Integrated water planning … at a University … in a State … in the Future

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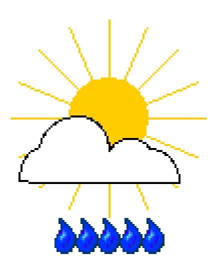
The report of the Utah State University Water Initiative Task Force

Members

David G. Tarboton, Chair
Michelle A. Baker
David Chandler
Christopher A. Conte
Joanna Endter-Wada
Christopher Fawson
Terry F. Glover
Thomas B. Hardy
Paul M. Jakus
Scott B. Jones
Richard T. Koenig
Thomas E. Lachmar
Chris Luecke
Mac McKee
Nancy Mesner
Richard C. Peralta
Pamela J. Riley
John C. Schmidt
David K. Stevens
Wynn R. Walker



March 31, 2003

We the undersigned members of the Water Initiative Task Force hereby confirm our concurrence with the full text of this report

David G. Tarboton, Chair

Michelle A. Baker

David Chandler

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Joanna Endter-Wada

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EXECUTIVE SUMMARY

Utah State University has diverse strengths in water sciences, engineering, and policy with existing programs in six colleges. Utah State University President Kermit Hall appointed the Water Initiative Task Force and charged us with recommending ways to strengthen water programs at USU that take advantage of this existing diversity and breadth of faculty expertise.

The Task Force includes representatives from the six colleges involved in water-related activity (Agriculture, Business, Engineering, HASS, Natural Resources, and Science) and from many academic departments, programs, and units shown in Figure 1. The Task Force met with colleagues, administrators, and stakeholders on- and off-campus and were encouraged and motivated by a broad and a deep-rooted enthusiasm and commitment among the USU faculty to pursue interdisciplinary efforts. Faculty members are extremely interested in the elimination of impediments to and creation of facilities for interdisciplinary collaboration in the water area at Utah State University. Off-campus feedback identified the need for graduates to be able to think broadly and knowledgeably across disciplinary boundaries.

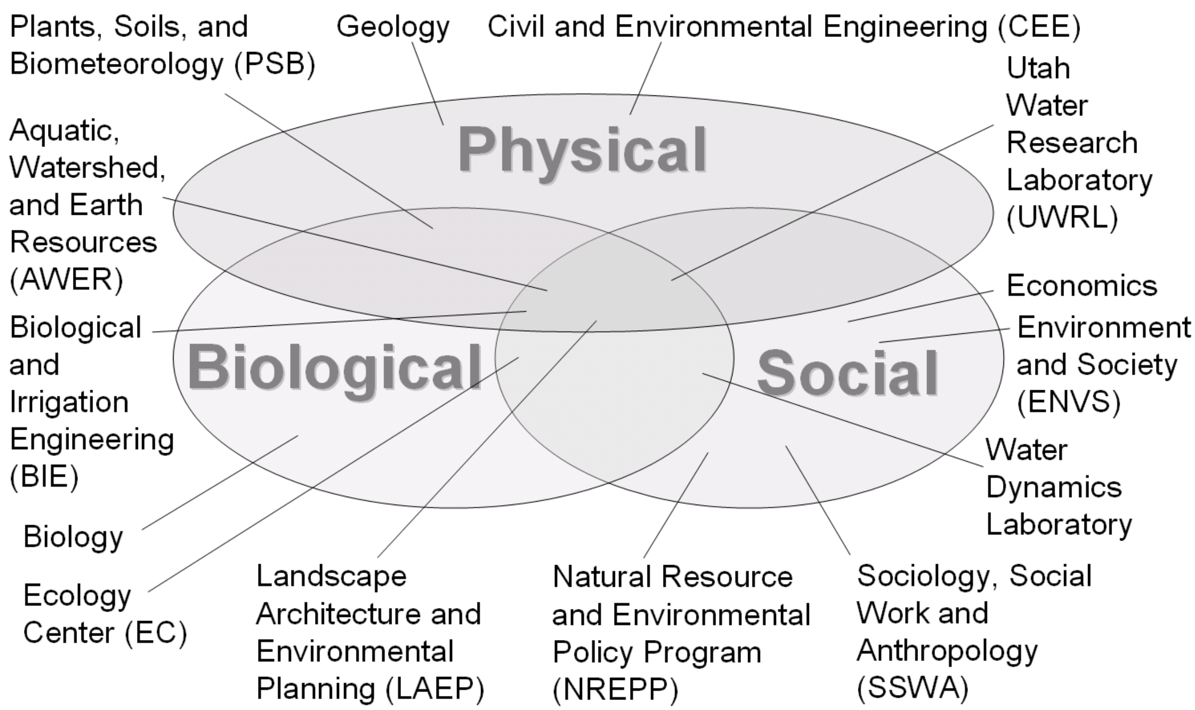

Figure 1. Utah State University departments and programs that contribute to the interdisciplinary water sciences.

The Task Force recommends the creation of an administrative unit at Utah State University that provides an overarching umbrella for the interdisciplinary study of and research in water sciences at Utah State University. An overarching umbrella unit is necessary to give Utah State University water programs national and international visibility and to provide capability for integration and synthesis among the somewhat fragmented programs that exist at present. This unit should create an environment for honest intellectual debate on all sides of water issues and provide leadership and creativity in addressing emerging water issues of the state, the western U.S. region, nation, and world. Most of the expertise and capability for such a unit currently exists on the USU campus, but a new administrative structure is required to move USU from its present status of less than the sum of the parts to one greater than the sum of the parts.

Specific actions that need to be taken by the new unit that are detailed in the report are
1. Water Science Synthesis Activities. A series of activities to focus USU faculty on the synthesis of interdisciplinary information related to water sciences.
2. Interdisciplinary Graduate Program in Integrative Water Sciences. Develop an interdisciplinary graduate program to meet the need for integrated interdisciplinary research and education in the Water Sciences area.
3. Experimental Watershed Initiative. Development of the research, data and measurement infrastructure to make the Great Salt Lake Basin, and within it the Bear River Watershed, into a microcosm for the study of water science and policy issues related to planning for growth in the Western US.
4. General Water Coordination Activities. A series of activities to promote and coordinate water science at USU and regionally, consisting of the promotion of regional water research partnerships, undergraduate education through water science initiative, and facilitation of the participation of water scientists and policy analysts in international water programs.

Broadly, the unit created might be one of (1) a new Graduate School of Water Science and Management, (2) a new Department, (3) a new Water Center, or (4) a decentralized committee/council. The Task Force evaluated each of these options and felt that an action as bold as the immediate establishment of a new school, which has been done elsewhere, was probably not feasible in the current budgetary climate. The recommendation is therefore for the establishment of a center whose mission is to implement the actions listed above and detailed in the report while at the same time starting the process and working towards the establishment of a School for Water Sciences at the graduate level as an ultimate goal.

I. INTRODUCTION

USU's Water Initiative Task Force

Utah State University (USU) President Kermit Hall appointed the Water Initiative Task Force and charged it with evaluating the current state of water-related education and research on campus. The Task Force was charged with recommending ways to strengthen water programs at USU that take advantage of the existing diversity and breadth of faculty expertise in water-related issues in order to restore Utah State University to a position of prominence in the study of water. Specific aspects of the charge were to:

- take stock of how USU performs relative to comparable peer institutions;
- address how USU should more appropriately fund and organize efforts in water-related programs;
- examine whether there is value in cross-disciplinary efforts in water-related programs;
- provide specific step-by-step recommendations as to how to strengthen water programs at USU as they involve graduate students, policy and research.

This report is written in response to this charge. In preparing this report, the Task Force sought input from a wide variety of sources. A number of visitors to campus were interviewed (Appendix 5). These people included National Science Foundation (NSF) program managers and lead investigators involved in large interdisciplinary projects at other institutions. These people also included federal researchers involved in large-scale watershed research. The Task Force examined the organization of prominent water programs at peer institutions (Appendix 4). The Task Force conducted round table meetings in Salt Lake City with state and federal agencies and non-governmental organizations and water stakeholders to hear their input (Appendix 6). The Task Force conducted round table discussions at Utah State University to hear input from the USU water community (Appendix 7). Telephone input was received from others who were too distant or otherwise unable to meet in person. Through this process, the Task Force has developed a sense of the potential within USU for developing the capability to provide intellectual leadership in the broad area of water sciences. The Task Force has also developed a sense of future opportunities and the challenges faced by USU in responding to these opportunities.

In this report, we review the current organization of water-related research, education and outreach at USU. We examine the history of water research and education to provide a picture of how the successful programs were built and have grown. We review state and land grant water science needs, summarizing the input received from the Salt Lake City round table meetings (Appendix 6), interactions with campus visitors, and colleagues from peer institutions (Appendices 4, 5). National water science programs are growing in response to the recognition of the broad scale of many water problems and we review initiatives and trends in federal science and water agencies (NSF, USGS, EPA, USDA) and associated organizations (Consortium of Universities for the Advancement of Hydrologic Sciences, Incorporated, CUAHSI, of which USU is a member). We also review international opportunities involving UNESCO (e.g. HELP) and USAID (e.g. CRSP) initiatives, to learn how to better position USU to respond to some of these opportunities. Much of our deliberation has focused on university governance. We specifically address the question "**What can a university administration do to foster the**

academic excellence and scholarship that brings prominence?" We discuss strategies for achieving prominence and options for increasing the effectiveness of water sciences at USU.

The Nature of the Challenge

The demand for bringing interdisciplinary expertise to bear on water-related problems is greater now than at any other time in the last half century. This demand spans needs at the local, state, regional, national, and international levels and is driven by increasing populations and larger scale changes in regional climates (e.g., global climatic changes and sustained drought). The availability of fresh clean water to sustain life and fuel economies is perhaps the most recurrent constraint in human history and it will remain so for the foreseeable future. In planning to meet society's growing thirst for water, planners are confronted with a range of problems from sustainable water supply to restoration or redesign to mitigate negative aspects of previous actions. Decision makers must consider multiple aspects: hydrological, environmental, social and ecological, in addressing these problems. The water sciences are naturally interdisciplinary and integrative because the underpinnings of many other disciplines involve water and the movement of water.

Utah State University has a strong group of physical, biological, and social scientists, and engineers located in six colleges, multiple departments, and academic units whose careers focus on water-related science, engineering, and policy problems (Figure 1, Appendix 1). Many of these individuals participate in significant local, state, regional, and international water resource related scientific and management programs. However, the current diffuse nature of these water-related activities across campus hinders the development of a sustained interdisciplinary focus involving collaborative research, applications, and extension services. Furthermore, the existing institutional structure of these various programs impedes the dynamic interactions among academic disciplines necessary to advance the science, engage stakeholders, and address the needs of society.

The challenge before USU as an academic institution is that it must integrate and synthesize water-related science and engineering activities across campus to focus its education, research, applied, and extension programs to meet the critical demand for ***integrated*** expertise. The University should provide an environment for honest intellectual debate on all sides of water issues and provide intellectual leadership on water science in the state, the western U.S. region, nation, and world.

II. ASSESSMENT OF CURRENT TRENDS IN WATER SCIENCES AND ENGINEERING

National and International Research Trends

During the past decade, pursuit of an in-depth understanding of the water cycle at global and regional scales has emerged as a major scientific thrust of a number of US agencies and research programs (NSF Hydrologic Sciences, NSF EPA Water and Watersheds Partnership, CUAHSI, NSF Freshwater Initiative, US Global Change Research Program, UNESCO HELP). These programs encourage (and in some cases require) interdisciplinary work because of the broad recognition brought out in a series of reports (National Research Council 1991; 1994; 1996; 1998; 1999; 2000; 2002) that management of water resources in the 21st century will require a more integrated base of scientific knowledge than in the past. These initiatives are part of a growing national recognition that critical frontiers of science occur at the margins where information from various disciplines overlap thereby providing a strong impetus for the emphasis of interdisciplinary research and education in university water sciences programs.

In this section, we describe some of these national initiatives and trends and the opportunities that they may present for Utah State University. Improved organization and representation of faculty breadth and strength is a critical step to USU participation in these initiatives. Such participation would certainly raise the visibility of USU water programs nationally and internationally.

The National Science Foundation (NSF) is the premier research funding agency within the US government, and one of the few that has received a significant increased federal budget at a time of declining funding overall. The Hydrologic Science program within NSF was initiated in response to an NRC report (1991) that articulated the emergence of hydrologic science as a distinct geoscience. The geosciences, especially **water and hydrologic sciences, are receiving significant increases in investment from the NSF**. Hydrologic science is likely to benefit from these increases through initiatives such as the Consortium of Universities for the Advancement of Hydrologic Science (CUAHSI) and the NSF Freshwater Initiative (Magnuson et al., 1995).

The Consortium of Universities for the Advancement of Hydrologic Science (CUAHSI, www.cuahsi.org) is an organization currently representing 68 US universities whose goal is to develop infrastructure and services supporting the advancement of hydrologic science at academic institutions. Utah State University is a founding member of CUAHSI, the Utah Water Research Laboratory (UWRL) having sponsored membership. The vision of CUAHSI is that by working collaboratively, the hydrologic science community can achieve a scale of investment in research infrastructure and accomplish goals that are beyond the reach of individual investigators or laboratories. The CUAHSI vision contains four main components: Hydrologic Observatories, Hydrologic Synthesis, Measurement Technology, and Hydrologic Information Systems. **Utah State University should continue to actively participate in CUAHSI and respond to opportunities to bid on hosting CUAHSI facilities such as Hydrologic Observatories, synthesis, measurement technology, or information system components**. The Bear River Watershed may be suited to the goals and size constraints (greater than 10^4 km^2) required for a CUAHSI Hydrologic Observatory. Institutional investment would help USU to position itself to be competitive for these facilities.

The NSF Geoscience directorate is also currently seeking to develop research and education programs in freshwater resources that are parallel with the CUAHSI initiative. The "freshwater initiative" is currently being scoped in workshops sponsored by the NSF, to address the call for "a more integrated, enlarged and focused program in water research in the US" issued in the 10-year outlook on Complex Environmental Systems (Pfirman and AC-ERE, 2003). Several emerging research issues for limnology that were identified at a 2002 NSF – American Society of Limnologists and Oceanographers sponsored workshop held in Boulder, CO include: inland waters as hotspots of biogeochemical activity; hydrodynamic controls of biogeochemical activity at a variety of spatial scales; the hydrogeomorphic landscape; global change and inland waters; emerging technologies. These topics are directly in line with existing research directions of several investigators at USU, yet **success in attracting federal resources to address these research challenges will require more explicit integration of these investigators' efforts**. These programs are typical of NSF in that they tend to focus on the physical and biological science aspects of water resource issues, but there is a growing recognition within NSF of the need to integrate social sciences, policy, and economic analyses, and management components in research to produce results useful to society.

The UNESCO HELP (Hydrology for the Environment, Life and Policy) initiative intends to create "a new approach to integrated catchment management through the creation of a framework for water law and policy experts, water resource managers and water scientists to work together on water-related problems." This initiative has been recommended to Water Initiative Task Force members by colleagues from outside USU. They consider the changes we propose to be a perfect opportunity for meeting the objectives of this initiative. The objective of HELP is to address the policy and management issues that are most critical to water users in several drainage basins around the world under several biophysical and socio-economic environments. Operationally, this is to be **achieved through field-oriented watershed research that will contextualize advances in hydrologic and ecologic science within the societal context**. The Bear River Watershed is well suited to the goals and size constraints (10^4 to 10^6 km^2) identified by this initiative.

Much national water-related research is under the auspices of the USGCRP (US Global Change Research Program), which is administered and funded though a host of federal departments and agencies (http://www.usgcrp.gov/usgcrp/default.htm). This program also coordinates scientific activities in the U.S. watersheds that are part of the international UNESCO HELP program. The broad goals of this program are to address key uncertainties about changes in the Earth's global environmental system, both natural and human-induced; monitor, understand, and predict global change; and provide a sound scientific basis for national and international decision-making. The National Oceanic and Atmospheric Administration (NOAA) program is a good example of the breadth of research under USGCRP. They fund research in the following areas: Climate and Societal Interactions; Applications of Climate Forecasts; Climate Information; Human Dimensions; Regional Integrated Sciences and Assessments; Climate Change Data and Detection; Climate Dynamics and Experimental Prediction; Climate Variability and Predictability (CLIVAR); Global Energy and Water Cycle Experiment (GEWEX) Continental-Scale International Project (GCIP); Global Carbon Cycle; and, Paleoclimatology. Similarly diverse research programs are administered through the Department of Agriculture, Department of Defense, Department of Energy, Department of the Interior, Environmental Protection Agency, National Aeronautics and Space Administration, NSF, and Smithsonian Institution.

Regionally the importance of interdisciplinary research and education has been recognized by the Inland Northwest Research Alliance (INRA www.inra.org), a consortium of eight regional universities, funded by the US Department of Energy in collaboration with the Idaho National Engineering and Environmental Laboratory. Utah State University is a member of INRA. A Subsurface Science Graduate Program was initiated in fall 2002 with 20 PhD fellowships awarded and distributed among the participating universities. The program comprises multi-institutional interdisciplinary courses that use state-of-the-art telecommunications methods to draw upon the complimentary strengths across the INRA universities. INRA is currently developing a focus on water resources and USU will in May 2003 host the workshop where this initiative will be developed. The water research workshop will focus on drought impacts and encompass effects of fire, water quality (impact to humans, fish, etc.), hydrological changes and trends, and water efficiency and conservation (both ground and surface water sources). **Utah State University should continue to actively participate in INRA and the development of its Water Research Initiative.**

In the international arena, the U.S. Agency for International Development (USAID) Collaborative Research Support Program (CRSP) focuses on the application of collaborative research in developing countries so that they can solve problems of agricultural production and utilization over the long term. Water resources and irrigation are significant factors in agricultural production. The major multilateral development agencies and banks are interested in multinational water compacts and the delivery of water, water quality issues in international community development, and the effects of urbanization and extended drought on water supplies in various parts of the world. **These programs are interdisciplinary by nature, and USU has both the international prominence and the depth of expertise to be well-positioned for the projected expansion in CRSP USAID programs**.

That diverse funding sources are often interconnected through large initiatives is illustrative of the exciting national and international opportunities available in the water area. Academic institutions that are able to integrate and synthesize the water sciences, and to gear their educational and research programs to meeting societal needs, stand to excel and gain national prominence. Faculty serving on the USU Water Initiative Task Force are convinced that tremendous opportunities exist to leverage USU's existing reputation in water by infusing it with new energy obtained through the focus on water provided by the current university administration. They are optimistic about and committed to helping USU gain new levels of prominence in water programs.

Assessment of Peer Institutions

Utah State University is not alone in recognizing that the time is right to develop interdisciplinary programs in hydrologic sciences, as proposed over a decade ago by the National Research Council (1991). We can take the opportunity to learn from experiences and successes at some peer institutions. Highlights are given here with details in appendix 4.

The University of Arizona formed a distinct and unique Department of Hydrology and Water Resources in 1966 that has grown in preeminence in the field of hydrologic science and the study of semi-arid hydrology. The University of Arizona has attracted world class faculty and prominent national funding from NSF to support the Sustainability of Semi-Arid Hydrology and Riparian Areas (SAHRA) Science and Technology Center (STC). A cornerstone of the success at the University of Arizona has been the longstanding and productive research collaboration with the regional USDA research watershed facility. One way that the University of Arizona promotes prominence is through bestowing the title of "Regents Professor" on successful faculty, such as the director of SAHRA. This rewards success with support for research and scholarly activities.

Oregon State University has a Center for Water and Environmental Sustainability that provides the opportunity for faculty to work together on large interdisciplinary projects. This program grew out of the recognition by engineering and science faculty that OSU could better capitalize on its diverse strengths in water. Oregon State University has a longstanding interest in the management of the hydrologic systems of wet coastal forests, as manifested through the close partnership with the HJ Andrews Experimental Forest (US Forest Service), which has several extensively instrumented watersheds. Prominent faculty members have recently been attracted to Oregon State University into endowed chair positions. The combination of these resources has attracted a growing student base to the OSU program.

The University of Nevada at Reno is somewhat newer to the institutional landscape, but actively pursuing growth and prominence by forming a Hydrological Science Department. Historically, they have leveraged considerable faculty expertise through soft-money scientists employed at the highly successful Desert Research Institute. Whereas this approach has given the students in their hydrology program ample access to expertise and research projects, the faculty identified several obstacles to growth of their program, namely:

- Poorly defined administrative structure of interdisciplinary programs leads to a lack of departmental incentives for coordination (e.g. course offerings).
- Program viability depends on faculty roles, course offerings and space decisions made in several departments, without concern for the impact on the interdisciplinary program.
- Faculty turnover can dramatically affect the core curriculum offerings. This typically affects the program more than the host department.

In reviewing peer institutions, a few themes become apparent in their strategies for developing prominent interdisciplinary programs in hydrologic science. A very direct approach to achieving prominence is to "hire a star" to a named or endowed academic chair. With adequate resources, this strategy may be expanded to hiring a team. Duke University recently hired an entire research team from another university. The University of California at Irvine is pursuing the same approach.

Many of our peer institutions leverage their research capability through ownership of, or ready access to, experimental watershed facilities. The University of California Reserve system provides outdoor facilities with a common infrastructure for research. Other universities leverage existing federal facilities through mutually beneficial research collaborations.

Hiring faculty and developing outside research collaborations are common strategies for raising the profile of many academic programs, and are relatively simple. **The difficult task for each of these institutions has been developing an administrative architecture to support the interdisciplinary programs needed for institutional prominence in the study and management of water.** Programmatic success thus depends, in large part, on the degree to which the institution fosters the capabilities of its faculty and their interest in working together.

The University of California (UC) at Santa Barbara has a remarkable story to tell in the development of a new, interdisciplinary unit (see http://www.esm.ucsb.edu/about/ and appendix 4). In 1991, in response to a report issued by the State of California defining an increasing need for trained environmental professionals, the Regents of the University of California established the School of Environmental Science and Management at UC Santa Barbara to train graduate students in rigorous, interdisciplinary approaches to environmental problem-solving. A master's program was designed to offer courses in natural and social sciences, as well as ecology, management, and risk assessment. Twelve years later in 2003 the Donald Bren School of Environmental Science & Management enjoys a national and international reputation with diverse faculty committed to interdisciplinary teaching and research and a new 84,000 ft^2 building that has received a distinguished national award for being the greenest laboratory building in America. We know of the need for trained water professionals. **Can something like this happen at USU in 10 years? With boldness of vision, resources, and the right leadership, we could make it happen**.

The organization of intellectual ingredients necessary for the study of water is complex and diverse. Figure 2 provides one perspective on this breadth indicating the need for water resources management to draw from a wide range of applied and basic sciences and engineering.

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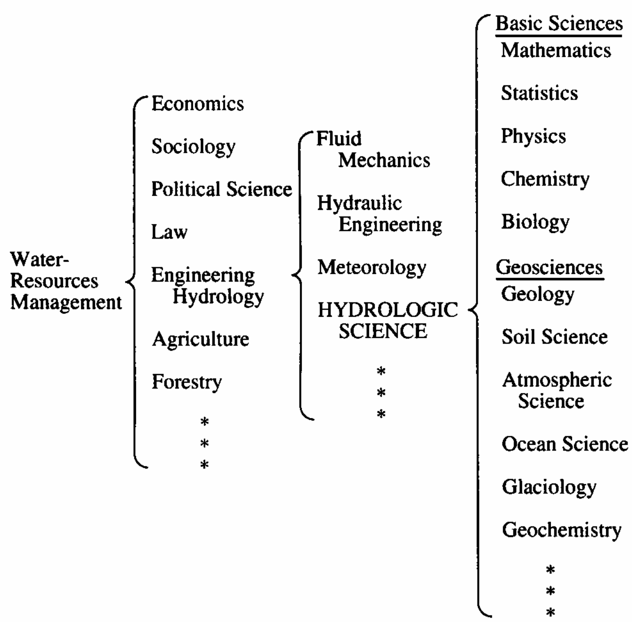

Figure 2. Water – the intellectual ingredients for its understanding, forecasting and management (modified from National Research Council 1991)

In examining this figure it is easy to appreciate the challenge in providing coherent academic programs in water. Many of these intellectual ingredients are present at USU. The challenge for us is to coordinate these elements and build integrated academic and research programs.

III. ASSESSMENT OF WATER RESEARCH, EDUCATION, AND OUTREACH AT USU

History

Utah State University has a long and distinguished record of accomplishment in water-related education, research, and extension. The history of water-related activities is provided in Appendix 3, but we briefly outline that history here. Established as a Land-Grant college in 1888, the Utah Agricultural College and the associated Utah Agricultural Experiment Station (UAES) quickly focused on water as a limiting factor in agricultural production. Early research teams were interdisciplinary in nature, consisting of engineers, agronomists, horticulturalists, and soil and plant scientists. The first graduating class of four included two irrigation engineers.

A broader vision for the role of water in Utah began to form in the 1940s as industrial growth led to increased interest in the development of water resources for power generation. At USU, research and development of water for hydropower resulted in water research by scientists without a direct link to agriculture. Increased interest in hydropower and other non-agricultural water-related research, in conjunction with growing interest in international development, eventually culminated in the establishment the Utah Water Research Laboratory (UWRL). The UAES retained its focus on agricultural research, while the UWRL was open to hydrological engineering issues not necessarily connected to agriculture.

Concurrent with research by UAES and UWRL, the development of what would eventually become the College of Natural Resources began early in the 20th century with the establishment of the School of Forestry and Range. This unit focused on research related to forests and wildlife management. Beginning in the 1960s and continuing though the present day, research into both terrestrial and aquatic ecological systems has highlighted the role of water quality and quantity for the maintenance of healthy ecosystems. Since the early 1990s, the college has added significant expertise in the human dimensions of natural resources, and those faculty members are now organized into the Department of Environment and Society. Thus, the college now has an interdisciplinary group of faculty in the physical, biological, and social sciences.

From its founding, USU responded to critically emerging water-related needs by having its administrators and faculty create new research programs. As a result, the 21st century finds USU with a broad array of faculty with strong interests in water-related research. The piece-meal approach to addressing water research, with its associated disciplinary structures, however, may have had the unintended side-effect of “divorcing” scientists with similar research interests from one another. On the other hand, one of the university’s greatest strengths is the large number and high quality of faculty members presently involved in water programs and the diversity of their expertise that spans the physical, biological, and social sciences and engineering (see Appendix 1).

Current Programs

USU currently maintains a number of very strong water-related programs and these are described in detail in Appendix 2. Water-related courses offered at USU are listed in Appendix 10. As illustrated in Figure 1, there are multiple departments and administrative units housed within six of the university's seven colleges that are involved in water research, education and/or outreach. The following synopsis highlights current programs.

The *Utah Water Research Laboratory (UWRL)* is the largest water program on campus. The UWRL represents a focus area of water-related research linked to academic programs within the College of Engineering. Research at the UWRL involves ground and surface water hydrology, ground and surface water quality, hydraulics, remote sensing, hazardous waste treatment, on-site waste water disposal systems, remediation of contaminated water in vadose zone and aquifer environments, watershed management, water resource systems, and natural systems modeling. The most recent UWRL annual report clearly documents a steady growth in state, federal, and private extramural funding attracted to the UWRL (Sims, 2001). In a recent review of similar water centers by the U.S. Geological Survey, the reviewer wrote "This is one of the top [water] centers nationally with a very strong research, education, information transfer, and collaborative (intrastate) program… This is an exemplary center in nearly every respect".

The *College of Engineering* has several excellent water-related academic programs, extension, and research emphases at the local, state, national, and international levels. These efforts are centered in *Civil and Environmental Engineering* within the divisions of *Environmental Engineering* and *Water Engineering* and *Biological and Irrigation Engineering* which includes the *International Irrigation Center*. The College/UWRL also maintains several unique water-related research, training, and outreach programs conducted through several laboratory facilities and institutes. These include the Systems Simulation/Optimization Lab, the Remote Sensing Services Lab, the Institute for Dam Safety Risk Management, and the Institute for Natural Systems Engineering.

Within the *College of Natural Resources*, the *Department of Aquatic, Watershed, and Earth Resources* maintains a strong academic and research program with elements covering hydrology, fluvial geomorphology, biogeochemistry, water quality, watershed and river management, fisheries, aquatic ecology, remote sensing, and geographic modeling. Faculty members in the *Department of Environment and Society* conduct research and/or teach courses dealing with water policy, planning, and management.

In the *College of Agriculture,* the *Department of Plants Soils and Biometeorology* maintains academic and research programs that are either directly or indirectly coupled to water and include fundamentals of water movement in soil, water use by evaporation and transpiration, physiology of water stress in plants, surface hydrological processes and controls and biogeochemical impacts on water quality. The Department also supports academics and research with several specialized laboratories including the Utah State University Analytical Lab, the Utah Climate Center, the Center for Water Efficient Landscaping, and the UNIDATA weather system.

Two departments in the *College of Science* are active in water research. The *Department of Geology* maintains water-related research and education in the areas of fluvial geomorphology and surficial processes, ground water geology, the influence of faults and fractures on subsurface fluid flow, and low-temperature aqueous geochemistry. The *Department of Biology* supports water-related research through work in the areas of hydrological and biological controls of nutrient cycling and energy flow in watersheds as well as fundamental life history studies that provide critical information in the broader context of water-related problems.

The *College of Humanities, Arts and Social Sciences* does not have a specific water-related mission. However, members of several departments in the college (particularly in *Sociology, Social Work and Anthropology*) have participated in water-related research, training, and technical assistance activities. These activities have occurred both domestically and internationally, both independently as well as collaboratively with the College of Natural Resources, Utah Water Research Laboratory, the Department of Biological and Irrigation Engineering and the International Irrigation Center. The *Department of Landscape Architecture and Environmental Planning* (LAEP) provides a holistic approach to design and environmental planning including stream corridor rehabilitation. Much LAEP work involves alternative futures analysis of which water is a significant part.

The *College of Business*, mainly through the activities of the *Department of Economics*, is involved in a number of research, education, and outreach programs in the water area. This includes collaborative efforts with the UWRL and focuses on water economics in light of natural resource policy issues, valuation of water-related amenities, risk assessment of dams/other structures, integrated water management in the international setting, marine/fisheries economics, and policy research.

