

W3190: Management and Policy Challenges in a Water-Scarce World

Statement of Issues and Justification

Water is a focal point of science, economics and policy debates in the western United States. It is also a resource of growing concern in other regions, such as the southeast and central US (Sun et al., 2013; Tavernia et al., 2013). In light of climate change, depletion of major aquifers, urban growth in water-scarce areas, and increasing demand for environmental goods and services, creative approaches are needed for reallocating water efficiently among competing uses. Without innovation in water management policies and techniques, water-related conflicts between nations, states, agricultural, urban and environmental uses, as well as between ground and surface water irrigators, will continue to intensify and expand. According to a recent World Economic Forum survey of global authorities (i.e., 700 global business, government and nonprofit leaders), four of the top ten planetary threats of greatest concern involve water: #3 Water crises; #5 Failure of climate change mitigation and adaptation; #6 Greater incidence of extreme weather events (e.g., floods, storms, and fires); #8 Food crises (Walton, 2014; World Economic Forum, 2014). Water management or policy advancements developed here in the US can potentially transfer to other regions of the world to benefit a much larger subset of society (e.g., Gohar and Ward, 2010; Dinar and Nigatu, 2013; Ward et al., 2013).

Multistate project W3190's proposed research addresses a variety of water management issues, with an overarching goal of increasing society's net benefit from limited water resources. The suite of research questions and methods described below will test the feasibility and economic efficiency of innovative water management practices, policies, and institutions. Insights gained will also improve the design of existing tools. W3190 members will engage stakeholders (including policymakers) in this research agenda by hosting informal meetings and formal workshops to facilitate information exchange and discovery of new ideas. W3190 members will also develop and deliver outreach presentations and publications for stakeholders that distill research findings into practical, science-based management tools and policy recommendations. These tools will empower stakeholders to objectively dissect complex water issues and correctly weigh benefits and costs of alternative options. If implemented, policy recommendations will help alleviate water conflicts.

The importance of W3190's proposed research is well-reflected in a recent report from the US-EPA (2013), which states "Protecting and efficiently managing our water resources is essential to maintaining a strong, vibrant economy. Changes to water use or impacts in one sector or region can produce ripple effects across the economy. The path to making better choices in using and managing our water resources begins with a better understanding of the economic and environmental consequences of the options available to us." Project-specific impacts of W3190's proposed work are described in a later section; however, examples include more cost-effective soil-salinity estimates, more economically-sustainable groundwater management, and increased provision of ecosystem-services.

Generations of researchers have dedicated their careers to designing and refining effective solutions to complex water conflicts. Although much progress has been made, each water conflict is sufficiently unique and complex to defy ready-made solutions. Thus, W3190 members

will continue a rich tradition of conducting research inspired by water users, managers, and policymakers' most-persistent or emerging challenges. We will use new data and techniques to improve understanding of various water conflicts, and design creative solutions that are both technically-feasible and promote economically-efficient outcomes. Highlights of W3190's proposed research questions follow; additional details are provided in the methods section.

A subset of W3190 team members will continue a long-term effort to document the location and severity of soil salinity issues in the western US. During the preceding multistate project (W2190), these researchers developed new calibration techniques, which they will now use to improve the accuracy of soil-salinity estimates that rely on remotely-sensed data. This work will ultimately increase the availability and reduce the cost of soil-salinity estimates for agricultural producers.

Advances in non-linear dynamic techniques have enabled researchers to detect complex patterns in time-series data that were previously indistinguishable (Huffaker, 2010). This new tool could improve our ability to predict extreme hydrologic events, which would enable water users to better anticipate and prepare for extreme hydrologic events, such as drought and flooding. W3190 team members will familiarize themselves with this new data analysis technique and explore its potential to improve statistical analyses of economic decisions and outcomes and the realism of bio-economic modeling results. Similarly, advances in laboratory and field economic experiments will enable team members to isolate human behaviors and market characteristics that influence water use decisions in ways not previously understood (e.g., Arocha and McCann, 2012; Suter et al., 2013). These insights will improve the design of water policies by identifying specific drivers of behavior that can be managed to achieve more-desirable water outcomes.

Another subset of W3190 members will continue studying groundwater management, and in some cases, conjunctive management of surface and ground-water. New datasets and insights from the field have stimulated fresh ideas, which team members will use to improve upon past efforts. For example, disaggregated groundwater pumping data have become available that will enable team members to better understand intraseasonal water allocation decisions on irrigated farms. New evidence also suggests that well-yield may be a more relevant driver of pumping than depth to water table or energy costs. Improvements to past modeling efforts are therefore needed, and will generate more-realistic estimates of the impact and efficiency of alternative groundwater management policies.

Surface-water issues have also evolved since the previous proposal (for W2190) was approved. Important transboundary agreements are now up for renegotiation, including the Columbia River Treaty (Osborn, 2012). This renegotiation process will occur under very different environmental and economic circumstances than in 1964, when the US and Canada signed the current version of the Treaty (Washington State University, 2011). Before negotiations begin, W3190 team members will identify potential points of contention, as well as negotiation strategies more likely to generate mutual agreement. This information can reduce the amount of time and legal resources consumed by the negotiation process, and increase the likelihood of achieving socially-optimal terms of agreement.

To the east of the 100th meridian (i.e., the symbolic boundary between the semi-arid west and moist east), symptoms of climate change are increasingly being felt, specifically less-reliable water resources for agricultural, urban, and environmental uses (Sun et al., 2013; Tavernia et al., 2013). Water users, managers, and policymakers in these regions are generally less-accustomed to water scarcity, and might therefore be ill-equipped to cope with future shortages. A subset of team members will inventory existing water policies and institutions in case-study regions, and qualitatively assess their potential to minimize losses arising from less predictable and more limited water resources. Recommendations for adapting existing tools to future water conditions will then be developed and shared with policymakers and relevant stakeholders. This work will transfer valuable lessons from the western US to policymakers in neighboring regions, so they can learn from the West's water-related successes, failures, and shortcomings.

