by more intensive analysis than usual of location data contained within archival materials, existing records, and maps" (Stoddard and Fredrickson 1977:42). Those areas within the reservoir found to have minimal silting were most easily addressed by standard survey techniques.

A silt layer varying from 2 to 5 cm covered several sites in Abiquiu Reservoir. When first observed in October 1974, they were covered by dense layers of surface lithics. Revisited in November 1975, the fine silt layer deposited in the interim effectively covered the majority of lithic scatters, rendering it impossible to undertake a detailed, controlled surface collection (Schaafsma 1978:27-28). In addition, silt deposition at AR-30 in excess of 8 feet made archeological investigation and relocation virtually impossible (Schaafsma 1978: 27).

Loss of Qualitative Data Relative to Strata and Features

Archeological data recovery is often dependent on the ability of the archeologist to subjectively discern certain values in a site that are not removable or quantifiable in the usual sense. Although natural and cultural stratigraphy can often be identified by analyzing the elements that comprise the strata, such as soil matrix for the former and cultural artifacts for the latter, the most useful indicators for the archeologist are color and texture. When not using arbitrary excavation levels, the archeologist will usually be keying efforts in accordance with visual and tactile distinctions that may have archeological significance. The presence or absence of distinctive or anomalous vegetation is another cultural indicator that does not readily lend itself to quantification. Vegetation may, however, be the only clue an archeologist has to burials, trash repositories, or food processing areas in a site.

In the acidic soils of the Southeast, an archeologist's primary inidicator of cultural activity will often be stains in the soil. These may be the only remaining evidence of a living area, burial, post mold, etc. In the Southwest, the bottom of an excavation level may often be discerned only by the clank a trowel makes when striking a hard occupation surface. To the degree that inundation results in the loss or muting of such distinctions in color, texture, culturally induced compaction surfaces, or other tactile or visual cues, it comprises a significant impact to the resource.

Lenihan et al. (1977:108) hypothesized that in certain soil types, such as sands and sandy loams, soil stains may be adversely impacted by inundation; whereas in compacted soils, such as clays and clayey loams, soil stains and colors would not be altered by flooding.

The loss through flooding of certain types of data, which were indicators of cultural features or activity areas, was documented by Garrison et al. (1979:73-77) in Table Rock Reservoir, Missouri. Three features exhibiting differential soil colors, textures, soil remains, and vegetation were first located above water level in late 1977. Approximately one year later, when the area was under nearly 3 meters of water, an attempt was made to relocate and examine the features.

The reddish color of the soil at Feature 1 was still recognizable, and associated lithics did not appear to have significantly altered. Feature 2, an area characterized by thick vegetation and red-brown silt-clay prior to inundation, was relocated after flooding only by the soil color; no original or replacement aquatic vegetation was present. Feature 3 was never relocated; the thick vegetation, readily apparent when the area was dry, had died as a result of flooding, and no aquatic replacement species were present (Garrison et al. 1979:73-77).

Whereas soil colors and textures, i.e., feature or stratigraphic indicators, did not appear to have been adversely affected at Table Rock, the vegetational indicators of features were severely impacted as a result of periodic inundation. Similar destruction of floral communities on site soils has been documented by Foster and Bingham (1978), Stafford and Edwards (1979), Winter (1977), and others. It is not known how continuous inundation would affect the formation of stable biotic communities on culturally modified soils.

In both Folsom and Chesbro Reservoirs in California, the distinctive soil colors associated with cultural occupation areas were not affected by periodic inundation (Foster and Bingham 1978; Stafford and Edwards 1979). A mixing and slight alteration of color was noted by

Stafford and Edwards (1979) at the waterline of a periodically inundated site. Wave action, terracing, and silt deposition made it difficult to determine the site boundary.

The typical soil type found in northern California middens can be characterized as a friable, gravelly loam. The integrity of texture for this soil type was substantiated by Stafford and Edwards (1979), Foster and Bingham (1978), and Stoddard and Fredrickson (1978). Soil particle analysis was undertaken on the inundated and noninundated areas of 4SC152 in Chesbro Reservoir. There was no distinct difference in the two areas; inundation had not, in this case, affected soil texture.

Adovasio et al. (1980:50-51) investigated three sites in Bluestone Reservoir, West Virginia. The soils of site 46Su3, almost always inundated, were predominantly clay and compact clay loams. Colors, and textures, as well as discontinuities, were readily discernible throughout the profile; continuous inundation had not affected the ability of the archeologists to determine soil profiles at the site.

A periodically inundated site in the same reservoir also exhibited distinct soil profiles, although the soils here had much less clay content and a more sandy loam (Adovasio et al. 1980:50-54). The limited flooding that the site had experienced may have been a contributing factor that permitted the archeologists to determine soil profiles.

In the Pacific Northwest, excavation has been conducted at Fort Coleville, Ksunku, and Chadiere, sites which have been inundated annually for 40 years, and distinct soil horizons, stains, housefloors, storage pits, hearths, etc., have been clearly in evidence (Chance et al. 1977). Some gleying of sediment colors may be occurring (Chance, personal communication), but generally both visual and tactile cues have been unaffected by inundation.

It appears from this sample that soil colors and textures are only slightly affected by inundation. The more compact or the higher the clay content of the soil, the better these cultural indicators are preserved.

