C. Project Description

1. List of Participants

Name	Role*	Institution/Org.**	Expertise	Previous IGERT
Graham E. Fogg	PI	Hydrologic Sci., UCD	Hydrologic systems	
Shu-Hua Chen	CoPI	Atmospheric Sci., UCD	Regional climate modeling	
Mark N. Lubell	CoPI	Env. Sci. & Policy, UCD	Water resources policy	0801430, trainer
Jay R. Lund	CoPI	Civil & Env. Eng., UCD	Water resources mgmt.	0801430, trainer
Reed M. Maxwell	CoPI	Geol. & Geol. Eng., CSM	Hydroclimate modeling	
Richard Howitt	FP	Ag. & Res. Econ., UCD	Resource Economics	
Tim Ginn	FP	Civil & Env. Eng., UCD	Model uncertainty	
Richard Grotjahn	FP	Atmospheric Sci., UCD	Meteorology	
Joyce Gutstein	FP	J. Muir Inst. Env., UCD	Outreach; env. justice	
Jan W. Hopmans	FP	Hydrologic Sci., UCD	Hydrology/climate coupling	
Robert Huckfeldt	FP	Political Sci., UCD	Pol. Sci., decision making	
Bertram Ludäscher	FP	Computer Sci., UCD	CS, informatics, data mgmt	
Isabel Montañez	FP	Geology, UCD	Paleoclimate reconst.	0982200, trainer
Kyaw Tha Paw U	FP	Atmospheric Sci., UCD	Land-atm. coupling	
James Sanchirco	FP	Env. Sci. & Policy, UCD	Resource economics	0801430, trainer
S. Geoffrey Schladow	FP	Civil & Env. Eng., UCD	Hydrologic systems; lakes	
C. John Suen	FP	Geology, CSU Fresno	Groundwater; isotope meth.	
James Quinn	FP	Env. Sci. & Policy, UCD	Informatics	0114432, trainer
Susan L. Ustin	FP	Hydrologic Sci., UCD	Remote sensing	0114432, CoPI
Bryan C. Weare	FP	Atmospheric Sci., UCD	Global & regional climate	

International participants

Name	Role*	Institution/Org.	Country	Expertise
José Luis Arumi	FP	Civil Eng., U. of Concepción	Chile	Hydrology; groundwater
Sonia Montecinos	FP	Center of Adv. Studies in Arid Zones	Chile	Atmospheric Sci.
Oscar Parra	FP	EULA Env. Sci. Ctr., U of Concepción	Chile	Environmental Sci.
Diego Rivera	FP	Civil Eng., U. of Concepción	Chile	Hydrology; irrigation

*FP: faculty participant; ** UCD: UC Davis; CSU: CA State University; CSM: Colorado School of Mines

2. Vision, Goals and Thematic Basis:

Climate change and related water problems pose some of the most formidable challenges to science and society today. Observations and modeling studies show that recent trends in temperature, river flows, and snowpack over the Western U.S. are changing significantly (Bonfils et al., 2007; Barnett et al., 2008). These trends will very likely continue and accelerate; extreme weather will occur more frequently, and sea-level rise will accelerate, possibly dramatically. Mediterranean-type environments such as California, the 7th ranked world economy, which produces 50% of the nation's fruits and vegetables with a limited water supply that depends precariously on snowmelt, will face enormous challenges in the coming decades. Major scientific gaps and socioeconomic factors preclude reliable predictions of climate change impacts on water resources, agriculture, and natural ecosystems on a sub-continental scale (e.g., California, Chile). Climate change requires attention from an unprecedented range of scientific disciplines, including atmospheric science, computational sciences, ecology, economics, engineering, hydrology, political science, and soil science, among others. Meaningful integration, analysis, and problem solving requires focusing research and training efforts on disciplinary interfaces connected by common objectives and problems.

Creating true integration in education and other endeavors is, in itself, a challenge (Jacobs, 1989), yet there are excellent examples in such efforts as the Manhattan Project, NASA's Apollo Moon Program, and the Human Genome Project (Fogg and LaBolle, 2006). The driving force behind each of these was a well-defined goal that marshaled the efforts and imaginations of diverse researchers, planners, and designers. The success of these projects can be attributed to funding, clarity of the goals as defined by the 'big problem,' and passionate belief in both the goals and their urgency. Similar passion and sense of urgency is present at UC Davis and our partner institutions, where concerns about the effects of climate change on water, ecosystems, and agriculture are addressed by many researchers, but have not yet been combined into a synergistic program. This IGERT in Climate Change, Water and Society (CCWAS) will tap into this energy to produce both cutting-edge research and graduates with the needed interdisciplinary perspectives and skill sets. In summary, the key unifying characteristic of this CCWAS IGERT is the urgency and gravity of the problem itself.

Climate and water phenomena are integrally linked, yet climate and water (hydrologic) sciences remain mostly disconnected both inside and outside the academy. Negative consequences of this include our inability to adequately predict future effects of climate change on sub-continental scale water resources. Similarly, social science in the academy is typically poorly connected to the climate and hydrologic sciences, hampering effective dissemination to individuals and political systems. The overarching goal of the CCWAS IGERT is to **produce new generations of scientists and policy makers and to transform both science and graduate education at the interfaces of hydrologic, atmospheric, and social sciences.** Specific objectives are to:

1. Train graduate students to be both deeply competent in one or more specific disciplines and broadly knowledgeable in the multiple disciplines required to address the linkages between climate change, water, and society.
2. Train graduate students to become acutely aware of policy issues and use this awareness to define research goals, and to communicate their research to decision makers and the public in a way that affects or transforms policy.
3. Train students to have an international perspective on climate, water, and society and are use that perspective to improve their research, whether their topics are domestic or international.
4. Train students to understand and use quantitative tools for modeling or interpreting hydroclimate systems, including accounting for the effects of human and policy decisions.
5. Develop the CCWAS concept into a vigorous, long-term graduate program that not only addresses fundamental and applied problems of climate change, but also strengthens the individual component disciplines.

There is currently a dearth of scientists with the necessary background in atmospheric and hydrologic sciences to perform research or problem solve at the interface between climate and hydrologic analysis. Accordingly, this IGERT emphasizes the unification of climate and hydrologic sciences into a nascent, graduate discipline that we will call *hydroclimatology*. Hydroclimatology is not a new term; many campuses offer undergraduate courses in it. In the context of this IGERT, however, hydroclimatology is a nascent discipline because it represents the unrealized unification of hydrologic, climate, and social sciences at the graduate level.

To better predict and understand local as well as global scale climate change and hydrology, models must integrate climate drivers with hydrologic feedbacks and human behavior. Moreover, as demonstrated in the current muddle of public opinion and governmental action on climate change, such models must take into account how societies will adapt to climate change and what feedback those adaptations will have on climate and hydrology. One key component to understanding societal adaptation is to learn how decision-makers (e.g., policy makers, and individual water users, such as farmers) make decisions under uncertainty. Without better coupling among climate, hydrology, and social science models, the predictive capability of hydroclimatology will be severely limited. One of the critical gaps in the current models is a better understanding of decision making in the context of natural, social, and political uncertainties, which can only be addressed with the integration of social science research. This information will not only improve the prediction of the models, but it is also critical for effecting positive change on the management of the earth's climate and water systems. In this way, the three legs of the 'tripod' — water, climate, and society — are inseparable for addressing the pressing issue of climate change, a field of science that is likely to dominate research and policy for decades to come. Accordingly, the CCWAS IGERT is designed to create a new standard of scientific collaboration that promotes the ability to work in interdisciplinary teams, using effective communication across disciplines, while still developing a deep knowledge of one's own field.

The graduate training and research efforts of CCWAS will focus on climate change and water in Mediterranean-type systems, with California and Chile as the main foci. Like other Mediterranean-type systems around the world (e.g., the Middle East, Mediterranean Europe, South Africa, Western Australia), these systems are major global economies that operate in water-limited environments and rely on stored water or mountain snowpack. These traits make the Mediterranean-type system particularly vulnerable to climate change effects on aquatic resources, drinking-water supply, and food supply. Complex interactions, feedbacks, and tradeoffs remain incompletely explored and understood. These issues will be important in determining land use changes, such as agricultural commodity production, urbanization, and water management and ecosystem functions. How society will mitigate and adapt to these changes through public policy and changing environmental behavior is vital. Importantly, current hydrologic and agricultural predictions are inadequate and unreliable at the resource-management scales.

Rather than organizing CCWAS around separate cores within traditional disciplines, it is organized around the disciplinary interfaces shown in red in Fig. 1. Each research project is defined at the interface between fields, and the training program is designed to provide the 'connective tissue' for each interface and the overall program. The training program is structured around a Designated Emphasis (DE) degree program that will appear on the diplomas along with the disciplinary Ph.D. degree. The DE includes a core introductory course, interface courses (Fig. 2), and an innovative capstone course that culminates in a "State of Climate and Water" conference and world café style forum in Sacramento, which will bring natural and social scientists together with government decision makers to identify the current state of hydroclimatology in Mediterranean ecosystems and the research gaps that will also provide CCWAS students with possible dissertation topics.

A unique feature of CCWAS is the opportunities for direct engagement with science and policy on climate change afforded to the graduate trainees by working with faculty, other scientists, policy makers in government agencies, and NGOs. Chile is beginning to adopt aggressive research and education programs on climate change and water (National Climate Change Action Plan, 2008) that will provide immediate international opportunities for comparative natural and social science. California is currently engaged in a range of aggressive actions, including the implementation of legislation (AB32: Global Warming Solutions Act of 2006) and creation of the interstate Western Climate Change Initiative, and a host of major long-term water and environmental management issues, ranging from the Sacramento-San Joaquin Delta to Federal Energy Regulatory Commission hydropower re-licensing. The state has adopted an aggressive strategy in dealing with climate change, and state agencies are developing programs to mitigate and adapt to climate change, involving many state agencies and substantial state resources for climate change research, in which UC Davis has been very active. Student opportunities in this IGERT will extend beyond participation in climate change research and will include application of research results toward active state policy-making.

In summary, there are important problems bridging the disciplines of atmospheric science, hydrology, and environmental policy that involve major decisions regarding water issues in Chile, California, and other Mediterranean-type ecosystems. This IGERT creates an educational structure for students that surpasses the capabilities of traditional disciplines by linking all of the affected disciplines into an integrative Ph.D. program that responds to the future demands of climate and water sciences as well as the needs of decision makers.