One final area of proposed research is inspired by growing interest among NGOs, agencies, corporations, and rural landowners in creative mechanisms for encouraging private provision of environmental goods/services, and restoration/maintenance of ecosystem functions (Bohlen et al., 2009; Cheatum et al., 2011; Institute for Natural Resources, 2011; Waage and Kester, 2013). W3190 members will undertake a diverse set of case-studies to explore novel ways of achieving society's numerous goals for limited water resources. Researchers will use a variety of methods, including a payments-for-ecosystem-services pilot program, bio-economic models, and laboratory experiments. Results will determine whether proposed mechanisms for encouraging private provision are technically-feasible and economically-efficient. Lessons and insights will be shared across case-studies to avoid common pitfalls and increase research quality and impact.

The proposed research has a high degree of technical feasibility. Our multistate team includes water professionals with rigorous training in conceptual, theoretical, and applied aspects of biophysical sciences and water resource economics. Team members also have extensive experience analyzing water management practices, policies, and institutions. Agricultural and natural resource economists comprise the largest portion of the team, followed by soil scientists. We would enthusiastically welcome colleagues from irrigation engineering, agronomy, and hydrology. Currently, the team lacks the critical mass necessary to attract new members from these disciplines, particularly junior researchers, who typically prefer multistate projects that involve well-established colleagues within their own discipline. We could foster more interdisciplinary collaboration by organizing some of our annual meetings in conjunction with other water-related multistate teams, such as WERA 1020 (Western Region Multistate Coordinating Committee on Water Resources).

Researchers from 21 states, USDA-ERS and USDC-NOAA are currently involved in W-2190; we anticipate many of these will sign-up for W3190. We also encourage colleagues in other states and agencies, who have an interest in water resources management or policy, to join the project. W3190's proposed research is ideally-suited for a multistate regional project because similar water issues occur in numerous states; data gathered by one state can inform analyses in other states; and project participants from different states have experiences using diverse, yet complementary, research methods. For example, most states in the West and a growing number of states in the East share concerns about the ability of current management practices, policies, and institutions to efficiently manage scarce water resources. Several states are affected by unsustainable extraction from the Ogallala aquifer, and most of these states have at least one

representative involved in the W3190 proposal. Multistate collaboration fosters the creative thinking necessary to address this complex management issue, in large part by facilitating exchange of diverse experiences, ideas, and methods. Similarly, in the case of ecosystem services provision, researchers from multiple states are tackling separate but related case-studies using different research methods. By exchanging information about the pitfalls and successes they have encountered, every case-study can learn from others' struggles, lessons, and insights. This should enable all collaborators to achieve a higher level of understanding and generate a larger impact than if they proceed alone. In summary, all three objectives of the proposed research will be addressed most effectively as part of the multistate W3190 project.

Stakeholders who will benefit from W3190's research and outreach include agricultural producers and consumers, irrigation and conservation districts, private water-supply organizations, state environmental/water quality management programs, and federal agencies such as the Bureau of Reclamation, Army Corps of Engineers, USDA and EPA. Fellow water researchers will also benefit. Each of these stakeholder groups are intimately involved in water use, management, planning, allocation, or policymaking decisions, and will benefit from our work in a variety of ways. For example, development and refinement of quantitative models and policy analyses will improve researchers and stakeholders' ability to evaluate field, farm, and watershed-level impacts of alternative surface and ground-water policies. Research results will also enhance policymakers' understanding of key characteristics of water policies and institutions that affect their ability to achieve efficient water allocation at less cost than traditional regulatory approaches. W3190's outreach efforts will enhance stakeholders' water-related knowledge and decision-making skills, which will enable them to design and implement water management practices, policies, and institutions that achieve more socially-desirable outcomes. More specific impacts of individual research questions are described later in the proposal.

Related, Current and Previous Work

Multistate project W-2190, titled "Water Policy and Management Challenges in the West," is the immediate predecessor to this proposal. It was authorized for the period October 1, 2009 to September 30, 2014. Scientists participating in W-2190 addressed three objectives: 1) develop farm-level irrigation strategies to address water quantity and quality problems; 2) examine regional water-related impacts associated with energy, environmental policy, and climate change; and 3) investigate alternative water policy and management institutions. Activities, accomplishments, and impacts for each of these objectives are reviewed briefly below. More details of W2190's accomplishments can be found in the project's annual reports, available at http://www.lgu.umd.edu/lgu_v2/homepages/home.cfm?trackID=11237.

Activities under Objective 1 focused primarily on two farm-level topics: deficit irrigation, and soil and water salinity. Outputs and accomplishments related to deficit irrigation stem from several research projects. One project developed and released a publically-available web-based tool, WARAT, which producers can use to learn about relationships between irrigation and crop yields for the central Great Plains states (Kansas State University et al., 2010). Producers can also use the tool to estimate farm profitability and risk under deficit irrigation. Another project generated a Certified Crop Advisor Training Module, which offers producers guidance on selecting crops well-suited to limited irrigation (Bauder et al., 2009). One final project adapted

the model, Water Optimizer, to simulate crop yields under deficit irrigation (Martin and Supalla, 2010; Martin et al., 2010). This tool enables USDA-RMA to adjust historical crop yields for limited irrigation scenarios, which is necessary to design an effective deficit or limited irrigation insurance product. In the absence of limited irrigation insurance, administrative policies have often prevented producers from receiving indemnity on crops that receive less than a full water supply. This inadvertently encouraged producers to allocate limited water supplies sub-optimally. USDA-RMA is still in the process of designing a limited irrigation insurance product; however, work by W2190 members has clearly influenced its development and stimulated new design ideas (Watts and Associates, 2013). Availability of a limited irrigation insurance product in the future will help mitigate agricultural income losses during water shortages, and increase the economic efficiency of water use on insured farms.