Conclusion

The information presented in this section reinforces the statements made elsewhere in this volume -- that reservoir impacts are not all good nor are they all bad. The mixed responses to inundation in the area of soil chemical analysis alone is indicative of the trend for all of the dating and analysis techniques; while pH is reduced, magnesium appears stable; where nitrate and phosphate concentrations are not altered, calcium and potassium are dramatically impacted. In each of the tested categories we found that results were variable; there was some continuity, however, nation-wide. Clearly, decisions regarding the selection of sites, the nature of site testing and excavation, and the collection of specific data elements within sites have to be prioritized based upon the ultimate impacts of flooding.

The kinds of questions that may be answered only through soil analysis will be difficult to address following flooding. Certainly that data will have to be gathered from sites prior to impoundment. Absolute dating based upon C-14, obsidian hydration, archeomagnetic, fission-track, and alpha-recoil dating are not compromised, although the latter two are affected in uranium rich soils. The thermoluminescent dating technique is impacted, but relative dating by seriation of response is still possible. Source identification analysis for most categories of material is still viable, as is microscopic analysis of artifacts.

Standard survey techniques are compromised by flooding and siltation. Flooding, however, does not appear to impact soil colors, features, or stratigraphy. Vegetational indicators of cultural activity are affected; these die back and are not replaced by stable aquatic species.

Not all of the potential dating or analysis techniques were researched during this study. Some areas received heavier emphasis than others simply because of the availability, or lack thereof, of the necessary samples for testing. Continued research into the usefulness of the full range of dating and analysis techniques is still needed to completely understand the long- and short-term impacts of freshwater flooding.

CHAPTER 5: MITIGATION

PROBLEM OVERVIEW

As indicated in the introduction, it is assumed that reservoirs will be constructed and that it is unrealistic to attempt total data retrieval from all sites in an impoundment zone. This is due not only to the practical problem that there are limited funds available for conducting archeological research in response to reservoir impacts but also to a more philosophical consideration. Even if unlimited funds were available, it is essentially impossible to retrieve all relevant archeological data from any particular cultural deposit. As the state-of-the-art changes, so do the myriad possible research questions that an archeologist could conceivably ask of any particular site.

The archeologist and the resource manager are confronted, therefore, with two polar options for mitigation of an adverse action: 1) salvage as much as possible of the most "significant" information in a given impact zone or 2) use all or part of the available funds on protective measures with an eye towards future data retrieval when methods and technology are more developed.

There are a number of considerations which occur on a philosophical and practical level regarding the adoption of either of these approaches exclusively or in combination. We will examine these considerations individually.

Significance As The Only Criterion For Mitigation

The Cultural Resources Management (CRM) literature has yielded lengthy discussions on the significance of analyzing one site over another or one problem orientation over another (Moratto 1975; Schiffer

& Gumerman 1977; Grady 1979). Questions of regional, local, and public significance (Moratto 1975), significance as "representativeness" (Hickman 1977), minimally acceptable data recovery standards, and the problem of tunnel vision regarding significance due to the parochial interests of certain researchers have all been raised. National Register criteria address these questions to varying degrees. Although the issue of significance is admittedly one of the primary concerns in determining where emphases should be placed in reservoir mitigation programs, it is only half of the equation. The other side is understanding which of those aspects of the resource deemed the most significant in any one instance are the ones that are also the most susceptible to negative impact by inundation.

The results of this study will provide much in the way of insights into that major issue, but these data become relevant only to the degree that they are internalized by archeologists and managers in decision-making roles. It is no longer acceptable to develop an orientation towards mitigation in a specific drainage system without considering the question of which archeological resources are the most vulnerable to adverse affects. The burden of familiarizing oneself with the conclusions of the Inundation Study and related studies is directly upon archeologists who serve as principal investigators in major salvage programs.

Sites As The Basic Unit Of Concern

Associated with the question of deciding upon which aspects of the resource to concentrate mitigation efforts is the related one of what is the appropriate unit of concern, i.e., sites, specific research questions, data categories, etc. The basic unit around which mitigation frameworks are often structured is usually the "site." This is unfortunate since it is not a particularly meaningful concept when considering susceptibility to inundation effects. Different classes of data within particular sites are often much more vulnerable to adverse effects than others. Furthermore, the interrelationship of sites in the drainage along with the associated environmental factors that influence site distribution and cultural behavior are often compromised by inundation, even if particular sites in the drainage are not. This is in addition to the more obvious problem that they are often an arbitrarily defined construct of the archeologist, and their perceived boundaries may not be meaningful in a cultural sense.

The Inundation Study has based its approach on the general and less restrictive concept of "archeological resources" which may or may not be site-specific. These include various classes of material remains such as lithics, ceramics, soil chemistry, and pollen, as well as different types of qualitative data such as soil colors and textures. The suitability of certain classes of material remains for different analytical or dating techniques is another area of inquiry. For example, the fact that obsidian samples remain intact in a site and undergo no impact on their contextual relationships or morphology does not necessarily mean they have not been impacted -- if their affinity for obsidian hydration dating has been altered.

These archeological resource categories have served quite well as basic units of study regarding archeological impact. The scheme also presents options at the mitigation stage which allow for selective data retrieval of the most threatened classes of data as opposed to total site excavation. It permits the archeologist who is sampling a broad range of cultural expression in a diverse population of sites to concentrate on data categories which are most likely to be destroyed by the inundation event.

On the macrolevel, the Inundation Study has been concerned with impacts on the class of information to be gleaned from intersite relationships. The impacts to remote sensing and other forms of area inventory, including general ecological data, can only be mitigated by conducting this form of data retrieval before flooding takes place. It is a critical aspect of any reservoir mitigation program, therefore, to emphasize analysis of the general environmental milieu within which cultural factors were operating. This critical information will be difficult to reconstruct after inundation has taken place.

