IGERT RESILIENCE AND ADAPTIVE GOVERNANCE IN STRESSED WATERSHEDS

PI and Lead Institution: Craig R. Allen, University of Nebraska–Lincoln
Other institutions: Emory University; International Institute for Applied Systems Analysis (Austria)

Much of the world – including the United States – is experiencing conflicts over finite water resources. Water shortages and the competition among stakeholders for water to use in agriculture, drinking, industry, recreation, and wildlife habitat have generated legal and policy battles. Resolving complex water resource issues requires the best and clearest scientific information from interdisciplinary and integrative science. There is a critical need for explicit training of future social and natural resource scientists, managers, and policymakers in integrative and interdisciplinary watershed-related sciences.

Intellectual Merit. Adaptive governance and adaptive management are innovative, integrative approaches that treat water policy and management as experiments. Resilience theory gave rise to adaptive management and focuses on the capability of complex systems of people and nature to absorb disturbance without losing critical structure and function. An understanding of resilience theory, and effective use of resilience's implications for research, water management practice, and policy, demands inter- and trans-disciplinary training in natural, social, and computational sciences. Such training is missing in graduate programs in the United States, but is necessary for the preparation of the next generation of natural resource scientists, managers, and policymakers to better respond to the challenges created by increasing demands for diminishing resources and the need to maintain and build resilience in stressed watersheds. This is one of the most complex and challenging societal problems. ***To address this critical need, the University of Nebraska-Lincoln proposes to establish an IGERT program in Resilience and Adaptive Governance in Stressed Watersheds.*** The proposed IGERT will increase scientific understanding of how resilience is generated in complex systems of people and nature, and will provide unique cross-disciplinary training for graduate students from natural, social, and computational sciences. Students will obtain a deep understanding of the complex and intertwined ecological and societal systems involved in managing water resources in the 21st century, and the development of sophisticated mathematical and computational tools for decision support, management, and restoration. In addition to exposing IGERT students to substantive and interdisciplinary academic knowledge, through externships the program will expose fellows to real-world applications that benefit from not only knowledge transfer, but the transfer of knowledge in a way that is useful to policymakers. Students will further benefit from comparative studies of compromised watersheds in the Great Plains region of the United States to watersheds in Eastern Europe (Tisza River, Hungary; Odra River, Poland).

Broader Impacts. The program will develop a new generation of scholars able to translate watershed science into effective policy and law based on a sophisticated understanding of linked social-environmental systems. The proposed IGERT program will also assist in fundamentally changing academic culture by coalescing individuals in natural science, social science, computational science and law around a common goal (over-appropriated watersheds), and providing opportunities for students, and also faculty, to interact on common projects and to share perspectives. Thus, the UNL IGERT will help to catalyze the dissolution of borders between the disciplines and formalize and further energize an interactive culture of exchange. The IGERT program also will integrate academic research and education with the needs of regional, national and global groups involved in watershed management, recovery and policy. Agencies will participate actively in training and mentoring of students through externships and in shaping the UNL curriculum in natural science, policy, and law. In addition, the program will aggressively recruit from and partner with higher education institutions serving underrepresented groups: Langston University, New Mexico State University, Little Priest Tribal College (Nebraska), and Sinte Gleska Tribal College (South Dakota).

Key words: biology, computer sciences, environmental science, adaptive management

C. PROJECT DESCRIPTION

C.1. LIST OF PARTICIPANTS

Coordinating Committee[1]**:**

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2. Sherilyn Fritz (co-PI)	UNL, Geosciences, *aquatic ecology, paleoecology*
3. Lance Gunderson	Emory University/UNL Adjunct, Environmental Studies, *adaptive management, resilience*
4. Ashok Samal (co-PI)	UNL, Computer Science and Engineering, *data mining, geocomputation*
5. Alan Tomkins (co-PI)	UNL, Public Policy, *public policy, governance, usable knowledge for policymakers*
6. Andrew Tyre (co-PI)	UNL, Natural Resources, *structured decision making*
-. Jan Sendzimir	Austria, International Institute for Applied Systems Analysis, *adaptive management, resilience* (international partner)

Additional Participating Faculty:

7. Steven Goddard	UNL, Computer Sciences and Engineering, *spatial decision support systems*
8. Kyle Hoagland	UNL, Water Center, *limnology, ecotoxicology*
9. Erkan Istanbulluoglu	UNL, Natural Resources, *hydrological modeling*
10. John Lenters	UNL, Geosciences, *climate modeling*
11. Gary Lynne	UNL, Agricultural Economics, *ecological economics, behavioral economics*
12. Sarah Michaels	UNL, Political Sciences, *environmental policy, knowledge transfer*
13. Larkin Powell	UNL, Applied Ecology, *conservation biology, adaptive management*
14. Brigitte Tenhumberg	UNL, Biological Sciences, *population modeling*
15. Steven Thomas	UNL, Ecosystem Ecology, *river ecology, restoration*
16. Dave Wedin.	UNL, Ecosystem Ecology, *ecosystem ecology*
17. J. Allen Williams, Jr.	UNL, Sociology, *environmental sociology, social change, social inequality*
18. K. Bryon Williams	USGS-BRD, *quantitative ecology, structured decision making*
19. Sandra Zellmer	UNL, College of Law, *environmental policy, law*
20. Vitaly Zlotnik	UNL, Geosciences, *hydrogeology, hydrological modeling*

International Partner: Jan Sendzimir, Austria, International Institute for Applied Systems Analysis, *adaptive management, resilience*

Externship Partners: The Nature Conservancy, Nebraska Game and Parks Commission, Headwaters Corporation, Nebraska Department of Natural Resources

IGERT Fellows will consist of Ph.D. candidates in the departments of Natural Resources, Computer Science, Geosciences, Political Science, Sociology, Agricultural Economics and Biological Sciences, but may include students from other natural and social sciences.

[1]Oversight of the proposed IGERT program in *Resilience and Adaptive Governance in Stressed Watersheds* will be the responsibility of a Coordinating Committee of seven faculty members whose expertise covers key components of the program. The Coordinating Committee will work with faculty in multiple campus units and at other institutions to achieve program goals. The committee includes five co-principal investigators plus one member from a cooperating U.S. institution and one member from an international cooperating institution. See Section C.5 for details about program management.

C.2. VISION, GOALS, AND THEMATIC BASIS

Vision and Goals. Much of the world is currently experiencing conflicts over finite water resources (Giordano and Wolf, 2003; Gleick et al., 2006). Diminishing water quantity and quality impacts have prompted the United Nations to designate this decade as "Water for Life." Former World Bank Vice President I. Serageldin and former UN Secretary B. Boutros-Ghali are two of the many leaders who have predicted that the international conflicts of the 21st century will be about water interests rather than about oil interests. Humans are rapidly depleting the supply of fresh water, adversely impacting both humans and ecosystems (Millennium Ecosystem Assessment, 2005). In the United States, water shortages have generated legal and policy battles over watershed management and the competing needs of different stakeholders for water to use in agriculture, drinking, industry, recreation, and wildlife protection (Giordano et al., 2002). Globally, water consumption has skyrocketed (e.g., in India over the past 30 years there has been an increase from two million wells to 23 million wells); and depletion and pollution of water results in the death of millions of people each year (e.g., De Villiers, 2003; Gleick, 2004). Water shortages are actually only half of the management challenge. Flood damages continue to mount despite enormous investments in river engineering designed to shunt water as quickly as possible downstream (Sendzimir et al., 2004). This engineering makes water storage more difficult, and creates the paradox of too little and too much water, and traps where existing infrastructure limits policy and management experiments.

Water conflicts are complex and managing water resources will require an integrative framework (Scholz and Stiftel, 2005). Adaptive governance and adaptive management are innovative integrative approaches that treat policy and management as experiments designed to determine and decrease uncertainties and identify thresholds for the successful management of complex systems. ***For adaptive governance and adaptive management to be successful there is a critical need for explicit training of future social and natural resource scientists, managers, and policymakers in the process of adaptive management and in resilience theory, which gave rise to adaptive management*** (Lebel et al., 2006; Gunderson et al., 2009). Resilience theory focuses on the capability of complex systems of people and nature to absorb disturbance without losing critical structure and function (Walker and Salt, 2006). For example, the greater the resilience of a system (e.g., a watershed), the less likely it is to cross a critical threshold and reorganize into a state that is qualitatively different and may provide fewer beneficial environmental services than it had previously. Because the state of a system following a transition is not predictable, it is usually in humanities' best interest to maintain and enhance resilience and avoid traversing critical thresholds (Holling, 1973; Folke et al., 2004). Resilience does not seek to optimize the outputs of a limited number of variables, or optimize system performance or efficiency (Walker and Salt, 2006). Optimization approaches often sacrifice resilience in favor of increased output, increasing a system's vulnerability to catastrophic change (Holling, 1996)**.** A focus on resilience seeks to maintain a system's adaptive capacity, its ability to evolve in response to changing conditions or outside disturbance, without undergoing a catastrophic shift (i.e., regime shift). Optimization approaches seek to maximize some function while a resilience approach focuses on preserving function in the face of environmental variation.