Outputs and accomplishments related to soil and water salinity stem from two projects: i) measuring soil salinity using electromagnetic induction (EMI) techniques, and ii) testing salinity tolerance and water requirements of bio-energy crops. In the first project, team members developed an award-winning salinity screening apparatus that has since been used in multiple western states (Hawks et al., 2009). They also determined that EMI can provide accurate field-scale soil salinity data, at high spatial resolution, in less time than conventional methods (Ganjegunte and Clark, 2011a). They have since used EMI techniques to track sources of salinity entering the Pariette Watershed in the Upper Colorado River Basin (Amakor et al., 2011), and produce salinity distribution maps for irrigated cotton soils in west Texas (Ganjegunte et al., 2013), turf root zones in New Mexico (Ganjegunte et al., 2013), and major soil series of El Paso, Texas (Ganjegunte and Braun, 2011). These maps, data, and techniques have improved the accuracy of agricultural producers' knowledge of salinity levels in their fields, which enables them to develop more tailored salinity management practices that improve yields and profitability. In the second project, multistate team members determined that sorghum cultivar SN110 and switchgrass cultivar Alamo perform well under elevated salinity (Ganjegunte and Clark, 2011b). A related study found that irrigated corn for bio-energy requires between 5,800 to 16,000 gallons of non-saline irrigation water to produce one gallon of ethanol, and generates a negative energy balance (Lacewell et al., 2012). This information benefits the bio-energy industry and crop producers by identifying technically and economically feasible irrigation options for bio-fuel crops.

Activities under Objective 2 of W-2190 focused on two topic areas: water-related impacts of climate change and energy policy, and management of water for recreational purposes. Much of the time dedicated to this objective was spent coordinating and participating in outreach activities and outputs (e.g., Hurd et al., 2011; Hansen, 2013; Michelsen et al., 2013). Our goal was to provide policymakers with information and insights about the potential economic impacts of climate change, and various energy or environmental policies. A brief summary of example outputs and accomplishments follows.

Some of the work conducted under this objective culminated in a special issue of the *Journal of Natural Resources Policy Research* titled "Climate Variability and Water-Dependent Sectors: Impacts and Potential Adaptations" [vol. 5(2-3), April-July 2013]. W2190 members contributed six of the eight peer-reviewed articles (Benson and Williams, 2013; Qualls et al., 2013; Golden and Johnson, 2013; Chandrasekharan and Colby, 2013; Schoengold et al., 2013), and two other

W2190 members served as guest-editors (Peck and Peterson, 2013). Peer-reviews were also provided by several other W2190 members. One example of multistate research highlighted in the special issue is Schoengold et al. (2013), which estimated the effects of drought and media coverage of wildfires on Colorado's whitewater rafting industry. Results highlight a need for the whitewater rafting industry to communicate more directly with media outlets about the quality and safety of rafting conditions in regions unaffected by active wildfires. To date, the special issue has attracted over 600 views through the Journal's website. This multistate efforts was possible because of the strong professional network developed through W2190, including with fellow W2190 member (now emeritus), Chennat Gopalakrishnan, Editor of the Journal of Natural Resources Policy Research.

In conjunction with W2190's annual meeting in Riverside, CA, in 2012, a free public symposium on "Water Policy in the West" was organized (Pittalwala, 2012). Three speakers from three different states presented and discussed the following topics: trends in U.S. irrigated agriculture; Texas State 50-year Water Plan; and California's water management conflicts and reconciliations. Fifty people attended the public symposium, including 15 members of W2190. The other 35 attendees were affiliated with the University of California, Riverside; Santa Ana Watershed Project Authority; Western Riverside Council of Governments; University of Nevada, Las Vegas; Kallisto Greenhouses; Western Municipal Water District; USDA-US Salinity Laboratory; and Jurupa Community Services District. This symposium raised public awareness of water management challenges across multiple western states, and showed how economic principles and analyses can help frame and resolve them.

Activities under Objective 3 of W-2190 focused on groundwater management, and water allocation between economic sectors or across state boundaries. One project's research results indicate that, given natural variation in depth to aquifer and saturated thickness, uniform groundwater extraction policies may be inefficient and increase rent inequalities (Peterson and Saak, 2013). In response to a stakeholder request, another project estimated the economic impacts of alternative water conservation policies in the Ogallala Aquifer (Amosson et al., 2009). Results of these studies have improved stakeholders' understanding of institutional frameworks that can either enhance or reduce economic efficiency of groundwater extraction/conservation policies. These policy-relevant insights are now being used by team members to design and implement a pilot groundwater trading program in Nebraska's Upper Republican Natural Resource District (Juchems et al., 2013). An intended outcome of this economic field experiment is to develop and implement market mechanisms to reallocate groundwater pumping across space to improve agricultural profits and environmental conditions. Team members intend to continue this exciting work under the proposed multistate project, W3190.

A subset of W2190 members focused their attention on water allocation and transfers across sectors or state boundaries. One multistate team participated in a workshop with Colorado policymakers to discuss methods and approaches to valuing water currently used in agriculture (Colorado Ag Alliance and Arkansas Basin Roundtable, 2013; Krebs, 2013a). The workshop was attended by about 150 people (Woodka, 2013), and generated several follow-up popular-press articles in regional newspapers (e.g., Krebs, 2013b; Brown, 2013), which expanded its educational impact to a much broader general public. Another team provided economic results that were used to inform U.S. Bureau of Reclamation negotiations with irrigation districts over

forbearance agreements (Schuster et al., 2012; Jones and Colby, 2010). These research and outreach activities have strengthened our team members' connection with stakeholders and helped alleviate the cost of water shortages and associated water transfer conflicts.