Zonation In Reservoirs As A Mitigation Consideration

It is critical that any mitigation strategy in a particular impoundment area includes recognition of the fact that, in addition to variable susceptibility of different material remains to inundation, location in the impoundment is another factor in differential impact. Although we use a five-zone model in this report, the three most critical zones of variability in a reservoir for the purposes of brief discussion are the permanent pool, the fluctuation zone, and those areas above the anticipated highest flood pool. Garrison (1975) conceived of a similar model using what he termed active, transitional, and static zones in his discussion. Grady (1977) used five zones, but one of them is the area of direct impact from the construction of the dam itself and is not relevant to our model.

In each of these areas, different classes of impact can be expected to dominate at different times. The initial flooding of areas within the permanent flood pool can be devastating in terms of mechanical impacts; but after a permanent pool is established, the prime consideration presumably becomes largely biochemical in nature. If this assumption is not true and mere presence in a saturated soil matrix for long periods of immersion would tend to displace cultural remains, this would indeed become a pivotal issue. Although there has been no indication of this possibility in reservoirs thus far examined, it must be remembered that our study sample is from present-day reservoirs which have only been in existence for a few decades. The projected lives of some reservoirs, however, can be figured in hundreds of years. Fortunately, corollary work in springs and sinkholes (Cockrell, Clausen) has revealed that stratified sites in those particular environments seem to have kept their contextual integrity for thousands of years of inundation. However, the sample is very small, and the evidence on this question is still inconclusive.

In the fluctuation zone (the "drawdown zone"), the prime consideration is almost always mechanical displacement of material remains. The area outside of the anticipated flood pool or high-water zone is one in which human impacts (resulting from increased accessibility) become paramount. Here, management of the dam after water is impounded may be the prime mitigation consideration.

In the mitigation model that will be presented in this section, reservoir zonation is a critical factor, and an attempt will be made to present a scheme that crosscuts the different agencies' terminology in favor of zones that are the most meaningful for the purposes of cultural resources management.

Underwater Archeology As A Postinundation Mitigation Alternative

A factor which must be evaluated in any reservoir mitigation scheme is what role underwater archeology may play in retrieving data after flooding has occurred. Most of the archeologists in the National Reservoir Inundation Study core team have had prior underwater archeological experience on a state or federal level and have been consistently involved with underwater data-retrieval problems during the course of their Inundation Study research. Therefore, they approach the question with a reasonable appreciation of the capabilities and limits of the existing technology for working with submerged sites. There is general consensus on the following two points: 1) Underwater archeology should not be considered as a planned aspect of any particular mitigation strategy. There is a misconception upon the part of many land-bound archeologists as to the supposed limits of data retrieval in underwater archeology, and they tend to overestimate the expenses involved. The fact still remains, however, that a great number of complexities are introduced into the situation when a terrestrial site is covered by water, and it will <u>always</u> be more cost efficient to excavate the remains before they are immersed. 2) The reverse of the issue, however, is that for sites already impounded (e.g., in reservoirs built before strong mitigation legislation was enacted), the use of underwater archeological techniques to retrieve new classes of data to speak to new research problems should be seriously considered. It is an indisputable fact that usable data exist in thousands of sites inundated by reservoirs and that the technology exists to get at much of it. Principal investigators involved in reservoir pool enlargement programs, for example, should consider the possibility of carrying out limited underwater investigations on major sites in the old pool before the water level over them is raised.

The applicability and feasibility of underwater archeological techniques in impoundment areas will exist in inverse relationship to the depth, turbidity, and cold of the water environment surrounding the site. Volume II of this report will provide a resource for principal investigators to better understand the limits and application of submerged site technology to reservoir mitigation programs.

Variability In The Construction Process

Another important factor in developing a mitigation model is that of differences in the bureaucratic stages of the reservoir construction process. An observation made very early in the course of development of Inundation Study research was that if certain mitigating actions could be worked in earlier in the construction process, it would result in much greater cost efficiency. A case in point would be to work archeological remote sensing formats into the standard aerial remote sensing that is conducted during a reservoir's planning stages. Often the mechanism is not organizationally present to authorize funding at this stage, but it can be demonstrated that it would be of enormous benefit if such agency organizational obstacles could be overcome.

It should be emphasized at this point that intelligent mitigation of impacts to archeological values in reservoirs cannot transpire if there is not strong communication and coordination between archeologists, engineers, and reservoir managers. This should begin in the early stages of planning and remain strong during the field phase when contacts between field archeologists and other reservoir scientists from the construction agency involved could make the ultimate difference in whether a site was effectively protected or not. This report can provide important guidelines and rules of thumb for understanding and dealing with inundation effects on cultural resources. But it is imperative that, on a case-specific basis, the advice of hydrologists and soil scientists is actively sought for implementing any mitigation plan.

Clarification of Legal Status of Inundated Sites

The last major consideration in developing a viable model for mitigation of inundation is related to clarification in the National Register and in state preservation guidelines of the status of cultural resources once they are inundated in reservoirs. A spot-check of various State Historic Preservation Officers has revealed inconsistency and confusion over this issue on a national level. In many cases, a National Register site is pretty much written off once the requisite mitigation actions have occurred and the resource is flooded. Quite often, however, a great deal of research value remains in these sites, and various postflooding management alternatives might be invoked to minimize further damage. It is hazy, however, as to what degree the legal mechanisms for continuing forms of protection over the site can be operationalized. Recognition of the fact that many classes of material remains may be only minimally affected by inundation may lay the groundwork for ensuring that protection should be extended to the postinundation period.