3. Major Research Efforts:

To stimulate collaboration toward a common goal this CCWAS IGERT will focus on the problem of water resources. CCWAS provides doctoral research opportunities that explore both the natural and social science questions essential to the future of water resource management in a changing climate. In the natural sciences, students will develop advanced modeling and statistical tools for better resolution of regional climate and hydrologic processes, and advanced methods for dynamically linking climate and hydrologic models; represent complex processes across multiple space and time scales; calibrate and analyze models of uncertainty propagation across multiple model interfaces; evaluate effects of shifting streamflow rates and temperatures on the viability of endangered species, such as salmonids in the sensitive Sacramento-San Joaquin Delta; and develop advanced methods for effecting greater subsurface water storage

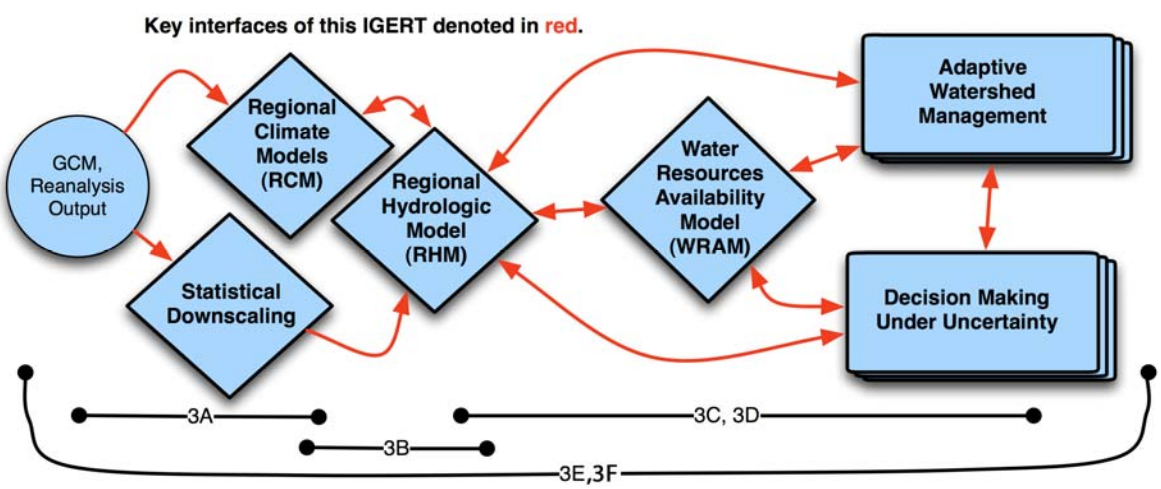

Figure 1. Major integrated research and training efforts. Key interfaces in red. Letters refer to sections in the report. E.g. "3A" corresponds to section 3A, GCM-RCM Interface.

and recovery. In the social sciences, students will analyze the costs and benefits of different adaptive water management options; study the development of mitigation policies over time; develop strategies for decision making under uncertainty; and learn the flow of scientific information through policy networks, and how different types of experts become recognized and capable of influencing the beliefs and decisions of other actors.

Some of the major research opportunities lie in the modeling of hydroclimatology at the regional scale and the translation of results into policy and management. Just as general circulation models (GCMs) have greatly facilitated interpretation of climate data and provided long-term forecasts at the global scale, there is an unmet need for regional climate models (RCMs) that are linked to regional hydrologic models (RHMs) to create a better understanding the future effects of climate change on water resources at the regional or sub-continental scale (e.g., California, Chile).

Recent reports emphasize the need for greater understanding of mesoscale climate (CAIICPP, 2010) in general and hydrologic issues (Bates et al., 2008) in particular. CAIICPP (Committee on Assessment of Intraseasonal to Interannual Climate Prediction and Predictability) recommends better interaction between modelers, operational (forecast) agencies, and users (including other agencies). Fostering such interaction is emphasized in this IGERT. CAIICPP also recommends improved statistical and dynamical downscaling techniques, and identifying and reducing systematic errors. Examples of research priorities in this vein include improved land-atmosphere feedbacks and handling trends (non-stationarity), both of which are components of this IGERT. More specifically to hydrology, Bates et al. (2008) emphasize tackling many gaps in current knowledge including: (a) how climate change is expressed at small scales due to topography, too limited spatial resolution, and too few ensemble runs of the climate models; (b) how extreme events occurring on short time scales offset seasonal changes, reducing the mismatch between global climate model and catchment scale (key for water management); (c) which models allow water managers to assess climate-linked impacts on freshwater resources; (d) what the water-related consequences of different climate policies and development choices are; (e) what the climate change impacts are on water quality (especially during extreme events) and aquatic ecosystems (temperature, flow regimes, water levels, etc.); (f) how climate change impacts water demand and other socio-economic issues; and (g) how to integrate reservoir and flood control systems with climate change knowledge. This IGERT addresses all these gaps by training a new generation of scientists who are capable of integrating the fields of hydrology, atmospheric science and environmental policy; have an international perspective of physical and political aspects of climate change; and are able to communicate with their research colleagues, decision-makers, and the general public.

The following sections outline the CCWAS research vision, including both near-term research ideas and some of the grand challenges that will sustain the CCWAS graduate training program long after the IGERT funding stops. The interfaces are indicated in red in Figure 1, and the section letters are shown at the bottom of the figure.

A. GCM-RCM Interface (Chen, Maxwell, Ginn, Grotjahn, Ludäscher, Ustin, Weare, Montecinos):

Current coarse resolution GCMs (e.g., Solomon et al., 2007) require additional steps to downscale climate effects to the level of ecosystems, including more analyses of uncertainty. Examples of potential dissertation topics include: (a) research on effects of hydrologic feedbacks at the GCM scale; (b) development of GCM-RCM models capable of simulating extreme climate events such as mega-droughts; (c) impact of regional climate change on frequency and severity of the extreme weather events, such as drought and west coast winter storms that can cause catastrophic floods. This topic also has potential for a number of research topics on management and societal aspects of extreme events; (d) development of more refined GCMs that require less downscaling so that loss of information or system dynamics through the downscaling process can be studied; (e) use of historical analysis and rescaling of model simulations to improve RCM simulations of present climate, which is still not adequately captured by the models in terms of variability of temperature, pressure and precipitation; and (f) estimating GCM-RCM uncertainty. Some specifics are provided below.

Our primary downscaling approach uses a regional climate model. The RCM will be based on the Weather Research and Forecast model (WRF; Skamarock et al., 2008), a community mesoscale atmospheric model, which will be adopted for dynamically downscaling GCM simulations to higher resolution (initially 4-km spatial interval) over California using a multiple domain nesting technique (Zhao et al., a and b, in preparation). Over the course of CCWAS and beyond, students and faculty will work with a wide variety of simulations driven by global CMIP5* output archived at the Program for Climate Model Diagnosis and Intercomparison, the primary international clearinghouse for global climate model simulations, including data sufficient to drive RCMs (Taylor et al., 2009).

The computational requirements of these RCM simulations are extreme and limit the number of model runs. To span the range of possible future climates and best capture the uncertainty, we focus on different models and IPCC (Intergovernmental Panel on Climate Change) scenarios and not different initial conditions. Our plans call for at least 16 combinations of 10-year GCM-WRF runs based on 4 historical and 12 future climate runs. Co-PI Shu-Hua Chen has extensive experience with WRF, including simulations of California climate using 6 different physics combinations of physics schemes (Zhao et al., in preparation). From those, she and her students will identify the best combination, in particular for winter storm temperature and precipitation, to use in our RCM.

The historical climate simulations are driven by 3 different GCMs and 1 reanalysis, where the reanalysis helps parse the bias due to WRF from that due to the GCM. The future climate simulations use the same 3 GCMs coupled with the WRF RCM to investigate the 4 IPCC AR5 scenarios. The primary IPCC AR5 estimates of future climate give 4 scenarios of radiative forcing: one low, one high, and two intermediate ‘mitigation’ amount scenarios. One primary focus of our downscaling will be to compare ten years of present climate versus ten years of future climate simulations consistent with CMIP5 guidance.

Other efforts will include downscaling techniques using statistical methods (instead of an RCM) and will analyze extreme precipitation events directly from the large scale flow in the GCM output (Grotjahn and Faure, 2008; Grotjahn in preparation). Though the statistical analysis is limited to extreme events, it is highly efficient, and will thereby allow the analysis of output from many GCMs.

B. Climate-Hydrology Interface (Fogg, Chen, Maxwell, Ginn, Hopmans, Ludäscher, Montanez, Paw U, Schladow, Suen, Quinn, Ustin, Weare, Grotjahn, Montecinos, Arumi, Parra, Rivera):

This is a particularly exciting time for climate and hydrologic scientists as the combination of computational means and scientific understanding make possible the first ever unified hydroclimate models, which will ultimately produce better climate and water resources analyses. Another critical spin-off of this scientific trend will be the first ever models of the hydrologic cycle, which is key to earth system science. Examples of potential dissertation projects include: (a) the interdependence between hydrologic feedbacks and atmospheric processes under climate change for Mediterranean-type (California and Chilean) systems; (b) the importance of groundwater, surface water, and agricultural (irrigation) management decisions for current and future climate; (c) the spatiotemporal scaling of both water management (irrigation) and land-energy fluxes in the atmosphere; (d) the roles of uncertainty and temporal variability in the management of extreme climatic events, such as flood or drought; (e) the role of coupled physics in downscaling hydrology from global to regional extents; (f) characterization of hydroclimate model uncertainty; and (g) the use of hydroclimate modeling to examine potential causes of deep (geologic) time climate fluctuations. Some specifics are provided below.

Regional hydrologic response to climate change under uncertainty will be examined through research in three areas: (1) hydrologic models for simulating the relevant, multi-scale, 3D phenomena, including surface and subsurface processes; (2) model efficiency sufficient to enable simulation of a large number of scenarios in a Monte Carlo or other framework; and (3) efficient, reliable coupling between the hydrologic, landscape processes, and climate models, which involves significant scaling from the soil and leaf level to the global level. Items (1) and (2) have already been partially achieved with the terrestrial hydrologic cycle model known as ParFlow (Ashby and Falgout, 1996; Jones and Woodward, 2001; Maxwell et al., 2007; Kolllet and Maxwell, 2008; Maxwell and Kollet, 2008; Kollet et al., 2010; Maxwell et al 2010). ParFlow was originally developed at the Lawrence Livermore National Laboratory (LLNL) and is ideal for this problem because of its properly-coupled physics and the unequaled efficiency achieved through fully parallel computation and state-of-the-art linear and nonlinear solvers. This model has been coupled to two atmospheric mesoscale models, ARPS (Maxwell et al., 2007) and WRF (Maxwell et al., 2010); the latter is a seamless fit between downscaling GCM, RCM and integrated hydrology. Additional research is needed, however, to properly address uncertainty within this coupling process that is also mentioned in 3A (above). While ParFlow (PF) has been used in a Monte Carlo approach for coupled simulations (e.g., Maxwell and Kollet, 2008; Meyerhoff and Maxwell, in preparation) — particularly for coupled PF.WRF simulations (Williams and Maxwell, in preparation) — the computational expense of ParFlow, WRF and PF.WRF is prohibitive for very large ensembles (~1000 members) and in these cases another approach might be needed. In other words, the hydrologic and atmospheric scientists must work together to both ensure adequate coupling of processes (without introducing significant error) and analysis of uncertainty. Feedbacks between landscape and atmospheric processes are key aspects of the coupling (Paw U, 1997; Pyles et al., 2003), which is also affected by the exchange of water between the surface and subsurface (Niswonger and Fogg, 2008), and snow hydrologic processes in the upland watershed (Rutter et al., 2009; Bales et al., 2006). The UC Davis-developed land surface model ACASA, which uses advanced turbulence transfer parameterizations, has shown accurate snowpack predictions in the SNOW-Mips project (Rutter et al., 2009) and is currently being coupled to the WRF model to examine landscape-atmosphere feedbacks.