The above sample of W2190's research and extension efforts highlights just a few examples of the team's outputs, accomplishments and impacts. Team members have devoted considerable effort to generating and disseminating new knowledge that is relevant to water managers and decision makers. Their collective goal has been to positively impact water policy and use, and evidence suggests their efforts have been successful. W2190 members also strive to positively impact their respective disciplines. One indicator of their scholarly productivity is the large amount of new knowledge on water issues they have published in both academic and applied outlets. Between 2009 and 2013, W-2190 members produced over 150 journal articles; 59 extension bulletins, popular press articles, and reports targeted to stakeholder groups; 93 professional presentations; 30 book chapters; 3 books; 1 special issue of a journal; and numerous other outputs (See Appendix W2190 publications for a detailed listing). Not all of these outputs are directly attributable to multistate efforts; however, many have benefited from cross-fertilization of group members' research ideas, methods, and outreach activities. This is facilitated, in large part, by the group's long history of meeting once a year to exchange ideas, which has allowed members to build and maintain strong professional ties. These ties generate new ideas, new opportunities, enhanced productivity, and cutting-edge work on water issues.

In sum, W2190 members have made significant progress toward meeting the project's objectives. Additional work is required, however, to address and extend some of the complex objectives originally proposed. New techniques and data have also become available that can enhance our ability to address existing and emerging water management questions. To minimize W3190's redundancy with other active multistate projects, a CRIS search was conducted to identify related projects. The search identified eight multistate projects that would complement, but not duplicate the activities we propose. The work proposed for W3190 focuses on water allocation and management issues in water-short regions of the U.S., including development of better models for understanding and informing these issues, and assessment of alternative water policies and institutions. In contrast, four of the eight projects focus on water quality. Three projects focus on technological aspects of irrigation scheduling, crop water use, microirrigation, and associated climate data. The remaining project is coordinating committee focused on creating linkages between existing groups of water researchers and practitioners. These related projects are briefly reviewed below and their potential synergies with this project are also discussed.

Four of the multistate projects focus on water quality: NC1186: Water Management and Quality for Ornamental Crop Production and Health; NE1045: Design, assessment, and management of onsite wastewater treatment systems: addressing the challenges of climate change; SDC358: Quantification of best management practice effectiveness for water quality protection at the watershed scale; and NC1190: Catalysts for water resources protection and restoration: applied social science research. Members of our multistate project have historically focused on water quantity issues, rather than water quality or wastewater management. One exception is a sub-objective related to water/soil salinity problems in the western U.S., which is not emphasized in other projects' objectives. Water quality concerns can certainly create or exacerbate water

quantity shortages, so specific water management issues that arise in the future may benefit from cross-project collaboration.

Three projects address technical aspects of microirrigation, irrigation scheduling, and associated climatic data needs: W_TEMP3128: Scaling microirrigation technologies to address the global water challenge; WERA1022: Meteorological and climate data to support ET-based irrigation scheduling, water conservation, and water resources management; and WERA102: Climate data and analyses for applications in agriculture and natural resources. Microirrigation and irrigation scheduling are two tools, among many, that may reduce consumptive water use. Improvements in the availability and quality of climate data for irrigation scheduling may be helpful in refining the irrigation management and policy assessment models we propose in our methods. The relatively narrow scope of these regional projects implies that they complement, but do not duplicate, the work outlined in this proposal.

The remaining multistate project of relevance is WERA1020: Western region multistate coordinating committee on water resources. The primary goal of this project is to enhance linkages between existing research and extension groups by hosting a biennial conference on western water resources, and develop a web-based communications portal for existing water researchers and programs. Through enhanced linkages, they hope to help prioritize western water issues, and develop multidisciplinary proposals to address them. Our project members would be interested in attending a regional water conference sponsored by WERA1020, and contributing to the development of multidisciplinary proposals. Our predominant expertise is in economics, which might complement their predominant expertise in watershed science and agricultural engineering. More interaction with this project may be desirable; potential complementarities should be explored through informal conversations between individual project members who already know each other.

Objectives

1. Characterize bio-physical and economic factors (and interactions) that influence water-use decisions and related market or non-market outcomes.
2. Develop or enhance methods to address emerging water management issues.
3. Evaluate and compare alternative water policy and management institutions.

Methods

OBJ 1: Climate change, declining aquifers, and rising public interest in ecosystem services are placing pressure on the ‘efficiency’ of water use in irrigated agriculture. Many economic factors influence farm-level water use, e.g., producer characteristics, output/input prices, and institutional policies. Biophysical characteristics, such as saturated thickness of an aquifer, climate variability, field size and slope, are also theoretically important drivers of water use and its heterogeneity across farms. With high-resolution bio-physical and water-use data, and new developments in behavioral and experimental economic theory, we can now test for drivers using empirical data. Conclusions will allow us to update our analytical and optimization models to reflect better understanding of the influence of biophysical and economic factors (and their interactions) on water management decisions. Improved models will also generate more-accurate

estimates of the farm-level impacts of climate change and proposed water policies. Changes in farm-level water-use decisions can affect other social goals, such as increased streamflow, reduced aquifer depletion, and aquatic habitat protection.