A PROPOSED MODEL FOR MITIGATION

Mitigation of anticipated impacts to archeological resources may take any combination of three basic forms:

1. Avoidance: If a cultural resource inventory indicates that there will be significant impact on valuable resources in the impoundment area, the option always exists to redesign the proposed construction in such a manner that the impact is avoided or at least minimized.

2. Data Retrieval: As much as possible of the threatened data base may be salvaged through archeological investigation. Criteria for selection of those archeological resources to be emphasized should depend on the assessed significance of the resource and their projected susceptibility to impact.

3. Protective Actions: May include the following:

a. Backfilling after partial site excavations -- this is often not done by archeologists prior to inundation of a site during the normal course of reservoir salvage but it should be standard operating procedure. Backfill material acts as a buffer to the mechanical effects of inundation.

b. Installation of energy-dispersing devices -- such structures serve to reduce the destructive force of mechanical impacts during the initial flooding process for areas in the permanent pool and in those areas subject to fluctuating water levels. Such devices include:

riprap
checkdams
breakwaters
cofferdams

c. Soil coverings -- which tend to reduce mechanical action to the surface of a site, including erosional and undercutting processes. Asphalt and gunnite have been experimented with to a limited degree by the U.S. Army Corps of Engineers and have been tentatively judged successful.

d. Soil sealants -- a discussion of the utility of different sealants will be presented in Volume II, Technical Report No. 7.

e. Managerial - this would include the creation of restricted-use areas for visitation in recreation areas and limitations on operation and maintenance activities, such as dredging, by the construction agency.

A discussion of several experiments in site stabilization and protection may be found in Volume II, Technical Report No. 1. These general mitigation alternatives may be visualized within the context of a two-dimensional matrix that delineates the nature of the archeological values to be impacted on the macro- and microlevels discussed earlier and the categories of impact that can be expected on any particular value.

A simplified restatement of such a matrix that appears in more detail earlier in this report is found in Figure 5.1.

Figure 5.1

Impact Categories / Archeological Resources	Large-Scale Data: Regional ecological considerations such as geomorphology, settlement patterns, faunal & floral distributions.	Medium-Scale Data: Site contextual data, stratigraphic and spatial relationships within a site.	Small-Scale Data: Differential impacts on common cultural materials including artifacts, features, analytical properties, etc.
Mechanical Impacts	Mechanical (siltation and erosion) and biogeochemical impacts to the reservoir drainage basin, including gross geomorphological changes; impacts to preinundation floral and faunal communities, etc.	Near-shore wave action, erosion and siltation of sites and site deposits.	Mechanical abrasion, freeze-thaw, and wet/dry impacts to artifacts and other cultural materials.
Biochemical Impacts		Biochemical alteration of site soil and contextual relationships.	Differential biochemical deterioration of archeological material categories.
Human and Other Impacts	Dam & barrow pit construction, roads, clear-cutting, etc.	Vandalism, recreational use. Impacts to shoreline by grazing animals; impacts by invader plant species, etc.	Removal of selected artifacts by collectors, etc.

A valuable framework for assessing mitigation alternatives in regard to particular impact on any cultural value is to consider the options in light of reservoir zonality described earlier. Thus, we round out our general mitigation model by adding one more conceptual scheme within which to operationalize the other elements; that is, the concept of reservoir impact zones which are represented by reservoir pool levels (see Figure 5.2). The impact zones can be summarized as: 1) permanent conservation pool, 2) shoreline fluctuation zone, 3) upper flood pool zone, 4) backshore zone, and 5) downstream zone.

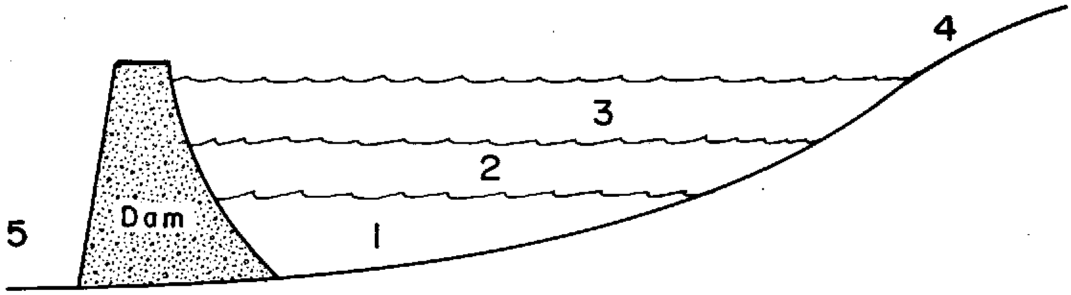
Physical Reality of Zones

Each of the impact processes listed in the matrix in Figure 5.1 tends to predominate in different reservoir zones at different points in the life of the impoundment. This will be demonstrated as we operationalize the model.

Bureaucratic/Legal Reality of Zones

Each of these zones has traditionally been accorded differential treatment by reservoir managers, archeologists, and cultural resource advisory bodies in past mitigation programs.

Figure 5.2



1 Permanent Conservation Pool
2 Shoreline Fluctuation Zone
3 Upper Floodpool Zone
4 Back Shore Zone
5 Downstream Zone

Zone 1 - Permanent Conservation Pool

This zone consists of that portion of the reservoir below the average annual drawdown. Archeological resources within this zone are inundated by the initial reservoir-filling episode and remain under a water column except in instances of severe drawdown.