The downscaled GCM-RCM-RHM PF.WRF framework is naturally suited to climate change impact assessment because it brings the global scale phenomena down to the (regional) scale at which resources are managed. As it provides a seamless way to bridge these scales, a number of projects can be easily focused on these topics. As described in Education and Training, one of the novel, innovative courses to be developed (by Co-PI's Chen and Maxwell) will also train students to use this modeling framework.

Because the PF.WRF framework is a unique RHM capable of simulating fluxes at all pertinent interfaces, it becomes an important tool for understanding feedbacks between the terrestrial and atmospheric hydrologic cycles. Recent work has demonstrated the importance of these interactions, particularly for groundwater (Maxwell et al., 2007; Jiang et al., 2009; Anyah et al., 2008; Maxwell et al., 2010), and has shown that these feedbacks may indeed amplify under a changing climate (Maxwell and Kollet, 2008; Ferguson and Maxwell, 2010).

While climate change impacts on the hydrologic cycle are an important anthropogenic stressor, they are not the only one. Management of water resources, for example pumping, irrigation and diversion, also has significant impacts on land-energy fluxes and land-atmosphere interactions. Observational work has shown that irrigation practices in the California Central Valley has decreased daytime peak summer air temperatures (Bonfils and Lobell, 2007; Lobell and Bonfils, 2008). This has been confirmed by modeling studies at a range of scales (e.g. Lobell et al 2006; 2009; Kueppers et al 2007). Recent work also studies not just irrigation but pumping and irrigation in combination, and the impacts on both hydrology and land-energy fluxes (Ferguson and Maxwell, 2010). These studies all demonstrate the need for modeling the fully coupled hydroclimate system.

C. Water Availability and Adaptive Watershed Management (Fogg, Lubell, Lund, Maxwell, Howitt, Ginn, Hopmans, Huckfeldt, Ludäscher, Paw U, Sanchirico, Schladow, Suen, Quinn, Ustin, Arumi, Parra, Rivera):

Adaptive management has been forwarded by a variety of scholars as a mechanism for responding to uncertainty through policy learning (e.g., Holling, 1978). Policy learning can occur through active experimentation with different management practices or by passively learning from the results of previous decisions on topics that include water use efficiency or water conservation, market and non-market reallocations of water, investments in storage infrastructure, water conveyance, water reuse, desalination, and improvements in system operations (such as conjunctive use of surface and ground waters). Current adaptation efforts are already underway, such as the Integrated Regional Water Management Plans that are now required in California to directly address climate change; however, most such planning and climate change preparation is not being implemented with much systematic analytical integration.

A key requirement of adaptive management is the integration of quantitative environmental models with economic models of ecosystem services. At UC Davis, we have developed the CALVIN statewide economic-engineering water model to analyze how the entire California water system can adapt economically to major changes in hydrology, infrastructure, technology, and water management policies (e.g., Tanaka et al., 2006). Another complex system model is the Statewide Agricultural Production Model (SWAP; Howitt et al. 2001), which was originally developed using positive mathematical programming to provide the economic scarcity cost of water for agriculture to CALVIN. SWAP predicts how change in water supplies affects crop choices, expected profits, and employment levels, and agricultural inputs like nitrogen and pesticides, CCWAS trainees have opportunities to more closely link models like CALVIN and SWAP to process-oriented hydro-climatological models that improve the ability to represent more localized water management decisions.

More theoretical economic models are needed to understand the link between learning and risk. Water and climate policy decisions often involve irreversible outcomes (e.g., large infrastructure investments and lost ecosystem services) coupled with limited information (Arrow and Fisher, 1974) and dynamic non-stationary processes (Leroux et al., 2009). Management decisions may influence the rate of learning, and the optimal course of action depends in part on the value of information expected to be generated (Springborn et al., 2010, Springborn, in preparation). Management decisions also may lead to endogenous perturbations in environmental change and behavior responses of the actors involved; decisions take place in the context of endogenous risk (e.g., Kane and Shogren, 2000; Katzner, 1998; Perrings, 2003).

Another important research activity is studying adaptive management in the field; this links with research on decision making under uncertainty, discussed below. Many different water management programs in California and Chile are described as using "adaptive management." Some of these water management programs are explicitly considering climate change effects but, as previous research has shown (Leach, Sabatier, and Quinn), many so-called adaptive management programs do not even have enough resources for environmental modeling. Climate change only increases the difficulty of making adaptive management more than a vague, non-science-based prescription. IGERT students will research the conditions under which adaptive management is successfully implemented.

D. Decision Making Under Uncertainty (Fogg, Lubell, Lund, Maxwell, Howitt, Gutstein, Huckfeldt, Ludäscher, Sanchirico, Quinn, Arumi, Parra):

Decision making under uncertainty is the fundamental issue in trying to understand how societies will respond to climate change (Webster et al., 2003). The decisions of individuals and organizations directly affect both mitigation (e.g., what type of car to drive) and adaptation (e.g., what irrigation methods to use). Much research is devoted to models of decision making under uncertainty, ranging from rational models of Bayesian updating to more psychological and behavioral models (Tversky and Kahneman, 1974), but important questions remain about how such psychological processes influence perceptions and actions regarding climate change, policy-related learning, the overall level of uncertainty and knowledge among key decision-makers, and cross-cultural differences in how uncertainty affects decisions.

CCWAS IGERT research will explore different definitions of uncertainty (e.g., risk versus ambiguity), strategies for dealing with uncertainty (e.g., active and passive adaptive decision making, heuristics, robust decision making), and appropriate strategies for communicating uncertainty. Decision making under uncertainty links the climate/hydrological models to the social science research in two main ways: First, hydroclimatological model predictions depend on how users will respond to climate change, which in turn depends on the political system and perceptions of policymakers and individuals. Second, model outputs include varying levels of uncertainty that will be useful in designing experiments to better understand how decision-makers respond to different forms of communicating uncertainty.

Laboratory experiments are a good research tool for exploring how people react to different types and presentations of uncertainty. Much of the original research on decision making under uncertainty was done through experiments (Tversky and Kaheman, 1974; Payne et al., 1993). This tradition continues in the context of many of the Decision Making Under Uncertainty (DMUU) programs funded by NSF. IGERT students will be able to draw on a variety of experimental facilities and experience at UC Davis. Co-PI Lubell and colleagues conduct experiments about social learning and uncertainty using a web-based platform for laboratory and field research. Trainer Bob Huckfeldt has conducted extensive experiments about how uncertainty and the structure of social networks influence political decisions and attitudes; the UC Davis political science department has a computer lab dedicated to such experiments. CWWAS students can adapt the Gameweb and political science computer facilities to study decision situations relevant for climate change, water, and society; for example, by including visualizations of model results and uncertainty, and by conducting field experiments with decision-makers, such as farmers and water district managers.

At the same time, it is crucial to understand how uncertainty, scientific information, and scientists themselves interact with the political system and policy networks. The normative model of the role of science in policy-making assumes that policy actors will use scientific information in ways that reduce conflict and produce better decisions. CCWAS students will develop and test hypotheses about how uncertainty *actually* enters into the decision calculus of individual actors and influences behavior. Six major factors are likely to influence how policy actors will use climate science to analyze uncertainty: political incentives, social values, decision resources, institutional structures, policy networks, and the format in which scientific information is presented. The lessons learned from field studies of uncertainty, decisions, and policy will also be useful for better designing effective science outreach efforts.

The attitudes and beliefs of the general public influence the political debate over climate change policy as well as the adoption of individual-level adaptation and mitigation strategies (Lubell, et al., 2007) The general public in the United States and other countries continues to have uncertainty about the causes and consequences of climate change, especially as linked to water availability at the community level. CCWAS social scientists will train students in a variety of public opinion research related to uncertainty, citizen social networks, political attitudes, and environmental behavior.

Field research in these settings involves qualitative case study methods and quantitative methods like surveys and network analysis. CCWAS students can integrate social and natural sciences in a variety of ways, for example by making survey responses geographically explicit so that individual respondents can be linked to landscape characteristics like predicted changes in precipitation (amount/timing) and temperature. Modern surveys via internet and telephone also allow for experimental manipulation of question formats and information presented, for example, evaluating how opinions about climate change are affected by different types of uncertainty visualizations and information. Empirical results about how decision-makers react to climate change and uncertainty can then be built back into hydro-climatology models, for example using agent-based models to represent the decision rules of actors on the landscape (Happe et al. 2006; Berger et al. 2006).

Potential CCWAS student projects on decision making under uncertainty are perfectly suited to Mediterranean-type ecosystems like California and Chile. For example, the Integrated Regional Water Management process mentioned earlier involves a wide variety of policy actors with different levels of uncertainty and access to scientific information. These policies ultimately target resource behavior among water users like farmers and water district managers, who also experience and react to uncertainty in different ways. Similar watershed planning efforts and water management decisions occur in Chile, providing a unique opportunity for comparative institutional and cultural analysis.