M.1.1 Evaluate field/farm-level water demand for various climatic and policy conditions

Previous farm-level research has focused on economically-optimal annual irrigation technologies and water application rates, and annual water demand assuming profit maximization and average climate (e.g., Schaible et al., 2010). Some work has accounted for annual climate variation and uncertainty on farm-level decisions (e.g., Peck and Adams, 2011). Less attention has been given in recent years to intraseasonal irrigation decisions under limited supplies and uncertainty about future weather. Most work in this area was conducted over 15 years ago (e.g., Bontemps and Couture, 2000; Bras and Cordova, 1981; Rao et al., 1990; Sunantara and Ramirez, 1997), when biophysical data was more limited and lower in quality. It is time to revisit and improve our models and understanding of field/farm-level irrigation decisions, using theoretical and empirical methods.

Team members will develop a stochastic optimization model to analyze water-use under various climate and policy conditions. Results will be compared to those from statistical analyses of actual on-farm water-use. Use data will represent multiple locations with different policies, such as prior appropriation, correlative rights with allocation limits, and water trading. Multiple years with varying climate conditions will be included. Results will improve understanding of the potential impacts of different climate and policy conditions on farm-level water-use.

Collaborators: U of Nebraska, Lincoln; U of Illinois, Urbana-Champaign; Kansas St U; Colorado St U; U of Wyoming; USDA-ERS

M.1.2 Laboratory economic experiments of groundwater users' behaviors

Based on theory developed by W2190 team members, laboratory economic experiments will be used to test how physical properties of groundwater resources affect incentives and behavior, and how policies influence pumping decisions. This research will inform groundwater management policy in western states by serving as a test-bed for policy initiatives. Results will be disseminated to both academic and policy audiences in relevant states.

Collaborators: Colorado St U; Kansas St U; U of Illinois, Urbana-Champaign; U of California, Riverside

M.1.3 Calibration of remotely-sensed soil/water salinity data to enhance future estimations

Soil/water salinity inventories are invaluable when initializing and validating basin and field-scale models. Without such inventories, one cannot scientifically document effects of changing water use patterns (e.g., new water distribution policies, on-farm management changes, or drought) on soil/water quality. Nor can you predict the effect of water use patterns on salt-impacted plant growth, regional water balances, and economic outcomes.

Maps of soil/water salinity within select locations will be prepared from soil/water samples and remotely-sensed electrical conductivity data. Soil samples will be used to calibrate remote-sensing data using protocols in Amakor et al. (2013a). Spatio-temporal aspects of soil salinity will be investigated in individual irrigated fields of pecan, alfalfa and cotton in the Rio Grande

Project area (Phillips and Michelsen, 2011), and alfalfa, wheat, and silage corn in the Bear and Sevier River Basins of Utah. Soil samples will be collected, following ESAP, US Soil Salinity Lab protocols, to validate remotely-sensed data using guidelines in Amakor et al. (2013b). Effects of soil variables (e.g., clay content, moisture) on data accuracy will be tested. Results will inform empirical soil salinity equations that use remotely-sensed data.

Collaborators: Utah St U; Texas AgriLife

OBJ 2: Growing water extractions from agriculture and urban uses combined with emerging demands for environment protection are increasing competition in western US for the already scarce water resources. Climate change is projected to exacerbate water scarcity and increase the recurrence and intensity of drought events (Adams and Peck, 2009; Hayes et al., 2011). These circumstances call for development of methods that support the design of sustainable water management policies.

To improve water management in semi-arid and arid regions, research must make use of recent advances in multiple disciplines to develop relevant new theories, numerical modeling frameworks, and empirical strategies. Over the last few years, there has been a rapid increase in both remotely sensed and field-level sensor data, as well as new econometric and statistical techniques to deal with such data. At the same time, there is growing interest in applying behavioral insights on irrigation decision-making into dynamic economic analyses.

Our objective is to develop modeling and analytical frameworks that: i) explain observed spatial and dynamic patterns of water use in agriculture better than existing models; ii) can be linked transparently to coupled natural-human system models that incorporate biophysical complexity; and iii) can provide relevant policy analyses for agricultural groundwater management. Activities under Obj. 2 will be informed by field-level data from Obj. 1, and will provide modeling and analytical support to Obj. 3.

M.2.1 Nonlinear dynamic techniques for detecting complex structural patterns in hydrologic data

Water researchers must become thoroughly acquainted with available data to construct informative models that successfully simulate complex real-world behavior. Substantial advances have occurred in nonlinear dynamic techniques that detect and characterize complex structural patterns in biophysical time-sequenced data (Ghil et al., 2002; Kaplan and Glass, 1995). Team members will use detected structures to link anthropogenic and climatic forcings with hydrologic processes of interest, such as droughts, stream flows, aquifer levels, water quality, and water-related ecosystem services (Sugihara et al., 2012). Results will then guide construction and validation of hydro-economic models useful for sound public decision-making.

Collaborators: U of Florida; Utah St U; Texas Tech U; U of Wyoming

M.2.2 Hydro-economic modeling of alternative drought management policies

Drought events can have large impacts on social welfare. Adjustments typically occur in irrigated agriculture and the environment. Although there are many farm-level options available for adapting to water scarcity, they require support from basin authorities in the form of well-designed water policies (Saleth and Dinar, 2004, p.9; Saleth et al., 2011). Water markets can also reduce negative economic effects of droughts. However, unintended environmental effects of water trading may weaken its advantages for society (Katz, 2013). Policies or institutions that

help balance economic and environmental objectives are needed. These issues illustrate the need for hydro-economic modeling that integrates multiple dimensions of water resources management to advance sustainable water management policies (Elbakidze and Cobourn, 2013).