Mechanical Impacts: Erosion occurs during initial inundation episodes; the extent of impact depends on filling rates, fluctuations in filling rates, geomorphological and vegetation variables, relative fragility of archeological resources, etc. Once sufficient depth of the water column is achieved, erosion will stop, with the exception of possible slumpage of saturated soils. The regime will change from erosion to deposition. Deposition may enhance preservation but will pose problems of data accessibility. Also, the weight of accumulated sediments may warp cultural deposits, although no indication of this can as yet be documented.

Biochemical Impacts: Biochemical impacts should be predictable on the basis of stream inflow data, soil/vegetation chemistry, and silt deposition rates. Depth of site in water column, water temperature, siltation rate, and duration of inundation should predict microbiological activity at specific sites. Biochemical process/decomposition rates should drop off dramatically once the reservoir ecosystem stabilizes and certainly after a silt mantle is deposited.

Human and Faunal Impacts: Impacts may result before inundation from dam and borrow-pit construction, clear-cutting, bank stabilization, and other activities associated with dam construction. After inundation, human impacts in Zone 1 should be negligible, except in instances of severe drawdown. Scuba divers and fishermen may pose threats, but these should be less significant than natural processes. Faunal impacts in this zone would be minimal, being primarily a function of postinundation burrowing by bivalves in cultural deposits.

Zone 1 Mitigation: There is potential for long-term preservation of resources in this zone if the mechanical impacts from initial filling episodes and human impacts from dam construction can be mitigated. On-site preservation may be a viable option. Attempts should be made to predict biochemical impacts so that materials susceptible to attack can be salvaged. Also to be considered is the problem of long-term loss of access to data if it is "preserved" under meters of silt for hundreds of years. Correlative to this consideration is the question of usefulness of any information so preserved when the larger environmental context of that information is lost.

Zone 2 - Shoreline Fluctuation Zone

That portion of the reservoir that is periodically exposed to shoreline processes (usually on an annual basis) is the shoreline fluctuation zone.

Mechanical Impacts: Continual to intermittent erosion due to nearshore wave action and wave-induced currents is a significant problem, as are secondary erosional processes such as wind deflation and water runoff. The latter two are enhanced by the absence of protective vegetation cover. Other significant problems include wetting and drying, freeze/thaw, invader vegetation, and so on.

The most critical preservation variables are wave approach and intensity and the nature of shoreline geology. In general, these will determine the eventual location and configuration of the reservoir shoreline, which in turn will determine which sites will be subjected to direct impacts from the high-energy beach zone. Shorelines will be much more predictable in poorly consolidated, sandy sediments, which will tend to form an equilibrium beach profile. Shorelines will be much less predictable in well consolidated, clayey soils or where heavy vegetation intervenes in the formation of a predictable beach profile. Pool-level fluctuation, which relates to reservoir function and watershed characteristics, is also an important variable in shoreline prediction.

Biochemical Impacts: Biochemical activity is predictably greater in the shallow water of the fluctuation zone because of increased light penetration, higher levels of dissolved O_2, high temperatures, etc. There should also be higher density and greater variety of organisms to attack perishable cultural materials; thus, preservation conditions are not as good as in Zone 1.

Human and Faunal Impacts: Human and faunal impacts, both intentional and unintentional, are greater at the reservoir shoreline than in any other zone. Recreational use of a reservoir is concentrated on the shoreline. Impacts may be particularly severe during a drawdown when sites, stripped of a vegetation camouflage, are both accessible and highly visible. In addition to direct impacts, boat wakes may be a significant source of waves, especially on small or sheltered recreational lakes which have insufficient fetch for the generation of significant wind waves. The same holds true for some portions of certain large lakes.

Zone 2 Mitigation: In most cases, excavation is probably the cheapest and most effective mitigation alternative in Zone 2. The intensity of mechanical and other impacts in the shoreline zone are such that few shoreline stabilization techniques can be judged both effective and cost-efficient over the long term. In all cases, the cost of maintaining the protective installation indefinitely must be added to the initial cost of the installation, making site stabilization in the shoreline zone an open-ended investment. One may also consider the use of site stabilization as a short-term or temporary alternative to excavation in instances where funds or an adequate research design are unavailable.

Zone 3 - Maximum Flood Pool Zone

That portion of the impoundment area that is subject to occasional inundation, e.g., during a period of extremely heavy runoff.

Mechanical Impacts: During the occasional flooding events that this zone would be subjected to, some erosional and slumping impacts may occur. The severity would be dependent on how quickly the waters rise and recede over any particular contour level in the reservoir. The longer the duration of the high-energy area, the heavier the impact. In most geological contexts, however, such a flooding event would be considerably less destructive than in Zone 2, for the high-energy zone is moving over areas that still have their vegetative mantle intact.

Biochemical Impacts: As in Zone 2, there will be some expected changes in this area's microbiological activity due to the radical change in the biochemical environment. If the event is of short enough duration, however, the inundated soils should reestablish their biochemical equilibrium fairly quickly, especially if the original botanical population has not been decimated.

Human and Faunal Impacts: Human and faunal impacts may be severe in Zone 3. In the canyon lands of the Southwest, weekend boaters make special efforts to visit Puebloan ruins that are much more difficult to reach during normal water levels, and the increased visitation takes a considerable toll. In other parts of the country, grazing livestock concentrate their activity on exploiting the newly rising beach zone. The result is heavy impact to surface materials. Cattle with their hooves may totally devastate the top 8 to 10 inches of topsoil in bands several meters wide for most of the extent of the reservoir.