A complete understanding of resilience theory, and effective use of resilience's implications for research, water management practice, and policy, demands inter- and trans-disciplinary training in computational, social, and natural sciences. Such training is missing in graduate programs in the United States, but is required if we are to prepare the next generation of natural resource scientists, managers, and policymakers to better respond to the challenges created by increasing demands for diminishing resources and the need to maintain and build resilience in stressed watersheds. This is one of our most complex and challenging societal problems. ***To help address this critical need, the University of Nebraska-Lincoln (UNL), along with its government, industry, and international partners, proposes to establish an***

IGERT program in Resilience and Adaptive Governance in Stressed Watersheds that will serve as the innovative foundation for a permanent interdisciplinary graduate program that: a) will place UNL in the forefront of graduate education programs in the world in the resilience/adaptive governance areas, and b) ensure students have the necessary training to engage in the innovative research and effective practice that is required to meet the global challenges of water quantity and quality**.**

The vision of the proposed IGERT is to provide unique cross-disciplinary training for a cadre of graduate students from natural, computational, and social sciences including a deep understanding of the ***complex and intertwined ecological and societal systems involved in managing water resources*** in the 21st century, and the development of sophisticated tools for decision support, management, and restoration. In addition to exposing IGERT students to substantive and interdisciplinary academic knowledge, the IGERT program will teach fellows about real-world policy applications that benefit from not only knowledge transfer, but the transfer of knowledge in such a way that it is useful to policymakers. ***The thematic basis of the program will focus on the management of over-appropriated watersheds*** in regions where agriculture is a dominant land-use, food production and critical habitats rely on limited ground and surface water resources, and disparate and long-term data exist but require synthesis.

IGERT fellows will primarily include Ph.D. candidates from UNL's schools of natural resources and biological sciences and departments of computer science and engineering, geosciences, political science, sociology, and agricultural economics. The program will provide one to three years of support per fellow (depending upon the department involved, and except for students beginning in year three, who will receive up to two years of NSF support and two to three years of university support) and train approximately 10 fellows per year, for a total of approximately 25 fellows trained by the end of NSF funding. Fellows will be exposed to and trained in the areas of resilience theory and adaptive management. They will receive training through an interdisciplinary curriculum and externships with NGO, industry, and government partners responsible for adaptive management and recovery of the Platte River watershed in the Great Plains. This training will be enhanced through exposure to the adaptive management of watersheds in Eastern Europe through the International Institute for Applied Systems Analysis in Vienna, Austria. As confirmed in Vice Chancellor Paul's letter of support, the requested NSF funding for the proposed IGERT training program will jump start a permanent interdisciplinary program of study in resilience and adaptive management, a development that fits in the UNL's strategic planning for interdisciplinary academics (see http://www.unl.edu/svcaa/reports/ for several reports on UNL's vision). Our conceptual framework is represented in Figure 1.

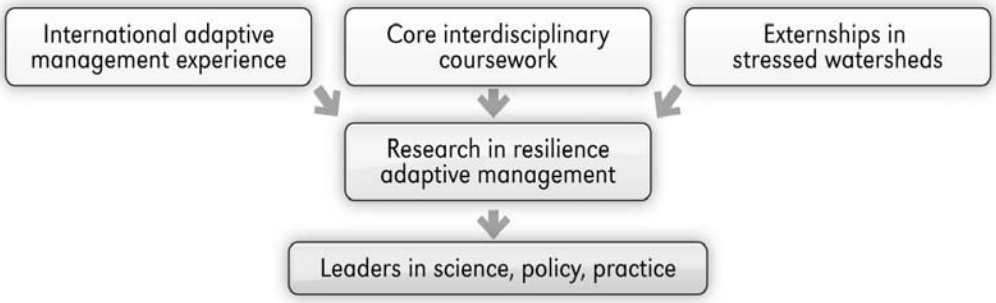

Figure 1. University of Nebraska-Lincoln IGERT overview.

The program's goal is to stimulate innovation in research, training, and application. Specifically, we will:

1) Provide graduate students with rigorous cross-disciplinary foundations in theoretical and applied aspects of watershed science, resilience theory, adaptive governance and management, computational approaches, and decision support. Our focus will be on critical data and analytical gaps ("*we are drowning in data but starving for knowledge"*) that occur at those mesoscales that link the small plots of short duration usually used in experimental biology with the large extents and time horizons often used in climate modeling. We will provide trainees with the analytical, empirical, computational, and applied tools necessary to understand how resilience (both ecological and social) is generated and maintained in stressed watersheds, and the critical interplay of water demand, availability, policy, and governance.

2) Provide graduate students learning experiences through controlled experiments in natural (ecosystems) and governing (adaptive management) systems with a focus on the Platte River in the Great Plains and through comparative studies of similar systems in Eastern Europe. Monitoring of these systems generates disparate spatial and temporal datasets at multiple scales with complex and non-linear interactions. The basic tools developed in this program will be broadly applicable to other environmental systems where social and ecological elements compete for scarce resources.

Four strategies (objectives) will be pursued to accomplish program goals (Table 1).

Table 1: IGERT Strategic Objectives	
1.	Provide a formal graduate specialization in adaptive management within participating departments by offering integrated coursework and seminars that focus on resilience and adaptive management in natural and social systems, computational techniques, conflict resolution, ethics, leadership, and how this conceptual framework can be applied in integrating science, policy, and law for effective governance of natural systems.
2.	Place teams of students in externships with government and industry partners to obtain real-world experience in problem-solving on watershed issues of societal relevance. Students will work in interdisciplinary teams, grouping natural scientists with social scientists and/or computer scientists, on research and engagement projects (including developing an adaptive management/governance plan for a regional watershed) to develop skills in cross-disciplinary problem solving, communication, teamwork, and transfer of knowledge and making knowledge usable to policymakers and administrators.
3.	Develop global perspectives and international cooperation through an international training program developed with the International Institute for Applied Systems Analysis (Austria) involving comparative studies of adaptive management of watersheds in the face of global change and global water shortage.
4.	Recruit minority students to University of Nebraska and provide them with the opportunity to pursue a unique multidisciplinary Ph.D. degree focused on adaptive management and resilience.

Background and Need. Resilience is the capacity of a system to remain within its current regime (Holling, 1973). Resilience is driven, in part, by scale-specific groupings of processes and biotic-abiotic feedbacks that provide systems with their characteristic structure (Peterson et al., 1998). When the resilience of a system is exceeded, a regime shift occurs, which has consequences for the various forms of capital (natural, social, economic) in a system (Folke et al., 2004). New regimes following a shift (also termed alternative states; Carpenter, 2003) may produce fewer of the ecological goods and services to which humanity is adapted. Furthermore, regime shifts may be difficult to reverse because of hysteresis (Scheffer and Carpenter, 2003).

Adaptive management and adaptive governance are approaches to understanding the ecological and sociological elements and thresholds of systems through controlled experiments where it is not disastrous to fail (Gunderson, 2000; Adger et al., 2003; Ostrom and Janssen, 2004). That is, adaptive management and governance are designed to identify and reduce key uncertainties and to use management and policy options as testable hypotheses. Within watersheds (i.e., within a drainage basin or catchment, which is likely to be homogenous in meaningful ecological and social ways as compared to other basins), ecological experiments might include manipulating water regimes while carefully monitoring the system;

in the policy realm, experiments might include simulations of behaviors such as purchasing of water rights from irrigators or adding incentives to encourage specific actions, such as enrollment in conservation reserve programs. Traditional resource management approaches have simply adopted regulations or implemented management without carefully monitoring for response and without explicitly determining alternative hypotheses of effect, and often failing to define explicit goals and objectives (Gunderson et al. 1995, 2006; Folke et al., 2005). Initial successes from inflexible policies often end in irreversible failure, e.g. "policy resistance" (Sterman, 2006; Sendzimir et al., 2007).