This research will develop an integrated hydro-economic model and apply it to drought-affected basins, specifically the lower Colorado Basin and Santa Ana Basin of southern California. The model will link a reduced-form hydrological component with a regional economic optimization module, and environmental benefits component. Several members of W3190 have experience building integrated hydro-economic models. By bringing their expertise together, we can synthesize lessons and insights, avoid common pitfalls, and develop a cutting-edge model. We will use the model to analyze effects of drought on water resources and users, and assess the performance of alternative drought management policies.

Collaborators: U of California, Riverside; U of Arizona; U of Wyoming; New Mexico St U; U of Idaho; Virginia Tech

M.2.3 Develop improved dynamic models of agricultural groundwater management

Previous groundwater economics models have ignored important aspects of producer behavior and aquifer dynamics. We hypothesize that neglecting well-yield in dynamic modeling of coupled natural-human agroecosystems will lead to large errors in predictions of the effectiveness of alternate management institutions and long-term sustainability. Management activities or institutions that sustain well-yields may provide a buffer against climate change and variability.

Most groundwater economics models use depth to water table, or energy prices as determining factors for irrigation water use (Koundouri, 2004). Because current models do not estimate the dynamic trajectory of well-yield resulting from groundwater pumping (e.g. Saak & Peterson 2007, Harou & Lund 2008, Bulatewicz et al. 2010, Brozovic et al. 2010, Varela-Ortega et al. 2011, Steward et al. 2013), they are unable to address dynamic interactions between hydrology, producer behavior, and environmental outcomes in areas where well-yields are of concern. Farmers commonly identify low well-yields as an issue, so the relevance of current hydrologic-economic models is limited.

A multistate team will build a dynamic groundwater model that includes well-yield and realistic producer decision-making based on research in Obj. 1, M.1.1. We hypothesize that, given nonlinearity of biophysical and social processes, the model will produce a number of thresholds at which the ability to sustain productive irrigation into the future becomes impossible. A second hypothesis is that failure to model well-yield will lead to large errors in estimates of common-pool externalities of groundwater pumping (Saak & Peterson 2007, Brozovic et al. 2010). In the past, estimates of groundwater pumping externalities have generally been small (Koundouri, 2004). Incorporating well-yield adds a further externality that may be nonlinear in depth to water.

Collaborators: U of Illinois, Urbana-Champaign; Kansas St U

OBJ 3: Alternative water management institutions and policies will be analyzed in the context of increased demand for water quantity/quality, increased supply-variability, and changing technology. This will enhance understanding of the drivers of legal, institutional, and policy

change. It will also enable prescriptive statements about water institutions and water policy, which will provide policymakers with options for increasing society's capacity to deal with water-related change.

M.3.1 Test alternative institutions' ability to provide ecosystem services

Water markets are increasingly used to reallocate water from low-value to high-value uses (Hansen et al., 2013). Markets can also improve other aspects of water use that have historically been addressed outside of the market economy (or not addressed at all), such as re-allocating water to environmental purposes, improving water quality, governing surface and ground-water interactions, and compensating for provision of water-based ecosystem services (e.g., flood prevention and control, reduced erosion, and improved riparian habitat).

Non-agricultural benefits of flood irrigation are an example of water-based ecosystem services. In headwater drainages where improved irrigation efficiency does not necessarily increase downstream flows, water's value is artificially low when based solely on direct benefits to agricultural production. Water's value would be higher if environmental and recreational benefits associated with wetland creation and late-season instream flows were included in its calculation (Peck et al., 2004; Smith et al., 2012; Sueltenfuss et al., 2013; Ward and Pulido-Velazquez, 2008).

In other cases, ecosystem function and services (e.g., coastal habitat; water-related recreation such as sport-fishing) are impaired when water resources are directed to human use. Quantity, quality and value of services in these situations often depend on complex relationships between spatiotemporal patterns of water use and ecosystem function. These characteristics must be included in our models and experimental methods to determine whether and how to mitigate ecosystem impact or restore ecosystem function.

The proposed research comprises several projects related to ecosystem services provision. These projects apply different techniques to different case-studies, but they have a shared interest in understanding the costs, benefits, and bio-economic challenges of ecosystem services provision. Multistate collaboration will facilitate exchange between projects, which will reduce redundancy in effort (e.g., literature reviews), avoid common pitfalls in modeling and implementing ecosystem services provision programs, encourage integration of ideas and methods, and disseminate shared insights to a larger audience.

This suite of related projects include: a field-experiment to initiate a 'payment for ecosystem services' (PES) pilot-program in southwestern Wyoming; a bio-economic model of *in situ* lake/river-based services (e.g., fishing) in the western US; non-market valuation of sport-fishing and related recreation; and a laboratory economic experiment on coastal ecosystem function along the Sea of Cortez.

The project in southwestern Wyoming will provide insights for agencies and NGOs interested in the ability of environmental markets to facilitate transactions between people who benefit from ecosystem services and those whose private decisions affect provision. The proposed pilot PES program will provide insights about the feasibility of ecosystem service markets, locally appropriate market design, tools for assessing ecological change, and approaches to educating landowners about the potential for PES programs to generate revenue.

The lakes/rivers project will develop an economic model with biological components to represent how changes in water use affect ecosystem function. The model will then be used to determine the effectiveness of alternative policies in conserving ecosystem services or recovering ecosystem function. Functional lake and river ecosystems are critical to the sport-fishing industry. The opportunity therefore exists for the lakes/rivers team to collaborate with the fishing team, if a case-study of mutual interest can be identified. The fish team will use non-market valuation techniques to estimate social welfare generated by sport-fishing and associated recreation. Through collaboration, the two teams could potentially estimate the costs and benefits of alternative policies that conserve or restore fish habitat. This information would help stakeholders determine whether specific conservation/restoration activities are economically-justifiable. If so, cost-benefit estimates could improve stakeholders' chances of securing funds to implement those activities.