Zone 3 Mitigation: Notwithstanding the above detailed impacts which may develop, this zone is still a lower priority than Zone 2 for mitigation; however, it should in many instances be seen on a par with Zone 1 for mitigation action. Site stabilization is a more viable mitigation alternative in this zone, since the high-energy level is short-lived and the open-ended commitment to preservation is not as demanding as in Zone 2. It is also important that management actions be taken during the flooding process in this zone in association with any excavation or preservation activities. Increased patrols by agency enforcement personnel along with the creation of no-wake zones would be beneficial in many cases.

Zone 4 - Backshore Zone

That portion of the reservoir beyond the level of the maximum flood pool which should never be subjected to inundation, extending upstream to include any or all of the immediate reservoir watershed, is the backshore zone.

Mechanical and Biochemical Impacts: No direct, but numerous indirect, impacts are present at this zone level. Constructing a dam on a watershed may alter upstream gradients and geomorphology and thus have broad implications for regional ecological changes. The ecological data base may be altered, and sites miles upstream from the reservoir may be directly impacted by stream regimen and geomorphological changes precipitated by dam construction.

Human and Faunal Impacts: The potential for human impacts in Zone 4 is great. A recreational reservoir may open up previously inaccessible areas to human visitation. Consequently, reservoir construction is in many ways comparable to highway or other kinds of construction activity: it may compromise cultural resources miles beyond the actual reservoir shoreline. Impacts from faunal activity are a minimal consideration in this area.

Zone 4 Mitigation: The extent of mitigation responsibility in Zone 4 will be a function of reservoir usage and anticipated backshore impacts. The kinds of mitigation alternatives will vary, depending on site visibility, fragility, etc. That is, excavation may be a most viable alternative if the resource is extremely visible and/or fragile; in cases where sites can be frequently monitored, stabilization might be an effective alternative, and if sites are well buried or otherwise difficult to recognize, then no action might prove to be the best mitigation alternative.

Zone 5 - Downstream

The area downstream from the dam, including the stream channel, floodplain, and terraces or other fluvial features, is included in this zone. Also included are any man-made landscape alterations that are a result, directly or indirectly, of dam construction.

Mechanical and Biochemical Impacts: Construction of a silt trap on a drainage often transforms the downstream channel into an eroding as opposed to an aggrading stream, resulting in floodplain erosion that may adversely impact cultural resources. In addition, changes in downstream water quality parameters (i.e., temperature, water chemistry, etc.) may alter the downstream ecology and the faunal-floral baseline.

Human and Faunal Impacts: Downstream human impacts may include such activities as recreation, irrigation, power generation, settlement, etc.

Zone 5 Mitigation: No clear-cut policy or authority for mitigating downstream impacts exists. In fact, there may be no precedent for an agency accepting responsibility for downstream impacts. This problem would appear to bear examination.

OPERATIONALIZING THE MODEL

The key to operationalizing the mitigation model is to ensure the greatest cost efficiency. That is largely dependent on how productive the interface is between the archeological community and the appropriate reservoir managers. Each agency works under somewhat different funding and operational constraints, and each deals with the cultural resource management issue as only one of a large number of environmental concerns which are peripheral to the agency's primary mission of providing flood control, irrigation, and power services to the nation. It behooves the archeological community in any particular region to become conversant with their counterparts in these agencies and to keep communications open regarding all projects in their area, even those that have not reached the mitigation stage.

Traditionally, dam construction agencies have not funded archeological activities past preliminary reconnaissance surveys until land modification activities associated with the construction of the dam (access road, etc.) start to take place. There may be some consulting of existing documents to support comments in a preliminary Environmental

Impact Statement, but it is rare that any serious field research is undertaken until that time.

It is the opinion of the Inundation Study researchers that it would benefit both the resource and construction agencies if more definitive action could be taken earlier in the process. Some focus on archeological resources inventory worked into the planning phases of the program could help in avoiding problems that are bound to arise during the construction period. By working archeological resource concerns into the standard environmental data-retrieval operation during the planning stage, much research could be accomplished for considerably less expense than if a special study had to be conducted later. This might include slightly modifying standard formats for aerial remote sensing, and geomorphological and soil studies.

The actual steps in the dam construction and maintenance process differ considerably for each Federal agency. However, they can all be schematically presented in four phases which are the meaningful units for archeologists concerned with mitigation. They are as follows:

1. Preauthorization feasibility study

2. Postauthorization advanced engineering and design

3. Construction phase

4. Operation and maintenance phase

We will discuss each of these phases, identifying what interface, if any, has traditionally occurred with archeologists at each point and suggesting new points of integration.

Preauthorization Feasibility Study

This is the stage in the reservoir planning and development process when a defined problem dealing with flood control, need for power, irrigation, etc., has been presented to a construction agency and the agency is given a mandate to explore possible solutions. This may or may not involve construction of a dam, and the agency is expected to generate studies which examine general feasibility of construction given only a preliminary assessment of possible environmental impacts. Many projects never go beyond this stage but are terminated on the basis of low cost-benefit ratio or obvious extreme environmental concerns.