Resilience and adaptive management are intricately linked (Gunderson et al., 2009) because resilience captures both natural and human elements of systems and the potential for catastrophic non-linear change and regime shifts, and adaptive management can explicitly test different strategies of managing these elements to understand and build resilience. Adaptive management and governance are increasingly recognized as effective tools for learning system dynamics where traditional replicated experiments are not possible. Recognition of these benefits has led to the requirement of the U.S. Department of Interior to adopt adaptive management approaches (Williams et al., 2007). Unfortunately, adaptive management approaches are often misapplied or misinterpreted. This situation creates an enormous gap in expertise and an important opportunity. ***We propose to fill this gap by training students in resilience theory and providing hands on experience in adaptive management and governance.***

Adaptive management, then, is a series of scientifically driven management actions (within policy and resource constraints) that use monitoring and research results to test hypotheses related to management and governance decisions and actions and incorporate feedback loops for modifying and improving future management actions. Adaptive management operates on the premises that: 1) Uncertainty exists in a managed system, and the identification and reduction of uncertainty can improve management; 2) Uncertainty can be reduced through adaptive management, though it is not eliminated; 3) Management decisions must be made despite uncertainty; and 4) Monitoring and research are accomplished as the application of management, are used to evaluate management decisions, and are able to iteratively reduce uncertainty, improve management, and modify the underlying assumptions (often manifest as models) on which decisions are based (Nyberg 1999).

Successful adaptive management requires the presence and development of a system of adaptive governance (Gunderson and Light, 2006; Hughes et al., 2007). Adaptive governance consists of formal and informal institutional structures and processes that create a social framework for policy development, experimentation that highlights scientific uncertainty, and evaluation (Pahl-Wostl et al., 2007). The effective management of systems of people and nature, where water is both critical and limited, requires the integration of multiple perspectives and the identification of common goals. Communication, conflict resolution, and leadership skills are critical for the next generation of environmental decision makers to foster a democratic process that creates an ongoing dialog, recognizes differences, and negotiates conflict (Langston, 2003). Yet the tools to foster effective communication and experiments in resource management and governance in conditions of increasing uncertainty are not commonly a component of graduate education. Natural, computational, and social scientists all have their own unique scientific vocabulary, and shared terms often have different meanings, making meaningful collaboration to solve complex problems difficult. Natural scientists often have a superficial understanding of the language and concepts in the legal and policy fields and how science is used in the public arena (Pollack, 2003; Graffy, 1998), and computer scientists often develop techniques that do not address the nuances of natural systems. ***These barriers undermine the effective translation of science into meaningful policy and practice.***

A partial remedy to the disconnection between science and policy requires that scientific results be presented to decision makers in a format that meets decision making needs. It also means that stakeholders from disparate fields should share a common vocabulary. Contemporary environmental decision support uses sophisticated technologies to collect, archive, process, integrate, and visualize

complex data to help make decisions in the face of scientific uncertainty (NAS, 2004). Better policy outcomes and better management will occur if there is a common knowledge foundation informing the discourse among environmental scientists, modelers, computer scientists, policymakers and administrators. ***One way to facilitate understanding among scientists is to create teams from diverse fields that together identify critical datasets; design collection and monitoring mechanisms; develop tools for modeling, integration, and prediction; and successfully accomplish knowledge transfer from scientists to policymakers.*** Although individual disciplines can identify relevant questions and experimental approaches, both the questions and resulting answers are more likely to be robust when framed in a broader interdisciplinary context. In addition to ensuring the outputs of the scientific collaborations are useful, it is critical to make sure that it is produced and communicated in ways of maximal utility for consumers responsible for policymaking and governing. Therefore, ***our proposed IGERT fosters cross-disciplinary collaboration and training focused on understanding resilience in stressed watersheds utilizing adaptive management and governance perspectives.***

The Platte River: An ideal training ground. The Great Plains region provides an ideal laboratory for investigating the complex environmental, economic, legal, and social systems that affect water quality and quantity within watersheds (Figure 2). The Platte River is in many ways a typical example of a Great Plains river. It is shallow, occupies a broad valley ("a mile wide and an inch deep"), and is highly braided. Until recently, the river was subject to annual flooding that moved a large amount of sediment, led to frequent changes in channel location, and regularly created and destroyed sandbars. A high variability in flow maintained a rich sandbar habitat with little vegetation, which is critical to the migratory birds of the central Platte valley. Approximately 300,000 shorebirds comprising more than 30 species migrate through the valley during the spring. Approximately 500,000 Sandhill Cranes and Whooping Cranes, their endangered cousins, stop along the river each spring during their northern migration. Cranes spend their

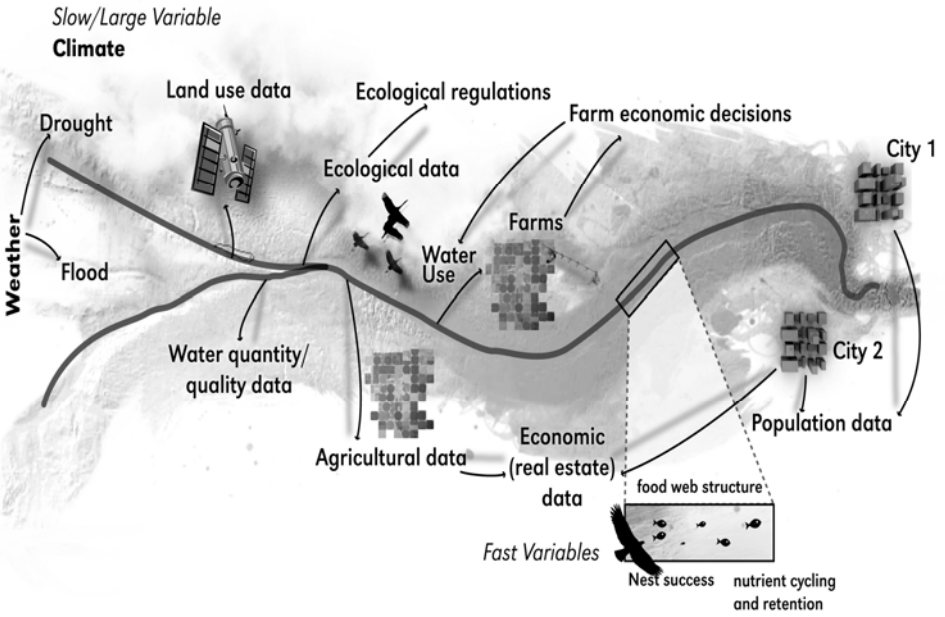

Figure 2. The Platte River, a complicated system with ecological, economic and social inputs and outputs, and data collected remotely and in situ and at varying scales in space and time. It can be viewed, and more easily understood, as a complex system with hierarchical structure and emergent properties such as resilience.

days feeding in adjacent agricultural fields and wet meadows in the river valley, then return to river sandbars each night to roost and avoid predators. The waters of the Platte River also provide the people of Wyoming, Colorado, and Nebraska with irrigation, industrial and drinking water, hydroelectric power, recreation, and ecosystem services. The Platte River is hydrologically connected to the Ogallala Aquifer, one of the largest and most important aquifers in the world.

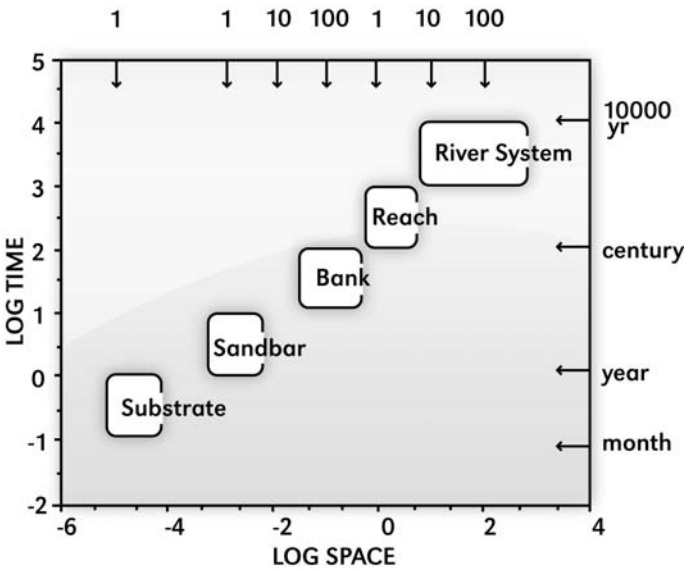

Figure 3. Logarithmic time and space scales of landscape structure of the Platte River. The temporal scale is based on dimensions in years and the spatial scale on dimensions in kilometers (adapted from Holling 1992), reflecting the periodicity and extent of key processes. Flooding was a key mesoscale process in this system.