Lastly, the Sea of Cortez project will identify key physical-economic relationships and interactions between stakeholders involved in the US-Mexico dispute over Colorado River management policies to improve coastal ecosystem function along the Sea of Cortez. This team will use laboratory experiments to assess alternative water allocation institutions' performance, *a priori*, including practical challenges to implementation and unexpected consequences. Results will help stakeholders narrow-down and prioritize a list of proposed policy interventions.

Collaborators: U of Wyoming; U of Northern Colorado; Texas Tech U; U of California, Riverside; U of Idaho; New Mexico St U; Colorado St U

M.3.2 Identify strengths and weaknesses in the capacity of Midwest water institutions (i.e., states that currently lack extensive irrigation) to deal with increasing water scarcity.

It is well-known that water resources in the West face pressures from growing urban and environmental demands, global climate change, and water quality impairment. Recent research indicates that areas of the Midwest are also likely to experience increased water stress due to climate change (Tavernia et al., 2013). Little research has been done, however, on the capacity for Midwest water institutions to deal with the many challenges arising from more frequent water stress. One such challenge is the expansion of irrigation into historically rain-fed areas (Williams, 2012; USDA-NASS, 2009, p.3). This trend raises concern about a potential future need for intersectoral water transfers.

Team members will conduct an extensive literature review to identify existing institutional pathways and impediments to efficient water allocation in Missouri and Illinois, including current laws, policies and procedures. Economic theory and lessons from the West will be used to identify relevant criteria for efficient water allocation institutions, which will then be compared to existing institutions in the Midwest. Types of transactions costs associated with modifying existing institutions will also be identified (McCann, 2013). Recommendations will be developed to improve the capacity of Midwest water institutions to efficiently respond to scarcity.

Collaborators: U of Missouri; U of Illinois, Urbana-Champaign; Michigan St U; New Mexico St U

M.3.3 History and future of water laws and transboundary treaties

Regulation, law and contractual relationships over water are affected by, and affect, water scarcity and private water-use decisions. Climate change, population growth, and water monitoring and measurement technology have the potential to drive broad changes in water-related institutions. This research will examine drivers of changing water law and regulation, and continued evolution of western water management toward more robust and varied water markets and consumptive-use-based water law.

A focal point for analysis will be the Columbia River Treaty, which will be open to potential renegotiation in 2014 under a very different environment than when it was first signed in 1964 (Osborn, 2012). This particular analysis will involve a review of historical documents and literature on the current Treaty to help identify benefits and costs that have accrued to various parties affected by the agreement. A game theoretic model will then be developed to represent the bargaining setting. Alternative renegotiation strategies will be analyzed to determine likely outcomes and associated distributions of net benefits. Our research will identify potential sources of conflict during the upcoming treaty renegotiation, and opportunities for mutually beneficial bargaining solutions. This will inform agency discussions and increase stakeholder understanding of the complex tradeoffs and incentives involved in the renegotiation process.

Collaborators: U of Washington; U of Idaho; U of Florida

Measurement of Progress and Results

OUTPUTS

O.1.1 Impact estimates for the effects of various climate conditions and regulatory regimes on representative irrigators and associated water resources. Presentations and a summary report to irrigator groups and water agencies. Presentation at a professional meeting, and a draft manuscript for submission to a peer-reviewed journal.

O.1.2 Research results will be disseminated to relevant academic and policy audiences through presentations and a manuscript published in an economics or interdisciplinary journal. Results will be communicated to policymakers in Colorado, Nebraska and Kansas to help improve the economic efficiency of policies aimed at conserving groundwater.

O.1.3 Basin-scale maps of soil and water salinity extent and severity under major crops in the Rio Grande Project area (e.g., pecan, alfalfa and cotton), and in the Bear and Sevier River Basins of Utah (e.g., alfalfa, wheat, and silage corn). Statistical results that quantify the effects of major soil variables (e.g., clay content, moisture) on data accuracy, and that validate remotely-sensed data from the study areas.

O.2.1 Manuscripts presented at a special symposium at a water association's national meeting. Submission of manuscripts to high-profile refereed journals in water science.

O.2.2 Working papers, policy notes, journal articles, and a workshop for policymakers to discuss the relevance of our findings for policy in the lower Colorado Basin and Santa Ana Basin of southern California.

O.2.3 A meeting with producers that rely on groundwater in Nebraska and Kansas to exchange information on the relative importance of different local hydrologic conditions in decision-making and risk management. Educational materials, maps, and other visual and multimedia products that allow producers, other decision-makers, and researchers to understand linkages

between agricultural water security, environmental conditions, and long-term aquifer sustainability. A case-study portfolio that highlights successful (or not) groundwater management institutions, policy insights from these cases, and a summary of W3190 involvement in efforts to improve management outcomes.

O.3.1 For the southwestern Wyoming project, transactions within a water-based “payment for ecosystem services” pilot program will result in a suite of tools to assess ecological and economic change at the watershed level. In the lake/rivers/fish project, optimal strategies will be identified for restoring or maintaining specific ecosystem service flows generated by in-situ water resources, such as lakes and rivers. Estimates of the social value of sport-fishing will also be provided to relevant stakeholders. The Sea of Cortez project will generate a white-paper for Colorado River policymakers to highlight challenges and other aspects of implementation that are not apparent otherwise.

O.3.2 A report containing recommendations for improving the capacity of Midwest water institutions to efficiently respond to scarcity.

O.3.3 Presentations and meetings with stakeholders involved in the Columbia River Treaty renegotiation. Professional conference presentation, and a journal article.

Outcomes or Projected Impacts

IMPACTS

I.1.1 By improving farm and field-level irrigation models, we will generate more-realistic insights about alternative groundwater management practices/policies and climate change impacts. By improving model realism, we can gain credibility with stakeholders, and have greater impact on their management/policy decisions.