Understandably, most agencies have been reluctant in the past to commit much in the way of financial support to archeological investigation at this stage. It should be emphasized, however, that concerns for impacts on cultural remains should be given equal consideration with concerns for impacts on natural resources at this stage. It would benefit the agency to apprise itself of the existence of any known resources of any great significance in the area. This is sometimes done through consultation with extant documents and local archeologists. Although funding full-scale surveys of all the alternative prospective impoundment areas at this time would not be justified, reservoir managers should evaluate the benefit of some active field inventory. Rather than justify this on the basis of a particular reservoir assessment study, it might be conducted on a regional or district basis. For example, a particular district office might evaluate the utility of funding development and implementation of an archeological sampling design in a system under its control. Developing such a generalized baseline inventory over time would permit reservoir managers to have a much better picture of potential problems that would arise in future impoundment modifications or construction programs. Such inventory activities could not technically be considered mitigation in the traditional sense of the word, since the impact has not yet taken place and any costs involved should not count against the authorized 1% limit for mitigation funding. It is, however, mitigation in the broader sense; i.e., when considering long-term impacts over an entire drainage complex. It would seem that over time such a program of planned rather than reactive inventory would be both less costly and more efficient.

A corollary to the reservoir-specific situation is the approach taken by the Corps of Engineers in the Galveston District regarding dredge-and-fill operations in their area. They have initiated a program of sampling surveys for shipwrecks in high-probability areas even where no immediate bottom modification activities are intended. At a comparatively small expense, they have greatly improved their chances of being able to identify problems with archeological resources in their long-range planning process.

Postauthorization, Advanced Engineering and Design Stage

During this phase of the reservoir construction process, the agency has made a tentative commitment to go ahead with a construction project, and Congress has authorized its funding. As a result of advanced design changes, the location of the dam or related land modification activities may still be somewhat altered, but the basic decision has been made. Traditionally, there has usually been no funding for archeological mitigation at this point. Still, an environmental impact statement is usually generated even if there had been one resulting from the first phase, since the old one may well be outdated. This will usually be done in conjunction with or as part of an overall General Design Memorandum which deals with such agency concerns as land acquisition, real estate assessments, etc. There has been at least one occasion in which a large-scale inventory was funded during this stage, but this is apparently the exception and not the rule. The main observation that could be made as a result of Inundation Study research is that a large-scale inventory is best begun as soon as possible, since it is a time-consuming process. If the agency waits for the actual construction phase of the reservoir to conduct such inventories, the mitigative option of avoidance is all but precluded.

Construction Phase

In this stage of the process, construction funds have been appropriated, and the first land modification activities have begun. Any archeological work undertaken using these funds can be considered mitigation in every sense of the word, and all expenses count against the 1% limit.

There are two basic problems that Inundation Study researchers have noted regarding the manner in which mitigation plans have been developed and implemented in the past. The first is the tendency for principal investigators to consider site significance as the only criterion when selecting a focus for mitigation activities. This, of course, indicates that a basic assumption has been made about the homogeneity of impacts from inundation on all archeological resources. This report should put that notion to rest, along with the associated attitude that archeological resources can be discounted once they are "lost" in a reservoir.

The second basic problem is the tendency for archeologists and reservoir planners alike to assume that impacts will be heaviest in the permanent pool (Zone 1), less damaging in the fluctuation zone (Zone 2), and nonexistent in the areas beyond the maximum flood pool (Zones 3-5). This concept of an impact hierarchy is in many cases inaccurate.

It has become clear from our research and field observations over the past four years that the area of most critical impact will be the shoreline fluctuation zone (Zone 2). The high-energy and wet/dry cycling associated with this area comprises a devastating impact on most classes of archeological resources. It should be noted, however, that the permanent pool (Zone 1) will undergo quicker and more definitive loss of access to archeologists. Consequently, we recommend that those areas of the fluctuation zone which are subject to frequent cycling be accorded equal weight with those areas in the permanent pool when considering mitigation alternatives.

Those sites or parts of sites which are located higher in the flood pool (Zone 3), where they will undergo only occasional inundation for short periods of time during exceptionally high water, may be considered less vulnerable to direct mechanical impacts. There is another problem, however, which arises when considering this zone along with those areas in the drainage which are beyond the maximum flood pool, and that is increased access to the general public.

In many Southwestern reservoirs, the water recreation areas created as a result of impoundment draw greatly increased visitation with accompanying human impacts to nearby sites. This can be variable in terms of impact severity. In some cases, visitor impact can be negligible while in other reservoirs it can be a major consideration. An example of the latter would be the deep canyon areas of Lake Powell formed by the Glen Canyon Dam on the Colorado River. Before the impoundment of waters in Glen Canyon National Recreational Area sites, the upper canyons were only visited by intrepid backpackers and climbers. With the greatly raised water level, thousands of weekend boaters are able to casually visit the highly visible Puebloan ruins which are the dominant prehistoric cultural expressions in the area. Consequently, vandalism has increased at a geometric rate, and some entire sites which were the focus of preinundation stabilization experiments by the Inundation Study were totally destroyed by visitors before the water even reached the sites.

In summary, the construction phase of the reservoir process has been typified by an overly simplistic view of an impact hierarchy. Traditionally, the construction agencies have not confronted the problem of alleviating impacts in areas not directly subjected to land modification activities. It is recommended that this approach be reassessed and more attention be given by both reservoir managers and contract archeologists to the zones of less immediate impact when developing mitigation schemes.

Operation and Maintenance Phase

Most dams in the United States were constructed before the 1974 amendment to the Reservoir Salvage Act (Moss-Bennett legislation) provided specific authorization for using construction funds to mitigate impacts to archeological resources. Consequently, the major Federal dam-building agencies are conducting mitigation in some older impoundments which are funded to the limit of 1% of original construction costs. For example, sites coming out of the old permanent pool during a drought period have been reexamined and excavated using this funding mechanism.

