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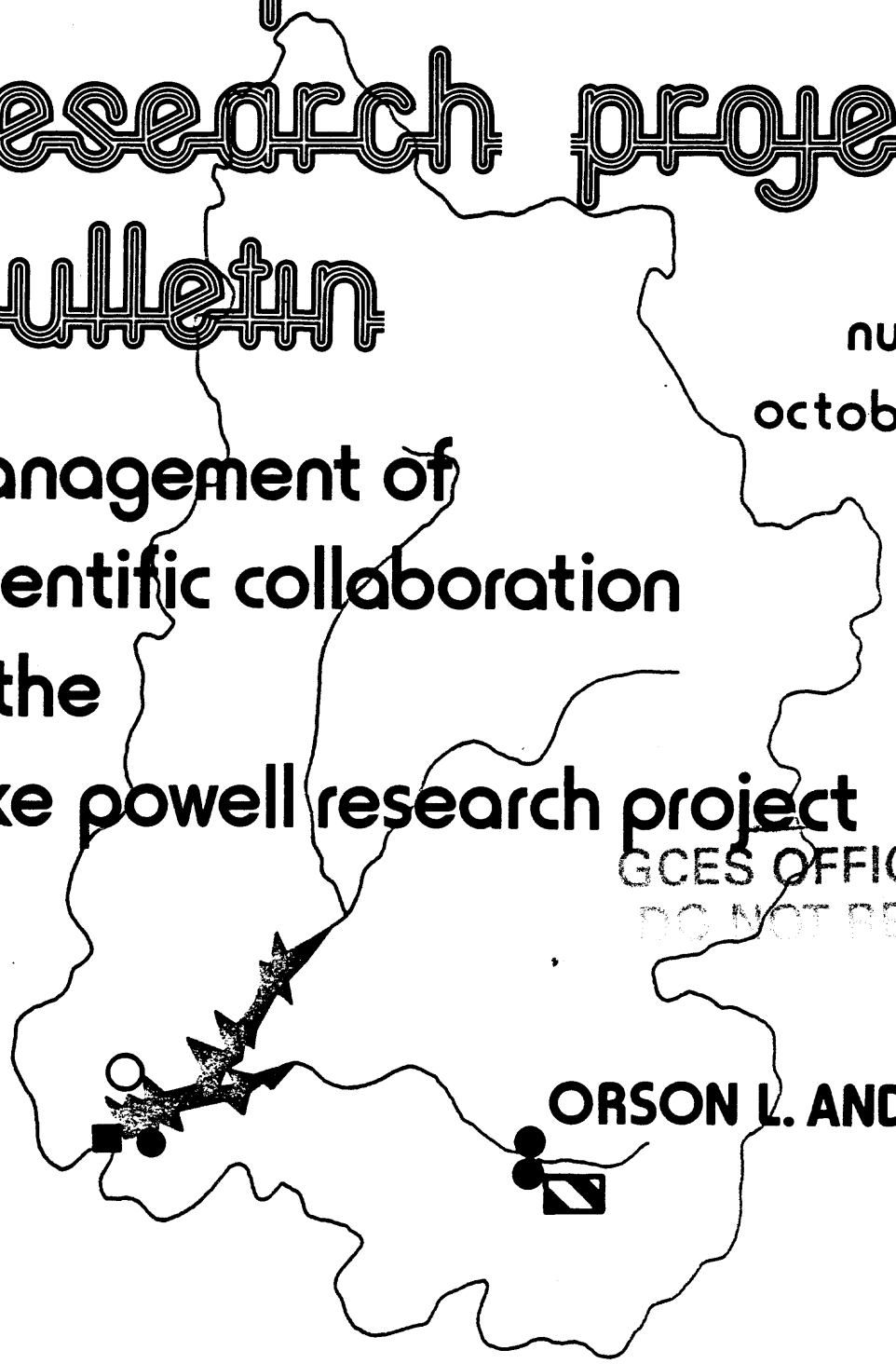

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Research Applied to National Needs

LAKE POWELL RESEARCH PROJECT BULLETIN

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COLLABORATIVE RESEARCH ON ASSESSMENT OF MAN'S ACTIVITIES
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MANAGEMENT OF SCIENTIFIC COLLABORATION IN THE LAKE POWELL RESEARCH PROJECT

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October 1975

LAKE POWELL RESEARCH PROJECT

The Lake Powell Research Project (formally known as Collaborative Research on Assessment of Man's Activities in the Lake Powell Region) is a consortium of university groups funded by the Division of Advanced Environmental Research and Technology in RANN (Research Applied to National Needs) in the National Science Foundation.

Researchers in the consortium bring a wide range of expertise in natural and social sciences to bear on the general problem of the effects and ramifications of water resource management in the Lake Powell region. The region currently is experiencing converging demands for water and energy resource development, preservation of nationally unique scenic features, expansion of recreation facilities, and economic growth and modernization in previously isolated rural areas.