USU Cooperative Extension is a fundamental component of the land grant mission (research-teaching-extension) of Utah State University. Extension programs are supported and delivered by campus-based specialists holding faculty appointments in all academic colleges and most departments. Extension has a long history of developing and delivering programs in water quality and quantity in urban, agricultural and natural environments. Six specialists and every agent with an assignment in agriculture, natural resources, horticulture, and family and consumer science are involved in some way with water issue programming. Current work includes the Utah State University Extension Water Issues Team, urban landscape water audits and promoting water conservation, involvement in the Center for Water Efficient Landscaping, and the Utah State University Analytical Laboratory.

The Utah State University *Ecology Center* is an example of an interdisciplinary administrative structure that may serve as a model for integrating water sciences at USU. The Ecology Center integrates the efforts of faculty and graduate students in three colleges and six departments to support and coordinate graduate education and research in ecology.

Program Integration Challenges

The breadth of these water-related programs provides Utah State University with tremendous potential for cutting-edge interdisciplinary research and scholarship. However, the diversity of water programs at USU also creates obstacles that hinder interdisciplinary research, education and outreach. These obstacles are the lack of both an integrated research front and integrated academic programs. Specifically:

- Many faculty simply are not aware of others with complementary interests. Likewise, administrators, in representing and promoting the university, often are not aware of the diversity of expertise that is available.
- The lack of physical proximity and regular interaction among faculty within different administrative units, limits encounters that promote collaborative activities.
- Each of the various administrative units designs and implements its water-related course offerings independently. This occasionally creates courses with overlapping content, and also does not allow educational gaps to be identified and addressed when new faculty are hired.
- There is unhealthy competition between units related to course offerings, research emphases and funding, both from within the university and from extramural sources.

More could be done to establish collaboration and joint research in the university community, as well as to coordinate undergraduate and graduate educational programs and course offerings. Although the university has a host of research and outreach programs, there is a general lack of discussion on water and other natural resource issues among researchers and outreach specialists that appears to be due to a lack of incentive or motivation to enter into this type of dialogue. These programs, in addition to many uncoordinated natural resource and water educational programs, make up the bulk of water-related activities on campus, but they lack a unified front to outside water management and funding agencies.

As for the current organizational structure of water programs at USU, the university's decentralized approach in the operation of the various programs on campus probably has resulted simply because the administration must depend on individual units to obtain funding if there is a small central funding base. Generally, more central control or administration of units is possible if there is a large central funding base. Nonetheless, better coordination of these units could create a more unified front when working on contracting activities with state, federal and international agencies and host nations.

Although there are a few interdisciplinary water-related research projects at USU, the overall level of interdisciplinary collaboration among the faculty within the various units on campus has declined in recent years. This is likely due in part to:

- changes in administration of departments and colleges that perhaps inadvertently de-emphasized collaboration in water research;
- shifts in funding priorities;
- shifts in research emphases as a result of natural faculty turnover;
- the retirement of senior faculty from various disciplines who regularly collaborated in water research; and
- the hiring of junior faculty who must respond to a reward structure that does not place interdisciplinary research at the forefront.

One of the obstacles hindering USU involvement in large, international interdisciplinary research projects is the criteria for promotion and tenure. Such projects often require long absences from campus, sometimes as long as several years. In these projects research is generally secondary to outreach, and thus fewer scholarly works tend to be produced. As a consequence, fewer faculty have been willing to participate in such projects in recent years. However, these projects broaden faculty, recruit promising graduate students, and generate large revenues via indirect costs, all of which support the basic research and academic mission of the university.

Utah State University has diverse strengths in the water sciences with existing programs in six colleges involving the physical, biological and social aspects of the water sciences**. Individually these programs are effective but collectively they are diffuse and fragmented. This fragmentation impedes USU's capability to provide a sustained interdisciplinary focus in its water-related discovery, learning, and engagement activities**. An interdisciplinary focus is critical to meet current and emerging research trends and societal demands. Leadership and coordination is needed to provide integration between these existing programs.

IV. STRATEGIES FOR ACHIEVING PROMINENCE

The difficult water policy and management issues that society confronts as it enters the 21st century challenge water scientists to work more effectively across academic disciplines in training students and conducting research, and to be increasingly engaged in meeting societal needs for water information and analysis. Exciting changes are occurring in the water sciences as professionals from various academic backgrounds respond to these challenges. National research organizations and private foundations increasingly are supporting interdisciplinary programs and research initiatives focused on water and are investing in institutions that have built capacity in this area.

Academic institutions that can effectively integrate and synthesize the water sciences, creatively develop new approaches to interdisciplinary education, and collaboratively design educational and research programs to address water issues of societal concern stand to achieve increased national and international prominence for their intellectual leadership and problem-solving capabilities. Thus, the compelling rationale for why USU should change its present course in water programs is that **society needs research and academic institutions to bring more sophisticated and decision-relevant science to bear on solving complex and urgent water problems**. As a publicly-funded, land grant institution in an arid state, USU has a responsibility and an opportunity to respond to that need.

Faculty members serving on the USU Water Initiative Task Force know that tremendous opportunities exist to meet societal water science and engineering needs by infusing existing water programs with new energy and an integrative mission. Task Force members would like to make USU the premier institution for the study of water science and management in the Western United States.

USU can achieve this distinction by creating a dynamic intellectual environment in which faculty and students are engaged, in an innovative academic program, and interdisciplinary research projects. Faculty and students must be empowered by the central Administration to respond to a set of incentives and rewards focused on fostering integration and collaboration both within the institution and through external partnerships. Task Force members are optimistic about, and committed to, helping USU gain new levels of national and international prominence in water. We are convinced that one key element in a strategy for achieving prominence in water is to work on the frontiers of scientific discovery through a collective, institutional effort that transcends the competencies of individual scientists, research teams, and departments. Such an effort needs to be broadly inclusive of the physical, biological, and social sciences, and engineering.

Another key to enhancing USU's reputation lies in training a new generation of water scientists, engineers, and managers immersed in the interdisciplinary understanding of water issues, problems, and solutions. This would require designing a new and innovative interdisciplinary graduate program that is focused on water as the integrating theme and is administered by a unit with the capability of engaging faculty to design and deliver a coordinated and integrated curriculum.

A third key to success is leadership. Whatever programmatic structure might be implemented to integrate water sciences, it would need to have a leader who is a senior-level faculty person with a national/international reputation for having a broad and inclusive vision (and who knows how to develop successful large research grant efforts). This leader would need to have excellent scientific credentials, administrative skills and experience, the ability to work effectively with diverse groups of faculty, and expertise in communicating well with a wide range of audiences. Most importantly, the leader should have interdisciplinary education and research experience, and should have worked on, or administered some large, interdisciplinary water projects. This person should have a vision and working knowledge of the possibilities, as well as the potential impediments, involved in synthesizing and organizing integrative intellectual work in academic settings. Realizing these visions will require bold and strategic actions on the part of USU's central administration that involve financial investment in water initiatives and changes in the organization of campus water programs.

Our recommendations for achieving prominence in the area of water consist of specific initiatives that water faculty would like to undertake and possible organizational changes that would be required for successful execution of these initiatives. We present the specific initiatives first, under the heading of "Water Initiatives and Opportunities." We then discuss alternative organizational models that should be considered to realize these opportunities. Although there is general consensus among Task Force members as to the desired activities, there is less agreement on the type of organizational change to recommend. We therefore recommend a process whereby a center is created whose mission is twofold: (1) to immediately begin implementation of the water initiatives; and, (2) to foster a collaborative, interdisciplinary, intellectually energized academic environment on all topics related to the science and management of water, with the ultimate goal of establishing a Graduate School of Water Science and Management.

Water Initiatives and Opportunities

1. Water Science Synthesis Activities. The wealth of water science activities at USU provides outstanding opportunities for synthesis. The Consortium of Universities for the Advancement of Hydrologic Science Incorporated (CUAHSI, www.cuahsi.org) recently defined such synthesis centers as a major need in the national hydrologic sciences programs. Utah State University is a member of CUAHSI. Figure 3 from the core proposal recently submitted by CUAHSI to the

National Science Foundation indicates the important role for synthesis in the pursuit of interdisciplinary water science advances.

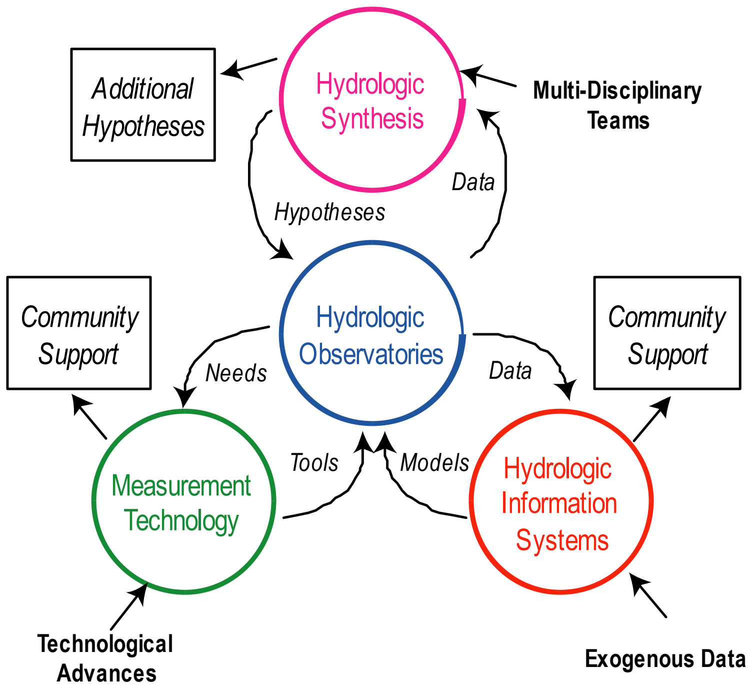

Figure 3. Principal CUAHSI hydrologic science programs (from www.cuahsi.org).

Although CUAHSI is a national effort, many of these concepts also apply to local synthesis within USU. In addition to the direct benefit from scientific synthesis, the development of synthesis activities at USU could serve as a model for national water science synthesis and position USU to be competitive in bidding to host a national CUAHSI synthesis center. CUAHSI will be seeking to develop a synthesis center and University's will have the opportunity to propose for the development of the CUAHSI synthesis center described in the CUAHSI core proposal just submitted to NSF (www.cuahsi.org). This is to be modeled after the National Center for Ecological Analysis and Synthesis (NCEAS) located near to UC Santa Barbara. Donor or matching funding toward a facility for such a center, in concert with a good water science synthesis proposal could attract such a center to Utah.

Specific activities and opportunities to promote scientific synthesis at USU include:

> 1.1. Annual USU Water Days conference. This conference would be modeled after the Hydrology Days conferences held by Colorado State University and the University of Arizona. This event would comprise presentations by USU faculty and students and provide a forum for sharing information about water research on campus. Regional participation would be encouraged.
>
> 1.2. Monthly or Bi-weekly Seminar/Cyberseminar. We suggest that the joint Water Seminar Series initiated in spring 2003 be continued and broadened to include an internet webcast of the presentations. This would allow national and worldwide participation in

seminars originating from USU. Such a Cyberseminar is one activity that CUAHSI is contemplating and Utah State University could provide this service for CUAHSI.

1.3. Research Development and Administration Support. Coordinated activities to increase USU's competitiveness in national and international pure and applied research activities through staff assistance in identifying interdisciplinary funding opportunities, in developing successful proposals, and in assisting with project accounting and administration.

1.4. USU Cooperative Extension Water Task Force. Synthesize existing extension programs in water quality, animal feeding operations, and water efficient landscaping. These extension programs would be linked to research nodes associated with climate variability, soil physics, and ecohydrology to enhance the ability of the University to support communities in their efforts to respond to future droughts and water shortages.

1.5. Coordination with Water Dynamics Laboratory. Encourage coordination and participation with the Utah State University Foundation's Water Dynamics Laboratory in its responsibilities of obtaining contracts, applying water skills, and in commercializing water-related skills or products.

1.6. Water and Climate Information System Initiative. There is an ongoing activity involving the Department of Plants, Soils and Biometeorology, the Department of Aquatic Watershed and Earth Resources, Computing Services, and the Utah Climate Center to provide an internet web portal for Climate data. This could be expanded to include regional water data, perhaps from an Experimental Watershed.

1.7. Water Policy Decision Making Involvement. Coordinated activities to increase USU faculty role in international, national, and regional water policy decision making.

1.8. Web Site. Host a web site on water activities and programs at USU.

2. Interdisciplinary Graduate Program in Integrative Water Sciences. We propose to develop and administer a graduate program focused on improving scientific understanding through integration of science, engineering and policy programs related to water. Degrees could be conferred by participating departments, as is the case with the Ecology Center, or by a new water unit that could function as a graduate degree granting department or school. Interdisciplinary Graduate Education Research and Training (IGERT) proposals (Belovsky et al., 2001; Tarboton et al., 2002 see Appendix 8) submitted to the NSF give details of the program envisaged.

3. Experimental Watershed Initiative. We propose to designate the Great Salt Lake Basin as a focal area to assess water science and policy issues as they relate to the needs of an expanding urban population. This basin is a microcosm for contemporary water resource issues in semi-arid lands because of rapid population growth on the Wasatch Front coupled with a variable climatic regime and frequent droughts. **Within the Great Salt Lake Basin, we propose to develop the infrastructure, core geospatial data and community linkages to serve water science and policy research in the Bear River watershed.** This 19,000 km^2 watershed

provides an excellent opportunity to showcase the capability of USU faculty to address issues of water supply, water quality, and equitable resource allocation while serving the state of Utah. The watershed includes area from three states ranging from snow fed alpine to semi arid climatic regimes, giving rise to a range of science, policy, and legal issues. A basic issue for the region is that the water supply is dependent on snowmelt, so it is particularly vulnerable to climate variability. The Bear River and Bear Lake are valuable resources for meeting the societal and ecological needs of the watershed, such as the Bear River Migratory Bird Refuge, and of the Great Salt Lake Basin. Bear River supplies two thirds of the input to the Great Salt Lake, a unique ecosystem supporting threatened bird populations and the $100M annual fishery of brine shrimp. Meanwhile, Bear Lake is used for irrigation storage and is an important recreational resource. Sections of the river are water quality impaired due to land use activities within the watershed. Although this problem remains a considerable issue, the water demand and quality impacts are expected to increase with population growth and land use development within the watershed. Additional dam projects to develop water for consumption by Wasatch Front municipal areas have been proposed. Complete understanding of surface/ground-water interactions needed to manage water resources within and between basins is lacking. The timing is ideal for a concerted program of action-oriented interdisciplinary scientific research that can be used in conjunction with collaboration and public dialogue to provide communities and decision makers with a set of choices for development of the urban rural fringe within this watershed. Development of a planning atlas similar to the Willamette River Basin Planning Atlas (Hulse et al., 2002) may be a useful first step in this initiative. Finally the size of 19,000 km^2 fits in the range (> 10,000 km^2) being targeted by CUAHSI for Hydrologic Observatories. So, with sufficient infrastructure and core geospatial data, Utah State University could compete for the Bear River to be a CUAHSI hydrologic observatory in the near future. We expect this would give appropriate leverage to attract funding from other programs developing experimental watershed networks, such as the USEPA and UNESCO HELP. Furthermore, it would represent an outdoor classroom to provide undergraduate and graduate students with hands-on learning. This initiative would engage the expertise and involvement of a wide range of faculty members and students from across campus. Appendix 9 expands on the experimental watershed initiative.

<u>4. General Water Coordination Activities</u>. These activities are focused on promoting and presenting in a coordinated way USU water science activities. Specific activities and initiatives include:

> <u>4.1 Regional Water Research Partnerships</u>. Establish water-related partnerships with the University of Utah, Brigham Young University and Inland Northwest Research Alliance Universities, USDA ARS Northwest Watershed Research Center, Western Region River Modeling Initiative, U.S. DOE watershed and environmental programs, CSREES Western Regional Research committees in water policy and valuation of natural resources.
>
> <u>4.2. Undergraduate Water Science Initiative</u>. The water sciences provide an excellent context in which to introduce basic mathematics, chemistry, physics and biology that are core to many USU degree programs. In conjunction with the appropriate departments promote the development of a set of core undergraduate courses that focus on using water

to introduce these sciences. A similar initiative is being pursued at MIT (Terrascope – see http://web.mit.edu/terrascope/www/).

4.3. International Research, Training and Technical Assistance. Facilitate the participation of water scientists and policy analysts in international water programs. Assist in the coordination of the implementation of international water development, water system, training and water policy programs using the wealth of experience that USU has had in the international water arena and the analysis of water science and policy issues in arid conditions.

Organization of Water Programs at USU

While Task Force members are fairly unified in their thinking about the questions of "why" and "what" USU should do to achieve prominence in water research and education, there is less of a consensus about the institutional mechanisms for "how" to realize the institution's full potential in this area. These differences of opinion are understandable given that interdisciplinary programs run counter to traditional academic organization along disciplinary lines. Suggestions of changes to traditional academic structures can be threatening, especially in tight budgetary times. The various ways in which interdisciplinary programs are administered at this and other academic institutions are reflective of political realities and of the challenges involved in trying to find mechanisms to promote cooperation and collaboration in a professional culture (academia) that tends to reward individualism and competition.

The Task Force discussed several alternative structures that might better encourage a strengthened program of water sciences at Utah State University. Some restructuring seems necessary to overcome institutional barriers to interdisciplinary work and to reallocate resources (faculty, time, space, money) to support a more integrated and synthesis oriented approach in water programs. Also, the ways in which faculty members and students function are largely determined by their position in the institutional structure. The department and college in which they are located, focus the work of faculty and students by shaping their institutional interactions and professional affiliations, influencing their intellectual paradigms, negotiating their role statements, defining their teaching responsibilities (faculty) and their curriculum (students), paying faculty base salaries, and providing operating space and administrative support services. Faculty members and students are recognized, rewarded, promoted and marketed by the units that employ and train them, and they respond to the needs, incentives and disincentives of those units.

The Task Force considered two general strategies for administrative structure reform: centralized and decentralized. Each of these strategies has merit, although the majority of the Task Force found greater support for centralized strategies. Centralized strategies include establishment of a new graduate School of Water Science and Management, creation of a Hydrologic Sciences Department, and creation of a new Center for Water Sciences. Decentralized efforts include creation of an administrative clearinghouse or coordination office to encourage sharing and cooperation among water faculty. An important advantage to the decentralized approaches is that they are more easily initiated.

In considering reorganization the Task Force is aware of the dangers involved, especially in an environment with decreasing budgets. Existing strong programs may be weakened or diluted if resources are reallocated. This would be detrimental. Emphasis should be on growing water programs rather than consolidation or reallocation so as to not weaken existing programs.

Graduate School of Water Science and Management

One proposal is to create a Graduate School of Water Science and Management that would consist of interdisciplinary graduate education and research programs focused on the study of water. This school would only administer graduate academic programs and the primary rationale for its formation would be to avoid the inherent difficulties of trying to train students in interdisciplinary paradigms when they are scattered in disciplinary-based departments and colleges all over campus. This school would have its own graduate students and some of its own faculty. Its students would first and foremost be trained to work in paradigms, models, data gathering and management strategies, and technologies grounded in interdisciplinary perspectives. They would secondarily gain a disciplinary specialty from some other department on campus. This reverses the normal emphasis on discipline-based specialization prevalent in graduate education where interdisciplinary work is secondarily pursued through a minor, emphasis, or certificate. However, this reversal is exactly in line with new programmatic thrusts of institutions such as the National Science Foundation that are promoting and underwriting integrated and innovative graduate education programs. Some of the most prominent and rapidly growing interdisciplinary graduate programs in the nation have been structured in this way, the most notable being the Donald Bren School of Environmental Science and Management at the University of California at Santa Barbara (see appendix 4).

Three strata of faculty would be involved in the Graduate School of Water Science and Management. The key to its success as a unifying force for water activities at USU is having a group of C*ore Faculty* with their primary appointments in the school. Having faculty who can prioritize and focus their efforts on interdisciplinary programs and activities is critical. Core faculty members would need to be highly entrepreneurial and would collectively shoulder the responsibility of building the Graduate School of Water Science and Management. They would serve as liaisons to the departments and units from which they came in order to maintain connections and facilitate collaboration between faculty in the School and faculty in other colleges. *Adjunct Faculty* members are those for whom water is a secondary emphasis and/or who are more comfortable working in a disciplinary context. Thus, they would retain primary faculty appointments in some other college but could choose to be an adjunct faculty member in the new school in order to be engaged at some level in its programs and activities. Core faculty would seek to include adjunct faculty on research projects as much as possible. *Affiliated Faculty* members are those who occasionally do research in water and who want to maintain a more informal affiliation with the school so that they can be involved in its programs and activities when relevant opportunities arise.

Such a Graduate School of Water Science and Management would be organized on an interdisciplinary basis and would operate in a highly entrepreneurial fashion. Its core faculty would function as a tight-knit and integrated team and would seek to foster collaboration in

water research and related activities across the entire campus. Its core faculty would work to obtain funding aimed at supporting interdisciplinary research and intellectual synthesis activities. They would take the lead in writing contract, grant, and foundation proposals and would specifically seek to help USU secure funding from some major national water programs. In addition, they would work together on devising a strategic plan aimed at involving other faculty around campus in water research and at elevating USU's national and international reputation in water. The main advantage of a school and the key difference between it and a center (described below) is that it would have core group of faculty with this interdisciplinary unit as their primary affiliation, and they would work with the Dean to build interdisciplinary programs.
The colleges represented on the Water Initiative Task Force (Agriculture, Business, CNR, Engineering, HASS, and Science) would need to cooperate in founding the Graduate School of Water Science and Management and could be actively involved in guiding its development. For these colleges, founding of the Graduate School of Water Science and Management would represent a joint initiative designed to help meet USU's strategic objective of promoting graduate education and research. These six founding colleges would support their faculty with this graduate college by allowing their primary appointments to be moved to the new college, but they would retain involvement of these faculty through joint and adjunct appointments and through allowing them to remain in their current office and lab space. The founding colleges would also align centers, labs, and other units with a primary emphasis on water in the new college in order to unify USU's water expertise.

The deans of the six founding colleges would serve on a "*Founders Council*" and would help to hire and then continue to consult with and support the Dean appointed to lead and build the Graduate School of Water Science and Management. The Dean of the new Graduate School of Water Science and Management would need to have excellent scientific credentials and administrative skills and experiences, as well as vision and working knowledge of the challenges and opportunities involved in organizing interdisciplinary, integrative, and synthesis oriented intellectual work in the water arena.

In order to facilitate functioning differently, this school might consider hiring a highly skilled professional staff person to be a *Collaboration Facilitator/Coordinator*. This person would be responsible for organizing meeting procedures, think tank sessions, and communication mechanisms designed to enhance integration within this school, promote collaboration between this school and the founding colleges, and build partnerships with external entities. This person would need to have strong academic credentials in the content area of water but would also need to be highly skilled in communication, facilitation, and team building procedures and techniques. This person would help faculty collaborate across disciplines, work toward conceptual integration, and interact in productive, efficient and effective ways. NSF has explicitly recognized that enhancing interdisciplinary team formation and management is a necessary component of building institutional capacity for integration and synthesis (Pfirman and AC-ERE, 2003).

Creation of a New Academic Department

The merit of this idea is to integrate within one department the majority of faculty and graduate student expertise in water resources and management, yet in an administrative structure more readily adopted than that of a school. The University of Arizona has achieved prominence in the study of water in large part because it was unique in the establishment of a Department of Hydrology. The University of Nevada at Reno has proposed a Department of Hydrologic Sciences to increase its prominence.

The primary division within USU, regarding expertise in water, is between the College of Engineering and the rest of the university. Most of the engineering faculty in the water area are within the Departments of Civil and Environmental Engineering or Biological and Irrigation Engineering. Possibly the water engineers in both departments could be joined into a single department. Alternatively, some joint appointments could help increase cooperation between departments.

There are potential gains to reorganization of water faculty elsewhere in the university. Reorganization at the departmental level would provide an opportunity to build stronger undergraduate programs in water science, allocate faculty time and responsibilities in ways that would eliminate duplication among existing departments, permit creation of a strong earth science-oriented water department focused on hydrology and related areas, further strengthen the Department of Aquatic, Watershed, and Earth Resources' (AWER) assemblage of ecologically-oriented water scientists, and be able to respond with more coordination to international, national, and regional water research initiatives.

Such reorganization might take its lead from the restructuring efforts in the College of Natural Resources that created AWER. This reorganization placed in one department almost all CNR faculty working in water-related fields. While this effort has already produced substantial synergistic benefits, the department merely represents those water-related fields on staff in the College of Natural Resources. Thus, the AWER department does not constitute a comprehensive assembly of water scientists, especially in the physical and earth science aspects of water science. Another limitation of the AWER department is that it is not integrated with faculty in the natural sciences in other colleges and therefore leaves other individuals as isolated entities in the College of Science or the College of Agriculture.

An opportunity thus exists to create a department with exceptional strength in the natural science of water. This department could focus on the physical science aspects of the field, such as climatology and meteorology, hydrology, hydraulics, earth science, and geochemistry. Reorganization would center around the core presently in AWER and in Biology, Geology and PSB, with ecologically-oriented faculty staffed in AWER and physical scientists in a restructured Earth Science Department. The Task Force did not consider what might be the college home of a new department.

There are potential negative aspects of reorganization into a department. There are many individual faculty members from the policy, social, and economic sciences who focus on water in their research. They are in the Department of Environment and Society in Natural Resources, in several HASS departments, as well as in the College of Business. Creation of a new department as outlined above may have the consequence of marginalizing the human dimensions of water sciences at USU. The Task Force has not assessed how many of these faculty members identify enough with the field of water that they might be willing to move to a new water-related college or department.

The commitment of faculty time to the activity of reorganization and the impact on existing colleges and the departments from which faculty are assigned is a concern for both the reorganization involved in a new school or a new department.

Creation of a New Center

Another approach is to create a new administrative unit such as a center to provide an overarching umbrella for the interdisciplinary study of and research in water sciences at USU. The USU Water Center could be established, based on the model of the Ecology Center.

The mandate of this center would be:

- To promote the synthesis of water science activities at USU.
- Develop an interdisciplinary graduate program in integrative water sciences at USU with degrees awarded through current academic programs similar to the way the Ecology Center functions.
- Develop an Experimental Watershed initiative to serve as a focus for unifying water science research activities at USU.
- General coordination and promotion of water science activities at USU.

The USU Water Center could serve as a cost center through which proposals might be developed like the Ecology Center.

The advantages of the Center approach are: 1) the opportunity for USU to be more competitive for funding at the program scale from federal level funding agencies (like NSF); 2) direct linkage between the director's success in promoting the vision defined here and his/her career success. The disadvantages are: 1) the director's bias will shape the resource that are sought and how they are distributed; 2) an additional administrative unit is created that does not solve the difficulty of having its faculty located in disciplinary departments; 3) the relationship between the new unit and existing units comes into question.

The objections to an additional center have been concerns over student credit hours and FTE divisions. These obstacles may be overcome by giving the center funding for buying out faculty time to remove the salary burden for teaching water science courses from the home departments of the faculty. The watershed science degree program that existed prior to the reorganization of CNR relied on voluntary cooperation of home departments for the teaching of required courses. This proved difficult due to it not having any control over funding.

The core functions proposed for an umbrella science center could be realized with minimal additional cost by drawing upon and reallocating some faculty resources already within the university. There is a danger in that these reallocations may be perceived as losses from certain departments or units. To avoid this, it is important that this initiative have the support of all campus water programs. We anticipate that this umbrella water center should report to the Provost or Research Vice President and a committee of deans such as the USU Water Resources Research Council. This unit would also need an active executive committee comprised of core faculty participating in the unit responsible for strategic planning. There should also be an external advisory board.

If additional funds are available to a center more resources could be brought to bear on critical initiatives that have the potential to attract large research grants in the future. The experimental watershed initiative has this potential, through CUAHSI, as well as by serving as a catalyst to focus national research on a local watershed due to the presence of the geospatial data infrastructure that would be developed. The interdisciplinary graduate program has the potential to attract funding through enrollment growth and serves the educational need of providing graduates qualified to undertake the critical water planning functions so urgently needed in the semi-arid Western US. The synthesis function has the potential to attract funding if we can be competitive in attracting the CUAHSI (www.cuahsi.org) synthesis center to Utah.

Decentralized Administrative Structures

Another approach is convening a committee to facilitate the interaction within existing units at USU to raise the level and visibility of interdisciplinary (cross-disciplinary, multidisciplinary) work. This approach has the advantages of not requiring any new positions to be created and parliamentary representation of the diverse interests on campus for distribution of committed funds. It has the disadvantage of taxing current program leaders and administrators with additional responsibilities and not having any individual responsible for success in attracting outside funding.

A committee, with name such as USU Water Science Coordination Council, with representation from the units within USU that are actively interested (such as biological, physical, engineering, social, economic, policy related representation) in contributing to interdisciplinary work on issues relevant to the movement of, management of, and policy governing societal manipulation of water could be convened. This committee would need representation from faculty that bring to it biological, physical, engineering, social, economic, and policy related perspectives. This committee should not be assembled based on administrative rank within the university, but based on scientific prominence and connection to the broadest range of program funding opportunities (e.g. CRSP). The task of this committee is to identify the opportunities for large, interdisciplinary projects at the state, national and international levels and to marshal the resources at USU to be competitive in winning awards. The Water Science Coordination Council would ideally be given some discretionary funds to seed interdisciplinary startup projects such as the Great Salt Lake Basin Watershed initiative, which has been proposed as a local laboratory. The products developed there will be of direct benefit to the state of Utah and will put the faculty involved in a position to use the data infrastructure to attract additional funding and funding for similar work in other locations.