In those cases where a lowered water level is the motivating event in planning postinundation research, it is highly recommended that archeologists and resource managers plan investigations as quickly as possible. Water retreating from a land face after long-term inundation creates a condition in which surviving resources are particularly vulnerable to additional impact. The saturated soils are weakly bonded and particularly susceptible to sheet erosion from runoff and wind erosion, especially since the protective vegetative mantle is gone. Cultural remains are also much more visible, and sites are more easily located at this time by archeologists and pot hunters alike. It is incumbent upon the archeologist to get to these resources before the vandals and before pioneer vegetal growth moves in to obscure sites and make resurvey more difficult. An additional consideration in this regard is the propensity for faunal impacts to increase. For instance, at Folsom Reservoir in California, surviving occupation floors were invaded by raccoons. They were exploiting the clams which had selected the organically rich cultural deposits as a home (Foster and Bingham 1977).

A final point must be made regarding archeological investigation during the operation and maintenance phase: When dealing with already inundated sites, the archeologist should make strong use of the information in this report and others that addresses the question of biochemical impacts to analytical and dating techniques. It is, for example, not a wise use of funds to extract numerous soil samples and have them analyzed in a situation where they are going to have minimal value because they were subject to leaching and homogenization.

Conclusion

Bjorn Simonsen, a Canadian archeologist, has written about impacts on certain maritime archeological resources in Canada. He states that "the most common 'mitigative measure' employed by archeologists in the past has been salvage excavation. One cannot help but feel that this action has only too often been the result of direct exploitation of archeological resources by archeologists as there are clearly other mitigation choices available in many situations" (Simonsen 1978). Schiffer and Gumerman indicate in their section on mitigation in Conservation Archeology (1977) that to keep in tune with Lipe's conservation model (Lipe 1974), avoidance or protection are always the preferred alternatives to excavation. They also acknowledge in the same paragraph that " . . . application of the conservation model can become somewhat complicated with no clear-cut solutions indicated" (Schiffer and Gumerman 1977). Problems noted include the question of what "preserving" sites for the future really means, and they raise the issue of accessibility of preserved sites. This becomes an essential consideration when developing a mitigation plan for any reservoir. Research by the Inundation Study team has shown that many archeological resources may be preserved from significant damage resulting from inundation, but this could prove meaningless if accessibility to the resource is severely compromised.

One final quotation from Schiffer and Gumerman ought to be noted, since it probably represents the thinking of many archeologists on this issue:

> [O]ne might formulate the general principle that the preservation option (without further, immediate research capability) be reserved for nonunique sites. Thus portions of well-excavated sites and examples of common sites could be recommended for preservation, while rare types of sites -- data from which are likely to be in demand for research questions in the foreseeable future -- should be excavated using the best possible research design. Naturally, the cost differential will often make the preservation alternative more attractive to the sponsor; and this will require the archeologist to

> construct convincing arguments about the meaning of adequate mitigation in particular situations. . . . (Schiffer and Gumerman 1977)

Their remarks on this issue are well taken, but several observations on this philosophy need to be made. First, the unit of concern in their argument is "sites," and the problem with that orientation has been addressed earlier in this section. Suffice it to say that different components of sites suffer different impacts in many cases. There is a great deal of nonsite-specific environmental data that they are overlooking in their approach. Second, they have a misconception, as do many archeologists, about the relative costs of preservation as opposed to excavation. In many cases, a real commitment to adequately prepare a site for inundation with the goal of indefinite preservation, i.e., protection of most archeological resources present and installation of definitive site marking and relocation systems, may be far greater than the costs of excavation. Compromise measures, which they also suggest, are more feasible but are subject to many of the same expense problems which occur in a total protection plan.

As a general rule, a large site or series of sites judged to be significant by the archeological and cultural resources management community and worthy of definitive mitigation action should be approached in the following way:

1. The principal investigator on a mitigation contract should sit down with appropriate reservoir scientists -- i.e., hydrologists, soils experts, engineers, etc., -- and develop a realistic picture of what sort of reservoir dynamics are expected to take place over the archeological area involved. This report can provide much in the way of key questions and considerations to be discussed with construction agency personnel. It can also reveal the relative significance of various areas. With this enlightened perspective, a schematic plan for mitigation can be tendered.

2. The principal investigator may then apply a state-of-the-art research design that addresses relevant anthropological problems and regional research concerns. This may entail excavating certain sites in the impoundment area.

3. The research team then would sample the chosen sites, concentrating on those types of samples that represent archeological resources most

susceptible to inundation impacts; e.g., soil chemistry, monoliths, bulk carbon, thermoluminescent dating samples, pollen profiles, etc.

4. The research team should also retrieve adequate environmental data from those areas of the drainage around the site that will ensure the site can be seen in a meaningful paleoenvironmental context.

5. The team next attempts preservation of what appears to be a representative portion of the site or sites. This may take a number of different forms, each of which is discussed elsewhere in this report.

6. The researchers should ensure that the sites can be relocated either underwater or, when dry, when the area is covered by a silt mantle. Guidelines for doing this are presented in Volume II, Technical Report No. 8.

7. Finally, the archeologists should take action to ensure that the area is not impacted through the regular reservoir operation and maintenance process; e.g., make the relevant construction and management staff aware that they have an area in their impoundment that should be restricted from dredging operations. Also to be considered is the question of sites possibly retaining National Register status after inundation.

There is every reason to believe that, given the right approach, many archeological resources can be preserved in reservoirs for posterity in the context of a generalized protection program. However, it should never be confidently assumed that any particular site will be well preserved. Actions should always be taken that are predicated on a realistic picture of the problems discussed above which are involved in active site protection, and it is wise to accumulate as much data as possible prior to inundation, from any site for which preservation is intended.

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