The Project comprises interdisciplinary studies centered on the following topics: (1) level and distribution of income and wealth generated by resources development; (2) institutional framework for environmental assessment and planning; (3) institutional decision-making and resource allocation; (4) implications for federal Indian policies of accelerated economic development of the Navajo Indian Reservation; (5) impact of development on demographic structure; (6) consumptive water use in the Upper Colorado River Basin; (7) prediction of future significant changes in the Lake Powell ecosystem; (8) recreational carrying capacity and utilization of the Glen Canyon National Recreational Area; (9) impact of energy development around Lake Powell; and (10) consequences of variability in the lake level of Lake Powell.

One of the major missions of RANN projects is to communicate research results directly to user groups of the region, which include government agencies, Native American Tribes, legislative bodies, and interested civic groups. The Lake Powell Research Project Bulletins are intended to make timely research results readily accessible to user Groups. The Bulletins supplement technical articles published by Project members in scholarly journals.

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ABSTRACT

Some problems of operating a multi-disciplinary consortium engaged in assessing regional environmental impact are defined. The Lake Powell Research Project is such a consortium dealing with energy and water management problems in the Four Corners region of the United States. The management chosen by the Project leaves major decisions to a Steering Committee rather than to a Project Director. The advantages and disadvantages of this type of management of a consortium are analyzed. Special consideration is given to problems of integrating work of various disciplines and to the conveyance of research results to user groups.

MANAGEMENT OF SCIENTIFIC COLLABORATION IN THE LAKE POWELL RESEARCH PROJECT

INTRODUCTION

Multidisciplinary research has become an internationally accepted means of bringing scientific scrutiny to bear on complex problems. In the United States, this type of research has gained particular credence in the fields of environmental science and policy. The National Environmental Policy Act of 1969, for example, compels all Federal agencies to "utilize a systematic, interdisciplinary approach which will insure the integrated use of the natural and social sciences and the environmental design arts in planning and in decision-making which may have an impact on man's environment."

Underlying this national policy is the assumption that environmental assessment requires a spectrum of analysis much broader than that which any single scientific discipline can provide. A multidisciplinary research effort is necessary because environments consist of many diverse yet interactive elements and processes.

Public officials, as well as members of academic communities, increasingly find it necessary to answer two questions originally posed by ecologists: (1) How is the carrying capacity of a region affected by certain management decisions; and (2) What are the tolerance levels of man to the pressures generated by these actions? In order to answer such general questions, a systems approach is required in which interactions and feedbacks are exposed and examined. A conventional disciplinary approach to environmental problems, which can be labeled the "limited black box" assessment, is insufficient, because one cannot be sure that the important interconnections and feedbacks are exposed and examined. While multidisciplinary research is generally recognized as a desirable goal, the best prescription for organizing and operating a workable, efficient, and productive multidisciplinary research consortium is still a subject of debate.

A multidisciplinary consortium is here defined as a group of scientists whose backgrounds and training represent a number of different natural and social sciences. One major difficulty in the creation of an effective multidisciplinary team is the problem of establishing a balance between social science disciplines and natural science disciplines. Scientific organizations dealing with environmental impacts need to appraise the social consequences of proposed projects, as well as the physical, biological, and economic impacts. White[1] has emphasized that, in the case of reservoir construction, analyses of social and ecological impacts are usually inadequate. McKinney[2] has argued that the existing theoretical and technical abilities of social sciences found within university structures have not been sufficiently mobilized to perform broadly based analyses of societal problems. Weinberg[3] has suggested that new national laboratories need to be formed (involving great numbers of social scientists) called "natural socio-technological institutes," to assess society's problems.

THE LAKE POWELL RESEARCH PROJECT

The Lake Powell Research Project (LPRP) is a consortium representing approximately equal numbers of social and natural scientists, which was formed to assess the environmental impact of man-made changes in the Lake Powell region. The senior scientists are employed in nine universities, one museum, and one scientific institute, so the LPRP is an inter-institutional multidisciplinary consortium.

In this Bulletin are discussed some of the organizational and research issues which have developed during the operation of the LPRP and which are believed by the author to be common to many multidisciplinary consortia. Also discussed is how the LPRP has met or failed to meet these issues, in the author's view. Because of the author's involvement as a participant and organizer of the Project, this discussion cannot be a substitute for an impartial, independent case study of the Project. It is hoped, however, that these remarks, which represent an interim report, will be of interest to those evaluating multidisciplinary consortia.

SOME PROBLEMS IN THE OPERATION OF A MULTIDISCIPLINARY CONSORTIUM

The inception of any research organization is beset with organizational difficulties, and this is especially true for a multidisciplinary organization devoted to an assessment of environmental impacts. The research problem and tasks must be defined, the specialties which are essential to the performance of those tasks must be identified, integration of the separate disciplines must be accomplished, and the products of the research must be communicated to the appropriate users in society.

Choosing the Disciplines

One difficulty is that a specialist is needed to define a specialist's task. For example, two biologists defining a special environmental problem will easily recognize a number of different special tasks in biology, but may foresee only in some vague way the involvement of social sciences. Natural scientists are not often able to distinguish between a political science problem and a legal problem, or to distinguish between a sociological problem and an economic problem. Conversely, two social scientists approaching the same societal problem often will have corresponding difficulty distinguishing the several different roles of biology which are readily apparent to the biologists. The multidisciplinary consortium, consisting of individual specialists, is faced at the outset with the problem of selecting the disciplines which should be involved in the study of a particular societal problem, within the limits of an overall budget acceptable to the funding agency.