Other Administrative Opportunities

The Task Force also discussed the merits of redirecting or expanding the mandate of current administrative units to be more broadly representative of the faculty strength (and new opportunities) in "water". We discussed the issue of UWRL's focus on engineering and discussed the disciplinary differences between many engineers and scientists. We have generally used the term "Science" in this report in an inclusive sense, despite the objection of some who view science and engineering as distinct. We note that the National "Science" Foundation includes a Directorate for "Engineering" so this inclusive use of "Science" is not without precedent. This is partly a semantic issue, but is a view strongly held and we acknowledge the differing perspectives on this wording. The upshot of this discussion has been that the engineers at USU with interests in hydraulic engineering, water quality and irrigation engineering are very successful within their fields and see continued need/opportunity for their existing program trajectories. It is notable that engineering units identify the need for interdisciplinary approaches to engineering problems and are happy to collaborate with faculty from other disciplines on specific projects, but also see the need to retain the focus of their programs on engineering. An alternative strategy for increasing USU's water program campus-wide is to specifically move the UWRL out of the College of Engineering and give the UWRL a university-wide status and mandate to fulfill the overarching umbrella interdisciplinary role articulated here. The possibility of doing this has not been fully evaluated because it seems to be a drastic restructuring of a strong and effective unit.

V. TASK FORCE RECOMMENDATIONS

Utah State University has diverse strengths in the water sciences with existing programs in six colleges involving the physical, biological and social aspects of the water sciences. Individually these programs are effective but collectively they are diffuse and fragmented. We recommend the creation of an overarching umbrella unit to serve as a nucleus for the Water Sciences at USU to give USU water programs visibility and focus and to provide capability for integration and synthesis among programs. Broadly, the unit might be one of (1) Graduate School (no departments), (2) Department, (3) Center, (4) Decentralized committee/council. The advantages and disadvantages of each have been discussed above.

This unit should create an environment that encourages and supports large scale cross disciplinary research and education and provides intellectual leadership on water issues of the state, the western U.S. region, nation and world. This unit should embrace the "Engaged University" model of the land-grant university in coordinating discovery, learning, and engagement of activities dealing with water sciences. This unit should focus on the synthesis of knowledge generated from interdisciplinary research necessary for planning, forecasting and understanding the availability, quantity, quality and use of water resources. All aspects of planning, i.e. population growth, water resources development, water rights and policy, conservation, ecology, economics, sociology, are considered. This unit should also assist in the development of water research proposals and provide leadership for involving the relevant scientists and campus programs in responding to water science and policy initiatives that emanate from various regional, national and international agencies and research programs.

This overarching unit may be a new unit, or could be created from an existing unit. There are advantages and disadvantages to creation of a new unit or restructuring of an existing unit to provide this capability. A new unit could be created with a fresh purpose and clear synthesis role, but is an additional level of administration and potential cost. If an existing USU unit, department or program, such as the UWRL or AWER department, is to be restructured to provide the overarching umbrella leadership that we perceive to be necessary then it needs to be freed from being captive to any one college and have its mission redirected to encompass the full breadth of water activities at USU.

The Task Force felt that an action as bold as the immediate establishment of a new college, such as a Graduate School for Water Science and Management, like the UC Santa Barbara Bren School of Environmental Science & Management was probably not feasible in the current budgetary climate. The recommendation is therefore that a center be created whose mission is to implement many of the immediate actions that are detailed above while at the same time starting the process evolving and working towards the establishment of a School for Water Science and Management as an ultimate goal.

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APPENDICES

APPENDIX 1. USU Water Specialists

Name	Title	Affiliation	Speciality
Baker, Michelle	Asst. Prof.	Biology	Hydrological and biological controls of nutrient cycling and energy flow in watersheds
Barfuss, Steve	Adj. Asst. Prof.	CEE/UWRL	Hydraulic/physical modeling, hydromachinery, valve testing, flow meter calibration.
Bastidas, Luis	Asst. Prof.	CEE/UWRL	Hydroclimate, land surface and integrated catchment modeling, multi-objective and global optimization.
Bingham, Gail E.	Scientist	PSB/Space Dynamics Laboratory	Micrometeorology
Bishop, Bruce	Prof.	CEE/UWRL	Water Resources Systems
Blahna, Dale	Assoc. Prof.	ENVS	Water-based recreation; fisheries
Boettinger, Janis L.	Assoc. Prof.	PSB	Pedology
Bowles, David S.	Prof.	CEE/UWRL	Dam safety engineering, risk assessment, risk management, real-time reservoir flood operation and extreme flood hydrology.
Box, Paul W.	Asst. Prof.	AWER	GIS, Agent-based models, spatial analysis, ecosystem modeling
Brunson, Mark	Assoc. Prof.	ENVS	Environmental knowledge & attitudes, Outdoor recreation policy
Budy, Phaedra E.	Asst. Prof.	AWER	Fisheries Management, Columbia River Fisheries, Whirling disease, Aquatic Ecology
Bugbee, Bruce	Prof.	PSB	Crop physiology
Busby, Fee	Prof., Dean	College of Natural Resources	Watershed function
Caldwell, Martyn	Prof., Director Ecology Center	FRWS	Physiological plant ecology, emphasis on plant adaptation to environmental stress in arid and tundra environments; environmental photobiology
Caplan, Arthur	Asst. Prof.	Economics	Economics of water pollution control
Cartee, Raymond L.	Res. Asst. Prof.	PSB	Irrigated soils
Cerny, Teresa A.	Res. Ext./Asst. Prof.	PSB	Ornamental horticulture and landscape water conservation
Chandler, David	Asst. Prof.	PSB	Surface Hydrology
Chauhan, Sanjay	Res. Asst. Prof.	CEE/UWRL	Dam Safety Risk Assessment, real-time reservoir flood operation and extreme flood hydrology.
Conte, Christopher	Assoc. Prof.	History	Environmental History
Criddle, Keith R.	Prof./Dept. Head	Economics	Marine fisheries
Crowl, Todd A.	Assoc. Prof.	AWER	Aquatic Ecology, Conservation Biology, Tropical Biology
Daniels, Steven	Director	Western Rural Development Center	Rural development, natural resource policy.
Doucette, William J.	Prof.	CEE/UWRL	Aquatic chemistry, environmental inorganic chemistry
Drost, Dan	Assoc. Prof.	PSB	Sustainability
Dudley, Lynn	Prof.	PSB	Soil Chemistry
Dupont, R. Ryan	Prof.	CEE/UWRL	Environmental Engineering
Edwards, Tom	Assoc. Prof.	FRWS	Spatial ecology, landscape ecology, biostatistics and GIS
Endter-Wada, Joanna	Assoc. Prof., Director, Natural Resource & Environmental Policy Program	ENVS	Water policy; water and culture; human dimensions of fisheries

Evans, James Paul	Prof.	Geology	Structural geology, especially the influence of faults and fractures on subsurface fluid flow
Fawson, Christopher	Prof., Vice Provost	Economics/International Affairs	Water management, development
Gillies, Robert R.	Assoc. Prof.	AWER	Remote Sensing, Meteorology
Glover, Terry	Prof.	Economics	Risk assessment, water pricing
Gooseff, Michael	Asst. Prof.	AWER	Hydrology, Snow dynamics, Hyporheic Zone Ecology
Grenney, William J.	Prof.	CEE/UWRL	Development of multimedia decision-support systems for engineering applications
Griggs, Thomas C.	Asst. Prof.	PSB	Agronomy
Grossl, Paul	Assoc. Prof.	PSB	Geochemstry
Hardy, Thom	Prof.	CEE/UWRL	Natural Systems Engineering
Harrison, John D.	Res. Ext./Asst. Prof.	ASTE	Agricultural waste management and water quality
Hawkins, Charles P.	Prof.	AWER	Aquatic Ecology, Ecosystem Assessment, Stream and Riparian Ecosystems
Heaton, Kevin	Extension Agriculture Agent	Extension, Garfield/Kane Counties	Livestock water quality and drought. Director/Agriculture/Youth Agent
Hefelbower, Rick	Extension Horticulture Agent	Extension, Washington County	Landscape water conservation and drought. Horticulture/Natural Resources Agent
Hill, Robert W.	Res. Ext./Prof.,	BIE	Agricultural and landscape irrigation engineering, evapotranspiration measurement for crops and turf, irrigation water quality, hydrology
Hipps, Lawrence E.	Assoc. Prof.	PSB	Biometeorology, earth surface-atmosphere interactions, large-scale evaporation, radiation regime of plant canopies, remote sensing
Hoggan, Daniel H.	Prof.	CEE/UWRL	Computer Assisted Floodplain Hydrology and Hydraulics
Jackson, Earl	Ext.Water Quality Agent	Extension, Salt Lake County	Water quality, quantity and conservation; Slow-the-Flow program
Jackson-Smith, Douglas	Asst. Prof.	SSWA	Agricultural systems, water quality, land use and land management issues.
Jakus, Paul M.	Assoc. Prof.	Economics	Water quality, quantity, and allocation
Jenkins, Mike	Assoc. Prof.	FRWS	Disturbance ecology and management, insects, fire, snow avalanches
Jensen, Donald T.	Prof., State Climatologist	PSB	Climate
Johnson, Craig	Prof.	LAEP	Planting design, landscape restoration, urban wildlife planning, and applied landscape ecology.
Johnson, Michael C.	Asst. Research Prof.	CEE/UWRL	Hydraulic model studies, spillway analysis and operation, computational fluid dynamics
Johnson, Mike	Extension Agriculture/Horticulture Agent	Extension, Grand County	Landscape water conservation and drought
Johnson, Paul	Asst. Prof.	PSB	Conservation
Jones, Scott	Res. Asst. Prof.	PSB	Soil Physics
Kaluarachchi, Jagath	Prof.	CEE/UWRL	Groundwater Hydrology
Kasilingam, Babu	Res. Asst. Prof.	BIE	Canal system management, irrigation training, software development, distance education
Keith, John	Prof.	Economics	Water management, irrigation
Kemblowski, Mariush	Assoc. Prof.	CEE/UWRL	Groundwater Hydrology
Kershner, Jeffrey L.	Res. Assoc. Prof.	AWER	Fisheries Ecology, Fisheries Habitats, Fisheries Management
Kitchen, Boyd	Extension Agriculture	Extension, Uintah County	Agriculture water quality, conservation and drought. Dir/Agri/Youth Agent
Kjelgren, Roger	Assoc. Prof.	PSB	Water Efficient Landscaping
Koenig, Richard T.	Res. Ext./Asst. Prof.	PSB	Soils
Kolesar, Pete	Assoc. Prof.	Geology	Geochemistry, especially low-temperature aqueous geochemistry

Kopp, Kelly L.	Res. Ext./Asst. Prof	PSB	Landscape water conservation
Krannich, Richard	Prof., Department Head	SSWA	Natural resource/environmental sociology, rural community studies, and survey research design
Lachmar, Tom	Assoc. Prof.	Geology	Ground water geology, especially acquistion and interpretation of field data for ground water quality and quantity issues.
Lavoie, Caroline	Assoc. Prof.	LAEP	Historic irrigation canals
Lewis, David	Prof.	History	Western irrigation history
Lilieholm, Robert J.	Assoc. Prof.	ENVS	Forest management and economics; Urban Forestry; Urban Wildland Interface Issues
Luecke, Chris	Assoc. Prof./Dept. Head	AWER	Aquatic Ecology, Conservation of fishes, Fisheries Management
MacAdam, Jennifer W.	Assoc. Prof.	PSB	Plant Physiology
Malek, Esmaiel	Res. Assoc. Prof.	PSB	Meteorology
McFarland, Mike	Assoc. Prof.	CEE/UWRL	Biosolids Engineering
McKee, Mac	Prof., Asst. Director UWRL	CEE/UWRL	Water Resources Systems
McLean, Joan E.	Res. Asst. Prof	CEE/UWRL	Soil Chemistry
McNeill, Laurie	Asst. Prof.	CEE/UWRL	Drinking water
Merkley, Gary	Assoc. Prof.	BIE	Canal system modeling and management, channel and irrigation hydraulics and system design, water system privatization
Mesner, Nancy	Res. Ext./Asst. Prof	AWER	Stream and lake water quality and stream monitoring, water quality, water policy, modeling
Messmer, Terry	Prof.	FRWS	Fisheries and Wildlife Extension Specialist, Wild ungulate and waterfowl management, wetlands ecology,
Moris, Jon	Prof.	SSWA	international water management, international irrigation settlement
Neale, Christopher M.	Prof.	BIE	Airborne multispectral remote sensing, Agricultural monitoring and irrigation water management
Newhall, Robert L.	Ext./Res. Associate	PSB	Soil and water conservation
Nicholson, John K.	Assoc. Prof.	LAEP	Historic irrigation canals
Norton, Jeanette M.	Assoc. Prof.	PSB	Soil microbiology
Pack, Robert T.	Res. Assoc. Prof.	CEE/SDL	Geomatics, LIDAR, Geoengineering
Palmer, Matt	Ext. Ag./Hort. Agent	Extension, Tooele County	Landscape water conservation and drought.
Parlin, Bradley	Prof. Emeritus	SSWA	International water management, international irrigation settlement, environmental assessment
Payne, Jack	Prof., VP for University Extension	ENVS	Conservation program adminstration, agriculture and natural resource policy
Pederson, Joel L.	Asst. Prof.	Geology	Geomorphology, especially fluvial geomorphology, paleoclimatology, and geoarcheology.
Peralta, Richard	Prof., Interim Dept. Head To be Director, Water Dynamics Laboratory	BIE	Groundwater and water resources systems analysis, modeling, optimization, conjunctive use, contamination remediation, water quality
Platero, Loralie	Extension Horiculture Agent	Extension, Cache County	Landscape water conservation and drought.
Rahmeyer, William	Prof.	CEE/UWRL	Hydraulic/physical modeling, sedimentation and erosion, flood plain resistance, hydromachinery
Ramsey, R. Douglas	Director, Remote Sensing/GIS Lab; Assoc. Prof.	FRWS	Remote sensing, geographic information systems, landscape ecology, spatial analysis
Rasmussen, V. Phillip	Prof. Asst. Director Ag Experiment Station	PSB	Geospatial extension specialist
Riley, Pamela	Prof.	SSWA	International water management, international irrigation settlement, impacts of irrigation on women farmers

Roberts, David W.	Assoc. Prof.	FRWS	Vegetation Ecology
Rupp, Larry A.	Prof./Dept. Head	PSB	Ornamental Horticulture
Schmidt, John C.	Assoc. Prof.	AWER	Fluvial Geomorphology, Large river dynamics, water policy
Seeley, Schuyler D.	Prof.	PSB	Sustainable orchard management
Sharik, Terry	Prof./Department Head	ENVS	Forest ecology, natural resource & environmental management, teaching & learning pedagogy
Simmons, Randy	Prof./Department Head	Political Science	Urban/household water issues, conservation, rationing
Sims, Judy	Res. Assoc. Prof.	CEE/UWRL	Site interactions affecting fate and behavior of organic chemicals in subsurface systems. On-site wastewater treatment systems (septic systems)
Sims, Ron	Prof., Director UWRL	CEE/UWRL	Biochemical processes in the environment. Remediation.
Smith, Geoffrey G.	Director	IOWE	Water Education
Sorensen, Darwin L.	Res. Prof.	CEE/UWRL	Environmental microbiology and environmental management
Snyder, Don	Prof. and Assoc. Dean	Economics	Water rights
Stevens, David K.	Prof.	CEE/UWRL	Biological and chemical engineering processes applied to surface and subsurface environments
Sturgeon, Stephen C.	Manuscript Curator	USU Libraries	20th century political and environmental history of water development in the American West
Tarboton, David G	Prof.	CEE/UWRL	Hydrology and Water Resources
Toth, Richard	Prof.	ENVS	Landscape Architecture, Large scale landscape analysis
Tullis, Blake	Asst. Prof.	CEE/UWRL	Hydraulic/physical modeling, hydromachinery, valve testing, flow meter calibration, pump engineering and pump intakes.
Urroz, Gilberto E.	Assoc. Prof.	CEE/UWRL	Erosion control, hydraulic structures modeling, groundwater modeling.
Van Miegroet, Helga	Assoc. Prof.	AWER	Biogeochemistry, soils, nitrogen dynamics, ecosystem ecology
Varga, William A.	Director, Utah Botanical Center	PSB	Intermountain native plants
Vinson, Mark R.	Research Asst. Prof.	AWER	Aquatic invertebrates, biomonitoring
Walker, Wynn	Prof., Assoc. Dean Engineering	BIE	Irrigation engineering/water resources management
White, Mike A.	Asst. Prof.	AWER	Terrestrial water budgets, global climatology, remote sensing
Willardson, Lyman	Prof. Emeritus	BIE	Drainage engineering and subsurface water management
Wurtsbaugh, Wayne A.	Prof.	AWER	Limnology, fish ecology, watersheds
Yap-Salinas, Humberto	Res. Prof.	BIE	Agricultural water management, privatization of irrigation systems, drainage & reclamation

ASTE= Agricultural Systems Technology and Education, College of Agriculture
AWER = Aquatic Watershed and Earth Resources, College of Natural Resources
BIE = Biological and Irrigation Engineering, College of Engineering
CEE = Civil and Environmental Engineering, College of Engineering
ENVS = Environment and Society, College of Natural Resources
FRWS = Forest, Range and Wildlife Sciences, College of Natural Resources
IOWE = International Office of Water Education
LAEP = Landscape Architecture and Environmental Planning, College of Humanities, Arts and Social Sciences
PSB = Plants Soils and Biometeorology, College of Agriculture
SSWA = Sociology, Social Work and Anthropology, College of Humanities, Arts and Social Sciences
UWRL = Utah Water Research Laboratory, College of Engineering

APPENDIX 2. Description of USU Administrative Units Involved in Water

Department of Aquatic, Watershed and Earth Resources

The Department of Aquatic, Watershed, and Earth Resources offers comprehensive educational opportunities for graduate and undergraduate students in hydrology, geomorphology, biogeochemistry, water quality, watershed management, fisheries, aquatic ecology, remote sensing and geographic modeling. Our faculty provides expertise in fisheries, the hydrologic cycle, conservation biology, restoration and management of aquatic and riparian ecosystems, and in the remote sensing and geographic analysis of the earth's landcovers. Graduates of our programs become teachers and researchers at major universities, scientists and managers for natural resource agencies, and professionals with consulting and non-profit environmental firms.

Research in the Aquatic, Watershed, and Earth Resources Department spans large spatial and temporal scales. Our faculty integrate physical, chemical, and biological processes to better understand ecosystem function. We embrace a hierarchical view of watersheds, scaling up from small-scale physical and physiological processes to derive patterns of ecosystem and continental dynamics. Our faculty generates over $2 million annually in pursuit of research projects ranging from the arctic to the tropics, and from space-based remote sensing platforms to subsurface soil and water processes. Research monies come from the National Science Foundation, Environmental Protection Agency, US Forest Service, Bureau of Land Management, Utah Divisions of Water Quality and Wildlife Resources.

Department of Biological and Irrigation Engineering, and the International Irrigation Center

The International Irrigation Center (IIC) housed within the department of Biological and Irrigation Engineering at USU was organized in 1980 to coordinate foreign technical assistance programs in agriculture, water sciences, and engineering. Use of the term "irrigation" in its title reflects predominant emphasis rather than an exclusive expertise. The IIC continues to support projects as diverse as remote sensing and GIS applications in agriculture, cadastral mapping of land ownership patterns, regional groundwater planning and management, and water quality management in both surface and subsurface water resource systems.

USU has a long history of international research, training, and technical assistance. Since the early 1950s the university has implemented over 100 major projects at a value of over US$135 million. Principal areas of involvement include irrigation development and management; arid land agriculture and livestock; management of natural resources; and institution building in irrigation, agricultural research and extension. In recent years USU has had international projects in nearly 30 countries on four continents.

In addition to the International Irrigation Center, specialized water-related research, training, and outreach programs in the Department of Biological and Irrigation Engineering are also conducted through three laboratory facilities. These are the Systems Simulation/Optimization Lab, the Remote Sensing Services Lab, and the World Irrigation Information Network (IrriNet). The Systems S/O Lab is currently involved in regional groundwater development planning and localized groundwater contaminant remediation projects. The Remote Sensing Services Lab (RSSL) is conducting large cadastral and land use surveys in the Dominican Republic as well as riparian mapping in watersheds throughout the US. RSSL owns and operates a remote sensing research aircraft with state-of-the-art digital cameras and thermal infrared scanners that have allowed the development of numerous applications in joint research efforts with several groups on campus. These applications are in diverse areas such as precision agriculture (yield and evapotranspiration estimates), hydrology (energy balance estimates of natural and irrigated systems) as well as mapping of wetland and riparian systems. The IrriNet facility is developing on-line training, technical assistance and applied research programs for worldwide distribution.

Department of Biology

The Biology Department's mission is to advance discovery in the biological sciences and to make knowledge of biological sciences available to students and the public through education and outreach. Biology is a broad field ranging from molecular genetics to ecosystem ecology. In general, the main focus of biology faculty is not on water or water issues; however, water is fundamental to all of life. Several faculty in the department conduct research in freshwater systems, including work in: hydrological and biological controls of nutrient cycling and energy flow in watersheds; quantitative genetics and evolutionary biology of *Daphnia*; and pathology and control of Whirling disease in trout and Tubificid worms. All three research programs are well funded by state and national agencies including the NSF, EPA and UT DWR.

Department of Civil and Environmental Engineering

Civil and Environmental Engineering (CEE) is concerned with planning, designing, constructing, and operating various physical works; developing and utilizing natural resources in an environmentally sound manner; providing the infrastructure which supports the highest quality of life in the history of the world; and protecting public health and renovating impacted terrestrial and aquatic systems from the mismanagement of toxic and hazardous wastes. The CEE Department has graduate programs in several areas, including Environmental Engineering and Water Engineering. Faculty CEE have joint appointments at the UWRL, and the research components of these programs are closely tied to the UWRL.

Environmental Engineering:

Water, soil, and air aspects of environmental quality and public health protection are the research thrusts of the Environmental Engineering Division. Strong areas of research in the division are hazardous waste management; treatment and control of toxic and hazardous waste, including geoenvironmental technologies for treatment of contaminants; water and wastewater treatment; natural systems engineering; and water quality management for lakes and rivers.

Water Engineering:

The goal of the Water Engineering division of the CEE Department is to conduct state of the art research in the fields of hydrology and water resources, groundwater, hydraulics and fluid mechanics to address the water research needs of the state of Utah as well as nationally and internationally. Research to create new knowledge is an integral part of the academic program. The program recognizes the interdisciplinary nature of many water research problems and seeks to foster and maintain collaborative links with other units on campus and other universities and research organizations in pursuing this research.

Ecology Center

The Utah State University (USU) Ecology Center is an administrative structure in the University that supports and coordinates ecological research and graduate education in the science of ecology, and provides professional information and advice for decision makers considering actions that affect the environment.

Administratively, the Center is part of the University's Division of Research, and integrates the efforts of faculty and graduate students in 3 colleges and 6 departments. Participating faculty have tenure in their home departments, and graduate degrees are conferred in the participating departments. Over 30 courses are associated with Ecology Center programs. With state support in the University budget, the Center's program is a major mission of the institution.

Academically, a primary Center purpose is to provide a basic scientific underpinning for the basic and applied ecological programs in the Colleges of Agriculture, Natural Resources, and Science. But many of its research projects address applied natural resources and environmental problems.

Department of Economics

The Department of Economics, jointly administered by the Colleges of Agriculture and Business, has carried out a number of research, education and outreach programs in the water arena since the 1960s. Research into water rights, markets, and pricing in the Sevier River Basin of Central Utah during this early period was some of the first economic research in the western U.S. on these issues. USU economists were also involved in the Colorado River Assessment project of the early and mid-1970s. At this time, and into the 1980’s, considerable research was completed on the economic impacts of water transfer from agricultural uses to potential energy development uses.

The current research and outreach teams within the Department of Economics can mainly be divided into the following areas that describe the current mission of research and outreach in the broader water arena:

- Water economics including the consideration of water development, water rights/institutional arrangements, water allocation and management, water markets/pricing within the context of state and national policy.
- The valuation of water-related amenity services and water quality for information input to public natural resource policy issues, with some interdisciplinary efforts in water quality and tools for managing water quality.
- Management of natural resources related to water quantity and quality, such as control of soil erosion and pollutant runoff.
- Organization and provision of cooperative and public goods, including water institutions.
- Marine/fisheries economics and policy research in cooperation with National Marine Fisheries Services and other NOAA divisions.
- Integrated water management in the international setting, and currently a project with USAID in Morocco, with current negotiations ongoing to develop interdisciplinary research and policy projects in Guyana and a new CRSP initiative emanating out of USAID.
- Risk assessment of large dams and other water structures with the Institute for Dam Safety Risk Management, Utah Water Research Laboratory.

Most water-related research conducted by members of the Economics Department is with state and federal water policy agencies, with activities generally channeled through the Utah Agricultural Experiment Station. Although there are interdisciplinary projects in which economists participate, the general level of collaboration between economists and other water scientists has waned in the past two decades. While the current organizational structure does not explicit reward multidisciplinary research, the entrepreneurial incentives of the grant and contract system have resulted in collaboration between economists and engineers, sociologists, and scientists in the College of Natural Resources.

Department of Environment and Society

The Department of Environment and Society offers graduate and undergraduate educational opportunities that focus on understanding the interface between human and natural systems. An interdisciplinary group of applied economists, environmental educators, geographers, land planners, policy scientists, recreation specialists, and social scientists comprise the faculty. The department seeks to promote scholarship relating to the human dimensions of natural resource and environmental management, apply social science concepts and approaches to better understand human-environment interactions at a range of spatial scales, and enhance the effectiveness of policies, planning, and administrative processes that affect sustainable use of the natural world. The department currently offers three undergraduate degrees (Environmental Studies, Geography, and Recreation Resource Management), three graduate degrees (Bioregional Planning, Geography, and Recreation Resource Management), and two graduate certificates (Natural Resource and Environmental Policy; National Environmental Policy Act). The department is awaiting approval for proposed graduate degrees (M.S. and Ph.D.) in Human Dimensions of Ecosystem Science and Management and a proposed graduate certificate in Natural Resource and Environmental Education. Many faculty in the department have conducted research on water-related issues, including work on human use of and values about water and wetlands, the politics of water allocation and development, river corridor and watershed planning, water-based recreation, water and wildlife, and social organization in irrigation systems.

Department of Geology

The Mission of the Department of Geology at Utah State University is:

- to provide training for future professional geologists directly through high-quality instruction and research involvement in geology. The department recognizes the critical role of other departments in providing supporting courses in areas such as chemistry, physics, mathematics, biology, computer science, and engineering;
- to contribute to the advancement of scientific knowledge in the field of geology through research activities in selected areas of expertise;

- to provide supporting courses and research services for professional programs in such areas as natural resources, soil science, landscape architecture & environmental planning, science education, civil & environmental engineering, watershed science, and physical geography;
- to enhance the liberal education of university students from other fields by providing high-quality instruction in geology, and developing an appreciation of the geology and natural resources of the state of Utah; and
- to promote an understanding of geology among the general public, and to educate the public with respect to the potential impact of geology on everyday life through service to individual citizens, community groups and public schools.

Research activities within the Geology Department are divided into four major areas: sedimentation and sedimentary systems, surficial processes, tectonics, and petrology and geochemistry. Water-related research, as well as education, although not an emphasis, is a key component within the Geology Department. Two of the eight faculty focus almost exclusively on water-related topics, one other conducts some water-related research and teaching, while a fourth performs some water-related teaching.

The four water-related areas within the Geology Department that are the focus of research and teaching activities are: fluvial geomorphology and surficial processes, ground water geology, the influence of faults and fractures on subsurface fluid flow, and low-temperature aquesous geochemistry. Seven water-related courses are taught within the Geology Department.

The three faculty members who perform water-related research have successfully funded over a dozen grant proposals during the past five years for a total of nearly $1,000,000 from agencies such as the National Science Foundation, the U.S. Department of Energy, the Nuclear Regulatory Commission, the U.S. Geological Survey, the Geological Society of America, the Utah Department of Environmental Quality, the Utah Division of Water Resources, and Cache County. Research topics range from the incision, faulting and geoarcheology of the Grand Canyon, to sequestration of carbon dioxide in geologic reservoirs, to various water quality and quantity issues within the state of Utah.

Department of Plants, Soils and Biometeorology

The movement and phase changes of water and the attendant processes have large effects on the soil-vegetation-atmosphere system. Much of the research in the Department of Plants, Soils and Biometeorology (PSB) deals with a myriad of biological and physical processes above and below the ground that govern the properties and function of the land surface. Most of these topics are either directly or indirectly coupled to water. Hence, the subject is a common thread making connections throughout our research programs, which include fundamentals of water movement in soil, water use by evaporation and transpiration, physiology of water stress in plants, surface hydrological processes and agricultural water quality. In a recent self-assessment, PSB has prioritized water as a topic for future collaborative efforts, but noted that there is currently very little incentive within the university for collaboration to occur. The department compact plan proposed that development funds be targeted to endow professorships and research assistantships in targeted focus areas (such as water or climate) and that funding from the Vice President for Research office be focused directly on broad collaborations to address the state's water issues.

PSB has four major service programs within the department that are related to water. Historically, the Utah State University Analytical Lab and the Utah Climate Center have served the needs of agriculture in the state though soil, plant, and water testing and developing products such as indices to monitor droughts, wetness, heat and cold stress. The more recent additions of the Center for Water Efficient Landscaping (CWEL) in 1998, and the UNIDATA weather system in 2002 address emerging needs of the state and opportunities for research at USU. CWEL was formed by the Utah State legislature, with the mission to conduct research and extension projects on water efficient landscaping for the state of Utah, and is playing an increasingly significant role in not just extending information on landscape water conservation, but also on helping shape policy for the state. CWEL provides information and resources to the public, the green industry and water purveyors regarding water conservation in the landscape. CWEL was created to conduct research on effective irrigation techniques, landscape water demand analysis, low-water use landscaping and plant water needs, and to promote water conservation and quality. CWEL disseminates information to water purveyors, the green industry, and local USU extension offices to support public education in water-efficient landscaping. A newly established climate database, coupled to the UNIDATA weather system, will provide water researchers ready access to revolutionary amounts of information from around the world, vastly improving atmospheric, hydrologic and climatic modeling capabilities at USU.