E. Integration Through Computer Science and Informatics (All, led by Ludäscher & Quinn):

The integrative regional scientific analyses and policy applications central to the CCWAS mission require novel couplings of the regional data resources and modeling frameworks of several highly quantitative disciplines (e.g., downscaled RCMs, watershed-scale hydrologic models, water infrastructure plans, network analysis of decision processes, and water economics assessments). While we expect CCWAS students to learn the underlying concepts of several tools, each trainee will ultimately be responsible for mastering one of the many tools used in an orderly scientific workflow by an interdisciplinary team, learned in a trainer's lab, and collaboration with peers will generate the integration. Students in our participating disciplinary graduate programs all are required to master the quantitative tools of their field before their qualifying exams. CCWAS will expose them to the additional informatics tools needed for more effective team science. A team-science toolkit must include an understanding of reconciling semantics of heterogeneous information sources, designing and documenting scientific workflows (e.g., how to pass outputs of one model to a subsequent model), developing robust documentation and metadata, version control and data integrity, module validation, propagation of error, identifying outliers and anomalies, visualization, and robust tracking of information provenance. Working with these tools also provides experience with project management, best practices in data security, estimating computational requirement, and related skills essential to managing team science. With active participants initially in Colorado and Chile (presumably to expand to colleagues doing hydroclimatology in other Mediterranean and snow-melt driven systems), students will also need to master emerging open-source collaboration environments, and we expect most students to become proficient with some combination of content management systems, linked-data and other cloud data resources, remote cluster-computing, and related eScience skills required for large-group collaborative science,

Specifically, tools for conceptual and data modeling, process modeling, data analysis, and workflow automation will be an integral part of a dedicated computer science and informatics course (ECS-268), and of a summer training workshop on *"eScience Tools and Cyberinfrastructure".* Similar to conventional scripting approaches (e.g., in Perl or Python), scientific workflow tools such as Kepler (Ludäscher et al., 2006b) allow scientists to chain together complex scientific applications from pre-existing tools or other applications and workflows. These tools also facilitate the deployment of certain workflows on computer clusters and clouds, e.g., by automating job submissions, execution monitoring, on-the-fly analysis, and archiving (Ludäscher et al., 2009). The ability to automatically track and subsequently query data lineage relations and provenance information also provides unique opportunities for scientists to not only describe and execute their computational methods (i.e., as workflows), but also to “explain” (or just debug) their results based on provenance information and trace graphs (Freire et al., 2008; Bowers et al., 2008; Altintas, in preparation; Anand, 2010).

The CCWAS program will also advance computer science and eScience by germinating specific Ph.D. dissertation topics at the various science and computing interfaces (Fig.1). Core areas for research include management and integration of scientific data (Ludäscher et al., 2006a), scientific process automation and workflows (Deelman et al., 2009; Ludäscher et al., 2009), data lineage and provenance (Davidson et al., 2007), fault-tolerance in scientific workflows (Crawl & Altintas, 2008), management of real-time data streams (Rueda & Gertz, 2008), optimization of dataflows (Zinn et al., 2009), parameter sweeps (Abramson et al., 2009), and code-coupling (Podhorszki et al., 2007), among several others.

F. Chilean Analysis & Exchange:

Because the climate, hydrology, geology, and agricultural systems of California and Chile are so similar, numerous research opportunities exist in the area of comparative analysis. On the other hand, the differing government and cultures between the two regions pose some fascinating social science contrasts. Much of the hydroclimate and social science research will spring from the California-based research, but the transferability of those methods and findings first to other Meditarranean systems and to other environments must be examined. Application to the Chilean system offers the vital first step in generalizing the research globally. Some potential research genres include the development of models/methods of decision making under uncertainty for the different cultural ‘landscapes’; hydroclimate consequences of having a more glacial dominated cryosphere in the Andes as compared to the Sierra Nevada; water management consequences of having a less prolific aquifer system beneath Chile’s Central Valley as compared to California’s Central Valley; and hydroclimate effects on agricultural production (as determined by water availability) in California and Chile.

A fully functioning scientific collaboration requires two-way exchange. One half of this exchange is already happening through the MOU between the Chilean government (Becas Chile) and UC Davis that fully funds Chilean students to pursue degree-track graduate studies at UC Davis. CCWAS would contribute the other half of the exchange by sending our IGERT Fellows to Chile for research and training.

Program Director Graham Fogg and Trainer Jan Hopmans already have cooperative research with U. of Concepción on the effects of warming on snowmelt timing and seasonal water supply. Similar types of runoff timing signals also exist in California, where a century of data are available, and will be used to calibrate the PF.WRF model of hydrology, which will ultimately form the basis for calibration of similar models for Chile. Trainer Geoff Schladow also is collaborating with Universidad de Concepción faculty on the response of lakes to climate change, while Chen is collaborating with Montecinos (Center for Advanced Research in Arid Zones (Centro de Estudios Avanzados en Zonas Áridas); CEAZA) on regional weather modeling. By the end of 3-4 years, we anticipate having the foundation in place for ongoing comparative analyses of CA and Chile watershed responses to warming, and for parallel modeling efforts of both systems. CCWAS faculty also have links to Chilean social scientists, which will be further developed as part of the IGERT. This will allow inter-country, comparative analysis about policy responses to climate change, the structure of policy networks, and the decision making processes of different types of actors (e.g., farmers and water managers). These types of comparative analyses are rare and valuable in both the natural and social sciences. It will be very informative to students in both Chile and California to engage in a comparative analysis through conversation and research collaborations.

4. Education & Training:

A. Background and Educational Perspective:

The motivation for interdisciplinary graduate education is to solve the problems that cannot be handled through traditional, single discipline approaches; to stimulate individual disciplinary progress through cross-pollination from other disciplines; and to train the next generation of interdisciplinary scientists and decision makers. Therefore the motivation for interdisciplinary education is strongly problem driven. Certain interdisciplinary “challenge problems” require not less disciplinary strength, but teams of people from the appropriate disciplines that are capable and highly motivated to collaborate toward common goals (Jacobs, 1989). Such collaboration requires that the team members care deeply about the end goal of the work, need each other to reach that goal, and are able to communicate effectively with one another.

While the fundamental social problems and scientific challenges identified by the CCWAS vision are a strong motivation, simply bringing students and faculty together in ways that helps them communicate and develop integrated research is not enough. A strong and effective program must also include a mechanism that draws the participants into a collaborative process that is actively pursued by the participants. In CCWAS, the collaborative process will develop through a two-year, six-quarter capstone course, while the communication and community aspects of CCWAS will come through a core course, interface courses, and domestic and international internships.

Why hydroclimatology as an academic program and why now? Hydrology and atmospheric science have remained rather separate because, historically, they have managed to achieve their respective objectives concerning relatively short-term water problems and weather without much help from each other. Although climate change is not the sole reason for integrating hydrologic and atmospheric sciences, it has presented us with the impetus for reexamining both disciplines. Analysis of climate change mitigation *and* effects requires climate modeling over long time scales, and research is showing that the climate models need to improve by incorporating hydrologic feedbacks (Anyah et al., 2008; Maxwell et al., 2007 and 2010). Similarly, hydrologic models of the effects of climate change on water resources require tight coupling with the climate models for simulating precipitation, evapotranspiration, and temperature, among others. Nevertheless, hydrologists and atmospheric scientists are routinely granted Ph.D. degrees even though they lack the knowledge and tools to integrate their models for better predictions and analysis. Some Ph.D. students are getting the necessary, integrated background, but only if they happen to be with the handful of groups who are trying to model hydrology and climate change. This training problem can be addressed by interface courses aimed at the key interfaces between hydrologic and climate models, and students will want these courses in order to improve both types of models while creating the next generation of hydroclimatological research.

Why social science with hydroclimatology and why now? Both hydrology and climate science have had their share of scientific successes *without* commensurate benefits to society and actual problem solving. For example, climate scientists have made great strides in understanding effects of greenhouse gases, yet large fractions of the public and informed decision makers remain unconvinced. The failure to integrate scientific findings into policy results from an insufficient understanding of how decision makers process scientific information, how the structure of social networks influences the flow of scientific information, and how institutions shape the incentives of decision makers to use science. At the same time, many of the individual and policy decisions regarding climate and water resources directly affect the inputs into climate and hydrological models. Hence, the hydroclimatological models are necessarily incomplete without understanding feedbacks from social, economic, and political processes.

The CCWAS training program addresses these gaps at many levels, but we do not attempt to turn natural scientists into social scientists or vice versa. Rather, the natural and social science elements are designed to create synergies and cross-pollinate the various involved disciplines. CCWAS coursework will expose students from other disciplines to theoretical concepts and methods from multiple disciplines without sacrificing the core disciplinary training that is necessary to push at the frontiers of various fields. At the same time, the capstone course and internship opportunities provide the venues for students to bring all of their disciplinary and interdisciplinary training to bear on a common challenge and set of activities.

B. Focus Group of UC Davis IGERT Fellows:

In designing the training program, we conducted an online focus group of past and current fellows of two existing IGERT programs at UC Davis. The focus group was provided a description of the overall objectives of CCWAS and the major training elements, and asked to provide written recommendations. The fellows enthusiastically supported the CCWAS concept and predicted that it would attract many high quality students who would become leaders in the science and decision making related to climate change and water. They recommended that the IGERT be as integrated as possible with existing graduate programs by limiting the number of new courses that would be required for any particular degree, thereby ensuring timely progress. They also stated that internships were quite valuable, and that CCWAS trainees should have the freedom to choose the time and place so as to maximize fit within the individual student's program and schedule. The fellows asserted that science communication is very important and should be built into the core course. Importantly, these IGERT veterans engaged in a second-year project that many thought functioned more as a detour away from their dissertation research than as a bridge. Therefore, in CCWAS, our second year capstone course and conference is designed to integrate within and accelerate each fellow's dissertation research.

These on-the-ground perspectives of the UC Davis IGERT fellows were helpful in designing the CCWAS education and training plan. We have decided to take this input a step further and ensure that CCWAS fellows play a significant role in the ongoing management and oversight of CCWAS. We plan to have at least two fellows on the CCWAS Executive Committee.

C. M.S. to Ph.D. Bridge Program with California State University, Fresno (CSUF):

CSUF is a Hispanic-serving institution located in the San Joaquin Valley at the base of the Sierra Nevada mountains, the main source of California's water, including the irrigation water that sustains this extremely productive agricultural valley. Because of this setting, many students at CSUF are tuned in to the ongoing and future effects of climate change on the mountain ecosystem, agriculture, regional water supply, and the farm economy. Through our CSUF collaborator, Dr. John Suen, CSUF faculty in Earth and Environmental Science, Civil and Geomatics Engineering and Political Science programs have committed to coordinating the M.S. curricula in Geology, Civil Engineering and Public Administration to enable graduates of these programs to become CCWAS fellows. Through the cyber-enabled distance learning facilities at UC Davis, Colorado School of Mines and CSUF, students at CSUF will also be able to enroll in certain CCWAS courses and participate in video conferencing. CSUF students who are potential CCWAS fellows will also be invited to participate in the Capstone Conference, described below. There is already an MOU in place allowing CSUF students to enroll in and receive credit for UC Davis courses.

D. Connections with Colorado School of Mines and Chilean Partners:

As with the CSUF partnership, the connections with Colorado School of Mines (CSM) and the Chilean partners will enhance the CCWAS research and training program. At any given time, at least one of the IGERT Fellows will be a CSM student under the joint mentoring of Co-PI Reed Maxwell (faculty at CSM) and one or more UC Davis–based IGERT trainers. The CSM CCWAS fellows will spend their first year of the program at UC Davis and their second year at CSM. Just as with the UC Davis students, CSM fellows will graduate with an existing degree title on their diplomas (Hydrologic Science and Engineering), but a CCWAS emphasis will also appear on their transcript. In year two, CSM student(s) will stay plugged into the ongoing CCWAS activities at UC Davis through our already considerable distance learning and web conferencing capabilities that are described in the Facilities section. Moreover, because of modest airfares between Sacramento and Denver, both Maxwell and CSM students can easily frequent the UC Davis campus for in-person participation. CSM aims to continue this program beyond the 5-year term of the IGERT, greatly extending the reach of CCWAS into U.S. graduate education.