Choosing the Priorities in Disciplines

Another difficult problem facing a multidisciplinary consortium is the coordination and focusing of research efforts to achieve the goals and tasks selected by the project. When the objective of the consortium is to apply (within a limited budget) scientific knowledge to the amelioration of society's problems, the definitions of these goals and tasks must be precisely drawn. Proper definitions of the goals of the project in terms of a particular societal problem inevitably enhance the relevance of some disciplines and diminish the relevance of others. Decisions on relevance, in turn, require decisions on budgetary allotment.

Leadership of the consortium has to be established in such a way that progress toward and achievement of project goals is objectively examined, reviewed, and rewarded. The leadership of the consortium has to be sufficiently strong to be able to deny or curtail proposed research not effectively related to project goals.

Establishing the Multidisciplinary Peer Group

In order for a multidisciplinary organization to be successful, it is necessary to establish a representative polity, administrative structure, and lines of communication. The organization becomes a multidisciplinary peer group which performs many of the same functions as the peer organization in the individual scientists' disciplines. This peer group has to provide the opportunity for scientists to obtain rewards for their work in common endeavor. Since those involved in multidisciplinary research risk criticism for lack of specialization in their own individual disciplines, the peer group of the consortium itself needs to provide a means of compensation through which individual success in interdisciplinary cooperation can be rewarded.

Communication of Research Results

A scientific investigator working within his discipline alone need only communicate his research results to peers in his specialty through technical publications. However, in a multidisciplinary consortium it is necessary for the individual investigator to communicate his results not only to his peers in his specialty but also to his colleagues in other specialties within the consortium and to user groups seeking general information about the work of the whole project. It takes a special effort to describe research results in a form free of the jargon of specialty so that a unified product can be achieved by the multidisciplinary research. Further, since the research results are to be applied to societal problems, there is a great urgency for rapid dissemination of information. Thus, the consortium has to establish a special mechanism for publishing timely results outside of the usual disciplinary channels.

Integration of the Disciplines

One of the problems of a multidisciplinary consortium is that there is tension between the need for integration on the one hand and the internal logic of an individual scientist's investigations on the other.

A comprehensive study of a societal problem requires simultaneous analysis by numerous disciplines. Unless some attempt at integration is agreed upon by the scientists involved, the result would be parallel but unconnected findings. It is very desirable to have all the disciplines combine their knowledge toward the analysis of the societal problem, its conceptual framework, the project goals and tasks, and the production of research reports. It must be recognized that various disciplines converge on a special problem at different rates and with different degrees of cooperation. Attempts at integration must therefore be flexible.

The multidisciplinary consortium must develop a conceptual framework which enables

the integration to proceed steadily, which accounts for the needs of various disciplines, and which allows for changes as goals are progressively refined by disciplines and subsets of the consortium.

When the integration is accomplished, the consortium can be regarded as being interdisciplinary. Before integration, the group is merely multidisciplinary.

MANAGEMENT BY A STEERING COMMITTEE OF A CONSORTIUM

Structure of the LPRP

The problems described in the previous sections have been handled within the LPRP through assignment of the major policy-making power to a Steering Committee composed of some of the Senior Investigators of the Project. This mechanism was chosen in preference to appointment of a Project Director with centralized authority.

The founding members of the LPRP were persuaded in 1971 by Dr. William C. Ackermann, Director of the Illinois State Water Survey, that a Steering Committee would be an effective management structure for an interinstitutional, interdisciplinary consortium. The experience of Project members has confirmed his judgment.

The membership of the LPRP Steering Committee originally included representatives from social sciences, even though in the Project's first year funding was granted only to natural sciences. A decision was made by the Steering Committee at an early date to aim for equal representation of natural and social science disciplines within the Project. The gradual achievement of the goal of parity between the social and natural sciences[4,5,6] is shown in Table 1.

The Steering Committee has assumed responsibility for (a) directing the evolution of the Project, (b) approving new senior personnel on existing subprojects (or disciplines), (c) eliminating, consolidating, or realigning old subprojects (or disciplines), and (d) controlling publications and publicity.

Three members of the Steering Committee were appointed to solve the day-to-day problems of the Project: the Coordinator of Natural Sciences, the Coordinator of Social Sciences, and the Executive Secretary. The Executive Secretary is a full-time or nearly full-time position; the Coordinators are part-time positions occupied by Professors with concurrent academic duties.

These three executives of the Project share the problems of coordinating the scientific activities; editing and publishing Project reports; maintaining liaison with Federal and state government, educational institutions, and tribes in the Lake Powell region; and planning and supervision of Project meetings. The Coordinator of Natural Sciences serves as the focus of responsibility for the overall Project to the sponsoring agency, RANN (Research Applied to National Needs) of the National Science Foundation.

The distribution of disciplines by home institutions among the 26 Senior Investigators of the Project is shown in Table 2.