A rich array of processes that operate at characteristic scales in time and space are reflected in the landscape structure of the Platte River ecosystem (Figure 3). Among these processes, flooding, mostly in the form of a spring surge, is critical to ecosystem function. Federal and non-federal water projects in the Platte River Basin include 15 major dams established to provide flood control, irrigation, power, and recreation; but these have also largely eliminated spring flooding. In three of the past five years, large stretches of the big bend reach (the central Platte in Nebraska) of the Platte River have gone dry. Existing channels have stopped meandering and become incised. River banks and sandbars have been further stabilized by vegetation, including trees that have progressively invaded the Great Plains along river courses. Stabilization by trees and other vegetation has made it difficult to restore the river to its former state by simply restoring the process of flooding (thus the system exhibits hysteresis [Figure 4] – a condition whereby the 'path in is not the same as the path out'). Hysteresis has been further entrenched and strengthened by the invasion of the Platte River system by the non-native species *Phragmites* ("common reed"), which further fortifies island and shoreline banks and is much more difficult to remove than trees.

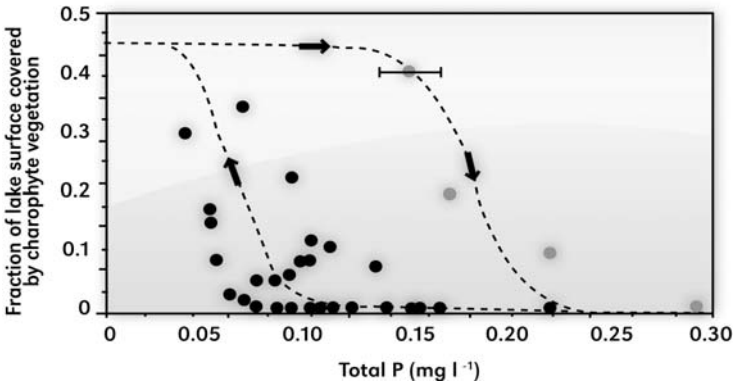

Figure 4. Hysteresis in a shallow lake system (Scheffer et al. 2001). Grey circles are phosphorous levels as the lake shifted from a clear state to an eutrophic state. Black circles represent phosphorous levels as they slowly decreased over time with management. To shift the lake back to a clear state, phosphorous had to be reduced to levels much below that which induced the shift in the first place. Hysteresis is present in many complex systems, including governance systems, when trust is breached by a governing body, for example.

Despite intense management efforts, Platte River waters are designated as over appropriated, its communities are declining, its economic system is based on limited commodities that require large water inputs and are thus doubly vulnerable, and its ecological systems are endangered. Water shortages have given rise to a series of interstate legal battles over watershed management; the impacts of irrigation on river flow; and the competing needs of different groups for water to use in agriculture, recreation, industry, drinking,

and for wildlife protection (specifically federally listed species such as the Interior Least Tern, Piping Plover, and Whooping Crane) (NRC 2004).

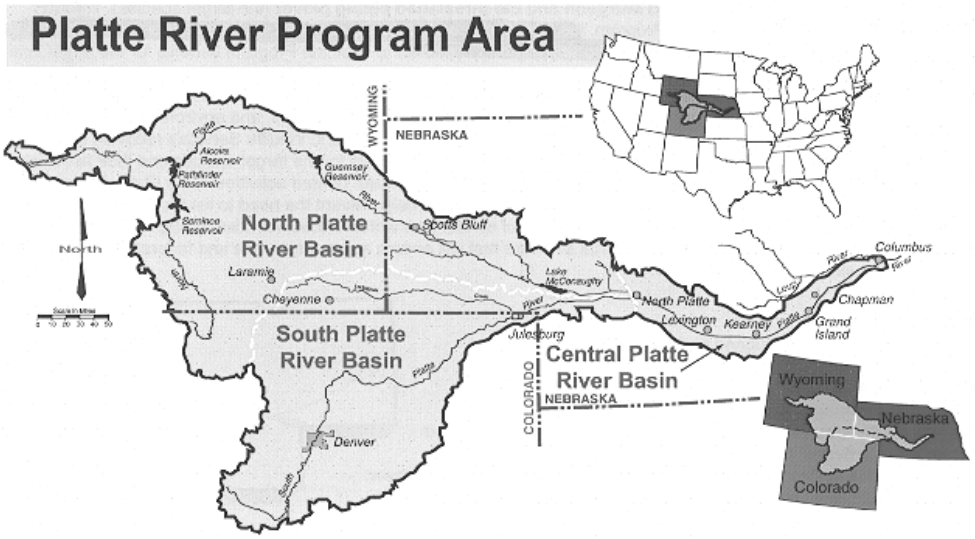

Figure 5. The Platte River watershed. In addition to draining the foothills of the Rocky Mountains in Wyoming and Colorado, the Platte River also drains a large area of the sandhills of central Nebraska, which is not shown in this graphic

Because of the importance of water resources, many local, state and federal agencies have developed extensive sensor networks that have been collecting large amounts of data relevant to the management of the Platte River watershed (Figure 5). Nonetheless, the physical interconnectedness of groundwater and surface waters is sufficiently complex on its own, and there are still many gaps in the critical data needed to address environmental and social issues; the region's cultural and economic systems are equally complex. The irrigation systems of the Great Plains constitute an enormous investment in social, economic, and political infrastructure, creating one of the most complex irrigation societies in history. This system and culture are resistant to change, highly engineered, and perhaps inflexible and only marginally resilient. In addition, the majority of land in the Platte Basin is privately owned, and the lack of federally-owned land impacts the legal and human infrastructure and the ability to enact new policies or experiment with new management. Moreover, the legal systems for regulating surface and groundwater use differ among the three Platte River watershed states. The complexity of these social and legal systems contributes to the challenges of developing effective management solutions for regional watersheds.

Dramatic demographic shifts in the human population are occurring throughout the Great Plains region, including depopulation, influxes of immigrants, and the creation of a bimodal age distribution. For example, from 2000 to 2004, 71 of Nebraska's 93 counties lost population, a trend also present throughout the 1990s. This out-migration, particularly from larger, sparsely-populated rural counties, has been accompanied by economic downturns. Two counties in rural Nebraska are now among the 20 poorest in the United States. These trends are symptomatic of the overall plight of the U.S farm economy. As recently as 2001, 75% of farm households earned more than 50% of their annual income off the farm. A majority of all farms survive today largely by government subsides. In light of these often dire circumstances, the sale of water to other users by landowners is becoming increasingly likely. Thus, the fate of farming on the Great Plains and the longevity of its water resources, and all that depend upon them, are increasingly in doubt. For this watershed and others, it is critical to know where the ecological and sociological thresholds occur before actually crossing them.

A tri-state recovery initiative (Wyoming, Colorado, and Nebraska) for the Platte River was adopted in 2007 following more than a decade of negotiation in the shadow of litigation. The plan explicitly adopts an adaptive management approach to river recovery, with the enhancement of populations of endangered species (particularly whooping cranes, least terns, and piping plovers) as explicit goals, as well as a more general goal of enhancing the resilience of the watershed. A governance committee comprised of stakeholders from the three states, the federal government, environmental interests, and water users, with the assistance of several subcommittees, has been in place since 1997. The adaptive management plan is funded at approximately $300 million over 13 years (until 2020) and is being implemented under the auspices of the Headwaters Corporation (http://headwaterscorp.homestead.com/) in a private-public partnership with the Platte River Recovery Implementation Program (http://platteriverprogram.org/) (see Table 2).

Table 2: The Platte River Recovery Implementation Program

Efforts to relicense Kingsley Dam on the North Platte River in western Nebraska, the presence and decline of threatened and endangered species, and the U.S. Fish and Wildlife Service's 1994 Biological Opinion on Platte River operations provided the background for conflict over the Platte's vital water. Rather than engage in lengthy litigation over limited water resources and the recovery of individual species, the governors of the three basin states joined with the secretary of interior in July 1997 to sign the "Cooperative Agreement for Platte River Research and Other Efforts Relating to Endangered Species Habitat along the Central Platte River, Nebraska."