Universidad de Concepción is already sending graduate students to UC Davis through the MOU arrangement between UC Davis and the Chilean government. CCWAS will complement this by sending IGERT fellows to study at the Universidad de Concepción and CEAZA (University of La Serena), while also opening up the CCWAS cyber courses (described below) to students and faculty at these institutions. Further, CCWAS will be open to unfunded participation by the Chilean students at UC Davis whose dissertation research overlaps with the CCWAS scope. In addition to providing numerous research opportunities, Chilean internships for CCWAS Fellows will enrich their education and training in three ways: (1) gaining international perspective that is a prime educational objective of CCWAS; (2) taking courses in Chile on topics that are not offered at UC Davis or CSM, including hydrology of the Andes and Central Valley complex, and Chilean management and policy concerning climate, water, and agriculture; and (3) improving their Spanish communication skills to further the collaboration and research integration. All of our Chilean partners speak English, but we will attempt to recruit Spanish-speaking CCWAS fellows to facilitate the collaboration, especially as related to Chilean public perceptions and policy.

E. Designated Emphasis (DE) in Climate Change, Water and Society:

CCWAS fellows will have an integrative, flexible program leading to a Ph.D. degree in their home department/program, and a Designated Emphasis (DE) in “Climate Change, Water and Society” will also appear on their diplomas. The CCWAS IGERT will provide an enriched academic education and professional training for fellows as well as opportunities for the participation of other, unaffiliated students. While our research goal is to integrate climate, hydrology, and social sciences, our training goal is to integrate research, academic coursework, and interactions with policy makers and others beyond the university. Thus a CCWAS IGERT student is one who can understand and conduct scientific research, and effectively and professionally translate that research beyond the university so that it may be useful in society. The education and training is designed to accomplish this outcome. The DE will draw courses mainly from the following UC Davis Graduate Programs: Agricultural Economics, Atmospheric Science, Civil and Environmental Engineering, Computer Science, Ecology, Geology, Hydrologic Sciences, and Soils and Biogeochemistry. The DE will have two tracks for students to choose from: one emphasizing hydroclimatology, the other emphasizing the social science aspects of climate change. Students in each track will be required to become competent consumers of the science in the other track. Although we anticipate recruiting some social science students who can also crossover into graduate level

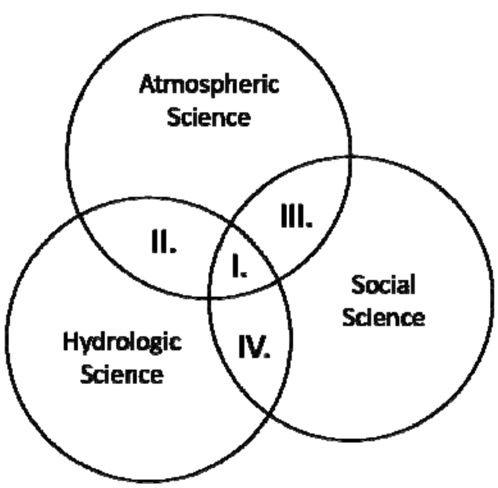

Figure 2. Curriculum structure of the CCWAS IGERT indicating the three core disciplinary areas, as well as the core integration (I) and interface areas (II, III, and IV)

hydroclimatology, it will also be possible for social scientists to satisfy requirements of the DE by taking more fundamental courses in climate and hydrologic sciences. We will specifically recruit some students who already have M.S. degrees in climate or hydrologic sciences to the social science track. These recruits will be instrumental in bridging between the natural and social sciences.

Figure 2 shows the curriculum structure for the DE in CCWAS. The core disciplinary areas are hydrologic, atmospheric, and social sciences. The levels of integration are as follows: I. a core class and one capstone course that will be taken by all students, and informatics courses open to all students; II. hydrologic and atmospheric science interface courses; III. social and atmospheric science interface courses; and IV. social and hydrologic science interface courses. Categories II, III, and IV link disciplines and also satisfy individual disciplinary requirements. In addition, integration and collaboration are fostered with seminars and retreats, as well as with domestic and international internships (Table 1). CCWAS builds on the already rich collaborative and integrative research at UC Davis, where our interdisciplinary graduate group structure has connected disparate fields for over thirty years.

Table 1. CCWAS IGERT Program of Study.

	Year 1 (Units*)	**Year 2 (Units*)**
Fall	Core course (4) Interface and/or Disciplinary (4-8)** *Capstone-seminar background (1)* Responsible Conduct of Research (1)	Interface and/or Disciplinary (8-12)** *Capstone-seminar planning (2)*
Winter	Interface and/or Disciplinary (8-12)** *Capstone-seminar background (1)*	Interface and/or Disciplinary (8)** *Capstone conference (4)*
Spring	Interface and/or Disciplinary (8-12)** *Capstone-seminar planning (1)*	Interface and/or Disciplinary (8-12)** *Capstone writing (3)*
Summer	Informatics workshop; Science communication workshop	Informatics workshop; Science communication workshop
Internships	Location: CA, CO or Chile	Location: CA, CO or Chile

*Most UCD courses are 4 units.
**"Interface" courses satisfy both graduate degree *and* CCWAS DE requirements. "Disciplinary" courses satisfy graduate degree requirements.

F. First-Year Core Course: Hydroclimatology- Intersection of Science and Policy (HISP).

This course, which is part of category I (see Figure 2) and therefore required for all CCWAS fellows, will be closely coordinated by the CCWAS Director and co-taught by faculty from both natural and social sciences. The aim is to introduce students to the range of theoretical and empirical foundations in each of the CCWAS disciplines. After providing a foundational background on climate change and hydroclimatology, the course will use case studies to examine problems from scientific and social perspectives. This course will also provide training in public communication, working with the media and public officials, and environmental outreach using the tools of traditional and new media.

G. Capstone Course: Issues in Climate and Water Science in California (ICWSC):

One of the most innovative aspects of CCWAS is an exciting capstone course to stimulate integration across the entire IGERT. The course involves students in real world decision-making processes for which there are no 'simple' answers, and requires the multiple natural and social science disciplines to connect intensively. The principal goal of the capstone course is to give students hands-on experience with team-science-based problem solving in an arena where success requires organized scientific workflows incorporating tools from multiple disciplines, and engaging public policymakers and power stakeholders as well as academics. The course will expose students to the individuals and institutions actually setting water policy in California, and to a lesser extent, Chile, give them an opportunity to understand and report on the information and modeling needs of the policy community, including information gaps, and to participate in formal cooperative planning and conflict resolution among the principal actors. Throughout this two year experience, we expect CCWAS students to identify opportunities and funding to address high-priority scientific gaps that they can address as components of a thesis while collaborating with an agency or stakeholder on impacting public policy.

The capstone course is designed as a new integration mechanism to replace the traditional "second year" research project that is central to many existing IGERT programs. While the second year project does have some value in terms of integration and future publications, many past IGERT students view it as lingering too long and ultimately a detour to their graduate studies. Instead, we strongly believe that the IGERT training should be a bridge to dissertations. The capstone course achieves this goal by helping the students formulate and refine their dissertation topics, while also producing at least one of the peer-reviewed articles that will partly satisfy their dissertation requirements.

The capstone course follows a two-year schedule. In the first two quarters of year 1, IGERT students will take a one-unit seminar (*"Capstone-seminar background,"* Table 1) where they research background issues related to climate, hydrology, and policy, respectively, through discussion, literature reviews, and weekly invited seminar speakers. California is a global center of innovation in climate and water science and policy, home not only to national research and data centers (e.g., USGS Menlo Park, Scripps) but also highly developed and influential state institutional and legal frameworks for planning water policy (e.g. the California Water Plan) and climate adaptation (e.g., the California Energy Commission, Assembly Bill 32, Senate Bill 375). The seminar speakers will be chosen from the scientists, designers and leaders of these programs and initiatives, and will be asked to both give talks and engage with students in a structured, Socratic-method discussion on the science gaps as well as pitfalls of scientific input into the hydroclimatological policy arena. Student teams will be chosen to summarize a number of topical areas, such as (1) a policy network analysis of the major institutions and leaders (under Lubell, Huckfeldt and others); (2) data resources and gaps and model uncertainty (Fogg, Chen, Ginn, Maxwell, Ustin, Quinn and others); (3) informatics infrastructure – data management, data standards, information discovery, descriptions of scientific workflows (Ludäscher, Quinn); and (4) economic impacts (Sanchirico, Howitt and others). The product of the year 1 capstone seminars will build on the team analyses to a series of white papers summarizing the core issues and knowledge, information infrastructure, and institutional settings. The white paper, which could also provide the basis for additional proposals for extramural funding, will provide the basis for the second year of the capstone, which will culminate in Winter Quarter the delivery of a conference on "Climate and Water in California and Chile: State of the Science" for invited participants representing scientific and policy leaders in regional-to-global hydroclimatological issues from California, Chile, and other Mediterrannean-climate countries as appropriate.

The Spring Quarter of year 1 and the Fall Quarter of year 2 will be devoted to the "Capstone-background planning," wherein seminar speakers continue to visit but the process of planning the year 2 Winter Quarter conference occurs (Table 1). The planning includes identifying the agenda of hydroclimatological and policy issues, indentifying and inviting the key actors, and engaging in mock world-café-style forums in preparation for the Winter conference. The conference will occur in Sacramento with the collaboration of the UC Sacramento Center, and be summarized in a report modeled after the IPCC. The UC Sacramento Center provides a physical space that is convenient for policy-makers in Sacramento, as well as an established contact network in addition to those of the faculty trainers. A core goal of the capstone course is to identify critical research gaps that will become dissertation research topics or will help students refine their topics. While the faculty will have leadership in the capstone course, the CCWAS program coordinator and director will have key roles in the execution of the course, logistic arrangements, and student coordination.

In the two planning quarters (Yr 1 Spring and Yr 2 Fall) students will be organized into two or three teams that contain a mixture of disciplines. Each year the course will tackle a critical question or problem area in hydroclimate science that involves multiple (sometimes opposed) stakeholders. Examples include: What additional water storage is needed for the Central Valley? How should reservoir operation change with future climate? How will future Chilean water availability parallel California's? What science and policy advances are needed to replace diminishing surface storage with subsurface storage? How does hydroclimatological uncertainty affect decision making, including potential distrust of science, and what can be done about it?