Choosing the Subprojects in the LPRP

All Senior Investigators periodically participate in workshops in which the

Table 1: Changing Profile of Disciplines in the Lake Powell Research Project

SUMMER 1971

Senior Scientists in Funded Projects			Steering Committee		
Natural Science		Social Science		July	September
Environmental Science	1	None	Environmental Science	1	1
Atmospheric Science	1		Geology	1	1
Biology	2		Geophysics	1	1
Geology	2		Biology	1	1
Geochemistry	1		Remote Sensing	1	1
Geophysics	1		Medicine	1	1
Hydrology	1		Anthropology	0	2
	9		Geology (ex officio)	1	1
				7	9

SUMMER 1972

Senior Scientists in Funded Projects				Steering Committee	
Natural Science		Social Science			
Environmental Science	1	Anthropology	3	Environmental Science	1
Atmospheric Science	2	Economics	2	Geophysics	1
Biology	2	Medicine	1	Geology	1
Geology	2	Law	2	Biology	1
Geophysics	2	Political Science	1	Anthropology	1
Geochemistry	1		9	Medicine	1
Hydrology	3			Law	1
	13			Economics	1
				Geology (ex officio)	1
					9

NOVEMBER 1973

Senior Scientists in Programs Approved by Steering Committee				Steering Committee	
Natural Science		Social Science			
Atmospheric Science	3	Anthropology	2	Atmospheric Science	1
Biology	3	Economics	3	Geochemistry	1
Geology	3	Law	3	Geophysics	1
Geochemistry	1	Medicine	1	Biology	1
Geophysics	1	Political Science	3	Anthropology	1
Hydrology	2	Sociology	1	Medicine	1
	13		13	Economics	1
				Political Science	1
				Geology (ex officio)	1
					9

Table 2: Distribution of Disciplines According to Home Institution of the Senior Investigator

Home Institution	Discipline
o Utah State University	Sociology
o Dartmouth College	Geology and Geochemistry
o John Muir Institute	Atmospheric Sciences
o Northern Arizona Society of Science and Art, Inc.	Atmospheric Sciences
o University of Arizona	Anthropology, Political Science, and Hydrology
o University of California, Los Angeles	Geophysics, Geology, Hydrology, and Law
o University of California, Santa Barbara	Political Science
o University of New Mexico	Biology and Economics
o University of Rochester	Medicine and Sociology
o Western Washington State College	Anthropology
o Northern Arizona University	Atmospheric Sciences

conceptual framework of the Project is formulated and reviewed. This overall framework consists of the Project's societal problem and the consequent tasks and goals of Project research. The conceptual framework is the basis for determining the Project's components, which are called research topics and subprojects. The Steering Committee determines which research topics and subprojects are consistent with the conceptual framework. Senior Investigators are in charge of the various subprojects which are discipline-oriented. A subproject is initiated by one or more Senior Investigators by the submission of a formal subproject proposal to the Steering Committee. The Steering Committee reviews the proposal and often requires the Senior Investigators to defend, in an oral presentation before the entire Project membership, both the merit of the scientific work proposed and the budget. Subprojects are judged on (1) relevance to the conceptual framework, (2) professional competence of investigators, and (3) anticipated feasibility and quality of the research. Negotiations with the sponsoring agency on behalf of the proposed subproject are conducted by the appropriate coordinator.

When the Steering Committee determines that a new discipline (subproject) is needed in the Project, the appropriate coordinator has the responsibility for

nominating scientists, making arrangements for an oral presentation of the proposed research before the senior scientists, and supervising the submission of a formal proposal describing the proposed research. The Steering Committee has the responsibility of determining which disciplines (subprojects) should be added or subtracted and which senior personnel should be added to or eliminated from the Project.

One of the advantages of an interinstitutional consortium, such as the LPRP, is that it is relatively easy to avoid the bias of identification with a particular university, department, or institute. In this way, many of the constraints often imposed upon consortia by university operational rules are minimized. No one university department can become dominant in the Project, and the best environment is created for emergence of a unified project identity.

Recruiting

When a consortium is established within the structure of a university department or institute, the director of the consortium is disposed to use the talent available within the department or institute rather than to undertake the burden of negotiation for talent outside his immediate authority. It is for this reason that many consortia which have been established for environmental assessment are biased in favor of those disciplines represented in the institute or department organizing the study.

The LPRP is not constrained by this particular bias in its recruiting, since only a minority of its scientists come from any particular institution or any one discipline. In recruitment, scientists are sought who have experience and training in problems directly associated with the Lake Powell area, irrespective of their institutional affiliation.

Integration of the Subprojects

The LPRP has adopted two methods to achieve integration among the separate disciplines: the utilization of techniques of systems analysis and the assignment of responsibility to Chief Scientists.

A systems analysis subproject was funded for the express purpose of designing an impact simulation model which would transform alternative decisions related to water management and power management into a set of physical, economic, and environmental consequences. Not unexpectedly, the systems analysis approach has been more useful to some disciplines than to others in achieving progress towards integration.