College of Humanities, Arts and Social Sciences (History, LAEP, Political Science, and Sociology, Social Work and Anthropology)

The College of Humanities, Arts and Social Sciences (HASS) does not have a specific water-related mission. However, members of several departments in the college (particularly in SSWA) have participated in water-related research, training, and technical assistance activities. These activities have occurred both domestically and internationally, both independently as well as collaboratively with the College of Natural Resources, the Department of Biological and Irrigation Engineering, and the International Irrigation Center.

These faculty members have participated in a range of research activities on the social aspects of water management, organization and conservation. Recent research from SSWA has included evaluation of irrigation settlement and resettlement schemes; gendered impacts of irrigation projects; social implications of a future severe, sustained drought in the Colorado River Basin region; approaches for enhancing local community response to the implementation of federal water quality (TMDL) standards; and farm operators' implementation of management practices designed to ameliorate water quality concerns. Political Science research has focused on household water use in Utah including elasticity of demand and cities' structures of water pricing and alternatives for rationing water. Some faculty in the department of Landscape Architecture and Environmental Planning (LAEP) pursue water related teaching and professional design activities. These activities include stream and riparian corridor restoration projects, conceptual plans for integrated historic irrigation canals within city scapes and sustainable regional and environmental planning. LAEP faculty recently wrote a history of canals and ditches in Logan with suggestions for urban development around these structures.

The present strength of the college relevant to water is in the qualified and experienced faculty. This is also a potential weakness as a number of this faculty have just, or will soon be retiring. Several newly hired faculty are very interested in involvement but need incentives to evolve in this direction. In particular, if SSWA doesn't encourage new faculty the international vigor of the department will disappear. The domestic side is less endangered with several well-qualified faculty with potential to be strong players. A primary need is for better communication and coordination with other units on campus to promote interdisciplinary activity.

Natural Resource and Environmental Policy Program

The mission of the Natural Resource and Environmental Policy Program (NREPP) is to contribute to understanding and solving the tremendous public policy challenges involved in determining sustainable and equitable uses of natural resources and ensuring future environmental quality. Public policy challenges, particularly related to water resources, stem from the fact that natural resource and environmental decision-making often involves scientific/technical complexity and uncertainty, diverse stakeholders, difficult trade-offs, and substantial controversy. Solutions to these challenges require substantial public debate, mechanisms for mediating environmental conflicts, problem-solving innovations, increased scientific integration, better interface between the domains of science and policy, management adaptations, and transboundary approaches from a political and administrative system that is inherently fragmented.

While NREPP faculty and students are engaged in scholarship on a wide range of topics, many of them have been involved in research and education directly focused on water policy, planning, and management. They have researched issues involving water rights, fisheries, water transfers, in-stream flows, impact assessment of water projects, management of irrigation systems, operation of dams and other water infrastructure, wetlands, water pricing structures, and water conservation strategies. The NREPP faculty who have been the most heavily involved in water-related research are generally from the program's cooperating departments of: Economics; Environment and Society; History; Landscape Architecture and Environmental Planning; Political Science; and, Sociology, Social Work, and Anthropology. Other NREPP affiliated faculty who are in disciplinary departments related to the biological and physical sciences are involved in science and engineering that is highly relevant to water policy.

The NREPP was initiated in 1991 and developed with the support of all eight USU colleges and with more active participation from sixteen departments or units. A Faculty Advisory Committee guides program development while a much larger group of Affiliated Faculty participates in program activities. Students from all over campus have participated in the NREPP's graduate certificate programs, seminar series, internships, and symposia. Currently, the NREPP administers two graduate certificate programs, conducts a successful policy seminar series, offers symposium courses in conjunction with the Quinney School of Law at the University of Utah, and provides service to the state of Utah in the natural resources policy arena.

Utah Water Research Laboratory

The mission of the Utah Water Research Laboratory includes the following activities that are related to stewardship of water quantity and quality:

- facilitate research that supports education and teaching within a university environment
- conduct research that is directed at solving multimedia water-related problems of state, national, and international scopes
- cooperate with academic departments and other academic research units in generating, transmitting, applying, and preserving knowledge in ways that are consistent with the land grant university mission of Utah State University
- conduct research that provides for a technically informed water-related policy that can be used to ensure and improve human health and environmental assets in Utah, the United States, and globally
- facilitate research, testing, and design activities that involve training university students to provide services to audiences that are external to the university
- provide research-based training on water-related subjects to governmental and private organizations and to the general public.

The UWRL Mission is based on the philosophy that activities related to water science and engineering be organized to integrate research, testing, and design components with university and public education. The context for water includes multimedia aspects that incorporate atmospheric, surface, and subsurface earth components, and that address environmental as well as public health issues.

In its mandate, the UWRL is required to devote resources toward the solution of state water problems. This has traditionally required a focus within the UWRL toward engineering and applied science in the water arena, which is consistent with and supportive of the mission and problems of many of the natural and water resources management agencies in the state. Since its creation in the mid-1960s, the UWRL has maintained research programs that touch upon water problems throughout the state and that continue to enjoy the support of state and federal water management agencies. Current annual funding levels at the UWRL are approximately $9 to $10 million, of which approximately 80 percent is from outside grants and contracts. A partial list of funding agencies includes EPA, NSF, the Bureau of Reclamation, the US Army Corps of Engineers, the US Department of Justice, the US Department of State, the US Forest Service, the US Department of Energy, various agencies within the state, some local and state government agencies from other states, and various private sector organizations. The UWRL houses approximately 23 faculty, 30 professional engineers and research scientists, 70 graduate students, 80 undergraduate students, and 10 secretarial and administrative staff.

The UWRL also houses the Utah Center for Water Resources Research (UCWRR) that was established by the Water Resources Research Act of 1964. The purposes of the UCWRR are, 1) foster interdepartmental research and educational programs in water resources, 2) administer the State Water Research Institute Program funded through the U.S. Geological Survey at USU for the State of Utah, and 3) provide university-wide coordination of water resources research.

USU Cooperative Extension

Cooperative Extension is a fundamental component of the land grant mission (research-teaching-extension) of Utah State University. Extension programs are supported and delivered by campus-based specialists holding faculty appointments in all academic colleges and most departments. All specialists also carry split appointments with research and/or teaching. For example, a specialist with an extension responsibility in water quality also holds a parallel research appointment to compliment work in this area. Extension programs are organized and delivered at the county level by Extension agents. Agents are MS-level personnel with 100% Extension appointments charged with identifying local information and educational needs and organizing programs to meet these needs. In most situations, these programs are developed with the aid of a cadre of campus-based specialists.

Extension has a long history of developing and delivering programs in water quality and quantity in urban, agricultural and natural environments. Six specialists and every agent with an assignment in agriculture, natural resources, horticulture, and family and consumer science are involved in some way with water issue programming. Current water-related programs include:

- In response to water programming needs and the immediate drought situation, the Utah State University Extension Water Issues Team (WIT) was formed in March 2002. It is composed of specialists and agents with expertise and assignments in the areas of water quality and quantity in home, landscapes and agriculture.
- Extension agents along the Wasatch Front (Utah, Salt Lake and Davis Counties) have been involved in conducting urban landscape water audits and promoting water conservation in these areas for the past five years.
- Two Extension specialists are members of the board for the Center for Water Efficient Landscaping (CWEL) and receive funding to support research and extension activities from the Center.
- The Utah State University Analytical Laboratory (USUAL) analyzed soil, plant tissue and irrigation water samples for the public, state and federal agencies, and university researchers. Extension works closely with the USUAL in the promotion of water testing and interpretation of test results.

Programming related to water issues is ubiquitous in Extension. With the current drought situation in Utah, the issues of water quantity, conservation, management and quality have become increasingly important. Continued urban development will place additional quality and quantity demands on what are already limited water supplies. Extension has committed to taking a leadership role in developing and delivering water education programs in Utah. In order for Extension and Utah State University to continue to deliver effective programs, the following must occur:

- Achieve and maintain critical mass for Extension water programs. Currently, specialists and agents contributing to water programming in Extension have many other responsibilities. Consequently, individuals have relatively little time to devote to water issues. Future staffing needs should consider the importance of water and need for more personnel to develop and deliver water programs in urban and agricultural settings.
- Enhanced cooperation and communication between Extension and research/teaching faculty involved in water. A wealth of information is generated by campus-based faculty. Much of this information makes it into journals but may not be communicated to the public and other agency users in Utah. Extension should be the vehicle for information delivery. Enhanced cooperation with campus-based research/teaching faculty would facilitate information dissemination.
- Expand offerings in emerging areas. New areas such as secondary and gray water use for urban landscape irrigation, xeriscaping and low water use landscapes, and policy decisions and changes will require greater research and educational efforts in the future. Additional personnel will be required to meet demands in these emerging areas.

APPENDIX 3. Utah State University and Water: A History in Broad Strokes.[1]

by Chris Conte, Associate Professor of History

Utah State University sits atop an alluvial bench at the base of the Bear River Range overlooking the riparian path of the Logan River. This picturesque setting notwithstanding, the university's location places it between the mountain watershed and the Great Basin, the water's final destination. In large part, the university's founders envisaged its role as an arbiter in water issues. Research and education therefore focused on the agriculture and range science whose central problems focused on land use, and in particular, finding and using water in an arid setting. Over the years, as the Utah Agricultural College transformed itself into Utah State University, an increasingly bureaucratic and compartmentalized institution, water issues remained a central academic focus. However, the process has led to a decentralized mix of initiatives embedded in the programs of the university's colleges, research centers, and departments. This overview history charts that process.

I. Land Use Dilemmas and Utah State's Mission

The Great Basin environment has supported humanity for thousands of years, and water, in the form of snow, rainfall and runoff has helped to shape settlement patterns and land use throughout. Native American peoples who occupied the Basin were peripatetic. With an eye toward seasonal weather variation, moisture availability and shifting food resources, they exploited the favorable ecological patches such as riparian zones and the pinyon-juniper woodlands. Their long experience and sophisticated environmental knowledge helped them to develop a complex food production system whose technology included water diversion and fire. When Mormon settlers entered the Basin in 1847, they lacked this important environmental knowledge and set about trying to recreate an agricultural system that mirrored their previous homes in the mid-West, where moisture availability and deep, fertile soils favored settled farming communities. The Great Basin's aridity simply would not allow this arrangement without extensive water diversion.

Utah's pioneers began to divert water for irrigation purposes on July 23rd, 1847, when they dammed City Creek in what is today central Salt Lake City. These early agricultural engineers successfully irrigated 5 acres of potatoes. A mythology grew around the story and the subsequent manipulation of the streams along the Wasatch Front. The common motif finds Utah's pioneers making the desert bloom as a rose using community cooperative irrigation companies and crude surveying and construction methods. Irrigation company records, however, reveal that water rights disputes, under capitalization and technological failures often led to angry litigation, and in certain localities, agricultural collapse. On some sites along the Wasatch Front, inappropriate land use led to soil and water degradation rendering some lowland useless. In these situations, communities expanded their experimentation to rainfed agriculture on the high mountain benches. [2] Whatever the local arrangements, between 1847 and the late nineteenth century, Utah's ad hoc experiment in arable agriculture dramatically altered the landscape at the base of the Wasatch Front.

In order to supplement their precarious trials with cultivation, Utah's early settlers formed herding pools and over the years grazed increasingly large numbers of sheep and cattle on the summer ranges in the mountains and on winter forage on the valley grasslands. A series of late nineteenth century mudslides that plagued Wasatch front communities confirmed that the summer mountain ranges had been drastically overgrazed.[3] By the late 1880s, early Mormon land use patterns had created a complex of problems in this fragile environment that the fledgling communities could not easily solve. Ecological degradation was a recognizable and serious problem, especially in the upper watershed, where any deterioration in water supplies affected almost everybody in the Territory. As Utah approached statehood, its economic survival depended on an institution to address the vexing problems faced by *farmers and ranchers in arid lands.*

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[1] My intention here is to present the broad outlines of water-related research and education rather than a catalogue of names and projects.

[2] For an overview of the process, see Tom Alexander, "Irrigating the Mormon Heartland: The Operation of the Irrigation Companies in Wasatch Oasis Communities, 1847-1924," *Agricultural History* 76 (2002), 172-187.

[3] See Marcus Hall, "Repairing Mountains: Restoration, Ecology and Wilderness in Twentieth Century Utah." *Environmental History* 6.4 (2001), 584-610.

II. The University Mission and the Agriculture Experiment Station

On March 2, 1887 Congress passed the Hatch Act, which established agricultural experiment stations in connection with the land-grant colleges established the Morrill act of 1862. In 1888, Utah established at Logan both an Utah Agricultural College and the Agricultural Experiment Station. The joint appointments of the early College Presidents as Director of the Agriculture Experiment Station demonstrate the institution's impetus to solve the state's growing environmental problems associated with land use and water.

The Agriculture Experiment Station therefore concerned itself with water issues, which was the limiting agricultural element in this semi arid region. Under early directors, such as John Andreas Widtsoe (1900-04), the Station's program focused intensely on problems of the crop producing power of water on Utah soils. From its inception, the Station's research program was necessarily interdisciplinary. It retained agronomists, horticulturalists, soil and plant chemists, and engineers, all of who made irrigation science. Research workers considered such topics as natural water for irrigation; early vs. late irrigation; water requirements in relation to crop yield, percolation and soil fertility; seepage; time and frequency of irrigation; orchard and vineyard irrigation; water supply studies and canal capacities. Much of this work was carried out at the Greenville farm in North Logan. Early research also linked the water production of mountain watersheds to the success of agriculture below. Revolutionary studies of snow pack helped clarify the relationship among snow depth, water content, melting rates and water availability.

Orson Winso Israelsen's career at Utah State from 1914 through 1954 highlights the links increasing diversification of water-related research through his affiliation with both the College of Engineering and the Agricultural Experiment Station. Israelsen began his career studying water rights, drainage systems, irrigation, ground water and in Utah, Idaho and Nevada then, later in his career he carried out international research in the Middle East, Southeast Asia, India, and South America. Israelsen's papers provide a wonderful overview of water research at Utah State, which ended just as the Utah Water Research Laboratory came into existence and continued this his legacy of broad ranging research on a truly global scale.

By the late nineteen forties, the Utah State's administration felt the need for a more specialized center to carry out water-centered research in the areas of water and power, which one proposal called "the rock of Utah's future." The report justified funding by arguing that Utah's industrial growth in steel, chemicals depended upon the growth in the power industry, which turned on dams and diversions of Utah's water sources. The report claimed further that more efficient uses of water would increase agricultural production by at least 60 %, which meant farm homes for 32,000 people. Thus, the report continues, as industry and agriculture grow, Utah will need well educated water scientists to solve the water problems which will arise, and to give thee guidance necessary to increase the efficiency of water use."

When the second annual conference of Irrigation and Drainage Research Workers, with delegates from the Western State s met at Logan Jan. 22-24, 1945, they recommended that a lab be established to provide adequate facilities for irrigation and drainage studies in the following areas:
1. Utilization of ground water.
2. Conveyance of water
3. Application of water to soils
4. Drainage of irrigated land.
5. Soil, moisture and plant relations.
6. Deterioration of irrigated lands
7. Erosion and sediment transportation
8. Institutional management phases of irrigation enterprises

The report added as justification for the creation of a Utah Water Research Laboratory the University's impending relationship with Iran through the State Department and the United States Department of Agriculture, which spoke to the issue of education. With more foreign students entering the university to study irrigation and drainage, the lab would be able to offer adequate resources.

By the late 1960s, the UWRL had established its regional and international reputation. Its research focus clearly set on the understanding of the dynamics and manipulation of water flows in order to ensure human progress. As Jay Bagley stated in 1969:

> Fundamentally, water resource development entails the modification of a natural hydrologic system so that its flow characteristics better conform to specific needs. The construction of physical works to store and convey water alters the existing flow pattern and brings about a new hydrologic equilibrium better suited to man's needs. Without such modification, social and economic potentials may be suppressed.[4]

Another concern, according to Professor Bagley, was the unrealized potential of water that served non-development needs. He claimed that the "tremendous volumes of water being wasted by phreatophytes which occupy large areas along stream and river channels was well as the broad valley bottoms represent a heavy tool levied against those supplies yielded and potentially subject to management."[5] In order to illustrate his point, Professor Bagley laid out the following equivalencies: 7.5 acre feet of water equal: 1 duck; 190 lbs of trout; 1 cow; 10 tons of alfalfa; 6 average families; 3,000,000 kwh of electricity; 30 tons of steel; 90 tons of copper. His message suggested a philosophy that stressed the interception of water for beneficial human uses.

Despite the growing international and the increasing scale of their interventions and projects, hydrological engineering at Utah State retained its focus on the social benefits it could provide. In this way, two of the institution's most important research centers – the Agriculture Experiment Station and the Water Laboratory – continued to fulfill the university's original mission to serve society's economic needs.

III. Forestry and Natural Resources: Promoting Nature over Culture

While agricultural engineers and scientists studied problems associated with water flows, it fell to Utah State's foresters to assess the health of the mountain landscapes where they originated. A 1902 assessment of the Wasatch Range found ecological degradation due to overgrazing unprecedented in the West. Of course, the people living in communities below the mountains, such as Manti, knew the situation all too well. From the late 1880s to 1902, they had borne six floods, and four more of increasing severity before 1910. In 1902, the people from Manti and other towns requested that the Forest Service establish reserved in the mountains above their communities. Even after the formation of forest reserves in the Wasatch, the abuse continued, in part because Forest Service policy aimed only to control grazing rather than eliminate it.[6] A 1943 report from the Utah Agriculture Experiment Station framed the consequences for water supplies downslope.

> About 80% of the land in northwestern Utah is grazed by livestock. A large part of this area contributes to the water with which some 464,204 acres of farm and pasture land are irrigated and the water which some 384,000 people use in their daily lives. Suffice it to say that, without it, there would be virtually no settlement in Utah. Thus the water which flows from northwestern Utah's range lands contributes millions of dollars to the agriculture of the state and to industry as well. There is little question that the water from the mountain ranges actually is of greater value than is the forage that grows on the mountains.[7]

What happened on the mountain rangelands had become the concern not only of the Forest Service, but of the farmers who depended on a stable supply of runoff for their scientifically engineered irrigation systems. Forestry science, a field formulated in Europe and preoccupied with sustain yields of marketable timber, seemed ill-equipped to study the ecological functions in Rocky Mountain forests whose botanical make up differed markedly from their cousins in Europe and the eastern U.S. Moreover, given the extensive use of forest reserves for grazing in the West, the boundaries between forest and rangeland ecologies blurred appreciably.

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[4] Jay Bagley, "A Perspective of Contemporary Water Planning and Management Problems in Utah. Utah Water Research Laboratory, August 1969," p. 4

[5] Ibid., p. 11.

[6] See Charles Peterson, "Small Holding Land Patterns in Utah and the Problem of Forest Watershed Management," *Forest History*17 (1973), 5-13

[7] Utah Agriculture Experiment Station, "After Victory: Report of Cooperative Planning Program for Utah and the Wasatch Front," Utah State Department of Publicity, June, 1943.

As early as 1914, Professor George Hill taught a course at the Utah Agricultural College that stressed the management of forest plants grazed by livestock. This was USU's first course in range management. In 1920, the College formed the Department of Range and Forestry and a major was approved in 1925. By 1929, the departments had become the School of Forestry and Range and in 1934 it offered the first courses in Wildlife Management. These programs eventually evolved into the College of Natural Resources. Like their counterparts in engineering and agriculture, CNR faculty couched their mission philosophy in economic terms. The recreational opportunities, grazing, wildlife and water that forests and streams provided constituted goods and services useful to society. Nonetheless, the history demonstrates clear differences in the ways ecologists and engineers came to ascribe value to resources, including water.

IV. Conclusions

At issue are mentalities. This historical interpretation suggests that although Utah State's interdisciplinary research centers (Ecology Center, Agricultural Experiment Station, Utah Water Research Laboratory) have fostered collaboration, the ways ecologists and engineers conceptualize water issues differs significantly. From the disciplinary perspectives of hydrological engineering, the value of research and education lay with its problem-solving approach to water management through technological applications at the regional or local scale. Water engineers at Utah State needed to know exactly how water flows in order to enhance human health and welfare. This practical approach was important in Utah's often-capricious environment, where historically the population has depended on agriculture. Biological scientists and ecologists have come increasingly to value water's value to habitats that support healthy ecosystems, whose welfare exists outside society's material needs. As with hydrological engineers, water figures prominently in their research and educational efforts. However, work in Utah State's CNR was more likely to focus on understanding heretofore unknown processes that damage ecosystems at a variety of scales, and of late, prescribing ways to manage or restore them.

Despite their cultural divide, both the hydrological engineers and the natural scientists share the need to justify their existence to funding agencies. A more rigorous investigation of the intersection of hydrological sciences and engineering might well reveal other points at which research from one side of the divide informs the other. Society's practical needs for water and its increasing cognizance of the ecological problems of resource depletion should spur the academy to more consilient approaches.

Appendix 4. Summaries of Assessments of Peer Institutions

University of California at Santa Barbara

Following is from the UC Santa Barbara web page (http://www.esm.ucsb.edu/about/).

> "In 1991, in response to a report issued by the State of California defining an increasing need for trained environmental professionals, the Regents of the University of California established the School of Environmental Science & Management at UC Santa Barbara to train graduate students in rigorous, interdisciplinary approaches to environmental problem-solving. A master's program was designed to offer courses in natural and social sciences, as well as ecology, management, and risk assessment.
>
> In 1994, Jeff Dozier, professor of earth systems science, was named the School's founding Dean. Faculty appointments began in fall 1995. The School accepted its first students into the professional master's degree program in the fall of 1996, and graduated its first class of 20 students in June 1998. For the 2002-03 academic year, 104 master's students are enrolled. In 1999, an intercampus MBA emphasis in Corporate Environmental Management was initiated that integrates natural and social sciences with business and law; 10 students are currently participating in this interdisciplinary emphasis.
>
> In December 1997, the School was formally renamed the Donald Bren School of Environmental Science & Management in honor of a major gift from the Donald L. Bren Foundation. The Bren gift supports the School with funding for Bren Fellows, numerous faculty scholars, visiting lecturers, conferences, and the intercampus MBA emphasis.
>
> The School inaugurated its Ph.D. program in the fall 1998, and graduated its first three doctoral students in the spring of 2002. Fifteen Ph.D. students enrolled in the fall of 2002, six of whom are participating in the Economics and Environmental Science program, which is supported by a grant from the National Science Foundation. Overall student enrollment is expected to stabilize at approximately 120 master's students and 50 doctoral students.
>
> To date, 18 professors with national and international expertise in science, economics, law, and management, and committed to interdiscplinary teaching and research, have joined the Schoool's faculty. The School plans to appoint three additional full-time faculty members for the 2003-04 academic year. These teachers are joined by several adjunct and affiliated professors. The School also recruits top visiting faculty and lecturers each year from other graduate schools, who teach individual courses and seminars.
>
> When Jeff Dozier returned to full-time teaching at the Bren School in the fall of 2000, Dennis Aigner, formerly Dean of the Graduate School of Management at UC Irvine, was appointed the second Dean of the Bren School. Dean Aigner brings an increased focus on the corporate and legal aspects of environmental problem-solving, as well as a vision of the Bren School's leadership in cutting-edge research and integrated environmental solutions.
>
> In January 2000, construction began on Donald Bren Hall, and this remarkable example of sustainable construction opened in April 2002. The building comprises 84,672 gross square feet, including three floors of teaching and research laboratories, four floors of offices, several terraces, and a communal courtyard. A large commons and five conference rooms also provide space where faculty, students, and visitors can interact and exchange ideas.
>
> Bren Hall has been given the U.S. Green Building Council's LEEDTM Platinum Award--one of only two awarded nationally--for being the greenest laboratory building in America. It is a physically realized manifestiation of the School's environmental programs, and is a frequent selection for architectural and landscaping tours and awards for sustainability. The School is compiling complete information and statistics about sustainable building practices as a resource for other builders."

The University of California at Santa Barbara is host to the National Center for Ecological Analysis and Synthesis, a synthesis center that is being used as a model by CUAHSI for its proposed Synthesis center. UC Santa Barbara also holds an IGERT award in Economics and Environmental Science (http://www.ees.ucsb.edu/). There is a lot that USU could learn from The University of California at Santa Barbara. Following are notes and suggestions gleaned from a telephone discussion David Tarboton had with Jeff Dozier in February.

In building an interdisciplinary program Dozier warned to be cognizant of the distinct anthropology of different disciplines and different practices such as whether students are admitted to work with faculty, or as a cohort who can select their major professor after an initial exploratory period. He suggested that communication needed to be clear through written policies on these matters. The interdisciplinary program needs to have an administrative structure that facilitates faculty buy in, through control of FTE's and a role in tenure and promotion decisions. There needs to be a core faculty committed to the program as their primary educational function. The course requirements for an interdisciplinary program need to be carefully structured to provide sufficient core disciplinary knowledge that a PhD, which is by definition a significant contribution to knowledge within a discipline can be achieved while fostering sufficient interdisciplinary breadth. Dozier described the UC review and promotion process that strives to achieve faculty excellence through salary rewards throughout a faculty members career. There are steps within each rank and progress through these steps requires formal review of publications, research agenda, teaching, service on National committees, etc. Salary raises associated with these steps are separate from cost of living increases and are budgeted from the university as a whole. Dozier noted that the good departments are those that are objective about putting faculty up for promotion review. He also indicated the importance of patience in hiring. They have a policy that once a position is granted, it is not taken away if it is not promptly filled. Departments also do not, as a matter of policy, lose a position if tenure is denied. However faculty departures for other reasons (retirement and resignation) result in a process where the need for positions is re-evaluated. In terms of outdoor experimental facilities the UC Natural Reserve system provides a common infrastructure for research. Each facility has a manager and research coordinator and provides office, laboratory and computer space. In terms of national initiatives, Dozier suggested focusing in stable initiatives, such as LTER's (Long Term Ecological Research sites). He noted that there is not an LTER in Utah.

Giannini Foundation & Division of Agricultural and Natural Resources – University of California System

The Giannini Foundation is a research and outreach program that promotes agricultural and natural resource economics programs throughout the University of California System. Currently, the director is located at the Davis Campus, but ongoing programs in water economics, environmental economics, and natural resource management exist at the Davis, Berkeley, Riverside, and Irvine campuses. There are cooperating programs with the Bren School of Environmental Science and Management at the Santa Barbara campus and at the San Diego campus. The Giannini Foundation also cooperates with the university-wide Division of Agricultural and Natural Resources (ANR), which is headed up by a university-wide Vice President. These programs are also coordinated with other water, environmental and natural resource centers and research units throughout the University of California system.

At the Davis campus, there are 9 faculty members out of 24 total that teach and do research in the areas of water economics, environmental economics, and natural resource policy. One faculty member holds an endowed chair position with salary and research operating funds, and another holds a university distinguished chair position, again with position and research operating funding. At the Berkeley campus, there are 11 faculty members out of a total of 21 that teach, do research, or are engaged in state-wide and regional outreach programs in the water, environmental and natural resource management arena. Two of these faculty hold endowed and distinguished university chairs. Five of the eleven faculty are affiliated with other resource research centers at the Berkeley campus such as the Energy Center, and the Center for Climate Change both centers of which have ongoing water use and policy related research activities. The climate change-water connection in research is a well renown program at the Berkeley campus. Additionally, the outreach program in water economics, pricing, and water-related environmental issues is well known nationally and internationally. The water and environmental policy programs that exist at the Riverside campus are mainly administered out of the Department of Environmental Sciences within the College of Natural and Agricultural Sciences (NAS), but there is one cooperating researcher that comes from the Economics Department in another college. There are 5 economists in the Department of Environmental Sciences that are engaged in research and outreach program administered by NAS and the Giannini Foundation, and one also holds a University of California administration position.

Some of the well-known programs in the water arena that have come out of the programs of the Giannini Foundation and cooperating projects include the federal water pricing and conservation programs of the West Side U.S. Bureau of Reclamation District, the California state-wide economic-engineering model for water allocation, pricing, conservation and balance in use system known as the CALVIN project, the water conservation outreach programs, the salinity control projects, the pesticide residue-water reservoir control programs, the climate change programs and the relationships of climate change and the economy programs, the energy-water use programs, and the world bank environmental and water development programs in the international water arena.

There is an interesting combination of researchers from various disciplines that are members of the Bren School of Environmental Science and Management at the Santa Barbara campus where cooperative Giannini and ANR programs are currently ongoing. There are hydrologists, various environmental scientists, biologists, economists, legal studies professionals, management and financial specialists, and atmospheric scientists who are all faculty members of this school. The most recent Dean of the school is a prominent economist who has been an administrator, fundraiser, and prominent researcher in the water and resource economics arena as well as in statistics at the University of Southern California, the Berkeley campus, the Irvine campus, and now at Santa Barbara. There are 5 other economists who are members of the school's faculty, three of whom are also affiliated with the Economics Department in another college at this campus, where one holds an endowed chair position with position and research operating funding. Another economist is the editor of one of the leading environmental economics and management journals in the environmental and economics field. This school also provides funding and engages in a rather well funded program of research enabling them to bring in visitors for certain periods. In the economics area, recent visitors have been the lead environmental and global climate change economist for the World Bank, a renown international trade and environmental impact economist from Queens University in Canada, a leading global environmental policy program in the economics profession, and two leading environmental policy economists from the Kennedy School at Harvard University. This school is the organizational focal point for environmental and water-related research and education programs at Santa Barbara and cooperates with various basic science and social science departments on campus to promote research and multidisciplinary education programs.

Colorado State University

Water-related research, education, and outreach programs at Colorado State University (CSU) are brought together under an organization known as the Water Center. This organization came about as issues associated with water became increasingly prominent in the state. In 1990, the water resources engineering efforts at CSU were designated as a statewide "Program of Excellence" by the Colorado Commission of Higher Education. Concurrently, CSU designated water resources as a a Program of Research and Scholarly Excellence. As the cross-disciplinary nature of water resources research became clear in the 1990's, the University placed all water programs under the umbrella of the Water Center.