During the conference itself (Yr 2 Winter), at least a half-day of the meeting will be devoted to a "World Cafe" (Brown et al. 2005) roundtable event. We have used this approach successfully in a number of events designed to bring high level policy makers in California (heads of agencies and major programs, in planning and infrastructure agencies, and major regulators, -- identified during the Capstone Background Planning quarters) together to develop science-based regional visions and apportion responsibilities for coordinated planning and investment. The exercises consist of participants assigned to individual tables of approximately 6 people, each of which is tasked with evaluating and reporting on a major element of the overall vision. Exercises to date have involved 100-200 participants, and have typically had three rounds, each of which evaluated 3-6 questions (in this case, developed by the capstone course in consultation with a professional World-Café facilitator from University of California Cooperative Extension), typically replicated at 3 tables each. After plenary discussions, the facilitators and student reporters write summary reports. World Cafés have an established record of effectiveness in California planning (for example, launching the "Planning Blueprint" process used to develop 40-year land use plans throughout the state, and a comparable effort, the California Transportation Futures study, for the state transportation plan through 2050). As a result, the format is now accepted by many of the major agency and stakeholder groups, promoting attendance and attention from policy elites.

Another component of the Capstone conference will be presentations, both oral and poster, by IGERT members. The focus will be on student presentations, however other IGERT members such as our foreign collaborators, internship advisors, and IGERT trainers will also have the opportunity to present research results. These 10-15 minute presentations will prepare CCWAS trainees for making similar presentations at professional society conferences.

Spring Quarter of year 2 is reserved for the "Capstone-writing" phase, in which the students compose IPCC-style position papers that define the state of climate/water/social science in the context of California and/or Chile. These papers will define potential dissertation topics that IGERT fellows may elect pursue in subsequent years.

The capstone course includes a student mentoring feature because, at any given time, all CCWAS fellows will be enrolled. That is, second year students will be involved in the background seminar along with year 1 students, helping the year 1 students build on the white paper topics considered the previous year. The year 1 students will also help with conference planning, with an appropriate division of responsibility between the junior and senior students. This tiered system will be fully in place for the second year of the program; in the first year of the program more responsibility will be placed in the hands of the faculty trainers.

The capstone course and State of Science conference achieve multiple training goals. Students will develop organizational and leadership skills that are usually lacking in traditional disciplinary programs. The conference will demand scientific communication to a variety of non-technical audiences. The students will directly interact with policy-makers, thereby building a professional network that will help them find jobs after graduate school. The conference will identify the core interdisciplinary science questions that need to be answered in order to move forward climate and water management policy.

H. Interface Course Examples:

UC Davis is rich in courses relating to climate, water, ecosystems, and policy, making the campus uniquely positioned to carry out this IGERT. Nevertheless, our current curricula will be altered significantly through the addition of some new courses and modifications to existing courses to fulfill the integrative vision described in Figure 2. Students from both natural and social sciences will take disciplinary depth courses and interface courses that cross natural and social sciences. These courses will also fulfill graduate group requirements so that no additional time to degree results. CCWAS fellows must take at least two interface courses in at least two of the dual-disciplinary categories in Figure 2 (e.g., a social science student will take two in area III and two in IV; a hydrologic science student will take two in area II and two in IV). In addition to other CCWAS-related courses, the following interface courses will be offered:

Climate Modeling: Global to Regional Scales (Weare, Chen, Grotjahn; interface area II): In this modification of an existing course, students in the natural sciences will learn the most important modeling tools used in global climate change studies. Topics will include the basic model physics, driving forces, model limitations, dynamical and statistical downscaling, and uncertainties associated with global and regional model projections. Emphasis will be given to understanding the reliability of future projections.

Biosphere-Atmosphere Interaction (Paw U, Snyder; interface area II): In this course about carbon and water exchange at the landscape-plant-atmosphere interface, students will get an overview of the positive and negative feedbacks to climate change tied to this interface, and the degree to which water and carbon cycles interact with global and regional climatic variations. Students will run landscape-plant atmosphere models under different land-use and climate scenarios, and will evaluate and discuss their results.

Linking Climate and Hydrologic Models (Chen, Maxwell; interface area II): This new course will include theory at interfaces between the atmospheric and terrestrial hydrologic systems and will be team-taught by Chen, an expert in regional climate modeling and Maxwell an expert in regional hydrologic modeling. This course will combine the current courses taught by Chen and Maxwell, on WRF (delivered at UC Davis) and ParFlow (delivered at CSM) in an innovative, distance-learning environment. IGERT students will each sit in UC Davis and CSM classrooms with full, two-way videoconferencing between the two campuses. This will also provide delivery of an innovative course to non-CCWAS students at both campuses. The course will be problem-based and will introduce the models, their structure, physics and application, then the interfacial fluxes across the land surface and the coupled PF.WRF model. Simulations will be carried out that provide a relevant framework for students to both understand complex hydroclimate phenomena and to provide a platform from which to start their research.

Integrated Surface Water Hydrology (Maxwell; interface area II). This class was developed by Co-PI Maxwell and delivered twice at CSM. It focuses on an integrated perspective of hydrology, spanning atmosphere to deep groundwater and has a specific emphasis on understanding interactions between the land-energy and the terrestrial hydrology balances. The class is project-based and students integrate both theory and modeling throughout the class. It will be delivered at UC Davis during Spring quarter as part of the Y1 curricula, and will be offered in subsequent years through our cyber classrooms.

Model Uncertainty (Ginn and others; interface areas I, II): This modification of an existing course will cover parameter identification and uncertainty analysis of multiphysics models linking hydrologic and atmospheric processes. The course's core is the use of multivariate statistics and Bayesian and maximum likelihood methods that express parameter estimation as optimization problems solved using "snap-on" codes (UCODE, 2009; PEST, Tonkin and Doherty, 2007). These tools make possible the indirect inversion of massively coupled numerical models of spatiotemporal dynamic processes in general. The course provides the basics of maximum likelihood estimation in the earth sciences context and branches from there to describe the capabilities and the limitations of quantitative parameter estimation and local sensitivity analysis, with inclusion of global search techniques such as genetic algorithms. Key enhancements to the course will be identification of novel and unconventional quantification of uncertainty measures most important for social science and policy applications.

Responding to Environmental Change (Lubell and others; interface areas III and IV): This modification of an existing course will introduce students to models of decision-making and environmental policy from multiple disciplines. Topics include economic decision making, cultural evolution, conservation and development, and institutional analysis as applied to environmental change and conflict. A major focus is how individuals and society respond to uncertainty and environmental change. Multiple social science disciplines are involved, including anthropology, political science, economics, psychology, and sociology.

Environmental Policy Process (Lubell; interface areas III and IV): Introduction to selected topics in the policy process, applications to the field of environmental policy as well as frameworks of the policy process and political behavior. Theories covered include the Advocacy Coalition Framework, Institutional Analysis and Development, multiple-streams theory, and punctuated equilibrium. The class focuses on applying these theories to interpret a common case study, as well as policy stakeholders from the case studies as invited speakers.

*Water Policy and Politics (*Lubell, interface areas III and IV): This existing course provides an overview of water policy starting with economic analysis of common-pool resource management, negative externalities, and public goods. Substantive water management topics include water quality, water supply, drinking water, aquatic biodiversity, international water conflict, and climate change. The overarching theme of the class is how integrated water management must forge cooperation among multiple stakeholders to solve integrated problems.

Air Quality Policy (Anastasio; interface areas III): This existing course is a team-based, in-depth investigation of an air quality problem with a mentor from government or industry.

Water Resources Management (Lund; interface area IV): This two course series covers the engineering, institutional, economic, and social basis for managing local and regional water resources, including use of computer modeling to improve water management, planning theory, system maintenance, regionalization, multi-objective methods, risk analysis, institutional issues, pricing model application, economic development, forecasting, operations, and other topics.

Informatics for Team Science: Scientific Data and Workflow Management (Ludäscher, Quinn, interface areas I, II, III and IV): Three new courses will address informatics tools, beyond those students will have received in their disciplinary graduate programs, that we believe will both provide intellectual integration, and better enable students to be members of, or manage, team science and large-scale collaboration. They teach methods and tools relevant for data-intensive and compute-intensive eScience. The first course will focus on data modeling and management, including the role of metadata and ontologies to facilitate scientific data management, sharing, and collaboration within and across disciplines. This course will include hands-on training (via discussion sections) and group projects on scientific data management using state-of-the-art tools and systems (e.g., tools for annotating, publishing, sharing, and querying scientific data). A linked “Geospatial Studio” course, also coordinated with the core geospatial analysis course for new graduate students (GEO 200C), will provide hands-on exposure to the use and misuse of the principal framework data for regional analysis, including imagery series, land use and land cover, soils, geology, as well as census, water infrastructure, natural resource economics, and public health and epidemiology datasets essential to understanding public policy. The final course will focus on the principles and practice of scientific workflow management, and cover advanced topics such as scientific workflow design, deployment on cluster and cloud platforms, data lineage tracking, and efficient provenance management. The hands-on part of this course will employ state-of-the-art workflows tools such as Kepler (Ludäscher et al., 2006b) and include exercises relevant to coupled hydroclimatology models and codes, and their applications to water planning, valuation of ecosystem services, impacts on land management and public health, and implications for policy formulation.

I. Seminars and Retreats:

In addition to the Capstone seminars, the CCWAS IGERT will periodically co-sponsor seminar speakers in existing seminar series, such as the Ecology, Economics and Policy seminar series, the Land, Air and Water Resources seminar series and the Hydrology Graduate Group seminar series. This will help to bring issues pertinent to the CCWAS IGERT into other campus programs.

In conjunction with the CCWAS Capstone Conference, held annually beginning in the Winter quarter of year 2, we will host a half-day annual retreat for IGERT students and faculty, our external advisors (see section 5), and our independent evaluator (see section 6). This will provide a time for annual assessment, both internally and externally. By holding this retreat in conjunction with the conference, it will allow our advisors to participate in the capstone event and provide immediate feedback. The annual retreats will encourage reflection on the questions: How is our research contributing to and transforming science? How is our IGERT contributing to and transforming modern graduate education? How is our IGERT contributing to policy changes?

The seminars, annual retreat, and additional ad hoc events such as field trips and barbeques will provide opportunities for general and focused multi-disciplinary discussions, permit informal mentoring opportunities, and stimulate a sense of camaraderie among all participants.

J. Internships:

IGERT fellows will complete at least one internship. Leaders in academic and non-academic settings are eager to host our students in internships and have provided letters of commitment. U.S. internship opportunities include California Department of Water Resources, California Energy Commission, and National Center for Atmospheric Research (NCAR); International internship opportunities include Universidad de Concepción, CEAZA (University of La Serena) and the Chilean Ministry of Agriculture. We have already begun making arrangements for housing and language education at the institutions of our Chilean partners, who have been most accommodating in considering the well-being of CCWAS fellows in Chile. International exchanges with sister institutions in Chile will expose students to non-U.S. perspectives while providing opportunities for global dissemination of their CCWAS research. In these exchanges, students will not only continue to develop their research at the interface of scientific disciplines and the social sciences interfaces, but also apply their studies to local and regional conditions either in the U.S. or Chile. These internships will be enriched through participation in the JMIE Environmental Leaders Program (Gutstein; see section below on Outreach Opportunities).