The LPRP's second method of integration is to choose research topics which represent elements of the societal problem and involve investigators from several disciplines. Two investigators from different disciplines are appointed by the Steering Committee as Chief Scientists and are responsible for drawing together information from all the disciplines connected to their topic. They integrate the research so that a final report can be produced on time. The Chief Scientists and research topics in the LPRP work for 1974 to 1976 are shown in Table 3.

Budget Control

Although the Steering Committee of the LPRP has no direct funds of its own,

Table 3: Interdisciplinary Research Topics of the Lake Powell Research Project

	Topics	Disciplines of Chief Scientists
1.	Level and Distribution of Wealth Generated by Resource Development	Anthropology and Economics
2.	Institutional Framework for Environmental Assessment and Planning	Political Science and Atmospheric Science
3.	Institutional Decision-Making and Resource Allocation	Political Science and Geology
4.	The Implications for Federal Indian Policies of Accelerated Economic Development of the Navajo Indian Reservation	Anthropology and Law
5.	Impact of Development on Demographic Structure	Medicine and Sociology
6.	Consumptive Water Use in the Upper Colorado River Basin	Hydrology and Law
7.	Prediction of Future Significant Changes in the Lake Powell Ecosystem	Geochemistry and Biology
8.	The Recreational Carrying Capacity and Utilization of the Glen Canyon National Recreation Area	Biology and Economics
9.	Impact of Energy Development around Lake Powell	Geophysics and Law
10.	Consequences of Limiting the Lake Level of Lake Powell	Hydrology and Geology

it does exert financial control over the Senior Investigators by determining the level of budgets which may be submitted to the funding agency to be considered as a part of the LPRP. Thus, in order for individual scientists to be participants of the LPRP, they must submit to the financial controls of the Steering Committee. The Steering Committee determines the level of the total budget which is to be proposed to the sponsoring agency. This judgment is made after the coordinators discuss with the sponsoring agency the approximate level of a total budget consonant with the planned extent of research. The Steering Committee then apportions the overall proposed budget among the subprojects according to the merit of individual proposals within the conceptual framework. This process of apportionment, and the difficult decisions involved, are major issues of debate within the Committee. Through budget control, the Steering Committee directs the evolution of the

Project's scientific effort (see Table 1) by providing a financial incentive. Researchers who propose work closely related to the Project's stated goals are able to propose larger budgets to the sponsoring agency.

As illustrations of research direction by budgetary control, the Committee has (a) postponed for 2 years the beginning of one subproject (air plume analysis), (b) terminated two subprojects (systems analysis and impact analysis) after 2 years of work; (c) reduced the level of activity from one biannual period to another by condensing three hydrology subprojects into one; (d) denied a proposed major increase in budget (biological limnology) in the second biannual period; (e) increased substantially the level of activity of two subprojects (political science and law) by budgeting new personnel in the second biannual period; and (f) added two new subprojects (sociology and resources of the Kaiparowits Plateau) in the second biannual period.

The Steering Committee has adopted a formal method for considering new disciplinary additions to the Project. Scientists of established reputation are asked to consider whether they could perform the desired research within a given budget allotment and within the goals set by the conceptual framework. If a scientist is interested, he gives a formal presentation, as discussed in a previous section. For example, the Committee considered remote sensing as a possible subproject, and presentations were made by two scientists in the field. The Committee voted not to add this element to the Project in view of the expenses involved. A subproject on land use in the Kaiparowits region was for a time considered as a desirable addition, and in response to a query, a formal presentation to the entire Project was made by well known scientists in this field. The Committee decided that the cost of the land use subproject as proposed was too great to be incorporated within the financial constraints of the Project. A subproject on land use was not added as a subproject, but elements of land use were incorporated into other approved subprojects. Scientists from two different institutions responded to the request for proposals in sociology, but eventually decided that they could not operate within the proposed budgetary allotment. A sociologist from another institution submitted a proposal that could be approved within the fiscal and policy priorities of the Project. The Committee required a formal presentation before the entire Project by a proposed new senior investigator in political science before an increase in the political science subproject budget was approved.

After all budget allocations are approved by the Committee, the Natural Science Coordinator formally submits the budgets and the associated proposals of the subprojects to the sponsoring agency on behalf of the senior scientists and their respective institutions. When finally approved by the sponsoring agency, the grants are funded directly to the participating institutions, and the senior scientists, through their individual institutional fiscal officers, control spending within their own subprojects. Thus, the approval of budgets is centralized, but the control of spending is decentralized.

Interactions of the Project with the Sponsoring Agency

As the consortium gradually formulates its overall research program, which

is developed by including input from all Project disciplines, it is almost inevitable that the chosen direction of research will depart somewhat from the announced program and expectations of the sponsoring agency. This assertion of independence by project scientists is a source of tension between the sponsoring agency and the management of the consortium.

Other tensions arise from criticisms by outside reviewers of project research made at the request of the sponsoring agency. These criticisms often reflect disciplinary bias, for most reviewers as individuals represent one particular discipline among the several contained in the consortium. Another source of tension is that the objectives and tasks of a broadly based consortium straddle several divisions of expertise and authority within the sponsoring agency.