The Water Center now combines the talents of personnel from 25 different departments and organizations at CSU. The "umbrella" includes the Colorado Water Resources Research Institute, the Natural Resources Ecology Laboratory, the Agricultural Experiment Station, and numerous Colleges and Departments. The key participating colleges are Engineering, Natural Resources, and Agriculture. The Water Center acts as a "coordinated partnership" with a goal of representing the best capabilities of CSU in water-related research, education, and outreach.

Oregon State University

Oregon State University has a diverse set of academic and research programs with strong links to water. Departments of Forest Engineering, Fisheries and Wildlife, Atmospheric Science, Civil, Construction, and Environmental Engineering, Crop and Soil Science, Forest Science, Geosciences, and Rangeland Resources all have substantial interests in the study of inland water. Marine research and academic programs are conducted at the Hatfield Marine Science Center and the Departments of Biology and Environmental Sciences. These diverse programs are linked together with the Center for Water and Environmental Sustainability.

The Center for Water and Environmental Sustainability (CWESt) is a research center at Oregon State University with strengths in both social and environmental sciences. The center serves as a catalyst and coordinator for diverse projects that cross traditional college and department boundaries. CWESt's goal is to promote sustainable use of environmental resources through research, education, and technology transfer. CWESt administers a graduate degree minor program where students specialize in one of three areas (sustainability, water resources, and hazardous substances) and then gain some background in the other areas. Graduate students gain degrees in their home department and then participate in this inter-disciplinary minor.

A number of water-related facilities work to enhance cooperation and integration of the water sciences programs on the OSU campus. Two experimental watersheds provide excellent opportunities for research and teaching. The HJ Andrews Experimental Forest is an NSF-sponsored Long Term Ecological Research site located approximately 50 miles from the OSU campus. The streams located in this watershed have been extensively instrumented for measurement of water quantity and quality characteristics. A data base extending back to the 1950's is accessible to all researchers interested in this site. The instrumentation and long term records provide a resource that allows researchers from around the globe to write successful research proposals and conduct extensive research on the site. The high level of scientific activity provides educational opportunities for OSU students and greatly enhances the reputation of the university in the area of environmental sciences. In addition to the Andrews Forest, a local watershed has been secured for the university for teaching and research activity. Oak Creek is located within university property, is managed as a protected area, and provides a means of water science students to gain valuable experience in the measurement of hydrologic processes.

The Center for Water and Environmental Sustainability provides opportunities for faculty to work together on large interdisciplinary projects. The Willamette River Basin Planning Atlas, Trajectories of Environmental and Ecological Change (Hulse et al., 2002) is one of the products of these interdisciplinary collaborations. The atlas provides a detailed examination of how the Willamette Basin might change between now and the year 2050, when an additional 1.7 million people are expected to live in the region. Working together as the Pacific Northwest Research Consortium, the project was a major undertaking of scientists from OSU, the University of Oregon and the U.S. Environmental Protection Agency. Results of the analysis offered some surprising hope for the future of the Willamette Basin's environment and will be used by local and regional planners.

Appendix 5. Summaries from Persons Interviewed.

Delworth Gardner Visit

Del Gardner, Professor Emeritus at both the University of California, Davis and Brigham Young University visited USU and met with the Task Force. He was Director of the Giannini Foundation of the University of California System and in the role of coordinating resource economic research and agricultural economics research throughout the University system, but most particularly research at the Davis, Berkeley, Santa Barbara and Riverside campuses. In this role he coordinated economics research in the water arena, as well as developing his own research in resource economics and water economics in particular. He was the Department Head of Economics here at USU prior to going to the University of California, Davis. Earlier, he held an appointment in the Agricultural Economics Department at Colorado State University. He is a fellow of the American Agricultural Economics Association, and held other offices in that association, and is a former President of the Western Agricultural Economics Association. He has done resource development work as well in Latin American nations and in China. He holds degrees from the University of Wyoming and the Ph.D. from the University of Chicago.

<u>Future Trends in Water Research:</u>

1. Research of institutions and property rights in the water arena.
2. Investigation of the hidden subsidies that we have within western states that stand as prohibitions to optimum water pricing in order to develop conservation programs that need to be developed in, particularly, the western U.S. region.
3. Research on the competing uses for water and how these competing uses impact current and future water institutions, markets, and pricing.
4. Investigation of the transfer of water rights under the Doctrine of Appropriations rights system in order to satisfy new demands for water use such as for instream uses, managing ecologies, meeting the demands of urbanization in the western U.S., and for developing long range plans to manage drought cycles.
5. Water issues and research involves several basic disciplines, and these disciplines should be talking to each other and debating the policy issues as well as developing data systems and basic scientific frameworks in order to solve water problems. There needs to be a mechanism to induce collaboration amongst scientists in order to do research and provide information and data for solving policy issues.
6. Future research in the water area is going to be connected to institutional and environmental research. There may not be distinctions made in the future that separate water issues from environmental natural resource policy issues. USU needs to be ready to respond to these issues at the region, national and international levels.
7. Policy issues and underlying policy analysis frameworks are increasingly becoming quantifiable, and correctly should be in order to provide data and basic social science and science/engineering frameworks that can be used to develop information about both the physical/biological relationships that involve water and the policy issues that involve water.
8. In following up on item 7 above, Gardner suggested that an intense effort currently, and probably carrying on into the future, is the valuation of amenity services and ecologies, and the valuation of the tradeoffs between alternative strategies in resource management.

<u>Organization Concerns in the Water Research and Education Arena</u>:

1. Gardner suggested that he felt USU was and is currently viewed as a leading institution in water research. The Utah Water Research Laboratory was organized and initiated, in his view, in order to carry out a broad mission of water research for Utah and the western region. He asked questions of the committee about the current organization of the UWRL and if it was continuing to meet that particular mission. He discussed some of the organization that existed back during the time that he was here at USU and suggested that the organization of that era was a good model to follow as far as providing institutional incentives for water research in various fields of study.
2. Currently, water research and education is more complex and is connected to a broader based set of research objectives, such as environmental and ecological systems, water development objectives, watershed management, water and urbanization and development policy, and the understanding of the role of water in complex physical/biological relationship in addition to policy arguments. So the organization to do research may be complex, but there needs to be incentives to do research and to induce scientists, using

different basic theories and methods, to come together to respond to not only issues of developing information that emanates from these basic sets of theories and new theories, but to respond to public policy concerns.

3. Gardner was skeptical about what he called interdisciplinary research and education. He suggested that the interdisciplinary departments were the weakest units of most universities. He suggested that the discovery comes from the basic theories and developed base knowledge of the various base disciplines in the physical and biological sciences, engineering, and in the social sciences, including economics. However, he suggested there needs to be an organizational mechanism developed so that the scientists from each of these disciplines talk to each other, debate the policy issues, and share data that needs to be passed amongst scientists to address problems. He suggested organizing to respond to water issues both policy and technical concerns by putting together multidisciplinary teams to address the issue using each discipline's basic body of knowledge and new discovery.
4. The influence that a university or other research institution has on solving problems comes from their published record and the information and data that are generated from that published record. Each discipline needs to be able to further their body of knowledge and discovery and then publish the results under peer review. So each discipline that is included in a response to an issue should have a full stake in research effort. Research projects should be designed to encourage this full participation from the basic disciplines. Gardner expressed some concern about the nature of international projects that do not provide opportunity for basic and applied research, and therefore little opportunity to further the body of knowledge and to publish. He suggested that there are other organizations whose assignment and organization is more conducive to implementation and handling technical assistance in these international projects. However, he did suggest that good research could be done using international projects if they are organized correctly.

Interview with Doug James

Doug James was the Director of the Utah Water Research Laboratory from 1976 until 1991. He left Utah State University to become director of NSF's Hydrologic Sciences program. Dr. James met with David Tarboton and Tom Lachmar in Salt Lake City while attending the a American Society of Limnologists and Oceanographers meeting there. He was asked to discuss his role as the Director of the UWRL, and also to provide suggestions as to how water research and education might be strengthened at USU.

In describing his role as Director of the UWRL, Dr. James explained that initially he reported annually to a group consisting of the Vice Presidents for Research and Extension, as well as the Deans of several colleges. He went on to comment that in the beginning of his tenure as Director, the UWRL received proposals from and funded research in departments in colleges other than just engineering. These practices ended when Bruce Bishop became Dean of the College of Engineering, at which time the water lab became more closely aligned with that college. Dr. James mentioned that during his tenure he tried to hire new faculty in fields that were more compatible with other departments. He also stated that he didn't have much interaction with the USU Research Foundation because it was perceived as not being "researchy" enough. In fact, Dr. James used the departure of Paul Tullis from the water lab to the research foundation to illustrate this point. Dr. James also stated that he regretted not making the water lab an academic department. Finally, he suggested that the Utah Water Research Council (a group comprising the VP for Research and several deans) be re-activated to provide guidance over the affairs of the UWRL. This, he indicated became less active during Bruce Bishop's tenure as Dean of Engineering.

In regards to suggesting how water research and education at USU might be strengthened, Dr. James suggested that USU consider developing a synthesis center along the lines of the National Center for Environmental Studies at UC Santa Barbara. The three areas of water research that he thought such a center could focus on, based on needs suggested by CUHASI, were large-scale field studies, instrumentation, and hydrologic information systems. He thought that a smaller scale, prototype synthesis center could be created initially on campus, which could then be developed into a full scale center and moved off campus. He also suggested that the faculty or a group of the faculty active in water research should select one or two interdisciplinary topics to focus on. The topic of using remotely sensed data for hydrologic studies was one the he suggested as being worthy of such a focus, perhaps in partnership with SDL. When asked about trying to develop the Bear River into a potential CUAHSI observatory he indicated that we would need to identify the important policy questions that need to be answered there and what study of the Bear River might contribute to hydrologic science nationally. When asked about the importance of interdisciplinary work he indicated that the NSF believes there are many new frontiers in science that cannot be approached along traditional disciplinary lines. This is the basis for NSF's philosophy and emphasis on interdisciplinary work. With regard to education, he added that NSF feels students need a broad background but need depth in a discipline.

Interview with Nancy Grimm

Members of the Water Task Force met with Dr. Nancy Grimm during her visit to the Ecology Center at Utah State University in January 2003. Dr. Grimm is one of the principle investigators on the NSF-sponsored urban LTER project and a member of the associated Integrated Graduate Education and Training grant (IGERT). This long-term study of the urban area of central Arizona focuses on the Phoenix metropolis. The overall question being addressed in this study is: How does the pattern of the city alter ecological conditions of the city and its surrounding environment, and how do changes in ecological conditions feed back to the human social system? Her research is focusing on watershed biogeochemistry and stream ecology in an urban setting. This entails studies of atmospheric deposition, accumulation of materials on human-made surfaces, redistribution of materials during storms, nutrient transformations in soils, and ecology and biogeochemistry of recipient systems such as retention basins, urban ponds, ephemeral stream channels, and groundwater. Dr. Grimm indicated to the group that the establishment of a director and staff associated with a research center on urban ecology was essential to their groups success in getting both the LTER and IGERT proposals funded from the National Science Foundation. Once these programs were in place, additional funds for associated projects were much easier to access. Dr. Grimm encouraged us to attempt to establish a water center at USU. She indicated that we had the needed expertise in a broad area of water sciences, but that we needed support from our institution to enhance our collaborative efforts.

Interview with Knute Nadelhoffer

Dr. Knute Nadelhoffer is the present program director of the Ecosystems Studies program at the National Science Foundation. This Division of Environmental Biology program funds much of the biologically-based ecosystems science that occurs in North America. Members of the USU Water Task Force visited with Dr. Nadelhoffer during his visit to the Ecology Center at USU this February. Dr. Nadelhoffer's research is aimed at improving understanding of interactions that determine ecosystem structure and function across wide ranges of space and time, Although his research is not directed towards aquatic systems, he works in a variety of interdisciplinary teams, including groups working on land-water interactions and a research group comparing arctic ecosystems in North America and Eurasia. He indicated that our group ought to be especially well suited to compete for a variety of types of interdisciplinary programs at NSF. He in particular indicated that both the IGERT and the Biocomplexity programs were seeking groups that demonstrated integration of physical, biological, and social sciences in the environmental sciences. Dr. Nadelhoffer was clearly impressed with the strength of faculty presently at USU and with the strong support that our university receives from NSF presently. He indicated that our interests in water sciences could use the present Ecology Center at USU or the National Center for Ecological Synthesis at the University of California at Santa Barbara as models for our synthesis activities.

Interview with Danny Marks

Dr. Marks is a research hydrologist for the USDA Agricultural Research Service, stationed at the Northwest Watershed Research Center (NWRC) in Boise ID. He is a prominent snow hydrologist and is familiar with the western institutional landscape for water science and emerging national opportunities. He was interviewed in conjunction with his presentation to the inter-college water seminar series.

1. He responded to a query of the loss of prominence at USU in water in the following way: Over his research career, he has interacted with hydrologists at the UWRL. He observed that many leaders in the field have passed through USU and identified retention as a problem. He identified two causes for this. The first is that scientific hydrology outside of the purview of the traditional boundaries of engineering approaches has not been sufficiently valued. Second, the efforts of many faculty have been redirected toward consulting activities with a resulting decrease in the level of research activity.
2. He reinforces the point that USU should consider building closer ties to NWRC. He emphasized the joint benefits from such collaboration: He has offered to teach a field snow hydrology course there and that the ARS has the facilities to house grad students in Boise. He also makes the point that USU is well positioned to become a center for snow hydrology (his field) and should take the opportunity. NWRC is actively seeking to partner with USU hydrologic scientists and Ecology Center faculty to address emerging issues in "ecohydrology" at NWRC. He

notes that the best way to attract top students is to pursue the highest level of science and not to be overly concerned about applicability to policy. Lastly, he emphasizes that USU should develop the field component of the curriculum to become a national leader in hydrologic science.

Interview with David Goodrich

Dr. Goodrich is a research hydrologist for the USDA-Agricultural Research Service Southwest Watershed Research Center, Tucson, AZ. He gained an international reputation for disciplinary work and has since focused his efforts on promoting interdisciplinary approaches to resolving water resource problems. At the invitation of the USU faculty, he presented the experience of the Upper San Pedro Partnership, a consortium of 21 agencies, NGOs and private firms that formally cooperate in the implementation of comprehensive policies and projects to assist in meeting the water needs of the Upper San Pedro Basin, which straddles the AZ – Mexico border. His presentation demonstrated the benefit of an interdisciplinary approach to research and policy on a watershed scale. He emphasized the need for partnership with all levels of institutions within the watershed, and defined partnership as: working together to gather and share data, information, and ideas; lending political and/or institutional support for each other's projects; identifying and leveraging funding resources. He presented the strategies and lessons learned through the partnership:

- Picking a place (e.g. watershed) is the most effective way to foster interdisciplinary science. The needs/problems of the "place" are drivers for integrating science & policy, however, collaboration cannot be dictated. Build the program (as least the foundation) and they will come if there are compelling science/social issues. The optimal size for the "place" is one large enough for a sufficient number issues but small enough for the issues and political/managerial entities involved to be manageable.
- Motivation for policy makers for joint work are: community based decision making (not imposed from outside); avoidance or cooperation on litigation; thorough interdisciplinary science that is not typically available in the consulting community to make complex management decisions.
- To accomplish these goals scientists don't have to give up publishable research to work with decision makers.
- Long-term presence-commitment counts. The presence is required to build relationships and trust. This requires significant commitment by senior scientists, much of which may be devoted to communication and meetings. These needs cannot be addressed within typical 3-year grant cycle.

He concluded by stating that we can and must work together to address "major" challenges – think big science. We can do interdisciplinary research – but its hard work.
Greater scientific gain per unit effort will be made at the interface between disciplines than focused efforts within a discipline. We must engage and work in partnership with policy and decision makers. Much of David Goodrich's experience in the San Pedro is directly applicable to and provides rationale for our efforts to create an experimental watershed for interdisciplinary research within the Great Salt Lake Ecosystem.

Appendix 6. External Round Table Discussions

A series of roundtable discussions were held at the Utah Division of Natural Resources Building in Salt Lake City on January 29-30, 2003. These meetings allowed Water Task Force members to discuss critical and emerging water issues with representatives from Utah State and local governments, federal agencies, and private, non-profit stakeholders. A complete list of participants and affiliations appears at the conclusion of this appendix. Each session was one and a half hours in length, with participants consisting of task force members and 4-6 representatives. The task force presented participants with three "open-ended" discussion topics, leaving the guests to freely take the discussion in any direction. Discussion topics introduced by facilitators included emerging research issues, the key skills needed by new employees, and "outreach" by USU personnel to water policy makers and stakeholders.

By far the greatest number of comments could be related directly to the issue of population growth in Utah, with nearly every participant mentioning some problem associated with growth. Perhaps the most frequently mentioned growth-related problem dealt with efficient use of water, either through the role of water rights transfers, changes in water pricing, or other water conservation methods. A representative from an agricultural organization highlighted the need to maintain the current distribution of water rights, stating that increased efficiency in urban water conservation is paramount. Other roundtable participants believed that the distribution of water rights must be re-examined in view of the tradeoff between rural, urban and environmental uses for water, with comments coming from state, federal, and environmental advocates. Several of the technical needs that water officials mentioned (lawn water requirements, delivery and metering of gray water, soil moisture meters) relate directly to rapid growth occurring in wild land-urban interface zones. This new development is often beyond the reach of existing urban infrastructure and houses use wells and septic tanks.

One suggested means of water conservation is water pricing, an issue raised by local, state, and federal agencies, as well as a representative of a non-profit environmental conservation organization. Opinion with respect to the feasibility of pricing water was divided, however, with at least one state agency representative stating that the public will not accept changes in water pricing and water management. It is clear from comments by state agency representatives at other sessions, however, that this view is not universally held, and that research into water pricing should be undertaken. Participants were also interested in research concerning other ways to change water use habits (education, regulatory means) in order to promote conservation.

Following water rights and water pricing, water planning and modeling for both quantity and quality were major concerns for roundtable participants. Such models should be developed for use by planners and must reflect planners' needs. One representative of a state agency said that models with finer "time-steps" are required, while another state representative stated that a model reflecting the decadal drought cycle is needed. More than one state representative noted that Utah has historically been "reactive" to drought conditions as opposed to having planned in advance. Drought models should include a social component to gauge how the public reacts to drought conditions. A representative from the governor's office noted the need to plan for high tech industrial growth. Scientists from weather forecasting agencies noted the need to maintain data sources (monitoring stations) and for better forecasting models.

More generally, state and federal representatives noted that "watershed" level models are needed. Such models should include not just the physical flows of water, but also include components that allow planners to measure impacts on water quality, aquatic and terrestrial ecosystems, threatened and endangered species, and societal uses of water in natural settings (e.g. recreation). Such models would address concerns raised by non-profit environmental organizations about the environmental impact of low flows to the Great Salt Lake, a concern echoed more generally (*i.e.*, beyond the Great Salt Lake) by representatives from Utah state agencies.

Some research issues were raised by a limited number of participants. County health district representatives were concerned about wastewater research, noting the need to develop more efficient management of wastewater including operations of treatment plants, recycling of wastewater, and the growing use of decentralized wastewater systems. Representatives from a federal agency and a conservation organization raised the issue of water quality impacts associated with confined animal feeding operations. Federal, state, and local representatives addressed problems associated with water development, including the need to change dam operations, provide new dams, or increase diversions of water to urban and environmental uses. Representatives from all groups cited the need for research into conservation efficiency. Two participants—one from the state and the other from a federal agency—raised concerns associated with security of food and water supplies due to terrorism threats.

Discussions with respect to higher education led to some very clear recommendations for undergraduate and graduate education. Representatives from nearly every potential employer of USU graduates mentioned the difficulty of finding applicants who can (1) communicate and write clearly, (2) think broadly and knowledgably across disciplinary boundaries, and (3) come to the job with some "life experience." One representative stated that a master's degree is preferable because he assumes students who have written a thesis have more experiences with analytical, written, and verbal communication skills. With respect to the second issue, two state agency representatives said that USU should not teach "tunnel vision", defined as a narrow disciplinary focus. Others noted the need for employees to have a broad knowledge base. Two state participants and a conservation organization representative explicitly stated (in different sessions) the need for water engineers to have some knowledge of law and social sciences. A federal agency participant said that all potential employees should be prepared to deal with the "ecological-human interface". Many participants noted the importance of experience in the hiring decision, mentioning formal and informal internship opportunities for students as a way to obtain experience. Beyond the three key themes outlined above, many representatives expressed an interest in combined BS/MS degree programs.

For current federal and state employees, continuing education is an important need. Representatives suggested that distance education courses, on-line courses, or short-courses are all appropriate and desired means of maintaining and enhancing agency skills. Such courses can provide supplemental technical expertise and the broad, cross-disciplinary knowledge needed by water policy makers and planners that may not have been part of their formal degree-related academic training.

Finally, participants were asked to discuss outreach by USU personnel, or the ability of USU personnel to connect with agency representatives. With the exception of representatives from a farm organization and a county health district, all participants noted that better contact between USU and agency personnel is desired. The Governor's representative stated that a list of contact specialists is desirable. State and local officials frequently mentioned the need for better communication between USU scientists and local planners, as well as the need for education and aid to local water planners on watershed planning. Such aid should be designed to respond to time-sensitive, informational needs as opposed to the data and analysis produced through more time-consuming research projects. Outreach efforts should also include a public educational component on water quantity and quality issues.

Discussions with roundtable participants highlighted many issues useful to Task Force members. First, nearly all of the research issues identified by participants is multi-disciplinary in nature, that is, most research issues cut across the biological, physical, and social sciences and engineering. A multi-disciplinary perspective is needed to provide fully satisfactory scientific, engineering, and policy recommendations. Second, water-related higher educational programs should provide expertise in disciplinary subjects, but should also provide a multidisciplinary perspective in the research process. Federal, state, and local officials desire some form of distance education that provides a multidisciplinary perspective. Finally, USU can do better in providing local policy decision makers with information needed for water management.

We would like to thank the following who provided input to the Task Force through participation in round table discussions or on the telephone.

Name	Organization
Andersen, Matthew	Utah Division of Wildlife Resources
Anderson, Larry	Utah Division of Water Resources
Bradwisch, Bill	Utah Division Of Wildlife Resources
Brandon, David	Colorado Basin River Forecast Center
Brown, Kevin	Utah Department of Environmental Quality
Cook, Wayne	Upper Colorado River Commission
Coombs, Jeff	Tooele County Health Department.

Cuch, Forest	State Division of Tribal Affairs
de Freitas, Lynn	Friends of the Great Salt Lake
Flint, Tage	Weber Basin Water Conservancy District
Frankel, Zach	Utah Rivers Council
Harris, Reed	Utah Dept of Natural Resources
Heffner, Ken	U.S. Forest Service
Hiebert, Ron	National Park Service
Keene, Michael A.	Utah State Science Advisor Office of Technology & Science
Kimball, Dan	National Park Service
Lawler, Deborah	U.S. Bureau of Reclamation
McInerney, Brian	Colorado Basin River Forecast Center
Millis, Eric	Utah Division of Water Resources
Morgan, Bob	Utah Department of Natural Resources
Nelson, Skip	Natural Resources Conservation Service
Olds, Jerry	Utah Division of Water Rights
Ostler, Don	Utah Department of Environmental Quality
Petersen, Mark	Utah Farm Bureau
Pettengill, Tom	Utah Division Of Wildlife Resources
Pitkin, Jay	Utah Department of Environmental Quality
Trueman, Dave	U.S. Bureau of Reclamation
Waddell, Kid	U.S. Geological Survey
Wright, Phil	Wasatch City-County Health Department, Heber City
Younker, Gordon	Utah Association of Conservation

Appendix 7. Participants in USU Round Table Discussions

We would like to thank the following USU faculty who provided input to the Task Force through participation in round table discussions or in person.

Name	Affiliation
Bastidas, Luis	CEE/UWRL
Budy, Phaedra E.	AWER
Busby, Fee	College of Natural Resources
Caldwell, Martyn	FRWS, Ecology Center
Cockett, Noelle	College of Agriculture
Dudley, Lynn	PSB
Evans, James Paul	Geology
Gooseff, Michael	AWER
Hill, Robert W.	BIE
Hipps, Lawrence E.	PSB
Jackson-Smith, Douglas	SSWA
Kemblowski, Mariush	CEE/UWRL
Kjelgren, Roger	PSB
McLean, Joan E.	CEE/UWRL
McNeill, Laurie	CEE/UWRL
Neale, Christopher M.	BIE
Parlin, Bradley	SSWA
Rupp, Larry A.	PSB
Sharik, Terry	Environment and Society
Sims, Ron	CEE/UWRL
Toth, Richard	Environment and Society
Van Miegroet, Helga	AWER
White, Mike A.	AWER
Wurtsbaugh, Wayne A.	AWER

Appendix 8. IGERT Proposals

IGERT: Water for the Future: Integrating Water Sciences.
Proposal submitted to National Science Foundation October 2002, but not selected for funding.

Principal Investigator: David G. Tarboton
Co-PI's: Chris Luecke, Joanna Endter-Wada, Charles Hawkins, Larry Hipps
Lead Institution: Utah State University

Project Summary

Understanding the earth's natural water systems and managing the use of water resources is essential for life. Many contemporary water problems are complex. Graduate education in disciplines related to water must train water scientists, managers and professionals with more interdisciplinary knowledge, in order to interface with other scientists, resource managers, and public policy makers. This need is well demonstrated by the frequency of interdisciplinary water scientist positions advertised by universities and state and federal governments. People with adequate training and experience are lacking due to the nature of current academic programs. As our appreciation for the complexity of specific water management issues has grown, so has the rationale for emphasizing the links between *hydrology* (which considers the fluxes of water through atmospheric, terrestrial, and aquatic systems), *aquatic ecology* (which considers the biotic and chemical status and function of aquatic systems), and *social sciences* (which consider how humans interact with their natural environment and with each other).

Intellectual Merit. We propose a new interdisciplinary graduate degree program in Integrative Water Sciences at Utah State University that focuses on three thematic areas: Hydrology, Ecology, and Social Sciences. The program will focus on improving the scientific understanding of hydrologic and aquatic systems and the role of humans in those systems, with the aim of applying that understanding to water resources policy and management. This will be accomplished by integrating Utah State University's existing strengths and interdisciplinary programs in water research and graduate education which are currently dispersed in the colleges of Engineering, Agriculture, Natural Resources, Science, and Humanities, Arts and Social Sciences. Our vision is to change the culture of graduate education from a traditional enterprise focused on individual disciplines to one clearly emphasizing interdisciplinary perspectives. Our proposed program is designed to develop breadth of understanding at the nexus of water policy, hydrology, ecology and aquatic science in both the faculty and students. Key innovative aspects of our program are: (1) Three research integration courses designed to engage students in interdisciplinary research involving problem based learning, proposal preparation, and contribution to an interdisciplinary original research paper. (2) A set of common foundation courses that cover the basic sciences, management and decision-making skills. (3) A three month agency, industry, or non-profit organization internship, nationally or abroad, for all students. (4) Service as teaching assistants for classes outside of students' disciplines. (5) A diversity initiative that will reserve 20% of IGERT fellowships for members of under represented groups.

Broad Impact. Recent National Research Council recommendations strongly support the need for developing integrated research and education in the water sciences. The water sciences are naturally integrative because the fundamental hydrological processes responsible for the movement of water between the atmosphere, hillslope, river and floodplain environments, are the underpinnings for our understanding of ecology, climatology and geomorphology, as well as being important for the management of agricultural, urban and industrial water resources. An Integrative Water Sciences graduate program will have significant and broad impact as graduates of the proposed program will be well-positioned to become academic and institutional leaders in water issues. This educational program is essential as society is forced to deal effectively and creatively with crises in water allocation and quality concerns expected in the next decades.

Utah State University has a new president, provost and several new deans. This change in upper administration has created a dynamic new climate receptive to innovative ideas on curriculum integration. A recent university compact planning process resulted in the emergence of water as a critical theme, with the president indicating in his most recent State of the University address (September 12, 2002) the need to mount "a multi-disciplinary effort to restore Utah State to its historic prominence in the study of water." This high level administrative commitment provides us with a unique opportunity to re-design the graduate water sciences curriculum and build a university-wide interdisciplinary program.

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• C. Project Description

a. List of Participants

This project involves a diverse group of faculty in five colleges at Utah State University (USU) with the breadth of expertise in physical, biological, and social sciences necessary to support a strong, interdisciplinary program focused on water (Table 1, Fig 1.). David Tarboton coordinates the water graduate program within the Department of Civil and Environmental Engineering and, as PI, will direct this IGERT program if it is funded. This Integrative Water Sciences IGERT proposal will seed the formation of an interdisciplinary graduate program in Integrative Water Sciences at USU that will continue after the project is completed.