K. Ethical & Responsible Conduct of Research and Other Professional Development Opportunities:

CCWAS will partner with a nationally renowned program at UC Davis that prepares the researchers of tomorrow to conduct cutting-edge research in an innovative, ethical, and fiscally responsible manner. The Responsible Conduct of Research (RCR) Program, compliant with the America Competes Act, is taught by UC Davis faculty and outside experts and includes sessions on: conflict of interest, mentor/trainee relationships, research misconduct, research collaboration, data acquisition and management, authorship and publication, and human subjects research. CCWAS students will be required to attend one or more RCR sessions. Additionally, the Office of Graduate Studies provides professional development workshops, such as on grant writing, and specialized programs for underrepresented minority graduate students. The CCWAS Program Coordinator will assist students in creating personal professional development plans, including career goals, so that fellows can judiciously take advantage of the array of opportunities at UC Davis.

L. Outreach Opportunities:

As part of their education and training, IGERT fellows will be able to participate in a diverse array of outreach activities that are led by various Co-PIs. These activities will provide trainees with the opportunity to expand upon their research and course work, particularly from the core and capstone courses, and apply what they have learned to different audiences in a variety of settings. Examples include: the Davis Area EnvironMentor Program, led by the Department of Land, Air and Water Resources (LAWR) Outreach Program Coordinator and Professors Fogg and Hopmans. The EnvironMentor Program was created in conjunction with high school students from the Environmental Technology Academy at the minority-serving (50%) Highlands Academy of Arts and Design in Sacramento. High school students will be mentored one-on-one by IGERT fellows to develop an environmental research project over the course of the school year. The research projects will be first presented and judged locally, then selected projects will move forward to compete at the national level for university scholarships. Results of the established research projects are presented during a local Science Fair and judged by a group of faculty and environmental professionals. Three selected student winners will compete for scholarships and awards at the National EnvironMentors Science Fair. In the 2009/10 academic year, two of the three selected EnvironMentor students from the UC Davis (LAWR) chapter won the national competition in Washington, DC. A strength of our program is a student retention rate of over 80% compared to the EnvironMentor program national average of 33%. In 2010/11, the program will be expanded to Encina High School, which is one of the lowest 5% performing high schools in the State of California. Undergraduates may also be recruited to mentor the high school student, while they are in turn mentored by the IGERT graduate students.

As part of the CCWAS IGERT, LAWR's Outreach Program Coordinator will also partner with local English as a Second Language (ESL) instructors and CCWAS Fellows to implement climate change curriculum in ongoing adult education courses. The ESL students are primarily Spanish speakers and are recent immigrants to the country. The lesson plan includes teaching through the use of a novel, climate change “Jeopardy” game that would be presented by IGERT fellows. Furthermore, IGERT students will be able to continue such outreach activities through the JMIE's Environmental Leaders Program beyond the funding cycle. Joyce Gutstein created the JMIE Environmental Leaders Program, a professional training program, to help graduate students connect their research to community outreach contexts.

During international visits or through summer internships, the IGERT fellows can join the Universidad de Concepción EULA-CHILE Center for Environmental Sciences (Oscar Parra, director). The Center will provide an international vehicle for outreach and extension of research results, as well as extension-teaching opportunities for IGERT students and faculty. The

Center's outreach capacity includes disseminating scientific findings among students of elementary and college levels, public employees, and the public at large through summer school courses, public talks by scientists, environmental education programs, and the website. Activities aimed at scientists include a WaterUsers Organization Task Force at the Universidad de Concepcion, including development of a national handbook and a decision support system for irrigation, created by co-PIs Jose Arumi Ribera and Diego Rivera.

5. Organization, Management, and Institutional Commitment:

The PI will be responsible for oversight of and reporting on the CCWAS IGERT. An Executive Committee, made up of the PI; Co-PIs Chen, Maxwell, Lubell, and Lund; two CCWAS fellows; and the CCWAS Program Coordinator will provide oversight, resolve problems/issues, select the Fellows for the international internship, and support the PI in management and reporting responsibilities. Professor Hopmans will serve as the International Program Coordinator and Professor Chen will serve as the Curriculum Coordinator. A full-time CCWAS Program Coordinator will provide administrative support for program activities, including outreach, recruitment, and student advising; facilitate communications within the IGERT and with other campus entities; track students through their programs; assist with the CCWAS Capstone Conference; collect program assessment data; manage the budget and annual reporting; coordinate with partner institutions (CSM, CSUF, Universidad de Concepción and CEAZA); and make arrangements for international Chile-CA exchange.

An external advisory committee will be created that will include academicians, scientists and managers from California resource agencies, and decision makers from state and federal areas of government, representatives of the University of California Office of the President, and the Chile-California partnership. The advisory committee will meet annually as an integral part of the Winter Capstone Conference (see 4G) and concurrent annual retreat. Here, committee members will see student research through oral and poster presentations and participate as experts in the world café forums. The advisory committee will take into consideration the annual results of the program evaluation and recommend changes to CCWAS to correct problems and improve the program.

The home office of CCWAS will be located within the Department of Land, Air and Water Resources, where centralized meeting and seminar space will be provided. As detailed in a letter included with this submission, UC Davis Graduate Studies and College Deans will contribute $350,000 over the period of the grant to cover resident and non-resident tuition and fees, student recruiting, fees for use of campus cyber-enabled audio and video facilities, teaching buyouts for new course development, travel costs for visiting speakers, CCWAS social functions, and bridge fellowships for CCWAS students who are transitioning to non-IGERT funding.

Administration of CCWAS will put a high priority on maintaining close connections among IGERT Fellows and Trainers (faculty) through not only the shared classes but also regular professional and social enrichment activities. All CCWAS information and resource materials for existing and prospective fellows and faculty will be collected and displayed on an attractive CCWAS website that will grow into an important resource not only for CCWAS but for like-minded scientists and decision makers outside the program. The website will include a mobile web version that automatically displays legibly on smart phones or portable wi-fi devices so that students and faculty will be inclined to stay tuned into CCWAS. To capitalize on students' penchant for social networking, the CCWAS Director will maintain a blog about internal activities, issues, and observations, as well as relevant scientific and legislative news. CCWAS participants will be able to post comments and questions to the blog, leading to an online, interactive forum. Other modes of social networking will be explored for fostering collaboration and connections within CCWAS, including impromptu video conferencing on smartphones and inexpensive wi-fi touchscreen devices.

6. Performance Assessment/Project Evaluation:

To determine our success in recruitment and retention, we will collect data on 1) the number of graduate fellows appointed each year, their ethnic and gender make-up, and the percentage of the graduate students who cite the IGERT program as a reason they chose to attend UC Davis; 2) the percentage of IGERT graduate students who complete their M.S. and Ph.D. degrees; (3) the post-graduate pursuits of program alumni and their suggestions for how to improve the program; and (4) the number of collaborative research grant proposals and research papers submitted. Our achievement will be measured by comparing these same measurements with similar non-IGERT programs, such as the UC Davis NIEHS Superfund program. Results will be presented at IGERT meetings and other technical and/or educationally oriented meetings, and disseminated through publications in journals.

An external, independent evaluation of the IGERT will be conducted by Gargani + Company of Berkeley, California, which has 20 years of experience evaluating educational programs in science and other areas. The evaluation will focus on four outcomes that the IGERT will work to advance — student success, knowledge generation, training quality, and institutional change. Student success will be measured by students' progress through the program as demonstrated by the timing of educational milestones they achieve, such as passing qualifying exams and advancing to candidacy; the knowledge and skills that students develop in the program as demonstrated by the quality of their papers and their success on exams; and the careers students intend to purse and eventually undertake as demonstrated by their responses to survey and interview questions. Knowledge generation will be measured by the number of publications produced by participating faculty and students, and the perceived quality of this work by scientific peers on the advisory board. Training quality will be measured by the number and diversity of students who are recruited; the retention of participating students; the extent to which students, faculty, and the advisory board are satisfied with the program as gauged by surveys and interviews; and the dissemination of program results, methods, and models with educational researchers and professionals. Institutional change will be measured by surveying and interviewing students, faculty, university staff, and members of the advisory board about current and evolving institutional policies and procedures related to the IGERT. Wherever possible, Gargani + Co. will make comparisons of the evaluation results to benchmarks, for example by using data from prior years (proportion of minority students enrolled in the IGERT this year versus last year) or other students (the GPAs of students in related graduate groups). While these comparisons cannot be used to attribute causality, they can provide additional assurance that trends are moving in the desired direction. We expect to learn a great deal about our work from the evaluation and are committed to using results formatively. In particular, we will conduct regular milestone meetings with the evaluator in which we review results, set yearly program objectives, and make program modifications.

7. Recruitment, Mentoring, and Retention:

A. Recruitment and Broadening Participation: Based on our surveys of graduate students and general observations, we anticipate that CCWAS will be tremendously attractive for graduate students and will bring in top-tier students. An admissions committee will consist of the CCWAS Director (Chair), CoPIs, and Program Coordinator, who will also work closely with admissions advisors for the graduate programs to which CCWAS aspirants apply: Agricultural Economics, Atmospheric Science, Ecology, Hydrologic Sciences. Alternative routes to CCWAS will be through other graduate programs as well, including Civil and Environmental Engineering, Computer Science, Geology, and Soils and Biogeochemistry. Applicants can apply directly to the IGERT by indicating so in their applications, or IGERT trainers can nominate highly qualified applicants to the committee. Students will be admitted for two years of full support (half time in academic months and full time in summer).

Climate change will disproportionately affect economically disadvantaged people and developing nations (Solomon et al., 2007). Accordingly, it is a top priority of CCWAS to attract academically talented, underrepresented minority students. This will be partly accomplished through our M.S.-to-Ph.D. Bridge Program with California State University, Fresno (CSUF), a Hispanic-serving institution. With coordination from CSUF Professor John Suen and his colleagues, interested M.S. aspirants in Geology, Civil Engineering and Public Administration will gain the necessary curricula to qualify for admission to one of the CCWAS graduate programs at UCD or CSM:. The CCWAS Director and Trainers will also actively recruit these CSUF students by periodic visits to the CSUF campus and seminar presentations on CCWAS research and teaching results. We will also attract academically talented, underrepresented minority students by partnering with established, proactive university recruiting efforts and by offering students an exciting program that has (a) unique opportunities for training and professional advancement; (b) a clear path toward academic excellence that also addresses an urgent, global problem; (c) an attractive financial package; and (d) unparalleled resources. In addition to our outreach and recruitment efforts at regular graduate school information fairs, CCWAS will conduct targeted national recruitment of underrepresented students through active participation by our faculty, students and staff in national conferences of organizations, such as the Society for Advancement of Chicanos and Native Americans in Science, Historically Black Colleges and Universities-Undergraduate Program, the American Indian Science and Engineering Society, the Society of Hispanic Engineers, the California Louis Stokes Alliance for Minority Participation, California Alliance for Minority Participation, and the UC program Leadership Excellence through Advanced Degrees.