It is the experience of the LPRP that the best strategy is to seek to preserve its independence in planning its interdisciplinary research, even though this leads to the tensions described previously. In the time-span of the LPRP, several modifications of the program recommended by sponsors and reviewers have been rejected. In fact, some suggested changes were later withdrawn, and the sponsor's position in some issues was reversed. For example, an early recommendation was that systems analysis should dominate the Project and should constitute the largest subproject with the highest budget. Sometime after this recommendation was rejected by the Steering Committee, the sponsoring agency reversed its position. Another example was an early recommendation that the Project should not attempt energy studies since they would dilute research efforts applied to water management of environmental research. Later, at the insistence of the management of the Project, more emphasis was placed on regional energy studies.

On the whole, the relationship between the sponsoring agency and the LPRP has been very amicable. On a number of occasions, the sponsoring agency has protected the LPRP by funding studies which Federal agencies asserted would conflict or overlap with their own research programs.

Disadvantages of the Interinstitutional Consortium

In the experience of the LPRP, the major disadvantages of the interinstitutional consortium as an effective research unit solving broad-scale environmental problems arise from the fact that the senior members of the consortium are separated geographically. Serious budgetary problems arise from travel, telephone, and postage costs. Large expenses for travel and communication result in correspondingly lower amounts available for research.

Frequent meetings of the Steering Committee are impossible due to the expense involved, and the time for members of the Project to be together in one location is limited. Lack of frequent policy-making meetings has led to the progressive bureaucratization of the LPRP. An Executive Committee, composed of the two Coordinators and two additional members elected from the Steering Committee, has been created to deal with urgent policy matters in the absence of the full Steering Committee. This bureaucratization, arising from geographical separation, can be regarded as the establishment of Project unity and institutional identity independent of any single university department

or institute. However, members of the LPRP sometimes feel cut off from decisions by these formal procedures.

Decisions are sometimes made de facto by the Committee's executives, the Coordinators, in the press of day-to-day events. At times, unpopular decisions made by one or the other of the Coordinators have been interpreted in terms of interpersonal relations rather than in terms of the real issues involved. The same class of unpopular decisions, when made by the Steering Committee, has avoided personal grievances, allowing for focus on the issues. Even so, junior members of the LPRP sometimes feel they do not have an adequate voice in policy-making within the Project.

DIMINISHING OF DISCIPLINARY ORIENTATION

Stages in the Transition Away from Disciplinary Orientation

When a multidisciplinary consortium is organized to assess a regional environmental impact, the expectation is generally shared that disciplinary orientation of individual scientists will be rapidly replaced by willingness to engage in joint efforts in solving common problems. The experience of the members of the LPRP is that disciplinary orientation persists for a long period of time.

First, many scientists are accustomed to being in charge of their own specialized research and are apprehensive that their primary data will be inappropriately and prematurely used by others. Second, time is required for the scientists in one discipline to learn enough about the work of another discipline in order to define problem areas of common interest. Third, a great deal of basic data have to be acquired before interdisciplinary issues of regional scope can be defined as solvable problems within the restrictions of time and budget available to the consortium. In the case of the natural sciences of the LPRP, the transition away from disciplinary orientation occurred in three stages.

The first stage can be defined as the disciplinary phase, which involved the determination of and verification of fruitful areas of disciplinary research coupled with basic data acquisition. The second stage can be defined as the trial integration phase, which involved basic data acquisition and analysis in the traditional disciplinary modes, plus exercises in integration through methods of qualitative systems analysis. The third stage can be defined as the interdisciplinary phase, in which research goals were expanded and formulated to incorporate interdisciplinary research topics combined with analyses of data in the traditional disciplinary modes. It might be assumed that the interdisciplinary phase could be bypassed by the multidisciplinary consortium. The value in including it in the consortium is that it allows time for the scientists to become acquainted with the work of other disciplines through Project meetings. For natural sciences in the LPRP, the first stage took 1 year, the second stage took 2 years, and the third state began just a short time ago.

The Disciplinary Phase

The natural scientists of the LPRP began their work by proposing to define and correlate available research data in order to assess the existing (natural) scientific and environmental knowledge of the Upper Colorado River Basin. There were four related subdivisions within the natural sciences:

(a) Hydrology - A historical study centering on the use of the Colorado River since the turn of the century and the development of major river projects during that period, including recorded changes in hydrological conditions and agricultural practices.

(b) Biology - A pilot biological investigation aimed at determining indexes of water quality for analyses of eutrophication and shoreline terrestrial vegetational changes that are occurring with reservoir filling, fluctuating water (in Lake Powell), and changing water table.

(c) Dynamic Limnology - An investigation of the physical processes taking place in Lake Powell, including thermal and chemical structure and sedimentation rates and distributions.

(d) Environmental Impact - An analysis of the impact upon the regional environmental quality from technological enterprises (tourism, mining, and electrical power production) attendant with the impoundment of Colorado River water.