Table 1. List of Participants

Name	Affiliation	Name	Affiliation
David Tarboton	CEE, UWRL, NREPP	Paul Jakus	Economics, NREPP
Michelle Baker	Biology, EC	Jagath Kaluarachchi	CEE, UWRL
Luis Bastidas	CEE,UWRL	Richard Krannich	SSWA, NREPP
David Chandler	PSB, EC	Chris Luecke	AWER, EC
Keith Criddle	Economics, NREPP	Mac McKee	CEE, UWRL
Ryan Dupont	CEE, UWRL, NREPP	Christopher Neale	BIE
Joanna Endter-Wada	ES, NREPP	John C. Schmidt	AWER, EC, NREPP
Rob Gillies	AWER, PSB, EC	Richard Toth	ES, NREPP
Charles Hawkins	AWER, EC	Helga van Miegroet	AWER, EC
Larry Hipps	PSB, EC	Wayne Wurtsbaugh	AWER, EC

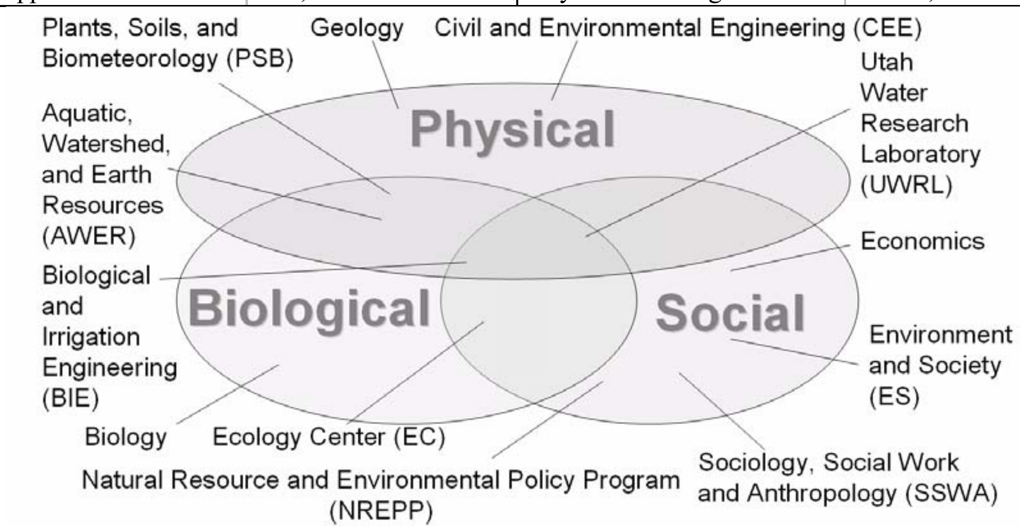

Figure 1. USU Departments and Programs that will contribute to the Integrative Water Sciences Program.

b. Vision, Goals and Thematic Basis.

We propose a new graduate degree program in Integrative Water Sciences. Our vision of this Integrative Water Sciences program is to change the culture of graduate education from a traditional enterprise focused on individual disciplines, to one clearly emphasizing an integrated interdisciplinary approach. With nearly 60 faculty in five colleges involved in water-related research, education and outreach, USU is uniquely poised to train a new generation of scientists to address rapidly developing needs in water resources research, policy and management.

At the heart of the process of integration proposed is a shift from a disciplinary to an interdisciplinary approach to research and education. Significant contemporary water challenges include the supply of water to a growing population, sustainability and restoration of aquatic ecosystems, viability of water resources research programs, and adequacy of institutional and physical water infrastructures (WSTB, 2001; Vaux, 2002). Addressing these challenges requires people trained for interdisciplinary work across the wide range of disciplines involved. The COHS (1991) addressed the dramatic role played by water in many earth environmental systems. This committee noted that "We cannot build the necessary scientific understanding of hydrology at a global scale from the traditional research and education programs that have been designed to serve the pragmatic needs of the engineering community." The committee concluded that "a hydrologic science program should not be hosted by a single department …" (COHS, 1991). Similarly CIAE (1996) noted the need for more integrative educational programs in limnology including cooperation between universities and agencies. The advent of a new administration at USU receptive to programmatic integration provides us with a unique opportunity to develop an interdisciplinary Integrative Water Sciences graduate education program.

At present, the water curriculum at USU is dispersed across the campus. This dispersed nature of water-related research and teaching programs limits the development of synergistic connections across disciplines. By providing a formal mechanism to encourage such collaborations and interaction, both students and faculty will benefit. Program level integration of the graduate curriculum related to water will provide more opportunity for students to participate in the interdisciplinary approach that every national review of water-related sciences curricula has mandated. Such an interdisciplinary approach brings people from different backgrounds together to jointly frame problems, agree on approaches to their solution, and gather and analyze relevant information (Golde and Gallagher, 1999; Pickett et al., 1999). This approach should lead to more theoretical and methodological scientific integration that better mirrors the integrated nature of the public policy and management problems that science is being called upon to address.

The traditional approach to water science education emphasizes mastery of more focused disciplinary knowledge and skills first, with integration and problem solving addressed later in the curriculum, if at all. Here we propose to turn this approach around and address integrated problem solving right from the start, teaching disciplinary knowledge and skills as they are needed in the context of understanding an interdisciplinary problem.

Our goal is to produce students who are better educated and prepared to participate in solving the interdisciplinary challenges of water science, management and policy in the future. Demographic analysis of recent Ph.D. recipients in Science and Engineering indicates a shift from traditional employment in education and basic research toward employment in applied research or positions in business and industry. In a 1991 survey, only 37% of science and engineering Ph.D. recipients were employed in academia (COSEPUP, 1995). Surveys of potential employers in non-traditional positions indicate a need for better communication skills, especially the ability to work with people from different disciplinary cultures. They also indicated a need for teamwork skills, which involves collaboration across disciplines and the ability to learn in fields beyond one's academic specialty (COSEPUP, 1995). USU's Integrative Water Sciences IGERT curriculum will provide graduate students with a diverse and versatile training, empowering them to effectively address contemporary issues in water science, policy and management, be more competitive in the job market, and better prepared to contribute generally to their future professions.

c. Major Research Efforts

Utah State University is a Carnegie Doctoral Research Extensive Land Grant University and USU researchers are involved in all of the major water-management issues of the Intermountain West, as well as elsewhere in the world. Many of the most pressing regional and global environmental issues, such as fresh water supplies and degradation in water quality, are directly connected to hydrological processes. These hydrologic processes affect and are affected by a myriad of physical, biological, and social processes. We are fortunate to have a diverse group of faculty at USU who engage in the range of disciplines required to address these complex issues and serve as the foundation in support of the proposed graduate program.

The three thematic areas that serve as foundation for this Integrative Water Sciences IGERT program are Hydrology, Ecology, and Social Sciences.

<u>1. Hydrology</u>

Hydrology is naturally integrative because the underpinnings of many other disciplines involve water and the movement of water. Hydrologic science is driven by the need to better understand variability in the hydrologic cycle as an integrated part of the earth system, and to understand the role of human activities in impacting and being impacted by this hydrologic variability. The hydrological processes involving movement of water between the atmosphere and hillslopes, groundwater, rivers, and floodplain environments are central to understanding related sciences such as ecology, geochemistry, climatology and geomorphology. USU Hydrology researchers are active in many areas of hydrology including surface hydrology and hydrologic modeling (Tarboton, Bastidas), snow hydrology (Tarboton, Chandler), land-atmosphere interactions (Hipps, Bastidas), remote sensing and climate (Gillies, Neale, White), groundwater (Kaluarachchi, Kemblowski, Peralta), soil physics and chemistry (Jones, Boettinger, Dudley), water quality (McLean, Stevens, Dupont), water requirements of urban landscapes (Kjelgren, Kopp, Johnson, Hipps), and water resources management (McKee, Bishop). Individual research contributions are too numerous to mention in the space available here. The opportunities for hydrologic science dissertations are many. Important problems remain in climate – hydrology interactions, questions of scale, spatial and temporal distribution of surface water balance, modeling groundwater and movement of below-ground contaminants, interactions of water with vegetation, and the challenge of utilizing hydrologic information in the policy arena. Communication of scientific understanding, analysis of risks, and decision-making in the face of uncertainty are fruitful areas for dissertation research. Hydrologic processes are crucial for advances in the broad area of Integrative Water Sciences.

2. Ecology

Aquatic ecology is the study of the inter-relationships among aquatic flora and fauna and their physical and chemical environments. Implicit in this definition is the importance of hydrology as a physical template upon which ecological interactions occur (Poff et al., 1997). Understanding aquatic ecosystem structure and function provides a basis for predicting impacts caused by human activities (Karr, 1991; Norris and Hawkins, 2000; Carpenter, 2002). Addressing human impact questions for policy and management requires a sound understanding of how scientific evidence is used in decision making processes. Aquatic ecologists at USU contribute important scientific knowledge for decision makers in areas such as conservation, preservation and restoration (Hawkins, Luecke, Crowl, Budy, Vinson, Kershner, Schmidt); biological and chemical water quality (Hawkins, Baker, Wurtsbaugh, Mesner, Van Miegroet); fisheries and other consumptive uses (Luecke, Budy, Kershner); and ecosystem services such as nutrient cycling, flood and drought mitigation, and recreation (Baker, Schmidt, Crowl, Brunson). Dissertation research opportunities in the Ecology theme can integrate with one or both of the other research themes. For example, identifying sources of nutrients in watersheds requires fundamental understanding of hydrological processes. Knowledge of the biology of aquatic organisms is essential in understanding impacts of these nutrients, yet characteristics of water quality and quantity that affect the distribution and ecological function of aquatic biota are controlled to some extent by human values, behaviors and management decisions.

3. Social Sciences

The social sciences, broadly defined, focus on understanding human behavior in various contexts and how this is shaped by the political, economic, and cultural systems through which people organize to interact with the natural world and with each other. Humans are a unique species, responding to sociocultual as well as biophysical constraints and opportunities in their process of adaptation, and they make decisions based upon a complex combination of knowledge, values, histories, intentions, habits, and conscious calculation. Understanding the role that humans play in the functioning of natural systems is very important but often difficult. Since water is a natural resource critical to sustenance and quality of life, humans have been especially interested in trying to understand and control the movement of water as it flows through the hydrologic cycle, in establishing rules that define who gets to use available water supplies and under what conditions, in ameliorating conflicts that generally arise over water, and in improving and protecting water quality.

USU has a strong and diverse group of natural resource and environmental policy analysts, economists, and sociologists, and many of those faculty do research on water issues. Some of these researchers are active in more specialized thematic areas within their disciplines that are relevant to this proposed Integrative Water Sciences IGERT, including public policy analysis (Endter-Wada, Simmons), resource valuation and optimization (Criddle, Glover, Jakus, McCoy), social impact and risk assessment (Krannich; Endter-Wada), public involvement and decision-making processes (Blahna, Brunson), landscape and environmental planning (Toth, Lilieholm), conflict management techniques (Daniels), and community and rural development (Jackson-Smith, Petrzelka). Ongoing water research involving these faculty and dissertation research opportunities are in the areas of analyzing public policies and conflicts that deal with water, the legal and institutional systems through which water is allocated and distributed, human behaviors and values in relation to water in various contexts, water pricing and the emergence of markets in water rights, incentive mechanisms for changing current water use patterns, water conservation behavior, attitudes and opinions about various water issues, and the adaptability of water management approaches and institutions to meet changing societal needs. The integration of the social sciences with the hydrologic and biological sciences is essential since the perspectives on and analysis of the role of humans in natural systems is often quite different between these groups of scientists (Endter-Wada et al., 1998).

d. Education and Training

The education and training goal for the proposed Water Science IGERT is to produce students capable of applying sound disciplinary skills in a collaborative team environment to solve complex interdisciplinary problems. Our students will gain cooperative work habits, good communication skills, advanced critical thinking abilities, estimation skills and the ability to frame and resolve difficult problems. This goal will be achieved through the implementation of a curriculum based on modern pedagogy (e.g. Felder and Brent, 1999) using problem based learning (King and Kitchener, 1994; Duch et al., 2001) and "just-in-time" teaching and learning methods (Novak and Patterson, 1998; Riel, 1998). This curriculum will offer early and continued exposure to systematic problem solving based on real world case studies.

This program is directed towards PhD students interested in obtaining an interdisciplinary education in the area of Integrative Water Sciences. IGERT fellowships will be offered to qualified applicants for the full period of their doctoral program (up to four years) without obligation to a major professor or ties to a particular disciplinary program or lab. The early focus of the curriculum on interdisciplinary work will encourage these students to think in an integrated way and design collaborative research projects. Teamwork and sharing of ideas to produce group products will be encouraged and recognized as dissertation contributions.

Developing and implementing a new crosscutting program requires changes in organizational structures and innovative concepts for laboratories and instruction. Understanding water is particularly suited to the development of an integrated program because it requires the incorporation of knowledge and skills from many scientific disciplines. We propose to develop the following integrative, team-oriented, problem solving curriculum (Table 2) to produce a new generation of water scientists, managers, and policy makers.

Table 2. Proposed Integrative Water Sciences IGERT PhD Program Curriculum

<table>
<tr><td colspan="3">Year 1</td></tr>
<tr><td>Semester 1</td><td>Semester 2</td><td>Summer</td></tr>
<tr><td colspan="2">Research Integration 1. Problem Based Learning Course (Two semesters credit)</td><td rowspan="4">Internship, Nationally or Abroad</td></tr>
<tr><td>Foundation Course 1</td><td>Foundation Course 2</td></tr>
<tr><td>Elective Courses</td><td>Elective Courses</td></tr>
<tr><td colspan="2">Research</td></tr>
</table>

<table>
<tr><td colspan="3">Year 2</td></tr>
<tr><td>Semester 1</td><td>Semester 2</td><td>Summer</td></tr>
<tr><td>Research Integration 2. Proposals</td><td></td><td rowspan="4">Research</td></tr>
<tr><td>Foundation Course 3</td><td>Foundation Course 4</td></tr>
<tr><td>Elective Courses</td><td>Elective Courses</td></tr>
<tr><td colspan="2">Research</td></tr>
</table>

<table>
<tr><td colspan="3">Year 3</td></tr>
<tr><td>Semester 1</td><td>Semester 2</td><td>Summer</td></tr>
<tr><td>Research Integration 3. Papers</td><td></td><td rowspan="2">Research</td></tr>
<tr><td colspan="2">Research and any outstanding coursework</td></tr>
</table>

In addition to the activities shown, there will be an ongoing seminar during the academic year, a group activity each spring break and comprehensive exams at the end of the second academic year. We expand briefly on each of these components below to convey the essence of the program, but details are limited by pre-proposal space constraints.

Research Integration

Integration of interdisciplinary research into the curriculum will be achieved through a sequence of three research integration courses.

- *Research Integration 1.* (Schmidt lead, Tarboton, Endter-Wada, Jakus, Gillies) This will be a problem based learning course focused on a current interdisciplinary water issue. The goals of the course will be: to allow in depth explorations of concepts and processes; illustrate the development and application of integrated models of physical, chemical, biological and human dynamics in water systems; provide involvement with agencies through access to problem statements; focus on how information can be organized and analyzed for structure and pattern; and use state-of-the-art visualizations, data analysis, and modeling tools to facilitate team problem solving. The group of instructors will lead the class through a data-driven and extensive study of a topical issue. As a learning community the class will learn the skills and disciplinary knowledge required through addressing the problem at hand. Learning communities recognize that students arrive with different skill levels, experiences and interests, and that this diversity strengthens the learning context (Riel, 1998). Classes will mostly be in the form of collaborative recitation/discussion sessions using just-in-time teaching pedagogy (Novak and Patterson, 1998). Working in small groups with individual instructors is intended to engage students and make them active learners. This mode of instruction provides learning in the context of the problem being addressed. Through this immersion in the learning process, we expect that students will end up with a deeper and broader understanding of water sciences, and of the utility of different approaches to problems. Moreover, we expect that the faculty collaborating on the project will also experience significant learning, as they adopt this novel pedagogy. All students in the IGERT program will be required to complete this two semester course during their first year.

- *Research Integration 2.* (Hawkins lead, Chandler, Dupont) This class has three goals: (1) Preparation of each student's dissertation proposal; (2) Identification of an interdisciplinary research paper topic (the subject of Research Integration 3) and (3) Formation of a student team to address this topic. One outcome of the Research Integration 1 experience will be the ability to work together on interdisciplinary teams. In Research Integration 2, students will be required to develop and critique proposals. First, there will be instruction on the general elements of a proposal and the proposal evaluation process. Then students will prepare their dissertation proposals. This process will be an individual exercise, but allows for teamwork on collaborative projects. Students will review and critique drafts of their peers' proposals providing opportunities to identify interdisciplinary paper topics. Students will be encouraged to include these interdisciplinary research topics as part of their individual dissertation proposals.
- *Research Integration 3.* (Baker lead, Bastidas, Hipps) The outcome of this experience is intended to be one publishable co-authored paper per three to four students. Students will work in teams formed in Research Integration 2. Draft student papers will be peer reviewed by other students in the class. Students will be encouraged to include these papers as part of their dissertation reflecting the interdisciplinary nature of their education, and to present results from these papers at appropriate regional or national conferences. IGERT funds for travel will be provided. These papers will develop important writing and presentation skills. This Research Integration 3 class will serve as a capstone experience for students giving them the opportunity to reflect on their learning and integrated research, and to provide feedback in the form of an achievement report listing key research findings and ideas for future research. These reports will be used in the assessment of the learning objectives of the program.

Foundation Courses

Four required foundation courses are proposed as part of this Integrative Water Sciences IGERT to provide common knowledge that will serve as a basis for interdisciplinary communication.

1. *The Physical Science of Water*. Hydrology, Climate, Geomorphology, Transport, Measurements. (Tarboton lead, Gillies)
2. *The Ecology of Water*. Biology, Chemistry, Biogeochemistry. (Wurtsbaugh lead, Baker, Van Miegroet)
3. *The Human Dimensions of Water*. History, Policy, Law, Cultural Aspects. (Endter-Wada lead, Schmidt)
4. *Water Management and Decision Making*. Ethics, Economics, Optimization, Risk and Uncertainty, Decision making. (McKee lead, Jakus)

Internship

Students in the program will be required to undertake a three month internship nationally or abroad with an agency or firm active in the area of water science, policy, and/or management. IGERT assistantship stipends will be guaranteed to cover these internships. This internship will occur during the first summer in the program, and represents a significant career development opportunity for the students. Approximately 20% of these internships will be targeted towards international opportunities to give the program a global perspective.

Diversity Initiative

We will reserve 20% of the IGERT fellowships for members of under represented groups. Their recruitment will draw upon our membership in the Minority Graduate Education at Mountain States Alliance and the Western Alliance to Expand Student Opportunities. The School of Graduate Studies at USU will provide 50% matching funds up to $50,000 on fellowships provided to students from under represented groups as part of a Graduate School diversity initiative. We have also developed strong relationships with several undergraduate educational programs at other institutions that focus on minority students, which can serve as feeder institutions to the Integrative Water Sciences IGERT program at USU. Haskell Indian Nations University in Lawrence, Kansas has worked with the College of Natural Resources at USU to provide BS degrees and employment with federal land management agencies for Native American students. Successful funding of the IGERT proposal would allow Native American graduates of Haskell to apply to the USU Integrative Water Sciences IGERT. The Minorities in the Aquatic Sciences (MAS) Program, sponsored by the American Society of Limnology and Oceanography and Hampton University, will participate in the recruitment of applicants for this IGERT program. Dr. Ben Cuker, (a professor of marine and environmental science at Hampton University, a minority serving institution) will serve as a member of the Integrative Water Sciences IGERT graduate selection committee. Additional graduate student recruitment opportunities exist through two USU Continuing Education programs that involve professional employees of the US Bureau of Indian Affairs and of tribal governments.

Our diversity recruiting will highlight the integrated problem based curricular aspects of the program involving learning communities that build diversity into the educational context. The services of the USU Multi-Cultural Student Services Program will be available for social and academic support of multi-cultural students. Everardo Martinez, the director of the program, will coordinate group educational and social activities. Dr. Martinez will also help with diversity recruitment, participate in the selection of students for the IGERT program, and assist in career counseling.

Other Water Science IGERT Program Elements

- *Elective Courses*. In addition to the research integration and foundation courses, elective courses provide breadth and depth to students programs of study as approved by their dissertation advisory committees.
- *Annual Group Activity*. Students will participate in a week-long excursion to a site of water science, policy and management interest, and meet with decision makers and managers active in the issues involved.
- *Teaching Assistant*. Each student will be required to serve as a teaching assistant for a class outside of their discipline. This will serve to reinforce further interdisciplinary knowledge and communication skills and will provide students with an important opportunity to develop their teaching abilities.
- *Seminars*. A Water Science, Policy and Management seminar series will involve invited outside speakers, as well as student presentations to help students develop presentation skills.

e. Management, Assessment and Institutional Commitment

Administratively, this program will be responsible to the Provost's Office and the School of Graduate Studies so that it does not become captive to any one department or college. As PI on this proposal, Tarboton will manage the Integrative Water Sciences IGERT program. An internal oversight committee will be formed comprising many of the faculty participating in the program, as well as the Dean of the School of Graduate Studies and the Provost. An external advisory committee will also be formed comprising directors of other IGERT projects and administrators of other interdisciplinary programs, as well as representatives from minority feeder programs.

Management and evaluation will be based on the following indicators of performance:

- Recruitment of a diverse cohort of talented students.
- Twice yearly satisfaction surveys completed by students in the program.
- Student evaluations of research integration and foundation courses.
- Student achievement reports from the Research Integration 3 course.
- Satisfaction surveys of agencies, firms, and organizations that provide internships.
- Number of students graduated through the program.
- Papers published by students in the program during graduate work, and in the two years following graduation. The quality of journals and quality of papers as indicated by citations will be tracked.
- Review by external advisory committee.

f. Expected Resource Commitments

This proposal is part of a broader effort at USU to create a "Center for Water Sciences." This effort has the support of the University administration. The University President in his recent State of the University address (Hall, 2002) identified the "first and most significant goal is to enhance the reputation of the University for learning, discovery and engagement." A part of this goal is the "multi-disciplinary effort to restore Utah State University to its historic prominence in the study of water." USU has a strong tradition in water research and education going back over one hundred years as the land grant university in an arid state. An agreement supporting the concept of an interdisciplinary program in Integrative Water Science has been signed by the deans of each college involved. The Dean of the School of Graduate Studies and the Vice President for Research have played an active role in the development of this proposal. The Dean of the College of Natural Resources has committed $120,000 per year for 5 years from an endowment fund to provide additional graduate fellowships directed at research on water issues.

g. Recent traineeship experience and results from prior NSF support

Existing interdisciplinary traineeship programs at USU related to this Water Sciences IGERT include:

- Natural Resources and Environmental Policy Program
- Ecology Center
- Inland Northwest Research Alliance Subsurface Science Graduate program
- EPA Star Graduate fellowships

These are not results from prior NSF support, but are briefly described here to indicate USU experience with interdisciplinary graduate research and education.

The Natural Resources and Environmental Policy Program (NREPP) administers two graduate certificate programs and sponsors a seminar series, providing all USU graduate students with optional interdisciplinary educational opportunities supplemental to their degree programs (http://www.cnr.usu.edu/policy). Seven colleges and thirteen departments participate in the NREPP, which offers 35 courses (both certificate programs), has issued 30 NREP certificates over the last seven years, and currently has 47 students in both certificate programs.

The Ecology Center integrates the efforts of faculty and graduate students in three colleges and six departments to support and coordinate graduate education and research in ecology. Over 30 courses are associated with Ecology Center programs and 33 MS and 18 PhD students have graduated with Ecology degrees in the last 5 years.

The Inland Northwest Research Alliance (INRA) is a consortium of eight regional universities, funded by the US Department of Energy in collaboration with the Idaho National Engineering and Environmental Laboratory. A Subsurface Science Graduate Program was initiated in fall 2002 with 20 PhD fellowships awarded and distributed among the participating universities. The program comprises multi-institutional interdisciplinary courses that use state-of-the-art telecommunications methods to draw upon the complimentary strengths across the INRA universities.

The US EPA provides support for exceptional PhD students through the Science To Achieve Results (STAR) graduate fellowship program. USU currently is providing training to 1 STAR-supported PhD candidate who is working on the relationship between aquatic biodiversity and ecosystem function.

The existence of these interdisciplinary programs at USU adds value to the proposed Integrative Water Sciences IGERT by providing us with the needed experience in coordinating such programs. Furthermore Policy, Ecology and Subsurface Science (groundwater) are important components of Integrative Water Sciences and IGERT students will be able to take courses, participate in seminars, and benefit in other ways from interaction with these existing programs.

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IGERT. Science, Policy, and Changing Landscapes: Critical Issues in the Great Salt Lake Watershed.

Proposal submitted to National Science Foundation October 2001, but not selected for funding.

Principal Investigator: G. Belovsky
Co-PI's: J. Endter-Wada, J. Schmidt, L. Shultz, R. Toth

Lead Institution: Utah State University

Project Summary

Integrative graduate education and research traineeship (IGERT) studies within the Great Salt Lake Watershed (GSLW) will link student researchers and a team of environmental scientists from Utah State University to government, industry, and special interest groups in a coordinated effort to provide comprehensive and integrated scientific information for public policy decision-making. Because the Great Salt Lake Watershed is a closed hydrologic system rife with conflicts over resource use, the setting provides unique challenges and opportunities for scientific and policy research. Our assumption is that growth can be channeled and water systems reconfigured to minimize loss of biodiversity and ecological resources. Students and faculty will be involved in several independent research efforts in the watershed, working in technology transfer teams to help local policy-makers understand the science associated with the complex, resource allocation decisions that must be made. The experiences gained from working in the IGERT team will expose students to real-world applications of their science, providing them with general perspectives and approaches while grounding them in the details of place-based problems. Internships and a studio environment will be used to frame research questions and integrate research findings in order to develop alternative future scenarios for the GSLW. Our goal is to train a new generation of environmental scientists that can synthesize scientific information to respond to land and resource use planning, management, and policy issues. The program will facilitate the coordination of local decisions within a framework of science-based analysis and informed debate and will contribute to the development of new models and skills in the management of resource conflicts.

Project Description

a. List of Participants

Name	**Department**	**Specialty**
Gary Belovsky (PI)	**Fisheries and Wildlife**	**Population ecology and modeling**
Joanna Endter-Wada (Co-PI)	**Natural Resource and Environmental Policy, Watershed Science**	**Natural resource policy**
John C. Schmidt (Co-PI)	**Geography and Earth Resources, Watershed Science**	**Geomorphology**
Leila Shultz (Co-PI)	**Forest Resources**	**Plant systematics and ecology**
Richard Toth (Co-PI)	**Landscape Architecture and Environmental Planning**	**Landscape analysis and planning, futures studies**
Michele Baker	**Biology**	**Biogeochemistry and ecosystem ecology**
Mark Brunson	**Forest Resources, Watershed Science**	**Public attitudes, knowledge, and behaviors**
Martyn Caldwell	**Rangeland Resources**	**Ecophysiology and effects of climate change**
Chris Call	**Rangeland Resources**	**Disturbance ecology**
John Crane	**Forest Resources, Utah**	**Environmental resource**

	National Guard	**management**
Ray Dueser	**Fisheries and Wildlife, College of Natural Resources**	**Wildlife ecology**
Thomas Edwards	**USGS Biological Resources Division, Fisheries and Wildlife**	**Wildlife habitat and spatial modeling**
Herbert Fullerton	**Economics**	**Economics of water use**
Richard Krannich	**Sociology, Social Work and Anthropology**	**Natural resource sociology**
Robert Lilieholm	**Forest Resources**	**Ecological economics**
James Long	**Forest Resources**	**Forest ecology**
James MacMahon	**Biology**	**Community ecology**
Nancy Mesner	**Geography and Earth Resources**	**Water quality, outreach education and extension**
R. Douglas Ramsey	**Geography and Earth Resources**	**Spatial modeling and remote sensing**
Mark Ritchie	**Fisheries and Wildlife**	**Spatial modeling of wildlife**
David Roberts	**Forest Resources**	**Forest succession and vegetation modeling**
Darwin Sorensen	**Utah Water Research Laboratory**	**Environmental engineering**
Neil West	**Rangeland Resources**	**Landscape ecology**
Paul Wolf	**Biology**	**Genetics, evolutionary theory**
Wayne Wurtsbaugh	**Fisheries and Wildlife, Ecology**	**Aquatic ecology**

b. Vision, Goals, and Thematic Basis

Rapid growth, lack of coordinated local planning, and inability to integrate scientific understanding with natural resource decision-making threatens quality of life in the greater Great Salt Lake Watershed (GSLW). Urban and rural areas in the GSLW are experiencing changes that are altering both natural and social systems. We propose a research and education strategy that will integrate knowledge across individual graduate research projects. In this proposal, university faculty and students are making a commitment to work with community leaders in a way that will give decision-makers access to scientific information and will expose students to the political realities of public policy decisions in which science is only one component. Our IGERT program will utilize resource modeling and bioregional land-use and conservation planning. Information transfers will take place within the framework of predictive systems to explore alternative futures under different development and management scenarios (Steinitz 1996). This program will create partnerships between the university community, government agencies, industry, environmental groups, and private stakeholders for applying science to the resolution of resource-based problems.

The complex web of interacting issues within the developing urban core of northern Utah is not unlike those that exist in other developing areas of the arid West, especially regarding the allocation of water resources. Decisions about land use in these areas are driven by the need for resources to support the expanding urban infrastructure. The cumulative ecological impact of community and individual land-use decisions on the local environment and on the larger landscape is far-reaching, yet largely ignored. The political decision-making process tends to ignore scientific knowledge because scientists rarely provide technical information that is focused on addressing management and policy issues. Urban expansion thus continues in the absence of scientific insights about the large-scale spatial and temporal implications of this growth.

Growing demands for water irrevocably link local communities in the arid Intermountain West. With U.S. Census Bureau estimates of approximately 1.8 million people currently in the GSLW, urban expansion will fill most of the vacant land in the more urbanized counties with an additional 1 million people within the next 20 years (QGET Technical Committee 1997). Management of projected urban growth is a major initiative in Utah. A private citizen-industry-university initiative organized by the Governor's Office of Planning and Budget, termed *Envision Utah,* integrates public input to develop growth management scenarios. Demographic changes have brought shifts in societal expectations with regard to the value of environmental resources, which are expected to become even more significant with the coming 2002 Winter Olympics. The GSL watershed has extensive, internationally important wetland resources that offer critical habitat for migratory and resident birds and inter-basin systems that drain forests and provide water for a growing population. These are key concerns for all citizens, but are of particular interest to environmental groups and Utah's large recreation and tourism industry.