The program has three main elements:
- Increasing stream flows in the central Platte River
- Enhancing, restoring, and protecting habitat lands for the target bird species
- Accommodating certain new water-related activities

These elements will be implemented according to underlying principles that require interests in land to be acquired only from willing participants and that avoid increasing tax burdens to local citizens by paying taxes or their equivalent on program lands. Program lands will be held by a Land Interest Holding Entity (rather than by the federal or state governments) and will be managed under a "good neighbor" policy.

An Adaptive Management Plan, which provides a systematic process to test hypotheses and apply the information learned to improve management decisions, is central to successful program implementation. The Adaptive Management Plan was developed collaboratively by program partners and cooperators under the guidance of experts and is centered on priority hypotheses that reflect different interpretations of how river processes work and the best approach to meeting program goals. The Integrated Monitoring and Research Plan (IMRP) will guide implementation of specific monitoring and research protocols to test the joint priority hypotheses and guide Program restoration and management decisions.

Complete program information is available at: http://platteriverprogram.org/aboutus.aspx

These components, and their timing, combine to create one of several ideal opportunities for experiential training of IGERT fellows. Expertise in adaptive management and governance is limited, and an IGERT in this area that leverages watershed management plans in the Great Plains will benefit from the substantial state and federal funding already committed to the Platte River project, to provide training in this area of expertise. In addition to the Platte River experiences, students will have other international and domestic opportunities to develop their skills, conduct research, and apply their expertise.

Why the University of Nebraska-Lincoln? UNL is poised to become one of the world's premier water research institutions. Currently, there are more than 150 affiliated faculty members devoted to water and water-related research. UNL has designated water as a "Program of Excellence" and invested millions of dollars in the past five years, hiring faculty at the junior and senior levels, acquiring new equipment and building new laboratories. UNL is innovative in its approach to becoming one of the world's premier water institutions; it has hired faculty in political science and economics with explicit interests in water,

along with hiring in the "traditional" water sciences. ***The development of an interdisciplinary, graduate training program in resilience with an intense focus on adaptive management is a next logical step in making UNL a premier water research institution.***

The university is well-situated geographically to host an IGERT program focused on watersheds, resilience, and adaptive management and governance using the Great Plans region as a focal area. UNL has recognized expertise in watershed research and management, and we are already establishing a cross-disciplinary M.S. and Ph.D. specialization in adaptive management and developing graduate courses in adaptive management that will form a crucial part of the foundation for the proposed IGERT program. The School of Natural Resources was created to explicitly create a multi-disciplinary research and education environment. The Nebraska Cooperative Fish & Wildlife Research Unit is currently hiring faculty in the area of adaptive management and structured decision making and will become a regional node of adaptive management expertise for the U.S. Department of Interior. Moreover, UNL is an active member of the Resilience Alliance, an international organization dedicated to investigating the processes that generate and maintain resilience and sustainability in linked social-ecological systems.

The activities of the faculty conducting water research are facilitated by the UNL Water Center, part of a network of nationwide centers designed to promote research and graduate training in each state and a campus-wide *Water Resources Research Initiative* aimed at enhancing research and education in all areas at the interface of water science, policy, and law. ***UNL is committed and well prepared to continue this interdisciplinary IGERT program after funding from NSF ceases under the auspices of the Water Resources Research Initiative.*** Current partnerships among departments in the environmental sciences, computational sciences, and social sciences will integrate these disciplines into our IGERT educational and research programs. UNL researchers are actively investigating the impacts of land use change and climate change on water systems and agricultural systems, including determining environmental and economic impacts of different management scenarios and developing computational tools for assessing impacts.

Planned Outcomes and Anticipated Impacts. ***The proposed IGERT will increase our scientific understanding of how resilience is generated in complex systems of people and nature.*** Landscapes and waterscapes, and the services derived from them, interact with social and governance systems of humans and the resilience of these systems is derived from the component parts and their cross-scale interactions. Experiments in Nebraska's Platte River watershed will be conducted by IGERT fellows advised by faculty and externship partners, and will probe the social and ecological aspects of resilience. Some of these experiments are already outlined in the Platte River Recovery Plan (http://platteriverprogram.org/) but need to be fully developed and implemented. Comparisons with stressed watersheds in Eastern Europe through the International Institute for Advanced Systems Analysis in Austria will help train students and determine the generality of results. UNL's membership in the Resilience Alliance (http://www.resalliance.org/) provides further opportunities for synthesis of results and comparison of case studies in other regions of the globe, including southern Sweden, southeastern Australia, and southern Africa. Collaborations with partners from IGERT programs in Alaska and Arizona will allow further interactions among diverse students (those IGERTS are represented on our external advisory board). Other anticipated outcomes of our proposed IGERT include:

- ***Crystallization of an effort to create an ongoing curriculum in adaptive management at UNL that will serve as a model for the integration of natural sciences, social sciences, law, and computational sciences in graduate education, and preparation of Ph.D. students at this exciting and critical interface.*** Students will develop expertise in sophisticated decision-support technologies to integrate complex environmental, hydrologic, and socio-economic data, and in using methods of adaptive management and governance. This comprehensive interdisciplinary training will prepare IGERT graduates to work in the public and private sectors to meet the established need for well-

informed decision support in water science, watershed management, and resilience at state, regional, national, and international levels.

- ***Fundamentally change academic culture in a region of over-appropriated watersheds where past water management disasters leading to the loss of irrigation waters and/or species are well documented.*** We will accomplish this by coalescing individuals in social, natural, and computational sciences around a common goal, providing opportunities for students and faculty to interact on common projects and to share perspectives generated by disparate backgrounds and training. This will provide a model for such interactions in other regions with similar stressed watersheds.
- ***Integration of academic research and education with the needs of regional, national, and global groups involved in watershed management, recovery, and policy,*** catalyzing the dissolution of borders between disciplines and formalizing and energizing an interactive culture of exchange among academics and practitioners. These NGOs and agencies, such as the Headwaters Corporations (a private corporation formed to implement recovery of the Platte River), the Nature Conservancy, the Nebraska Game and Parks Commission (and other state agencies), and the U.S. Fish and Wildlife Service, will participate actively in training and mentoring students through externships and in shaping the UNL curriculum in social, natural, and computational sciences.

C.3. MAJOR RESEARCH EFFORTS

Research Theme and Significance. The research theme of this program is understanding and enhancing ***the resilience of over-appropriated watersheds in the Great Plains*** – where agricultural production and critical biological habitats rely on fluctuating water resources – ***through adaptive management***. The research challenges and approaches presented below are areas of active research at UNL, and areas where interdisciplinary interactions have been initiated among faculty and students. These themes, identified as challenges and research approaches, will provide examples and case studies that will be integrated into and expanded with the proposed project, and serve as dissertation topics for IGERT trainees. Broad challenges and the general research framework are outlined as are specific examples of potential projects.

Effective adaptive watershed management and recovery necessitates quantification of aspects of the water cycle, ecological parameters such as fish and wildlife abundance, and collection of human demographic data, social data, and economic data, most of which have both spatial and non-spatial components. It also requires modeling of the environmental, economic and social impacts of management and governance strategies in the face of climate change and land-use change. These data are often stored in disparate and distributed databases at different spatial and temporal scales. The datasets need to be integrated in a manner that is both appropriate to address domain questions and to help decision makers develop resilient policies.

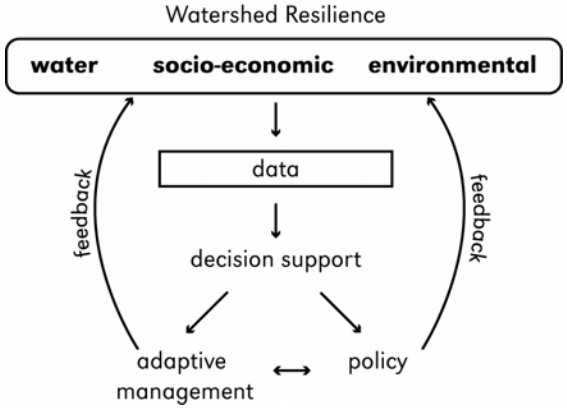

Figure 6. The components of watershed resilience in an active learning environment.

Furthermore, the adequacy of the datasets for solving different problems varies. Therefore, techniques to evaluate the quality of datasets and to propagate derived information and knowledge are also critical (Soh et al., 2008; Hong et al., 2008). Thus, addressing watershed and water management issues necessitates integration of natural, social and computational scientists with managers and policymakers (Figure 6).

The social-ecological challenges facing this system can be categorized into three major classes, each described briefly below. These challenges are faced in other watersheds across the world.