At the end of the disciplinary phase, sufficient data had been gathered to define three separate subprojects each in categories (a), (b), and (c), and two subprojects each in (d). Thus, 11 subprojects for natural science were generated and included in the proposal for the trial integration phases. For the natural sciences this represented a subdivision of disciplines into specialties and, in some ways, a move away from integration.

The Trial Integration Phase

The natural scientists together with the social scientists of the LPRP defined the societal problem for the focus of the Project's research as how to develop water resources and deal with the effects and ramifications of this development in the arid Southwest. This problem was addressed by formulation of the following goals:

- To study the problems inherent in water resource management with regard to water allocation, water quality, power production, recreation, and aesthetic values of the environment.
- To evaluate the expected consequences of alternative water management decisions upon the Lake Powell region.
- To study the decision-making process in the development of water resources, and to disseminate information pertinent to future decisions.
- To create a quantitative systems analysis model which is designed for use in the first three goals.

The following 11 subprojects were organized to acquire and analyze the basic data in order to help meet the above goals:

(a) Biological Limnology - To develop indices of eutrophication and measures of primary productivity,

and to understand impact of man on reservoir aquatic ecology.

(b) Shoreline Ecology - To examine the ecological changes related to rising water level in terms of nutrient and organic matter enrichment as a base for establishing indices for carrying capacity and public use.

(c) Heavy Metals - To examine the concentration of metallic cations in the Lake Powell ecosystem, as they occur laterally across the basin and vertically through trophic food chains, as one aspect of man's impact upon the quality of the environment.

(d) Streamflow Trends - To utilize dendrochronologic techniques to develop past runoff characteristics in order to better understand space and time variations in runoff and available surface water.

(e) Lake Evaporation - To develop data stations to record information to calculate evaporation losses via mass-transfer and energy-budget methods in cooperation with ongoing Bureau of Reclamation programs to determine net evaporative losses.

(f) Bank Storage - To determine more accurately the quantity and location of the infiltration of water into bank storage and to assess its availability to potential users.

(g) Physical Limnology - To examine factors related to meromixis in Lake Powell, and to provide baseline data on circulation and currents within the lake as it approaches full volume.

(h) Lake Geochemistry - To examine time-dependent distributions of chemical elements in the lake, and to quantify ions added to the lake by solution and/or chemical precipitation.

(i) Sedimentation - To determine sedimentation rate, distribution, and origin and methods of deposition as they may affect life of the reservoir and its usefulness.

(j) Background Air Quality - To analyze the state of the atmosphere in the Lake Powell region without the influence of man; to identify and define air quality parameters not presently being measured to facilitate measurements of change.

(k) Impact Analysis - To examine various environmental impact statements to develop a framework for utilization in policy definition and decision-making regarding utilization of the Upper Colorado River Basin.

Integration was accomplished by systems analysis methodology in which the total project was broken down into five subsystems. Subprojects (d), (e), and (f) were included in a subsystem called water cycle, subprojects (a), (c), (g), (h), and (i) in a subsystem called lake system, and subprojects (b), (j), and (h) were in a subsystem called quality of life. The systems analysis program connected these

subsystems to others involving social science components, especially law.

From the research accomplished in this stage within both the disciplinary subprojects and the systems analysis exercises, various disciplines found regions of common interest, and there emerged several groups related to interdisciplinary problems of regional extent. For the natural sciences, this represented a condensing into fewer topics of research, that is, progress towards integration.

The Interdisciplinary Phase

In this stage, the natural and social scientists of the LPRP defined the Project goals in terms of interdisciplinary problems. The interactions that had been developed by this time facilitated the identification of the 11 topics listed in Table 3. At this stage of integration, there is considerable interaction between natural and physical sciences. The discussion of integration in the social sciences has been treated in an associated paper.[7] In Table 4 is shown the Project research topics in which natural sciences are heavily involved. Chief Scientists in the topics represent the underlined subprojects.

An abstract of one of the research topics is presented on page 15. The contrast between an interdisciplinary research

Table 4: LPRP Research Topics in Which Natural Sciences Are Involved. (Chief Scientists Represent the Underlined Subprojects)

Research Topic	Subprojects
Consumptive Water Use in the Upper Colorado River Basin	Hydrology, Law, Political Science, Economics, Geochemistry, and Anthropology
Recreational Carrying Capacity and Utilization of the Glen Canyon National Recretion Area	Shoreline Ecology, Economics, Hydrology, Air Quality, Geochemistry, Sedimentation, and Biological Limnology
Prediction of Future Significant Changes in the Lake Powell Ecosystem	Geochemsitry, Biological Limnology, Physical Limnology, Hydrology, Sedimentation, Air Quality, Air Plume Analysis, Economics, Heavy Metals, and Epidemiology
Impact of Energy Development around the Lake Powell Region	Kaiparowits Resources, Law, Political Science, Economics, Sociology, Hydrology, Physical Limnology, Biological Limnology, Shoreline Ecology, Air Quality, Air Plume Analysis, Geochemistry, Heavy Metals, and Epidemiology
Some Consequences of Restricting the Lake Level of Lake Powell	Kaiparowits Resources, Hydrology, Geochemistry, Economics, Law, Political Science, Sociology, Biological Limnology, Shoreline Ecology, Physical Limnology, Sedimentation, Heavy Metals, and Anthropology
Institutional Framework for Environmental Assessment and Planning	Political Science, Air Quality, Biological Limnology, Shoreline Ecology, Heavy Metals, Hydrology, Sedimentation, Geochemistry, Physical Limnology, Air Plume Analysis, Kaiparowits Resources, Law, Epidemiology, Anthropology, Sociology, and Economics

topic and an undivided subproject may be seen by comparison with the subsection "The Trial Integration Phase."