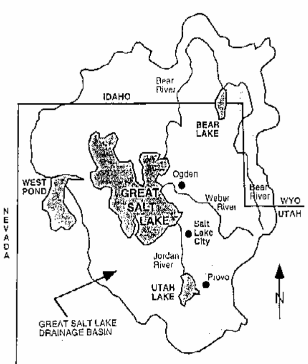

Figure : Great Salt Lake Drainage Basin

The Greater Salt Lake Watershed (accompanying figure) provides a natural setting for development of a program examining the long-term effects of local environmental change on the landscape. It also provides an unusual and challenging case study for the application of watershed principles (Adler 1999). We define the greater Great Salt Lake ecosystem as the lake, its natural watershed, and the more extensive rural areas that supply resources, particularly water, to the urban core that is constricted between the GSL to the west and the Wasatch Mountains to the east. Transbasin diversions and increased use of fresh water by agriculture, industry, and the rapidly expanding urban population has profoundly affected the salinity gradients within this hydrologic system and caused environmental transformations in a much larger landscape than that of the lake and its wetlands. The GSL is home to a thriving minerals industry (estimated annual revenues of $200 million) and an industry based on the harvest of brine shrimp (yielding $60 million in annual sales) and travelers spend more than $2.5 billion annually in the Salt Lake region and surrounding wildlands (Kemp 1999). These enterprises and activities play a major role in the regional economy, and organizations have been formed to represent these industries before Utah's legislative, regulatory, and resource management institutions.

Traditionally, decisions about growth and land use have not been made in a coordinated way. Communities make decisions at local scales while the cumulative impacts of these decisions have landscape level, even global consequences. Local decisions typically depend on part-time politicians, administrative personnel, and consulting firms whose staffs are constrained by project assignments and limited public resources. Scientific information is rarely effectively incorporated into local decision-making. In our model, current and future research in spatial modeling of resources and land-use and conservation planning will link with all our proposed educational outcomes.

Our goal is to train a new generation of Ph.D.-level scientists capable of working with citizens to identify choices among alternative responses to changing environmental conditions. As effects of human activities increase (such as water diversion, increased atmospheric deposition, and habitat fragmentation), the need to foster a holistic approach to understanding human-natural system interactions in urbanizing environments is critical and timely. The IGERT support will supplement the present strengths of Utah State University in Ecology, Natural Resource and Environmental Policy, Watershed Science, Landscape Architecture, and the various disciplines of natural resources. It will provide a program in which students work on different environmental problems important to local communities, integrate multiple layers of information to address common issues, and work as consultants to inform the policy-making process. This long-term, integrated, place-based research program will train students to work at the frontiers of theoretical knowledge while developing a long-term ecological record regarding natural and social perturbations within the greater Great Salt Lake ecosystem.

c. Major Research Efforts

A hallmark of the IGERT program will be a synergistic team approach to problem-solving, while maintaining rigorous, independent research agendas for each of the students involved in the program.
We will provide students with innovative classroom and research opportunities that enhance their understanding of basic ecological and sociological concepts and foster their applied ecology and problem-solving skills. These skills will include the ability to:

- Seek solutions to environmental problems that are based on rigorous science and advanced technology.
- Test and expand current ecological theory.
- Appreciate how different spatial and temporal scales influence potential solutions to environmental problems, which includes knowledge and understanding of tools like geographic information systems (GIS) and spatial analytical tools.
- Appreciate that economic and social activities are a pervasive element of ecological systems and must be

part of any solution to environmental problems, which involves development of risk assessment and cost/benefit analysis skills.

- Solve problems as team members, which involves constructively interacting with others.
- Communicate scientific knowledge to decision-makers that are not trained as scientists, which requires a willingness to step outside the framework of one's specialized scientific community.

To achieve these objectives, students will be able to choose from a number of relevant research areas, including, but not limited to, the following areas in which USU researchers are engaged.

The **effects of large-scale climate variations and local land use change on hydrologic and bio-geochemical cycles of river basins** are being investigated by **Baker, Belovsky, Schmidt,** and **Sorensen**. Relevant issues include the influence of hydrologic linkages within watersheds on ecosystem structure and function, including how alterations to natural flow regimes (or changes in landscape structure) influence these linkages; what implications these interactions have on water quality and quantity; and what kinds of management practices are best suited to maintain water quality and quantity One of the frontiers in ecosystem ecology is to understand the causes and consequences of spatial heterogeneity in ecosystem function (Carpenter and Turner 1998).

The relationship of biotic subsystems of the Great Salt Lake and **socio-economic settings** (**Belovsky, Endter-Wada, Wurtsbaugh)** will be a component of the IGERT program. New ideas are being developed on how the space-time dynamics of complex human, biological, and physical-chemical systems in a river basin can be studied in a management context. Socio-economic processes have a major impact on ecological conditions within a watershed, including rates of nutrient movement. Lake volume and chemistry effects on biotic composition are found in the examples compiled by Belovsky and Larson (1999). As runoff changes, salinity relationships become complicating factors in biodiversity (Belovsky et al. 1999; Wurtsbaugh and Berry 1990). Long-term research will identify non-point source pollution and explore associated socio-economic issues. Important issues include how will food web dynamics, nutrient cycling and biogeochemistry, might be affected by urbanization.

Knowledge of **individual species, community structure, and genetics (Belovsky, Edwards, MacMahon, Roberts, Shultz, Wolf)** can be used to predict the effect of climate and landscape change on keystone species. Research with biophysical models for rare plants (Shultz and Roberts 2000) has shown the importance of geochemistry and water resources in defining potential habitats, and can be expanded to include the vegetation of the GSLW. Research has shown that habitat fragmentation can reduce species diversity abundance of pollinating insects, resulting in a measurable effect on the genetics of plant populations**. Remote sensing (Edwards, Ramsey, Roberts, West)** and detection of long-term changes in grazing practices and riparian systems will incorporate Utah GAP analysis data and accompanying information on species distributions (http://www.nr.usu.edu/Geography-Department/utgeog/utvatlas/)**.** Fragmentation of once continuous native habitats forces many organisms to persist in small isolated population islands: consequences include increased rates of invasion of noxious weeds as well as changes in species richness and composition, genetic structure, and population dynamics.

Spatial models of landscape dynamics (Edwards, Ramsey, Roberts, Toth) will use satellite and overflight imagery to help determine the effect of urban and artificial disturbance patches on natural ecosystems and will take advantage of knowledge developed in earlier studies (Ramsey et al. 1995, Homer et al. 1997). The models have been used in simulated predictions for future human impacts, climate change, designation of wilderness areas, and problems of wildlife reintroduction http://ella.nr.usu.edu/~biodweb/. Edwards et al. (1997) have developed and tested statistical methodology for evaluating map accuracy and classification schemes, and quantifying ecological resources.

Landscape models (Toth, Edwards, Roberts, Mesner) provide an integrated planning tool for watershed developments. By developing futures scenarios, students have helped communities within the Greater Salt Lake Watershed determine the relative impacts of growth, economics, planning decisions, and conversions of land use (Toth et al. 2000). Needs and future visions of citizens will be developed based on focus groups and surveys, and then used as model inputs to develop alternate future scenarios. Futures studies are being conducted by faculty and graduate students in the LAEP program and will integrate findings from the IGERT GSLW program. Feedback from private and public stakeholders will be sought.

Natural resource policy and social science (Endter-Wada, Brunson, Lilieholm, Schmidt) research helps us understand why and how humans structure their interactions with natural environments and with each other. The social science of ecosystem management has two distinct components: one component concerns understanding mechanisms for public involvement in ecosystem management decision-making processes; the other component concerns integrating social considerations into the science of understanding ecosystems (Endter-Wada et al. 1998). USU researchers are experts in utilizing a variety of social science data gathering and analysis techniques (ethnography, interviewing, surveys, modeling). Their contribution to IGERT research will be to document human resource use patterns in the GSLW, analyze resource conflicts, tap local ecological knowledge, and work toward conceptual and analytic integration between the natural and social scientists affiliated with the project.

d. Education and Training

Several innovations will make this IGERT graduate education and training program unique. The program will be structured to overcome the individuality and narrow disciplinary specialization typical of university Ph.D. programs. Missing from such degree programs in the past has been translation of research findings into action, as well as participant diversity. Our goal is to train a new generation of Ph.D.s as environmental professionals equally equipped to conduct science in academic, industry, management, and policy settings. They will learn that solutions to contemporary natural resource challenges require increased scientific integration, problem-solving innovations, substantial public debate, management adaptations, and trans-boundary approaches from a political and administrative system that is inherently fragmented. Recruiting, mentoring, and retaining members of minority groups and women will be a high priority of the project, facilitated through utilizing existing NSF resources and programs established by the Ecological Society of America to identify potential applicants from minority groups. We will also develop an aggressive recruitment campaign utilizing our own extensive professional networks.

A major innovation will be in terms of the students' frame of reference. Even though IGERT students will be enrolled in existing Ph.D. programs at Utah State University, their educational and research experiences will be defined within the context of the interdisciplinary program. Graduate students will work with faculty mentors and community leaders in order to be responsive to needs of people within the GSLW, to ensure the integrity of the scientific data, to help compile and synthesize existing information, and to develop large integrated databases that will help in the spatial scaling from local to global issues. Students will be accepted into the IGERT program by agreement of the project PI and co-PIs, will participate in all required IGERT activities, and will define a dissertation project having to do with the greater Great Salt Lake Watershed. Their project proposal and dissertation will be defended before the GSLW project faculty and students for its scientific integrity as well as its policy relevance. IGERT students will be housed together in an IGERT complex consisting of a project studio, database library room, remote sensing/GIS facility, and graduate student offices.

As a component of the first year of their program, students will intern with industries, governments, land managers, and extension specialists in the GSLW. The purpose of these internships will be to ground students in the practical problems facing resource managers and decision makers. Students will develop the perspectives necessary to frame scientific questions to address these problems and will acquire the tools necessary to analyze land-use problems at a scale useful to local decision makers. They will learn to analyze issues within the larger framework of regional and global economies while helping local communities understand ecological events in the context of spatial dynamics and public policy.

Another key feature of the IGERT graduate experience will be involvement in a studio environment. Students will be required to enroll for two units of IGERT studio each semester they are on campus. The studio environment will be used to foster creative thinking, maintain an active dialogue among participants, and develop collegiality among faculty members and graduate students. Use of studio time will evolve over the course of the project. In years one and two, students will discuss their internship experiences, synthesize the state of knowledge about the GSLW by compiling a library of databases, and define dissertation topics. In years three and four, students will make presentations on their research but will also work in consulting teams to answer questions, provide information, and conduct analyses for various GSLW stakeholders (e.g. industry, government, resource managers, educators). Students will analyze issues via the instruments of their discipline and, in so doing, will develop a talking knowledge of other disciplines and build a universal language of discourse. Students will work to identify thresholds, trigger events, and alternative futures. A significant product emerging from these studio group activities will be the peer-reviewed and juried documents describing group solutions. Evaluation of the models will involve advisors and other stakeholders in the program, including representatives of local communities.

We will emulate successful models developed for large collaborative projects at Utah State University, including the studies for Utah National Guard Camp C.W. Williams, where we integrated biodiversity inventories, monitoring, and land management programs; the Hill Air Force Base Military Operation Area and adjacent public lands, where we developed predictive models of habitats of rare plants and animals and developed a geo-referenced bibliography; and, the Continuing Education in Ecosystem Management program, where professionals are trained to implement national policy by working with local land managers. We will also be able to take advantage of the methodology developed for the Alternative Futures Projects for the Mohave Desert which uses environmental drivers to predict the long-term effects of alternative scenarios http://ella.nr.usu.edu/~bioweb/mojavefutures/researchoverview.html.

We are requesting NSF support for the cost-of-education of a five-year training program for twenty Ph.D. students. Additional commitments from the College of Natural Resources, through partnerships with private foundations, will provide for the cost of extended research and faculty participation. The greater Great Salt Lake Watershed IGERT will coordinate and focus the efforts of graduate and undergraduate students working on natural resource-related programs in Biology, Engineering, Fisheries and Wildlife, Forest Resources, Geography and Earth Resources, Geology, Landscape Architecture and Environmental Planning, Political Science, Rangeland Resources, Social Science, and Soils and Biometeorology.

e. Management and Evaluation

Management of the **IGERT GSLW program** will be structured in the following manner. The PI and co-PIs will compose the ***Steering Committee*** and will be responsible for executive oversight of all aspects of the program. In particular, the Steering Committee will work to foster effective communication and good relationships with organizations active in issues related to the GSLW. Faculty and students associated with the program will be considered ***Program Associates***. They will be involved in the research and educational components of the program and will provide guidance on the critical issues that need to be addressed. At the inception of the project, an ***External Advisory Team*** will be assembled to provide recommendations for the research scope and direction of the project and to support internships related to the program. The External Advisory Team will be composed of representatives from local governments, the Utah Department of Natural Resources, the Great Salt Lake Planning Team (responsible for 1999 master plan), "Envision Utah" (the Governor's state-wide planning task force), the U.S. Geological Survey, representatives of industry, and members of the U.S. Fish and Wildlife Service, Army National Guard, Air Force, Bureau of Land Management, and Forest Service. In addition, we will enlist the participation of Friends of the Great Salt Lake, local chapters of the Audubon Society, and the Utah Rivers Council. We will hire a ***Program Manager*** to handle administrative details of the research and educational program, oversee the IGERT complex, coordinate meetings with the External Advisory Team, manage budgets, and maintain documentation for program reviews and evaluations.

Program evaluation will take place at several levels. Internally at USU, IGERT Program Associates will establish annual goals and work plans against which progress can be measured. In addition, Program Associates will be asked to evaluate the program annually and these evaluations will be used for program modifications. The Steering Committee will be responsible for evaluating student qualifications for acceptance into the program and monitoring their progress. Students will be evaluated annually, both by faculty and their peers, and provided with written feedback on their contributions to the program.

Several forms of external review will be incorporated into the program. Students will be evaluated by their internship supervisors. The project will host an annual two-day conference/workshop on research and findings related to critical issues defined by the Program Associates and the External Advisory Team. This annual conference will be formally evaluated. In addition, students will make presentations at public and professional meetings, participate in juried classes, and submit manuscripts to peer-reviewed journals. Data from Program Associates' research will be integrated in a web site, with interpretations that foster interdisciplinary understanding as well as scientifically defensible documentation. Use of the web site will be monitored and users will be given the opportunity to evaluate the information and design of the site.

f. Expected Resource Commitments

We have a signed commitment of $1.4 million as an institutional match for the IGERT training program. Approximately 50% of this amount is from waived indirect costs, approved by the Utah State University Contracts and Grants Office, with the remaining amount coming from new funds generated for the program. F.E. Busby, Dean of the College of Natural Resources (CNR), is committing $604,000 in new funds specifically generated to support the research proposed for this project. Costs of this program that are not part of other projects or requested in the NSF support involve costs of facility renovation, program development, and research expenses. The Dean's funds are not linked to existing federal contracts or awards. Another $112,498 will be provided from Utah State University as real dollar transfers for graduate student tuitions over a five-year period, as support for 20 Ph.D. candidates. Waived indirect costs will amount to $702,000. Joint funding of first year internships by the IGERT program and partner organizations will release additional matching funds to support research and technology transfer activities.

Facility support will be provided by a grant from the Quinney Foundation for renovation and reconfiguration of graduate student offices, labs, and work areas to support the approximately 20 new Ph.D. students and associated support staff. A commitment of $500,000 for this renovation is independent of the matching funds for the IGERT program reported above. The strong commitment by the institution and the enthusiastic support by a private foundation to foster collaboration in the integrative watershed-based studies within the Great Salt Lake ecosystem demonstrate the importance of this program and enhance the success of its novel approach to teaching and integrated research. The cost center for the proposed budget and institutional supplements will be the Ecology Center, a cross-disciplinary and multi-college collaboration of environmental scientists from Utah State University. Funds from the College of Natural Resources will be critical in providing the physical infrastructure for a collaborative environment, through the development of space for the integrative research program and for attracting a new cohort of students who will learn to integrate science and policy.

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Appendix 9. An Experimental Watershed Within the Great Salt Lake Basin

The Great Salt Lake Basin encompasses an area of 56,000 km^2 and represents one of the fastest growing urban regions in the country. This growth is dependent on availability of high quality water. The present expansion of population centers along the Wasatch Front is placing extreme demands on the water resources delivered by the natural ecosystems surrounding the urban core (Envision Utah, 2002). We envision using the Great Salt Lake Basin as a laboratory to investigate the interactions between human needs and desires and the ability of natural systems to accommodate their interests. Our integrative sciences approach will provide a means to understand the biophysical processes underpinning these ecosystems, examine the sociological processes that define the values people place on water resources and their environments, and to develop planning and policy approaches to create the sustainable societies of the 21st century. The Great Salt Lake Basin provides a number of opportunities to facilitate such studies. Although urban development has been rapid, we are still at the front edge of the development cycle. We have the opportunity to seek the balance between water conservation and water development in planning for future growth. Information, planning, and policies developed during the next decade will influence the future of our region. The diversity of natural systems present in the watershed, ranging from snow-peaked alpine forests to desert sage brush rangelands to the streams delivering water to the saline lake, allows this basin to serve as a model for most semi-arid regions of the western United States and is relevant to vast regions of the world where water needs are or will be extreme. Finally, the variability of Utah's present climatic regime provides us with periods of water surplus followed by extensive droughts. This variability magnifies issues of water development and water quality and heightens the needs for better planning efforts.

Within the Great Salt Lake Basin we propose to focus our scientific efforts on our local watershed, the Bear River. This watershed (Figure A9.1) presents an outstanding opportunity for providing focus and identity and integration of the research activities of water programs on campus. The Bear River is located in northeastern Utah, southeastern Idaho and southwestern Wyoming, encompassing approximately 4.8 million acres. The river originates at 13,000 feet in the Uintah mountains of Utah and travels north through Wyoming and Idaho before turning south and re-entering Utah. The course of the river extends approximately 500 miles and drops almost 9,000 feet between the mountains and the northern end of the Great Salt Lake. Over this course the balance between the volume and quality of the river's flow and the extent of diversions to societal demand has important consequences for the watershed and people in it. As the largest tributary to the Great Salt Lake, Bear River inflows are also critical for the Great Salt Lake ecosystems, yet may be viewed as losses from societal use. The broad range of issues in the Bear River watershed, combined with its relatively manageable size and number of political entities make it an ideal setting for interdisciplinary, action-oriented research. The timing is ideal for a concerted program that through collaboration of USU research and outreach with communities and public agencies will provide a set of choices for development of the urban rural fringe in the new West.

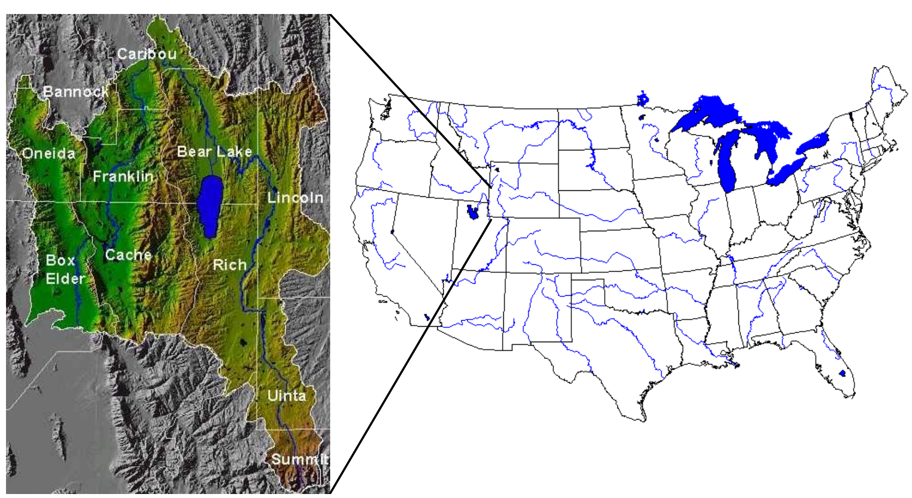

Figure A9.1. Bear River Watershed Location Map.

The heart of the problems for the Bear River, like much of the inter-mountain west, is the unprecedented population growth, with the change in water use that accompany conversion from agricultural to urban and suburban land uses.

The current land uses throughout the basin are primarily agricultural, with some agriculture related industry. Most of the population, and growth, is concentrated in Cache Valley in the lower portion of the basin, but similar growth in other sections of the watershed is projected. In addition to the increasing local demand, water previously allocated for agricultural use is being eyed as a drinking water source by the nearby growing Salt Lake City metropolitan area and other urban centers along the Wasatch Front. The traditional approach to resolving such issues has been to increase storage capacity; and reservoir and reservoir alternatives in the Bear are under consideration by water development agencies.

Our changing society has new expectations of the uses for water in the West, and many of these require developing a balance between consumptive and non-consumptive water allocations. In wet years, allocating water for "nature" is easily justified, but maintaining in-stream flows at the expense of irrigation use is contentious for both agricultural and urban landscape irrigators. Increasing abstraction of groundwater for municipal and industrial use will also impact in-stream flows. Sustaining adequate flows for the habitat of wildlife refuges (Bear River migratory bird refuge) and the Great Salt Lake ecosystems are of particular concern. Although a non-consumptive use, operation of hydropower dams is also contentious. Re-licensing of power plants requires environmental impact assessments and approvals. Important considerations are that dam operation can impact fish habitat, sometimes including the habitat of endangered species, as well as the aesthetics of the river. Portions of the Bear River, as well as other rivers within the Bear River watershed have been designated as wild and scenic rivers. The tradeoff between "nature" and societal needs has thus particularly sensitized and politicized dam re-licensing procedures with the recent power shortages in the Western U.S.

The Bear River watershed exemplifies many of the complex difficulties faced in water quality management. Grazing practices and land management in the upper watershed have led to increased sediment loads to the river from deteriorated tributary drainages. In addition, hydrologic modifications and land uses along the river have resulted in loss of riparian vegetation and subsequent heavy sediment and nutrient loads to the river. Bear Lake, located at the approximate midpoint of the river's entire length, is an oligotrophic lake which began receiving diverted Bear River water for irrigation storage approximately 90 years ago. The potential long term impacts of the river water on the lake's water quality are not well understood but are of concern. Dairies and feeding operations are scattered throughout the lower basin, with uncontrolled manure runoff and bank erosion in many cases. Urban growth in the lower watershed has resulted in increased volumes and pollutant concentrations from stormwater runoff and from poorly functioning septic tanks. Secondary treatment lagoons for urban areas and industries in the basin contribute significant loads of nutrients back to the river. Current activities to address these issues include a USGS NAWQA study and TMDLs developed for some reaches of the Bear River. These activities are clearly not enough to resolve the water quality problems of the watershed. The importance of this watershed to the state of Utah is underscored by the fact that the Bear River was the only Utah river nominated by Utah Governor Mike Leavitt for consideration for EPA's Watershed initiative (http://www.epa.gov/owow/watershed/initiative/index.html). This program supports comprehensive watershed based approaches for protecting and restoring water resources.

The integrated management of quantity and quality of flows in the Bear are complicated by the division among stakeholders. In addition to the 3 states and 7 counties which fall within the watershed's boundaries, this watershed spans 2 EPA regions and contains National Forest and BLM lands under several jurisdictions. Institutionally the Bear River is governed by an interstate compact. Coordination between the three states of this basin involves difficult regulatory issues and differences between local, state and federal priorities. USU faculty have focused on research projects to address the state and federal priorities and research needs, but most of the valley bottoms where the main stem of the river flows is private land. Addressing the needs and priorities of the private landowners within the physical and regulatory setting of the whole watershed will be critical to resolving many of the issues addressed above. This will require both and interdisciplinary approach and the investment of all stakeholders in a research partnership. Such a program requires a long term commitment by the University, but is expected to both successfully address the pressing needs of the sate of Utah and provide a showcase for the interdisciplinary program in water at USU.

A first step to this project is to develop an integrated geographic information database for the Great Salt Lake Watershed. This database will be essential for the research, educational, and engagement activities conducted as part of this project and would be of great use to watershed stakeholders. We intend that the database will be available for open access on a dedicated internet site as well as on CD-ROM. A database of this nature would initially contain existing biophysical and social information including, but not limited to satellite and aircraft based imagery, climate, topography, soils, geology, land-form, hydrology, transportation networks, administrative boundaries, demographic data, historic and current biologic field data, historic and current ground based repeat photography, natural preserves, wildlife habitat, wildlife migration paths, and past and current land management prescriptions. We also intend to create a geo-referenced database of literature relevant to the watershed that will allow individuals and organizations to quickly identify sources of information on areas or subjects in which they are interested. Much of the basic cartographic, physiographic, and biophysical, and social data layers for the watershed already exist in various forms but they have not been integrated into a geographic information system that can be used by those who must plan and make decisions in the watershed, the educational community, and citizens. The database would also provide excellent context for planning and attracting research and outreach programs to the project.

Appendix 10. USU Water-Related Courses

Number	Name	Catalog Description
AWER 3100	Fish Diversity and Conservation	Systematics, physiology, ecology, evolution, and conservation of major groups of marine and freshwater fishes. Stresses functional morphology, physiological ecology, and community interactions explaining fish abundance and distribution.
AWER 3110	Fish Diversity Laboratory	Focuses on field collection, identification, and habitat relationships of freshwater fishes in North America.
AWER 3600, Geol 3600	Geomorphology	Geomorphic processes, origin of landforms and surficial deposits. Emphasizes fluvial and hillslope landscape elements, and surficial geologic mapping.
AWER 3700	Fundamentals of Watershed Science	Study of water movement, hillslope processes, and nutrient movement in catchments, and its relevance to the properties, land use, and management of watersheds as natural resource units.
AWER 3820	Global Climatology	Emphasizes physical basis of climate (climate dynamics), as well as the mechanisms and processes for its fluctuations on sub-seasonal to interannual time scales (climate variations) and on regional to hemispheric/global time scales.
AWER 3900	Spatial Analysis	Analysis of geographic data, including spatial economic theory, spatial quantitative methods, and spatial distributions.
AWER 4490/5490	Small Watershed Hydrology	Detailed exploration of concepts of hydrologic processes in small, wildland watersheds. Concentrates on recent research findings concerning examining key hydrological processes. Particular attention paid to study of partitioning of water in the hydrologic cycle, sources for runoff generation, snow and snowmelt, and erosion. Features process modeling and parameter estimation techniques as related to wildland systems.
AWER 4500	Freshwater Ecology	Ecosystem analysis of physical, chemical, and biological interactions in lakes and streams. Application of these concepts for managing aquatic system.
AWER 4510	Aquatic Ecology Practicum	Integration of limnological theory and methods of conducting field and laboratory analyses of physical, chemical, and biological parameters in writing.
AWER 4530/6530	Water Quality and Pollution	Reviews biological and social problems caused by point and nonpoint source water pollution; toxicology; abiotic and biotic water quality parameters; and use criteria of the Clean Water Act. Graduate-level class will require additional readings of the peer-reviewed literature and an additional class meeting to have in-depth discussions of those readings. Each graduate student will be responsible for making a presentation at the beginning of class, and leading the discussion.
AWER 4600/6600, Soil 4600/ 6600	Principles of Surface Hydrology	Study of physical elements of the water cycle, surface hydrological processes, and watershed responses. Explores basic hydrologic concepts and terminology, as well as collection, analysis, and presentation of hyrologic data. Includes field laboratory.
AWER 4650/6650	Principles in Fishery Management	Emphasizes management of fish populations within context of community and ecosystem dynamics. Stresses use of simulation models to assess effects of growth, recruitment, and mortality on age-structured populations.
AWER 4750/6740	Fundamentals of Remote Sensing	Develops the scientific principles behind remote sensing. Examines the basic physics of electromagnetic radiation and the interactions of radiation with the surface and the atmosphere.
AWER 4930/6920	Geographic Information Systems	Examines structure and operation of Geographic Information Systems (GIS). Explores design, theory, and implementation of GIS software, digitizing, fundamentals of vector and raster GIS processing, georeferencing, map accuracy, and site location.
AWER 4940/6940, CEE 4940/6940	Snow Hydrology	Focuses on snow science, including atmospheric formation, precipitation, distribution on the landscape, metamorphosis prior to melt, and snow pack melt dynamics. Also covers related issues, such as snow melt modeling, remote sensing, water supply, and biogeochemical cycling.
AWER 5130/6130	Terrestrial Ecosystem Modeling	Introduces concepts of terrestrial ecosystem cycles, using computer modeling techniques. Includes discussions of modeling concepts, as well as in-class student projects.
AWER 5150/6150, Geol 5150/6150	Fluvial Geomorphology	Focuses on physical processes in streams that control their shape, plan form, slope, bed material, and distribution of channel bars. Emphasizes field analysis of these topics, and application of geomorphology to aquatic ecology and environmental restoration.