Over-appropriation of watershed resources. As a result of interstate legal battles over the role of groundwater pumping in the decline of river flows, recent Nebraska legislation requires that all state watersheds be inventoried and designated fully or over-appropriated with respect to water availability for current use. Similar legislation is present in other states in the Great Plains and the American west. This legislation necessitates compilation of available hydrologic data, improved estimates of groundwater recharge, and the creation of models of basin hydrology that adequately describe groundwater-surface water interactions. All fully or over-appropriated watersheds must develop integrated watershed management plans, with full inclusion of local stakeholders in the choices for balancing environmental, social, and economic constraints. In addition, burgeoning population growth along the Colorado Front Range has increased the potential for water marketing, which will require additional evaluation of complex and interrelated ecological, economic, social, and legal issues.

Climate change and drought. The Nebraska Sandhills form the largest sand dune area in the Western Hemisphere and overlie 65% of the High Plains Aquifer. Rivers originating in the Sandhills are responsible for the constancy of flow, and relative intactness, of the Lower Platte River. The Sandhills are stable and covered by native grassland; however, the geologic record reveals that large areas were destabilized and the dunes were mobile as recently as 900 years ago (Mason et al., 2004). Biological and atmospheric feedbacks affect the stability of terrestrial and aquatic ecosystems and their response to major drought. Droughts or climate change, interacting with landuse and landcover change, may destabilize and otherwise affect key mesoscale processes, such as spring surges on rivers and fire frequency and intensity on adjacent uplands. The complex biophysical interactions that control the stability of the Sandhills and recharge of the High Plains Aquifer affect regional water availability and thus management and economic viability of Nebraska and the seven neighboring states that overly the High Plains Aquifer.

Degradation of resource quality and resilience. A majority of streams, rivers, reservoirs, and wetlands in the Great Plains have excess nutrient concentrations and detectable levels of one or more agrichemicals, including pesticides and pharmaceuticals. Concomitantly, native flora and fauna are declining and non-native invasive species are increasing in quantity and extent. Reservoirs have decreased the availability of sediments. Contaminants and nutrients, originating from both point and non-point sources, impair local systems, as well as downstream water bodies, such as the Gulf of Mexico. Invasive species crowd out native species and can cause flooding or decreases in flow. Targeting and prioritizing areas and strategies for protection and restoration of water quality requires balancing environmental health and the economics of agricultural production.

Research Projects that Implement Resilience Theory and Adaptive Management. IGERT trainees will combine interdisciplinary classroom learning with experiential learning in the form of externships focused on the Platte River watershed and other Great Plains watersheds, as well as comparative studies of Eastern European watersheds. Student dissertations will focus on single watershed systems or on comparisons between U.S. and European watersheds. Externships that are complimentary to the dissertation topics will be developed with practitioners under the academic auspices of individual faculty and through the Universities Public Policy Center. In general, we propose to investigate the determinants of resilience in this complex social-ecological system. What elements and linkages within and among the ecological, social, economic and legal systems in place in the Great Plains build resilience or, conversely, erode resilience? To do so, we will build upon our expertise and continue to partner with a number of universities, NGOs, agencies, and stakeholders from the Great Plains region and elsewhere. These partnerships will allow us to address the generation of resilience in stressed watersheds through adaptive management. Because the accumulation of knowledge alone is not sufficient to ensure resilience, we will translate this knowledge base into action, using it to inform the public policy debates over water resources management and/or to contribute to strategic planning for watershed managers. Students will create and test comprehensive management scenarios with realistic social, cultural, and economic alternatives and related consequences.

The Platte River watershed serves as the chief, scientific foundation for our IGERT, and it is a system with limited but critical water resources, threatened grassland and wetland ecosystems, and major continental bird populations. An integrated systems water management approach also can serve as a model for other major ecoregions nationally and internationally, where food production and critical habitats also rely directly on water resources. Below we list eight research topics suitable for student trainees and that relate to ongoing research interest to IGERT PIs and collaborators. For each topic, we list the IGERT faculty involved in this area of research. In addition to the faculty listed, the following centers are actively involved with these programs: High Plains Regional Climate Center, National Drought Mitigation Center, Center for Energy Sciences Research, Center for Grassland Studies, Center for Advanced Land Management Technologies, Public Policy Center, Water Center, Nebraska Invasive Species Project, Resilience Alliance (International), and Applied Environmental Decision Analysis Research Hub (Universities of Melbourne and Queensland, Australia).

1. Analyses of the societal and ecological dimensions of resilient management in systems where water is the critically limiting resource. This includes the formulation of more effective policy through the development of social, cultural, and economic alternative scenarios. What are the drivers of resilience in this system? What are the key components and processes (social, ecological, economic) and how do we quantify them? Computational techniques, such as association rule mining, may be helpful in generating a list of candidate hypotheses that can then be examined by domain scientists. (Allen, Gunderson, Lynne, Michaels, Samal, Sendzimir, Tomkins, Zellmer).

***2. How can adaptive management and governance build and enhance resilience in stressed watersheds*?** How can a resilience framework applied to stressed watersheds advance our conceptualization of managing adaptively? Adaptive management has been interpreted and applied variously – what are the attributes of stressed watersheds that lend themselves to learning via adaptive management or that resist adaptive management approaches? Resilience of a system can also be a challenge – if the existing regime is trapped in a degraded state, then resilience is pathological and must be carefully lowered so as to allow a transition to a new regime. In such cases, we are interested in fostering transitions to new management regimes. (Allen, Gunderson, Michaels, Powell, Sendzimir, Tomkins, Tyre, Williams, Zellmer).

3. What are the critical thresholds to be avoided, and how do we identify them? Slow change may lead to rapid non-linear responses. Resilience management seeks to identify and avoid those thresholds. In the Platte River systems, which ecological, social and economic thresholds are important? In complex systems, increased variability may be associated with pending regime shifts, such as an oligotrophic lake transforming into a eutrophic lake (Carpenter and Brock, 2006). This has been documented for systems undergoing changes of regime (Kleinen et al., 2003; van Nes and Scheffer, 2003; Oborny et al., 2005). Are there leading indicators (such as increased variability) of thresholds in socio-ecological systems? Development of a framework to provide a conceptually unified and hence a simple view of the datasets from different domains will facilitate broader analyses by researchers. (Allen, Fritz, Lynne, Thomas, Wedin).

4. What are the tradeoffs among increasing water demands for agricultural, ecological, industrial (ethanol) and urban uses? How are these resolved in a way that enhances rather than erodes resilience? Comprehensive historic and contemporary water-quantity and water-quality information, land-cover characteristics, and population census data for birds and other major wildlife species exist, but it is not easily translated to policy or action because it is disparate, in different formats, and has been collected at grossly different scales. Integrating information from multiple sources (e.g., surface water, groundwater, and precipitation) to derive composite views of water quality and quantity and ecological services (as a first order approximation) will reduce the number of independent variables and may simplify the analysis. (Allen, Goddard, Hoagland, Lenters, Powell, Samal, Zlotnik).

5. Changing land-use patterns and the loss of structuring processes have affected the provision of ecological goods and services and potentially compromised watershed resilience. What ecological services might be affected? How do islands of diversity embedded in a working agricultural landscape add to the resilience of that system? Computational techniques to detect and monitor changes in both space and time at different scales may simplify the analysis and need to be developed. (Allen, Samal, Thomas, Wedin).

6. Simple models. The resilience paradigm has a number of assumptions (e.g., cross-scale interactions, thresholds, multiple stable states). Our students will critically test these underlying assumptions in the coupled socio-economic-ecological systems of stressed watersheds, which lend themselves well to testing. Most assumptions that have been tested have been only in the ecological realm (e.g., multiple stable states). Restoration of the Platte River provides an opportunity to test those assumptions. (Anderies, Istanbulluoglu, Lenters, Tenhumberg, Tyre, Williams).

7. Mining spatio-temporal change patterns across multiple datasets. A common theme in many of the problems described above is the identification of change in both space and time. Furthermore, these changes must be related in multiple datasets (e.g., water availability, population growth, alternate farming practices, wildlife population, etc.). New data mining techniques are needed to identify clusters of stability in space and time and to generate interesting rules that relate changes between different datasets as functions of space and time. (Goddard, Samal, Tenhumberg, Tyre).