The Office of Graduate Studies has and continues to establish nationwide partnerships between UC Davis and a select group of Historically Black Colleges and Universities, Hispanic Serving Institutions, and California State Universities. The Office of Graduate Studies has also formed collaborative partnerships with minority NSF/NIH sponsored research programs (MBRS, RISE, MARC, MORE, LS-AMP, AGEP and Bridges). UC Davis faculty present scientific talks at these campuses, serve as mentors to students participating in UC Davis Summer Undergraduate Research programs, and collaborate with Faculty Program Directors on research projects, and other program activities.

In addition, UC Davis, through the Office of Graduate Studies, provides the following career and professional development programs and services for underrepresented students in collaboration with faculty who serve as mentors, speakers, and consultants: the UC Davis Professors for the Future (PFTF) Program, Professional Development Series (PDS), AGEP (NSF sponsored Alliances for Graduate Education and the Professoriate), McNair Scholars undergraduate research program, and UC LEADS (Leadership Excellence through Advanced Degrees) undergraduate research program to prepare underrepresented graduate and undergraduate students for academic and research careers.

B. Mentorship and Retention: Mentorship at multiple levels is one of the most effective ways to retain students and to provide them with leadership skills. Trainees in our IGERT will enter graduate study with an identified research advisor in the home graduate group and be co-advised by another faculty from the other science discipline. Both mentors will help the student become familiar with UC Davis, the student's graduate program, and the IGERT project. Each trainee's guidance committee will include faculty trainers from at least two different areas of the IGERT who will provide students with access to faculty expertise outside the home discipline, help the student design an individualized curriculum based on the student's primary research areas, and suggest internship possibilities. Peer mentoring will entail a Big Brother or Sister senior IGERT student who meets informally with a new trainee on a monthly basis and offers support and advice from a student's perspective.

Mentoring students from underrepresented groups will also entail linking them with groups on campus that can provide additional social support networks. These include: Mixed Student Union, ACE (African & African Americans Cultivating Education), BRIDGE (Filipino Outreach & Retention Program), GAAAP (Graduate Academic Achievement & Advocacy Program), NE'UE (Natives Empowered through Unity and Education), and Chicano/a Latino/a Holistic Student Support Program.

At the campus level, UC Davis provides professional development programs for graduate students that include workshops on grant writing, interviewing for positions, and innovations in teaching. UC Davis' excellent programs, supportive atmosphere, and superb students, coupled with the close-knit IGERT community and the mentoring program, create a synergy that effects high retention.

8. Recent Traineeship Experience:

UC Davis currently hosts two active IGERT programs: "Responding to Rapid Environmental Change: From Genes to Ecosystems, Science to Society" (REACH; Sharon Strauss, PI; DGE-0801430), and Collaborative Research and Education in Agricultural Technologies and Engineering (CREATE; Karen McDonald, PI, DGE-0653984). Our proposed CCWAS program will benefit from their best practices and leverage/contribute resources from which all three programs will benefit. As described in section 4B (above), we conducted an online focus group of past and current fellows of the two existing IGERT programs at UC Davis to gain valuable hindsight from those who have engaged most directly in the IGERT experience. PI Fogg also met with PIs Strauss and McDonald to learn more about their strategies for evaluation, dissemination and long-term institutionalization of their programs. These meetings will become a regular practice if the CCWAS IGERT is awarded, to ensure continued improvements and progress in our program. All three IGERT programs will also benefit from the improvements to the UC Davis teleconferencing capabilities that will result if the CCWAS IGERT is awarded. We have also learned much about the institutionalization of IGERT programs from our highly successful "Transportation, Technology and Policy" program (TTP; Patricia Mokhtarian, PI; DGE-9870682). More than ten years after its inception, the UC Davis TTP Graduate Group offers both MS and PhD programs, employs about 50 graduate students and is one of the largest interdisciplinary graduate groups on campus.

Co-PIs Lubell and Lund have participated as trainers in the original UC Davis "Biological Invasions" IGERT, and continue as trainers in its renewed version (REACH). Lubell has mentored several IGERT students, as well as advised nearly every cohort of Biological Invasions and REACH students, especially on the design and analysis of environmental policy and behavior surveys. Topics include invasive pike in Lake Davis, yellow-star thistle on California rangelands, rancher valuation of land conservation tax incentives, and nursery/aquarium practices to reduce the threat of invasive species. These research projects have produced several publications authored by the IGERT students only. Lubell has also helped design the core course for the REACH IGERT. Lessons learned from these two IGERTS have influenced graduate education throughout UC Davis, including the development of other IGERT Programs.

9. International Collaboration:

As described in the Research and Education and Training sections, the international program is integral to the CCWAS IGERT because it is the means by which the California-focused work will be extended and generalized to other Mediterranean systems and beyond. Moreover, the international program will inject the global perspective that is paramount because climate change and associated water problems are planetary phenomena both in terms of the natural science and policy.

A CCWAS international collaboration committee will be chaired by Hopmans and will include the CCWAS Director, Program Coordinator and Chilean Collaborators Arumi, Montecinos, Parra, and Rivera. This committee will select and prepare CCWAS fellows for foreign collaborative research and education. The process will start with ad hoc interaction and discussions among the fellow, his or her U.S. mentors and one of the potential Chilean collaborators. These interactions would most likely be initiated through email and phone communication and during and after one of the weekly webcast seminars, including some seminars in which one of our Chilean collaborators would be the invited speaker. The fellow can then write a short proposal an international internship of one to four months. Selection will be based on performance in the program and intellectual merit of the proposal. Our Chilean partners have already indicated that they would serve as hosts and mentors to the visiting fellows while also connecting the fellows with visiting scholar/student housing and access to Spanish language training if needed. Because the Chilean hosts would be mentoring the fellows through frequent meetings, they would also ensure the student's welfare. Fogg, Hopmans, and Schladow have already visited Universidad de Concepción (both at the Concepcion and Chillán campuses) and CEAZA (University of La Serena), and have seen first hand the facilities and good quality living conditions that fellows would enjoy. We are confident that this will be the perfect situation for international internships and collaboration. Moreover, UC Davis faculty from the Department of Land, Air and Water Resources (e.g., trainer Hopmans) will be traveling the Universidad de Concepción (Chillán campus) somewhat regularly to assist in the development of a cooperative extension (CE) Water Center that will be the first ever CE program in Chile. The Center will focus on water supply and agricultural water management. CCWAS fellows in Chillán will therefore likely have some direct contact with UC Davis faculty while in Chile.

10. Recruitment and Retention History:

It is a top priority of CCWAS to attract academically talented students, particularly those who are traditionally underrepresented in STEM fields. As described in section 7 (above), UC Davis as an institution has numerous programs in place to attract and retain students. The Office of Graduate Studies has and continues to establish nationwide partnerships between UC Davis and a select group of Historically Black Colleges and Universities, Hispanic Serving Institutions, and California State Universities. The Office of Graduate Studies has also formed collaborative partnerships with minority NSF/NIH sponsored research programs (MBRS, RISE, MARC, MORE, LS-AMP, AGEP and Bridges).

In addition, UC Davis, through the Office of Graduate Studies, provides career and professional development programs and services for underrepresented students in collaboration with faculty who serve as mentors, speakers, and consultants. These include the UC Davis Professors for the Future (PFTF) Program, Professional Development Series (PDS), AGEP (NSF sponsored Alliances for Graduate Education and the Professoriate), McNair Scholars undergraduate research program, and UC LEADS (Leadership Excellence through Advanced Degrees) undergraduate research program to prepare underrepresented graduate and undergraduate students for academic and research careers. Students from underrepresented groups are more likely to continue their graduate education if they are linked with groups on campus that provide additional social support networks. These include: Mixed Student Union, ACE (African & African Americans Cultivating Education), BRIDGE (Filipino Outreach & Retention Program), GAAAP (Graduate Academic Achievement & Advocacy Program), NE'UE (Natives Empowered through Unity and Education), and Chicano/a Latino/a Holistic Student Support Program.

On the following pages we provide recruitment and retention information for four of the existing graduate groups from which we expect to draw the majority of our IGERT trainees. The tables include all requested information except for statistics on students with disabilities, which are not tracked by the UC Davis Office of Graduate Studies. We have provided separate figures for underrepresented minorities, which includes African American, Native American (includes Alaskan natives), Hispanic and Pacific Islander. Separate figures are also provided for gender. Finally, statistics for retention history for the past three years are provided as number of withdrawals based on whether students are still in the program as of Spring. The total number of Ph.D. students in all these programs is greater than listed in the tables because international students are excluded from the tables. The number of Ph.D. graduates in Hydrologic Sciences during the last 3 years is anomalously low, and can be attributed to a decline in the early 2000s in numbers of applicants to hydrologic sciences programs nationwide. During the last 12 years, however, Hydrologic Sciences has typically graduated 2 to 5 Ph.D.s per year, and as many as 10 in a single year. Since 2008, because of a resurgence in student interest in environmental science careers driven partly by climate change issues, both Hydrologic Sciences and Atmospheric Science have seen significant increases in applicants for both M.S. and Ph.D. objectives.

Letters of Commitment

1. **Jeffery C. Gibeling,** Dean of Graduate Studies
   University of California, Davis

2. **Steven Castillo,** Provost and Executive Vice President
   Colorado School of Mines

3. **Karen T. Carey,** Dean of Graduate Studies
   California State University, Fresno

4. **Randy Dahlgren**, Chair, Department of Land, Air and Water Resources
   University of California, Davis

5. **Howard V. Cornell**, Chair, Environmental Science and Policy
   University of California, Davis

6. **Cristobal Barros J.,** Secretary
   Ministry of Foreign Affairs, Chile

7. **José Antonio Galilea**, Minister of Agriculture
   Government of Chile

8. **Eduardo A. Holzapfel**, Dean
   Universidad de Concepcion, Chile

9. **Bernando Broitman,** Director
   Centro de Estudios Avanzados en Zonas Aridas (CEAZA)

10. **Kamyar Guivetchi**, P.E. Manager
    California Department of Water Resources

11. **Guido Franco,** Technical Lead for Climate Change Research
    California Energy Commission

12. **David Gochis,** Scientist
    National Center for Atmospheric Research