AWER 5170/6170, Geol 5170/6170	Fluvial Geomorphology Lab.	Field analysis focuses on physical processes in streams which control their shape, plan form, slope, bed material, and distribution of channel bars. Application of geomorphology to aquatic ecology and environmental restoration.
AWER 5200	Fish Habitat Relationships in Managed Forests	Examines biological and social factors influencing aquatic ecosystems and fish habitats within the context of forest management. Analyzes ecological relationships of fish habitats within forest ecosystem, and how these are influenced by forest management practices. Provides examples of forest habitat issues in major regions of North America, illustrating that both biological and social factors must be considered in developing management strategies and programs.
AWER 5330/6330	Large River Management	Focuses on constituencies participating in modern management of large river basins, including water developers, irrigators, municipalities, power consumers, recreationists, environmentalists, and scientists. Primary examples drawn from Colorado, Columbia, Rio Grande, and Missouri river basins.
AWER 5550	Freshwater Invertebrates	Ecology, collection, and systematics of freshwater aquatic invertebrates. Focuses on insects, but also covers crustaceans, molluscs, and annelids. Several weekend field trips and a collection are required.
AWER 5640/7640	Riparian Ecology and Management	Explores structure and function of riparian ecosystems and management options for maintaining sustainable ecological function.
AWER 5660	Watershed and Stream Restoration	Overview of the current theory and practice of watersheds and streams. Emphasizes field visits with restoration projects and specialists.
AWER 5670	Watersheds and Stream Restoration Practicum	Capstone experience. Development of a restoration plan for a site, involving site planning and design.
AWER 6230/7230	Fish Ecology	Reviews current literature on physiological, behavioral, population, and the community ecology of fishes. Particular emphasis placed on current literature relevant to management of sport and endangered freshwater species.
AWER 6520, CEE 6520	Applied Hydraulics	Basic fluid mechanics applied to wildland watershed systems and directed at nonengineering students. Explores nature of fluid state, fluid motion, and steady uniform and varied flow in open channels, under both subcritical and supercritical conditions. Surveys concepts of boundary layers, turbulence, convection, dispersal, and wave formation in unsteady flows. Emphasizes problem formulation and solving.
BIE 5010/6010	Principles of Irrigation Engineering	Soil-water-plant relationships; evapotranspiration and water requirements; effective water use; irrigation scheduling; infiltration; irrigation systems planning.
BIE 5110/6110	Sprinkle and Trickle Irrigation	Sprinkle and trickle irrigation system demand, system selection and configuration, emitter and sprinkler characteristics and sizing, uniformity and efficiency, pipe network layout and sizing, and system operation, management, and maintenance.
BIE 5150/6150	Surface Irrigation Design	Design and evaluation of surface irrigation systems. Field measurements for evaluating and improving uniformity and efficiency. Simulation of surface systems. Land leveling computation and equipment.
BIE 5250/6250, Bmet 5250/6250, FRWS 5250/6250	Remote Sensing of Land Surfaces	Basic principles of radiation and remote sensing. Techniques for ground-based measurements of reflected and emitted radiation, as well as ancillary data collection to support airborne and satellite remote sensing studies in agriculture, geography, and hydrology
BIE 5300/6300	Irrigation Conveyance and Control Systems	Design, evaluation, and operation of irrigation distribution systems. Measurement and monitoring of flows and water levels, and canal and pipeline automation. Simulation of system hydraulics.
BIE 5350/6350	Drainage and Water Quality Engineering	Introduction to principles and practices of drainage. Engineering investigation and design of drains. Formation and function of wetlands caused by irrigation and drainage systems.
BIE 5520/6520	Irrigation Project Operation and Maintenance	Organizing, administering, and financing irrigation and drainage projects. Operation and maintenance of irrigation distribution systems. Simulation of command area water demands.
BIE 5550/6550	Groundwater Systems Engineering I	Groundwater exploration; well drilling and testing; pumping plant design, operation, and testing; aquifer evaluations; siting of multiple well systems. Development of pumping strategies for water supply and environmental control systems. Introduction to conjunctive use.
BIE 6260	Hydrology of Irrigation Agriculture	Impacts of irrigation activities on local and regional hydrology, wetlands, and natural systems. Determination of components of field and project water balances, including evapotranspiration. Effects of water conservation practices and changes in efficiency on timing and disposition of water resources and return flows. Irrigation scheduling and use of computer models.

BIE 7350	Groundwater Systems Engineering II	System analysis techniques applied to aquifer and stream/aquifer management. Development of economically, quantitatively, and environmentally optimal strategies for alternative water policies. Modeling techniques for managing aquifer systems under volumetric, economic, and environmental management goals.
BIE3670, CEE 3670	Transport Phenomena in Bio-Environmental Systems	Core course in both biological and environmental engineering. Students develop a detailed understanding of the principles, concepts, modes, and methods of calculating heat and mass transfer. Emphasis given to contaminant and nutrient flux, along with their state transformations, in order for the biological or environmental engineer to evaluate options for production, clean-up, and control of bio-environmental systems.
Biol 5550	Freshwater Invertebrates	Ecology, collection, and systematics of freshwater aquatic invertebrates. Focuses on insects, but also covers crustaceans, molluscs, and annelids. Several weekend field trips and a collection are required.
Bmet 2000	The Atmosphere and Weather	Survey of the processes governing the behavior of the atmosphere and the phenomenon of weather. Basic physical principles of radiation, energy, evaporation, and heat transport are introduced and connected to atmospheric circulation and weather.
Bmet 3820	Global Climatology	Emphasizes physical basis of climate (climate dynamics), as well as the mechanisms and processes for its fluctuations on sub-seasonal to interannual time scales (climate variations) and on regional to hemispheric/ global time scales.
Bmet 4300	General Meteorology	Introductory meteorology for students with background in physical sciences. Emphasis placed on physical processes (quantitatively) in the atmosphere, resulting in general weather phenomena around the world.
Bmet 5400/6400	Introduction to Meteorology	Designed for senior and graduate students in different fields who desire some basic introduction to meteorology. Bridges a large gap between courses describing meteorological phenomena in broad and simple terms and other courses treating the atmosphere more theoretically.
Bmet 5500/6500	Land-Atmosphere Interactions	Examination of interactions between the surface and atmosphere. Consideration of flows of mass and energy in soil-vegetation-atmosphere continuum, and their linkage to local and regional climates. Detailed study of feedbacks between vegetation and atmosphere.
Bmet 5700/6700	Environmental Measurements	Examination of critical instrumentation and principles involved in measuring key properties of terrestrial environment. Consideration of measurements in soils, plants, and atmosphere.
Bmet 6300	Principles of Atmospheric Science	Introduction to fundamental physical principles upon which atmospheric sciences are based. Thorough description and interpretation of wide range of atmospheric phenomena.
Bmet 6410	Applied Agricultural Meteorology	Explores applied concepts in agricultural meteorology, with emphasis on weather-agriculture and microclimate- agriculture relationships. Includes crop modeling applications. Course materials, resources, and teaching provided in cooperation with Iowa State University.
Bmet 6800	Environmental Biophysics	Explores connections between biosphere and atmosphere at many scales. Introduces processes governing exchanges of mass and energy between surface and atmosphere, as well as connections to climate. Examines role of the biota at local to global scales.
CEE 3430	Engineering Hydrology	Processes and practical problems in: surface and groundwater hydrology, the hydrological cycle, rainfall-run-off and flood analysis, regional groundwater flow and well hydraulics, and the design of water supply systems.
CEE 3500	Civil and Environmental Engineering Fluid Mechanics	Explores fluid properties, hydrostatics, fluid dynamics similitude, energy and momentum principles, closed conduit flow, open channel flow, and flow measurement. Includes laboratory exercises in flow measurement, open channel flow, pipe friction, physical modeling, and data collection.
CEE 3510	Civil and Environmental Engineering Hydraulics	Unsteady flow in open channel and closed circuits, nonuniform flow in open channels, combined energy losses in pipelines, and distribution in pipe networks. Includes laboratory and computer exercises in data collection, pipe networks, and unsteady and nonuniform flow.
CEE 3640	Water and Wastewater Engineering	Engineering analysis and design of processes for treatment of water and wastewater. Major topics include water quality evaluation; physical, chemical, and biological treatment systems; design of facilities for production of drinking water and for treatment and reclamation of municipal and industrial wastewater; and management of residuals from water and wastewater treatment facilities. Laboratory evaluation of physical and chemical treatment technologies. Computer applications for process modeling and analysis.
CEE 3780	Solid and Hazardous Waste Management	Introduction to integrated management of municipal and industrial solid waste; household, commercial, and industrial hazardous waste; and resource recovery and recycling principles. Three lectures augmented by weekly laboratory to provide students with experience in wet laboratory, computer modeling, and field trip experiences related to modern solid and hazardous waste management principles.
CEE 5430/6430	Groundwater Engineering	Basics of contaminant transport and fate in soil water and vapor, design of groundwater recovery systems, and subsurface contamination remediation, including interceptor wells, well fields, stream-aquifer interactions, soil vapor extraction, separate phase recovery, biodegradation of soluble plumes, and air emissions.

CEE 5440/6440	Geographic Information Systems in Water Resources	Principles and operation of geographic information systems. Spatial hydrologic modeling done by developing a digital representation of the environment in the GIS, then adding functions simulating hydrologic processes. Includes term project on use of GIS in water resources.
CEE 5450/6450	Hydrologic Modeling	Case studies of hydrologic modeling and decision methods: (1) Real-time flood warning; (2) extended streamflow prediction; (3) probabilistic water resource management; and (4) physical modeling of ungaged basins.
CEE 5460/6460	Water Resources Engineering	Engineering design course covering a wide range of topics, including: surface and groundwater hydrology, statistical analysis, water law, hydroelectric power, water supply, irrigation, flood control, wastewater, drainage, dams and reservoirs, pipelines, open channels, and planning.
CEE 5470/6470	Sedimentation Engineering	Explores river response, sediment transport, sediment and watershed yield, flow resistance, scour and erosion, and floodplain management.
CEE 5500/6500	Open Channel Hydraulics with an Emphasis on Gradually Varied Flow	Theory and applications of steady uniform and gradually varied flow under both subcritical and supercritical flow conditions. Solutions to multiple-network canal systems by solving systems of combined ordinary differential and algebraic equations. Method for defining natural channel systems and solving steady-state flows in them.
CEE 5540/6540	Hydraulic Structures Design	Explores design of a variety of hydraulic structures. Students develop original computer programs and employ commercially available software to design hydraulic structures.
CEE 5550/6550	Hydraulics of Closed Conduits	Includes design and operation of piping systems; economics; feasibility and impact of pipelines; pipe, pump, and valve selection; transient and cavitation analysis; and pipeline operation and filling.
CEE 5560/6560	Environmental Hydraulics	Design of hydraulic structures, spillways, energy dissipators, fish passage, reservoir operation, ocean outfalls, and pumping stations. Includes principles of design and impact of structures on the environment, and the environmental properties and hydraulics of fluids.
CEE 5610/6610	Environmental Quality Analysis	Familiarizes students with various methods used for analysis of chemical parameters in environmental samples (water, soil, and air). Provides students with skills enabling them to make proper selection/ evaluation of analytical procedure and evaluate data generated.
CEE 5620	Aquatic Chemistry	Provides students with understanding of principles of aquatic chemistry, emphasizing chemical equilibria, acid-base reactions, complex formation, oxidation-reduction reactions, complex formation, and dissolution chemistry.
CEE 5670	Hazardous Chemicals Handling and Safety	Provides students with necessary skills and knowledge for working safely in areas associated with hazardous chemicals. Topics covered include: regulations, exposure routes, toxicology, chemical and physical hazards, personal protective equipment, sampling, monitoring, decontamination, and emergency response procedures.
CEE 5680/6680	Soil Based Hazardous Waste Management	Engineering management of hazardous wastes present in the vadose zone, including extraction, containment, and biological, chemical, and physical destruction technologies. Aspects include engineering characterization, problem definition, treatment, and monitoring. Analysis and design emphasized through problems, examinations, and report writing.
CEE 5690/6690	Natural Systems Engineering	Application of modeling tools commonly utilized in water resources systems for assessment of environmental impacts associated with engineered systems. Topics include: water resources modeling; physical, chemical, and biological process effects; assessment methods; data integration techniques; and impact assessment.
CEE 5700/6700	Field Sampling Techniques for Natural Systems Engineering	Provides students with hands-on approach to utilizing several of the most commonly applied spatial and temporal sampling techniques for data acquisition in support of natural systems modeling. Explores standard and advanced surveying techniques for water quality, stream geomorphology, and hydraulics, utilizing levels, total stations, laser levels, GPS, and hydroacoustic technologies. Integrative sampling strategies across spatial and temporal scales emphasized for multi-disciplinary studies.
CEE 5710	Pollution Prevention and Industrial Ecology	Explores pollution prevention and waste minimization concepts, focusing on implementation of these concepts in design of production processes and products. Discussion of pollution prevention/waste minimization concepts, energy and materials conservation, Life Cycle Analysis, materials and process audits, industrial process design for waste minimization and energy conservation, packaging, and ISO 14000.
CEE 5720/6720	Natural Systems Modeling	Provides hands-on approach to utilizing several of the most commonly applied modeling tools employed to estimate physical, chemical, and biological impacts of existing and proposed water resource systems. Focuses on utility and climitation of specific modeling approaches, while also stressing integrative multi-disciplinary nature of impact assessment frameworks.
CEE 5730/6730	Analysis and Fate of Environmental Contaminants	Provides students with understanding of methods used in analysis of environmental samples for organic contaminants. Examines various properties and processes determining the fate of organic contaminants in the environment.
CEE 5740	Natural Systems Engineering Laboratory	Computer modeling techniques applied to water resources systems for assessment of environmental impacts associated with engineering activities.

CEE 5760	Hydraulic Structures Field Course	Week-long course, with one day of in-class lectures and four days of field trips. Introduces students to field applications of hydraulic structures design. Field trips may involve backpacking to remote areas.
CEE 5810/6810	Biochemical Engineering	Fundamentals of bioreactor design and bioengineering. Emphasizes mathematical models of microbial and enzymatic processes in environmental and industrial biotechnology.
CEE 5830/6830	Management and Utilization of Biological Solids and Wastewater	Focuses on production, management, and disposal of biosolids and wastewater generated in food processing and wastewater treatment. Emphasizes beneficial use of biosolids and wastewater for agricultural production, forest enhancement, and land reclamation.
CEE 5880	Remediation Engineering	Physical, chemical, and biological principles associated with remediation of hazardous waste contaminated soil, water, sediments, and air. Topics include: source removal and source control, product recovery, chemical treatment methods, biological remediation concepts, in situ processes, ex situ processes, and integrated process design.
CEE 6400	Physical Hydrology	Fundamentals of hydrologic cycle and hydrologic processes. Precipitation, infiltration, runoff generation, evaporation and transpiration, and snowmelt. Representation of hydrologic processes in hydrologic models.
CEE 6410	Water Resource Systems Analysis	Systems formulation of decision problems. Solution by simulation and optimization, constrained and unconstrained optimization algorithms, case studies and applications to water supply, and quality and ecosystems management.
CEE 6420	Engineering Risk Assessment and Risk Management	Comprises both quantitative risk assessment techniques and a range of issues in risk management. Examples drawn from various civil engineering subdisciplines such as: environmental engineering, geotechnical engineering, hydraulics and hydrology, structural engineering, transportation engineering, and water resource management.
CEE 6480	Subsurface Flow and Transport Processes	In-depth coverage of unsaturated and saturated water flow, well hydraulics, salt water intrusion, and multiphase flow applicable to groundwater resources management and remediation. Includes basics of nonreactive and reactive mass transort processes due to various pollution events, and remediation strategies. Addresses special topics related to free-product recovery and migration, and vapor phase transport as applicable to remediation of hazardous-waste contaminated subsurface.
CEE 6490	Integrated River Basin/Watershed Planning and Management	Reviews fundamental building blocks of water resource institutions, emphasizing creation of institutions which are sensitive to a particular culture, economic, and political environment. Addresses institutional mission and regulatory roles, public participation, property and water rights, and elements of production.
CEE 6530	Unsteady Flows in Open Channels and Numerical Solutions of St. Venant Equations	Derivation and physical meaning of the St. Venant equations, types of water waves, solutions to unsteady free surface flows based on the characteristics, and direct and iterative implicit methods of solution. Emphasizes solving unsteady flow problems in channel systems.
CEE 6570	Potential Fluid Flow	Application of the principles and methods of classical hydrodynamics to the solution of problems. Closed form solution to invisual fluid flows obtained using complex variables and conformal mappings.
CEE 6580	Intermediate Fluid Mechanics	Survey of mathematical methods used in fluid mechanics, including: potential flow solutions (complex variables), laminar flow and turbulent flow solutions, boundary layer theory, and introduction to dispersion in fluid.
CEE 6600	Environmental Chemistry of Inorganic Contaminants	Inorganics of environmental concern discussed in terms of processes affecting their behavior in soil and water systems. Laboratory-scale experiments and computer models used to evaluate this behavior. Explores remediation of environmental systems contaminated with inorganic pollutants.
CEE 6620	Field Sampling and Analysis of Environmental Systems	Explores applied field sampling, as well as field and laboratory techniques used in the monitoring of environmental media. Includes theory and practice of field site monitoring and measurement of physical, chemical, and biological processes in the environment.
CEE 6630	Process Dynamics in Environmental Engineering Systems	Fundamental principles used in analysis and simulation of environmental systems. Emphasizes reaction kinetics, mass transfer, reactor analysis and design, and development and solution of mathematical models to describe natural and engineered environmental systems.
CEE 6640	Physical and Chemical Environmental Process Engineering	Principles of physical and chemical environmental engineering processes, including sedimentation, filtration, gas transfer, aeration, absorption, ion exchange, membrane processes, coagulation, flooculation, precipitation, oxidation, reduction, and disinfection. Process modeling and analysis applications in treatment of water, wastewater, industrial wastes, vapor treatment, and soil remediation.
CEE 6650	Biological Processes in Environmental Engineering	Theory and design of biological processes used in environmental engineering. Stoichiometric, energetic, and kinetic analysis of biological treatment processes; modeling and design of suspended growth and fixed-film processes for treatment of municipal, industrial, and hazardous wastes; nutrient removal; and bioremediation.

CEE 6660	Environmental Data Analysis and Experimentation	Data analysis and experimental design for environmental science and engineering. Graphical data analysis, parametric and nonparametric statistics, frequency distributions, hypothesis testing, propagation of variance, censored data, correlation and causation, parameter estimation, factorial experimental design and response surfaces, environmental monitoring and uncertainty.
CEE 6670	Environmental Process Laboratory	Laboratory testing to demonstrate physical, chemical, and biological principles utilized in environmental engineering processes.
CEE 6710	Environmental Engineering Microbial Ecology	Principles of microbial ecology applied to engineered and natural systems.
CEE 6740	Environmental Quality Modeling	Development and application of mathematical models for conventional and toxic pollutants in environmental systems. Description of advection, dispersion, sediment transport, partitioning, interphase transfer, and transformation kinetics applied to organic and inorganic pollutants. Equilibrium, steady state, and nonsteady systems.
CEE 6750	Eco-Hydraulics for Natural Systems Engineering	Provides students with advanced multi-disciplinary modeling course in the application of hydraulics and water resource modeling in light of impact assessment frameworks for natural systems modeling. Focuses on application on one-dimensional and two-dimensional hydraulic modeling as basis for examining quantitative impacts on stream and riparian ecosystems under altered flow, as well as channel conditions with particular emphasis on fish and aquatic macro-invertebrates.
CEE 7430	Stochastic Hydrology	Stochastic description of hydrologic variability in time, space, and space-time. Markov processes, time series synthesis and forecasting, spectral analysis, spatial interpolation and random field simulation, data imputation, and parameter estimation for physical models. Lattice and Markov chain Monte Carlo methods, simulated annealing, and Gibbs processes. Applications to rainfall, streamflow, groundwater quality and quantity, and subsurface characterization.
CEE 7440	Hydroclimatology	Study of droughts and floods as determined by long-term climate fluctuations. Dynamics of low-frequency large-scale climate variability. El Nino Southern Oscillation and its hydrologic impacts. Global climate change issues.
Econ 5560	Natural Resource and Environmental Economics	Economics of developing, managing, and conserving natural resources and the environment. Topics include resource use and conservation, environmental quality, public and private resource management, and valuation of nonmarket goods.
Econ 7500	Resource Economics	Focuses on formal economic models associated with optimal exploitation of renewable and nonrenewable resources. Applications to minerals, groundwater, energy resources, soil, forests, fisheries, rangelands, watersheds, wildlife, etc.
Econ 7510	Environmental Economics	Covers the theory of environmental policy. Topics include, but are not limited to, externalities, uncertainty and the choice of policy instruments, market imperfections and the number of participants, nonconvexities in the production set, the charges and standards approach, marketable emission permits, the environment and development, international environmental issues, and ecological economics.
EnvS 4110/6110	Fisheries and Wildlife Policy and Administration	Examination of policy issues and administrative approaches in fish and wildlife management, with particular emphasis on nonbiological issues facing wildlife managers and administrators. and testing interdisciplinary hypotheses pertaining to human-ecosystem interactions. Explores methods for integrating social and biophysical data.
EnvS 5320	Water Law and Policy in the United States	Introduction to policies, laws, institutions, and practices guiding western water allocation, emphasizing how to efficiently and equitably allocate increasingly scarce supplies. Explores reserved water rights, water markets, stream adjudication, public trust doctrine, basinwide management, and riparian management. visitors and nonhuman ecosystem elements.
FRWS 3700	Inventory and Assessment in Natural Resource and Environmental Management	Lectures, laboratory exercises, and field-based projects introduce students to the concepts, strategies, and analytical methods of natural resource and environmental inventory and assessment.
FRWS 3710	Monitoring and Assessment in Natural Resource and Environmental Management	Lectures, case studies, laboratory exercises, and field-based projects introduce students to the concepts, strategies, and analytical methods of science-based assessment of natural resources.
FRWS 3750	Geographic Applications in Remote Sensing	Overview of remote sensing systems, including principles, techniques, and applications of both aerial photography and satellite images. Provides information needed to understand and apply remote sensing to a wide range of resource applications.
FRWS 4050	Urban Fish and Wildlife Management	Concentrates on: understanding impacts of urbanization on wildlife and habitat; developing basic understanding of wildlife needs; completing urban wildlife habitat inventory; and preparing urban wildlife conservation and management plan.
FRWS 5400	Community and Ecosystem Concepts in Fisheries and Wildlife Management	Reviews factors controlling number of species, and their absolute and relative abundances in different habitats. Analyzes how species influence ecosystem structure and function (e.g., productivity, nutrient cycling, etc.).
FRWS 5460	Avalanche and Snow Dynamics	Fundamentals of snow and avalanche dynamics. Avalanche safety, forecasting, hazard evaluation, and control.

FRWS 5660/6660	Principles of Geographic Information Systems	Advanced introductory course in geographic information systems (GIS), with a focus on applications to natural resource research and management. Primary objective is learning basic functions of a GIS for use in data manipulation, data presentation, data inquiry, spatial analysis, modeling, and conversion of data into formats for use in other applications, such as reports and statistical analysis.
FRWS 5670/6670	Principles of Remote Sensing	Graduate-level introductory course covering principles, techniques, and applications of remote sensing. Designed to provide background necessary to make real use of remote sensing technologies in a variety of natural resource applications, or to stand alone as an up-to-date overview for those having a general interest in remote sensing technologies.
FRWS 5680/6680	Natural Resource Applications of Geographic Information Systems and Remote Sensing Technologies	Using the principles presented in the introductory courses, students in this project-based course research, apply, and evaluate geographic information systems and remote sensing technologies in relation to real-world, natural resource applications.
FRWS 5750/6750	Applied Remote Sensing	Covers the application of remote sensing to landcover mapping and resource monitoring at a quantitative level. Students instructed on the effects of atmosphere and surface interaction on the reflectance collected by electro-optical sensors, as well as on the proper use and interpretation of various calibration and classification algorithms.
FRWS 6200	Biogeochemistry of Terrestrial Ecosystems	Inputs, outputs, and cycling patterns of major nutrients. Emphasis on mechanisms for transformations, factors influencing process rates, and the impacts of management and global change on nutrient cycles and air and water quality.
Geol 5480/6480	Sedimentary Basin Analysis	Detailed coverage of techniques of sedimentary basin analysis, including depositional systems, provenance, basin modeling, and fluid and heat flow history. Survey of types of sedimentary basins worldwide.
Geol 5510	Groundwater Geology	Provides graduate students and senior undergraduates with understanding of fundamental principles of groundwater geology and hydrology, and helps prepare them for careers in hydrogeology or environmental geology.
Geol 5520/6520	Hydrogeologic Field Methods	Methods of collection and analysis of field data for groundwater studies. and distribution of channel bars. Application of geomorphology to aquatic ecology
Geol 5600	Geochemistry	Application of thermodynamics, solution chemistry, phase diagrams, and both radioactive and stable isotopes to the understanding of earth processes.
AWER 6160, Geol 6160	Hillslope and Landscape Geomorphology	Includes basics of hillslope weathering, transport, and hydrologic processes. Surveys classic and recent literature on hillslope-scale and landscape-scale geomorphic research.
Geol 6250	Mechanics and Processes in Earth Sciences	Fundamentals of solid and fluid mechanics with applications to the earth sciences. Applications to rock deformation, fluid flow, glacier movement, and slope stability. Designed for graduate students in earth sciences and engineering.
LAEP 5400/6400	Low Water Landscaping	Examines arid ecosystems, emphasizing the Intermountain West, and recreating such ecosystems in a range of amenity landscapes. Also covers procurement, propagation, establishment, and maintenance of plants appropriate for low water landscapes.
PlSc 3050	Greenhouse Management and Crop Production	Design and management of commercial greenhouse facilities. Production requirements of primary greenhouse crops.
PlSc 3300	Residential Landscapes	Functional and aesthetic relationships of plants and structures in the landscape in connection with installation considerations. Use of imaging and CAD software in initial computer design layout
PlSc 3400	Managing for Sustainable Landscapes	Interaction of expectations, maintenance needs, cost/benefit analysis, physiology, and ecology in managing landscapes on a sustainable basis
PlSc 3410	Practicum in Managing for Sustainable Landscaping	Practical experience in evaluating maintenance tasks required in managing a landscape, cost estimation of such tasks, and how to make changes to a landscape to reduce costs.
PlSc 3800	Turfgrass Management	Fundamentals of turfgrass science: species adaptation, identification, and cultural requirements; turfgrass growth and development; establishment; primary cultural practices (fertilization, irrigation, mowing); secondary cultural practices; pest management; integrated management planning for turfgrass systems.
PlSc 4100	Landscape Water Conservation	Explains why water conservation is important, and how water can be conserved through precision irrigation and conversion to low-water-use landscapes.
PlSc 4320	Forage Production and Pasture Ecology	Cultivation and management of legumes and grasses used throughout the world for grazing, stored feed, soil improvement, and conservation. Forage plant growth and development, nutrient and water utilization, and responses to environmental stress.
PlSc 4500	Fruit Production	Cultivars, physiology, anatomy, propagation, sites, soils, climate, culture, irrigation, fertilizers, insects, diseases, integrated management, plant and fruit growth and development, harvesting, storage, pruning, orchard architecture, environmental protection, and economics for both tree and small fruits.

PlSc 4800	Professional Turfgrass Management	Fertilization, irrigation, and cultivation practices for managed landscapes. Construction issues, including compaction, soil modification, and specialized construction practices for golf courses and sports turf.
PlSc 5100/6100	Landscape Irrigation Management	Explores how principles of evapotranspiration, soil and plant properties, and urban landscape sprinkler irrigation systems can be combined for proper irrigation scheduling. Evaluating and analyzing landscape water demand.
PlSc 5200/6200	Crop Physiology	The relationship between physiological processes and growth of whole plants. Energy balance and water use efficiency. Light interception and canopy geometry. Canopy photosynthesis and respiration. Carbon partitioning and source/sink relationships.
PlSc 5400/6400	Low Water Landscaping	Examines arid ecosystems, emphasizing the Intermountain West, and recreating such ecosystems in a range of amenity landscapes. Also covers procurement, propagation, establishment, and maintenance of plants appropriate for low water landscapes.
PlSc 6100/5100	Landscape Irrigation Management	Explores how principles of evapotranspiration, soil and plant properties, and urban landscape sprinkler irrigation systems can be combined for proper irrigation scheduling. Evaluating and analyzing landscape water demand.
PlSc 6220	Professional Experience in Water Efficient Landscaping	Internship component of water efficient landscaping master's program. Summer employment with water purveyors, consulting firms, and businesses involved in landscape irrigation.
PlSc 6230	Readings in Landscape Water Conservation	Background topics in water development and policy in the West. Current topics on various aspects of water conservation in urban landscapes.
PlSc 6240	Water Efficient Landscaping Seminar	Students develop skills in public speaking by presenting their summer internship experience to the Plants, Soils, and Biometeorology faculty. Students also work on a culminating academic endeavor for the program.
PSB 5200	Site-Specific Agriculture and Landscape/Horticultural Management	Integration of site-specific management technology, such as computers, GPS, yield monitors, variable rate controllers, mechanized samplers, and postharvest processing controllers with planning, tillage, planting, chemical applications, and harvesting to optimize off-site inputs and environmental/economical sustainability in crop or landscape management.
Soil 2000	Soils, Waters, and the Environment	Introduction to principles of physical and biological science. Discussion of current environmental topics, focusing on soil and the waters that contact the soil. Topics include water quality, global climate change, deforestation, soil conservation, and agricultural sustainability.
Soil 3000	Fundamentals of Soil Science	Fundamentals of soil science, emphasizing physical, chemical, mineralogical, and biological properties of soils, and how these properties relate to plant growth and environmental quality.
Soil 4000	Soil and Water Conservation	Applied soil and water conservation in an agronomic setting. Management of soil-water-plant-atmosphere continuum. Soil conservation techniques as they apply to actual situations.
Soil 4700	Irrigated Soils	Soil salinity, soil-moisture-plant relationships, water supply and quality, irrigation water measurements, soil moisture movement, and irrigation methods.
Soil 5050/6050	Principles of Environmental Soil Chemistry	Introduction to common chemical processes occurring among solid, liquid, and gas phases in soil systems. Emphasis placed on chemistry of arid land soils.
Soil 5620	Aquatic Chemistry	Provides students with understanding of principles of aquatic chemistry, emphasizing chemical equilibria, acid-base reactions, complex formation, oxidation-reduction reactions, complex formation, and dissolution chemistry.
Soil 5650/6650	Applied Soil Physics	Characterization of the physical properties of soils and other porous media. Measurement, prediction, and control of processes taking place in and through soils (e.g., water flow and solute transport), including atmospheric and groundwater interactions.
Soil 5750	Environmental Quality: Soil and Water	Senior capstone course for Environmental Soil/Water Science (ESWS) major. Students analyze current soil and water environmental quality problem(s), formulate remediation or mitigation plans, and present findings in oral and written reports.
Soil 6140	Unsaturated Flow and Transport	Measurement, prediction, and control of transport processes taking place in and through partially saturated porous formations (e.g., water flow and solute transport), emphasizing parameter estimation and multi-dimensional flow.
Soil 6190	Salt-affected Soils	Emphasis on chemistry of salt-affected soils. Topics include carbonate chemistry, cation exchange, and reclamation of sodium and salt-affected soils. Exploration of effects of sodium accumulation on soil hydraulic conductivity and the biochemistry of salt and potentially toxic elements.
Soil 6200	Biogeochemistry of Terrestrial Ecosystems	Inputs, outputs, and cycling patterns of major nutrients. Emphasis on mechanisms for transformations, factors influencing process rates, and the impacts of management and global change on nutrient cycles and air and water quality.
Soil 7200	Soil Interfacial Processes and Reactive Transport	Course divided into two blocks. Subject matter for first block is soil electrochemistry and surface chemistry. Second block applies material from first block to system in which transport limits reaction time.