8. Development and implementation of land use policies which navigate the objectives of different interest groups. Disagreements regarding water use creates difficult problems at local, state, and interstate levels in the Great Plains. Different decision makers have distinct roles and interests regarding water use in the Great Plains. Controversial issues often result in courts having to make a decision in favor or one interest group over another. Through examination of previous and on-going conflicts of water use and by including economic considerations and theoretical perspectives of fairness and confidence in institutions, students can develop a system of consensus building that includes all of the stake holders with the objectives of facilitating collaboration and cooperation and protecting critical environmental resources. (Hoagland, Lynne, Michaels, Tomkins, Williams, Zellmer).

In addition to work conducted in the Great Plains, two watersheds in Eastern Europe, as well as case studies of the Resilience Alliance, will provide trainees with comparative studies and collaborative international experience. The eastern European efforts are briefly described below. Additional specifics are available in section C.9. The international experience will help IGERT trainees place adaptive management and governance issues on the Platte River in a global perspective. Although many of the issues faced by stressed watersheds in the United States and Europe are similar, the social and geopolitical context is quite different. Two of those systems are described below.

Tisza River Basin, Hungary. The Tisza River Basin is one of the largest tributaries of the Danube and it experiences some of the most extreme flood dynamics in Europe, sometimes rising ten meters in fewer than 24 hours. Extreme flood events sometimes punctuate long dry periods. The salient challenge of this watershed under climatic uncertainty is whether the river basin's social-ecological systems can cope with and adapt to oscillations between extremes of flooding and drought. Land use, and hence water management, decisions must also address uncertainty from global economic dynamics, such as surges in grain prices related to increasing Asian demand. All European river systems must register competent basin management plans with the European Commission by 2015, so institutional development and integration at multiple scales (e.g., from regional to national to continental) will also influence the future sustainable development of this basin. An imperial history of top-down control from Vienna, Budapest, and Moscow has dominated decision making in this watershed for centuries. However, numerous shadow networks work at grass roots levels to explore alternative policies and practices related to land use, economic development, and river management. Decades of scientific research and public dialogue at all

levels of society create a foundation of data and experience that is already being exploited in many areas in attempts to initiate and sustain adaptive learning cycles related to river management.

Odra River Basin, Poland. Extreme floods caused extensive damage in 1997 but are not frequent enough to challenge the dominant drivers of Odra River development policy: flood control and barge navigation. These paradigms prevent attempts to experiment with the re-establishment of river pulse dynamics that might otherwise rejuvenate floodplain ecosystems and revitalize both tourism and fisheries. Demographic upheavals associated with World War II replaced the German populations with Poles evicted from present-day Ukraine, so the local knowledge base of the regional ecology and economy and how to sustain livelihoods in a river corridor was eroded and is only slowly being re-established. Transition from state socialism to democratic capitalism has devolved power officially to more local sources, but effective governance from local to national scales appears to take decades to develop through experience. Governance experience is being developed locally by a number of NGOs that offer a bridge between scientists, government, business, and local activists to integrate science, policy, and practice. However, while such bridges are called for in modernization of European Union law (standard mandates for participatory processes in policy determination), deference to regional, national, and European Union power centers suggests that it will take a long time for such opportunities to mature into fully adaptive decision processes.

C.4. EDUCATION AND TRAINING

In addition to research experiences, IGERT fellows will participate in specialized coursework, mini-courses (5-week modules), externships, and seminars designed to expose them to critical language, issues, and tools of watershed science and policy. Group activities will train fellows to integrate and apply knowledge by working with students in other disciplines in problem solving. The courses and activities will be the foundation for a formal unified graduate specialization in adaptive management within the participating departments. The repeated reinforcement of key concepts and skills in these activities over multiple years will develop scholars who can translate watershed science into effective policy based on a sophisticated understanding of linked social-environmental systems.

Coursework Requirements. We anticipate that most of the students pursuing the interdisciplinary adaptive management Ph.D. specialization will join the program in the first year of their graduate study and will be funded through the IGERT two to three years, after which they will be supported through departmental teaching assistantships, other external grants, or UNL (see letter of commitment in Supplementary Documents). Students who take advantage of the interdisciplinary adaptive management Ph.D. specialization likely will come from UNL's departments of natural resources, computer science and engineering, geosciences, political science, sociology, agricultural economics, and biological sciences.

As IGERT fellows, students will be ***required to take several common courses*** in addition to coursework required by their home department. Required IGERT courses are identified in Table 3 and described further below.

Table 3: IGERT Coursework	
Course and Faculty	Credit Hrs.
Adaptive Environmental Decision-Making in Stressed Watersheds (Tyre and Zellmer)	3
Resilience in Complex Systems of Humans and Nature (Allen)	3
Mini-course in Applied Adaptive Management (Gunderson)	1
Mini-course in Communication, Conflict Resolution, and Leadership (team)	1
Contemporary Issues in Watershed Management: Externship Experience and Watershed Adaptive Management (Tomkins and agency officials)	3-6
Electives (one course in each of three areas: Watershed Science, Social Dimensions, and Quantitative Approaches, listed below)	9
International Experience in Adaptive Management (1 semester – Sendzimir)	9
TOTAL	29-32

Adaptive Environmental Decision-Making in Stressed Watersheds. This introductory course will provide students with a firm foundation on adaptive management principles as they apply to water issues. It will introduce the intellectual framework of the IGERT via a series of lectures by UNL faculty and regional scholars and associated discussion sessions. It will be required in fall of Year 1 and will build a common intellectual framework and vocabulary among IGERT fellows and associates. Our intent is to expose students to the fundamental concepts, language, and methods of inquiry in water science, adaptive management, policy, and law. A central focus will be to foster an understanding of how scientific uncertainty impacts the decision-making process. In the latter part of the term, fellows and associates will work in interdisciplinary teams to characterize water issues from scientific, legal, economic, and policy perspectives and to propose interdisciplinary solutions. These projects will use contemporary case studies, in natural and agricultural systems, as vehicles to explore complex issues.

Resilience in Complex Systems of Humans and Nature. The idea of resilience (Holling, 1973), now known as resilience theory (Walker and Salt, 2006), has been developed by ecologists over the past three decades to explain surprising and far from linear dynamics of complex adaptive systems (Gunderson and Holling, 2002). Moreover, resilience theory is the basis for adaptive management, which embraces uncertainty of complex resource systems (Holling, 1978; Walters, 1986). This course, which will be required in spring of Year 1, will provide a review and synthesis of the concepts of resilience as developed by ecological theorists and applied ecologists, from the foundational publication in 1973 to current topics. This course will be based on the book *Foundations of Ecological Resilience* (Island Press, 2009, Gunderson, Allen and Holling), and taught by one of the authors.

Applied Adaptive Management Mini-course. This course was recently developed by L. Gunderson, A. Tyre, and S. Light to focus on relevant problems in adaptive management in compromised watersheds and rivers, focusing especially on the Platte, Missouri, and Upper Mississippi rivers. It will be taught by Gunderson, Tyre, Williams and other practitioners and theoreticians. This is a "hands on" course for managers and policymakers. Students in the IGERT will observe for one year, and will serve as teaching assistants in a subsequent year. This course was offered as a pilot in the summer of 2008, and will continue to be offered each summer hereafter.

Communication, Conflict Resolution, and Leadership Mini-course. We will develop a short-course in communication, conflict resolution, and leadership for IGERT fellows and associates. The course will be developed in conjunction with the UNL College of Business Administration and the Department of Agricultural Leadership, Education, and Communication, which have nationally recognized programs in leadership.

Contemporary Issues in Adaptive Watershed Management: Externship Experience and Watershed Management Plan. A special course will be created, to be offered during Year 2 of the curriculum, that will allow students to participate in an externship at a state (e.g., Nebraska Game and Parks Commission, Department of Natural Resources), federal (e.g., U.S. Fish and Wildlife Service), or nonprofit (e.g., The Nature Conservancy, Headwaters Corporation) organization. Externships will be focused on a real-world challenge in adaptive management of stressed watersheds. The purpose of the externships are four-fold: 1) to expose students to the kind of real-world policy environments in which they may ultimately work or that will be the audience for their research results, 2) to allow students to consolidate the knowledge they already have obtained and to learn more in-depth information about the matters they confront in their externship placement, 3) to allow students to work collaboratively on matters with real-world implications, and 4) to provide students a structured environment within which to formalize their dissertation topics. The externship will be coordinated by the Public Policy Center, a research and engagement unit of the university that specializes in working in the public as well as private policy sectors. Using a model developed at the University of Texas LBJ School of Public Affairs and adopted by other policy schools (e.g., University of Arkansas Clinton School of Public Service), students will be deployed into the "real world" while being expected to discuss their real world challenges and opportunities via a structured seminar. At their externships, students will work in teams that integrate expertise in natural science with engineering, computer sciences, policy, and/or law. An agency member and an IGERT faculty member will jointly supervise each student in his/her externship, and the teams will be supervised by the agency members and the Public Policy Center director. Each externship team will be required to produce a watershed adaptive management plan (e.g., an invasive species adaptive management plan) or a formal policy report that is jointly authored and made available not only to the agency but also disseminated via the Public Policy Center's website and/or via peer-reviewed publication and conference presentation opportunities. Oral presentations on projects also will be presented at the annual retreat (see below). Several externships are in place (see letters of commitment), and we are exploring other internships in the Great Plains region.