IMPACT OF ENERGY DEVELOPMENT AROUND THE LAKE POWELL REGION

Abstract

Coal resources at the Kaiparowits Plateau are the largest in Utah and the third largest in the region. The Kaiparowits coal resources are a desirable energy source for three western power-load centers (Southern California, Arizona, and northern Utah) because of the quantity and quality of the coal and because of transportation factors. Pressures to use this coal will continue to increase due to the energy crisis. Extensive exploitation of this coal for power production will require more water than is available from Utah's uncommitted allocation of Colorado River water. The course of the region's environmental quality and industrialization now depends upon the extent to which the Kaiparowits coal is exploited. The Project will consider the benefits and costs derived from alternate energy production modes, and will consider potential conflicts among users of the area. Extreme alternative futures to be considered for the Kaiparowits Plateau are: (1) a national coal reserve, (2) mining coal and transportation out of the region for energy conversion at the power-load centers, (3) minimum power production by mine-mouth powerplants, and (4) maximum power production by mine-mouth powerplants.

Consideration will be given to water quality and water allocation of the Upper Colorado River Basin; impacts upon agricultural air quality and recreation in the surrounding national parks; legal issues in transferability of water rights; water quality and air quality preservation; political issues in the pressure for reallocation of the water in the Colorado River system.

COMMUNICATION WITH USER GROUPS

The aim of the LPRP, like any consortium devoted to regional studies, is to supply useful and needed information to the users. User groups of the LPRP fall into the following categories:

(a) Interest Groups, ranging from environmental to developmental; for example, the National Water Resources Association, The League of Women Voters, The Sierra Club, and Friends of the Earth.

(b) Industries, including public and private utilities, coal, construction, oil, and other extractive enterprises, and recreation merchants and concessionnaires.

(c) Elected Public Officials, including Congressmen, Governors, State legislators, Mayors, and others.

(d) Federal Agency Officials, including such agencies as the National Park Service, Bureau of Reclamation, Bureau of Sport Fisheries and Wildlife, Bureau of Indian Affairs, Bureau of Land Management, Environmental Protection Agency, etc.

(e) State Agency Officials, including resource planning agencies for water and land use, fish and wildlife departments, health departments, etc.

(f) Local Officials, including regional planning agencies, planning and zoning commissions, city managers, etc.

(g) Tribal Officials, such as the Navajo Office of Manpower Resources and Navajo Health Authority.

(h) Universities and Professional Groups, such as the American

Association for the Advancement of Science, the University Council on Water Resources, and many other more discipline-oriented associations.

The communication provided consisted of several categories:

(a) Formal Relations - In the case of the Navajo Indian Tribe, an official agreement was signed between the LPRP and the Chairman of the Tribe which specified duties and obligations. This arrangement provided an opportunity for Project scientists, especially those in law and anthropology, to work at the capitol of the Navajo Nation, Window Rock, Arizona. Communication in this case consisted of, for example, identifying several jurisdictional problems of concern to the Tribe arising from the influx of non-Indians into the Reservation as a result of economic development. Another formal agreement was made between the Bureau of Reclamation and the Project which led to cooperative measurements of evaporation, and a cooperative well-drilling program.

(b) Service in Response to Letters of Inquiry - The Project is often asked to respond to public inquiries about special problems in the Lake Powell area. A typical example was the case of a resident of Utah asking the Park Superintendent of Glen Canyon National Recreation Area for information on the quality of water in Lake Powell. The Park Service referred the query to the Project and a response was made directly to the citizen from the Coordinators' Office.

(c) Seminars - A seminar was organized to provide information on the Project to industrial groups and tribal officials involved in the utilization of energy resources in the Lake Powell area.

(d) Hearings and Environmental Impact Statements - The Project has been in communication with the Bureau of Land Management and has sent Interim Reports describing data for possible inclusion in EIS reports. Members of the Project have been in contact with counterparts on the EIS writing teams for consultation in such areas as air pollution, water pollution, demography, water supply, and coal reserves.

(e) Bulletins and Interim Reports- The Lake Powell Research Bulletins and Interim Reports are the chief methods of communication of the Project's research findings to the user groups.

CONCLUSIONS

In the experience of the LPRP, the problems involved in directing an inter-institutional multidisciplinary project appear to be effectively managed by vesting policy-making power in a steering committee.

The mechanisms used to integrate directed multidisciplinary research change as the steering committee acts to solve the problems of managing the consortium.

At the present time, the chief integrative device of the Project is the utilization of chief scientists to lead groups working on selected research topics. Systems analysis also continues to provide an additional tool for integration.

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