Additional Required Courses. Students will be required to take one additional course (3-4 credits each) in each of three major areas of the IGERT, to be chosen from a menu of selected courses offered on campus (9-12 credits total): a) watershed sciences and ecology, b) social dimensions (law, policy, economics, psychology, history), and c) quantitative sciences (modeling, communication networks, databases, data mining). The courses will provide the student with breadth but also the ability to tailor choices to their specific needs and interests. Table 4 lists a sampling of existing graduate courses that will serve as electives and Table 5 provides a timeline for student completion of IGERT training.

Table 4: IGERT Elective Courses

(a) Watershed Science/Ecology	(b) Social Dimensions	(c)Quantitative Approaches
Introduction to Groundwater Modeling	Natural Resource and Environmental Economics	Ecological Statistics
Applied Groundwater Modeling	Environmental Law	Introduction to Data Mining
Modeling Vadose Zone Hydrology	Environmental Sociology	Differential Equations
Biogeochemical Cycles	Water Policy	Introduction to Partial Differential Equations
Limnology	Land Use and Natural Resource Economics*	Statistical Methods in Hydrologic Sciences
Ecosystem Ecology	Environmental Ethics *	Spatial Statistics
River Ecology	Ecological Economics	Mathematical Models in Biology
Hydro-climatology	Integrated Management	
Land and Water Dynamics		
Ecological Economics		
Planet Pathology		
Water in Geosciences		

* distance learning course, offered off-campus – and thus where appropriate available to minority undergraduates at the universities we have identified for minority outreach and recruitment

Table 5: Example Timeline for Program Completion								
	YEAR 1		YEAR 2		YEAR 3		YEARS 4-5	
	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring
IGERT Required Courses	Adaptive Decision-Making in Stressed Watersheds	Resilience in Complex Systems of Humans and Nature	Elective 1		Elective 3			
	Mini-Course in App. in Adaptive Management	Mini-Course in Comm., Conflict Res., & Leadership	Elective 2					
Research Activities	Research	Research	Externship, Research	Research	Externship, Research			
Other Activities	Retreat	Seminar	Retreat Grant writing Workshop	IASSA Exchange	Retreat	Seminar	Retreat	Seminar
Products			Externship, public policy forum, and mgt/policy report	Dissertation proposal	Externship present. at retreat		Complete Ph.D. dissertation	

Other Required Activities. IGERT fellows will participate in a number of other activities designed to develop them into a strong cohort. These activities include:

- ***An Annual Retreat.*** A two-day retreat will be held each year at one of multiple field stations in the state. The retreat will include oral and poster presentations by fellows and faculty; formal assessment and evaluation of student progress, program design and implementation; and short courses on selected topics. Each year the retreat will include a field excursion to a different aquatic habitat to discuss associated cross-cutting issues in the field.
- ***An Annual Conference in Water Science, Law, and Policy.*** UNL conducts a national conference in water science, law, and policy, which rotates among different groups on campus and addresses a different topic each year. Recent topics include "Finding Solutions to Multi-jurisdictional Water Conflicts" (2004), "Water Management and Policy in the Great Plains: Implications of Drought and Climate Change" (2005), "Adaptive Management for Resilient Water Resources" (2006), "Future of Water Use in Agriculture" (2007), and "Water Quality" (2008). During the conference, students will serve as hosts and meet with selected speakers for in-depth discussions. One of the keynote speakers will extend his/her visit to meet with students in a specialized mini-course.
- ***Law and Resilience Symposium.*** In September 2008, we organized the first symposium on this topic, sponsored by the UNL College of Law, the Center for Progressive Reform, and the Resilience Alliance, and papers presented there are being published in the Nebraska Law Review. Because of the success of this event, we expect to create a recurring symposium on this theme.
- ***Seminar Series on Water and Summer Water Tour.*** UNL's Water Center sponsors an annual seminar series on water and natural resource issues and a summer Water Tour, which brings together citizens, resource managers, state and federal agencies, and scientists to tour areas of the state with water-related problems.
- ***Responsible Conduct of Research Curriculum.*** As part of the institutional commitment to support high-quality intensive training of graduate students, the Office of Graduate Studies has developed a curriculum of formal and informal instruction in the responsible conduct of research. This curriculum, which includes a bi-monthly series of lectures, a graduate course in research ethics, and an annual half-day research ethics symposium, will be a required component of the instruction received by fellows.

- ***Grant Writing Workshops and Preparing Future Faculty Series.*** UNL hosts a series of programs designed to help graduate students prepare for careers as faculty members. These programs include an annual grant writing workshop and a formal graduate course devoted to preparing future faculty. This seminar hour course covers topics such as vita preparation and job search skills, teaching statement development, and mentoring and advising. The UNL Office of Research also offers an annual grantwriting workshop and research fair, providing opportunities to learn about funding trends and to talk with program officers.

Thesis Research and Advising. IGERT fellows will develop their dissertation projects by the middle of the second year of the program and present their dissertation proposal orally to IGERT faculty and fellows during a meeting of the spring seminar series. Research projects will embody the interdisciplinary themes of the IGERT program and be jointly supervised by a major advisor from the primary department and a co-advisor from another academic unit.

International Experience. To increase global engagement and broaden interdisciplinary backgrounds, we will provide IGERT students a semester of training at the International Institute for Applied Systems Analysis in Vienna, Austria to: 1) contrast the ecological and social challenges faced by similar, yet strikingly different, river systems; 2) train a cadre of graduate students in current techniques in resilience theory, adaptive management and governance, watershed science, and policy; and 3) lay the foundation for the next generation of European-American collaboration in interdisciplinary environmental science research. This international experience is further described in Section C.9.

Optional Experience. IGERT fellows, investigators or participants may choose to visit faculty involved with IGERT programs in Alaska (adaptation) or Arizona (urban systems) in order to learn from their successes and failures, and to continue to develop collaborations of mutual benefit.

Other Students' Participation in the IGERT. To broaden the experience of the IGERT fellows, they will have the opportunity to work closely with the Elementary Education Science Enhancement Project, a community project that connects young, low-income, urban, diverse, elementary students to the challenges of the environment and environmental science through after school programs led by School of Natural Resources graduate students. This program is designed to increase the participation of students from underrepresented groups in science. The outreach focus will be upon watershed challenges.

C.5. ORGANIZATION, MANAGEMENT AND INSTITUTIONAL COMMITMENT

Organization and Management. The training program will be administered by the IGERT Coordinating Committee (identified on page 1) with the addition of the Dean of Graduate Studies (Dr. Ellen Weissinger), one external agency representative, and a graduate student chosen annually by the fellows. This group will form the IGERT Steering Committee (ISC) (Figure 7). Each faculty member of the ISC will be responsible for overseeing a key component of the IGERT, including educational programs, recruitment and admissions, and advising and mentoring. The ISC will meet at least twice a semester. Once a year (or as necessary), the ISC will evaluate faculty participation in the IGERT based on a written evaluation from fellows, associates, and their faculty advisors. The Project Director (Dr. C. R. Allen) will be responsible for day-to-day IGERT decisions. Dr. Allen is Leader of the Nebraska Cooperative Fish and Wildlife Research Unit and Associate Professor in the School of Natural Resources, and sits on the Board of Directors of the Resilience Alliance. A half-time coordinator will assist the Project Director.
The Public Policy Center will serve as the coordinating entity for the externships. The Center is located in downtown Lincoln, in close proximity to the state's executive, legislative, and judicial government offices. The Center has conference room space for meetings with students and agency representatives, and has direct access to key policymakers in the region (Governor and agency offices, legislators and staff, trial and appellate court judges) who will help the students understand the possibilities and challenges for science impacting policy, law, and governance.