I.1.2 This research will provide a test-bed for groundwater policy initiatives. It will identify design flaws and strengths before policies are implemented, and thus improve policy design in the western US.

I.1.3 Calibration and validation results will enable researchers to develop empirical equations that quickly transform remote-sensing data into accurate estimates of field-scale soil salinity. This will improve availability and reduce cost of soil-salinity estimates. Spatial and temporal data for individual irrigated fields will enable agricultural producers to determine whether salinity warrants management adjustments.

I.2.1 There is growing concern that models used in public decision-making fail to capture the complexity of real-world dynamics. The U.S. House of Representatives Committee of Science and Technology held a special hearing, “Building a Science of Economics for the Real World,” about the failure of dynamic stochastic general equilibrium models to anticipate the current financial crisis (US Government, 2010). The Subcommittee Chairman stated (pp. 7-8), “Because our experts’ way of looking at the economy left them blind to the crisis that was building, we were unprepared to deal with the crisis... If this approach to economics is useless for the purposes of advising policy makers...what are we getting out of economic research funded through NSF?” Models that over-simplify reality are unreliable for public policy; our work will increase the reliability of future hydro-economic models.

I.2.2 A hydro-economic modeling tool that basin authority staff can use to evaluate alternative water institutions under drought. Increased understanding of strengths and weaknesses of alternative drought management policies in the lower Colorado Basin and Santa Ana Basin.

I.2.3 Models and policy recommendations will help local and regional decision-makers identify cost-effective ways to sustain aquifers that support agricultural production in the High Plains.

I.3.1 Southwestern Wyoming project: transactions in a water-based “payment for ecosystem services” pilot program will show agricultural producers the potential for environmental markets to improve economic and ecological outcomes. Lakes/rivers/fish project: identification of cost-effective ways to restore/maintain specific ecosystem services generated by in-situ water resources; estimated value of sport-fishing. Cost and benefit estimates will help stakeholders determine if specific conservation activities are economically worthwhile; this could help them secure implementation funds. Sea of Cortez project: reduce the cost to society of designing and implementing proposed policies by detecting challenges and pitfalls, *a priori*. Help stakeholders narrow-down and prioritize proposed policy interventions.

I.3.2 Increase Midwestern policymakers and water managers’ knowledge of the strengths and weaknesses of existing institutions for responding efficiently to water scarcity. Outreach efforts will transfer valuable lessons from the western US’s water-related successes, failures, and shortcomings to policymakers in neighboring regions.

I.3.3 This research will identify potential sources of conflict during treaty re-negotiation, and identify strategies for achieving mutually beneficial outcomes. Insights will inform agency and stakeholder discussions of the complex tradeoffs involved in renegotiating transboundary water agreements. This will reduce the time and legal resources consumed during re-negotiation, and increase the likelihood of socially-optimal terms of agreement.

Milestones

Mil.1.1 In 2015: Complete a literature review of intraseasonal irrigation decision models. Begin data collection with participating producers, which will continue for several years. 2016/17: Develop and solve an analytical model of intraseasonal water allocation. 2018: Empirically test the analytical model’s results using producer data. 2019: Share results at a stakeholder meeting and professional conference; draft a peer-reviewed journal manuscript.

Mil.1.2 In 2015: Conduct a literature review of spatially-explicit common pool resource use. 2016: Design a laboratory experiment to test hypotheses about the influence of physical properties of groundwater resources on economic behavior. 2017: Conduct experiments and analyze data. 2018: Draft a journal manuscript; present results at academic and policy conferences.

Mil.1.3 In 2015/16: Gather remotely-sensed electrical conductivity data for study areas. 2016/17: Collect physical soil samples from study areas. 2018: Analyze physical soil samples for salinity; compare to salinity estimates from remotely-sensed data. 2019: Determine if major soil variables (e.g., clay content, moisture) have a systematic effect on accuracy of remotely-sensed data.

Mil.2.1 In 2015: Develop computer code in R to automate nonlinear time series analysis (nlts) for hydrologic data. 2016: Follow procedures outlined in Sugihara et al. (2012) to develop

computer code in R to run Convergent Cross Mapping, which detects causal interrelationships in observed data. 2017: Apply code to detect structure and causal interrelationships in watershed applications identified by W3190 collaborators. 2018: Organize a special symposium at a water association's national meeting about watershed applications of nonlinear dynamic methods. 2019: Prepare and submit manuscripts.

Mil.2.2 In 2015/16: Develop and calibrate a reduced-form hydrology model for each basin that accommodates a variety of policy interventions and institutional arrangements. 2017/18: Simulate various climatic and policy scenarios. 2019: Disseminate results to policymakers and researchers.

Mil.2.3 In 2015: Develop initial modeling framework, with feedback from producers in the High Plains region. 2016: Calibrate model to data from Nebraska and Kansas. 2017: Organize a special session at Heartland Environmental and Resource Economics workshop about behavioral aspects of groundwater economics. 2018: Refine modeling framework; develop educational materials based on results. 2019: Refine educational materials based on feedback from regional producers and decision-makers.

Mil.3.1 Southwestern Wyoming project, 2017: Develop and implement a water-based "payment for ecosystem service" pilot program related to sedimentation reduction or fish/wildlife habitat. Lakes/rivers/fish project, 2015: Complete literature review of existing models for optimizing investment in ecosystem services provision, and of sport-fishing values. 2016/17: Develop a deterministic bio-economic model of ecosystem function and services provision. Conduct surveys of sport-anglers. 2018: Incorporate uncertainty into bio-economic model. Process angler-survey data. 2019: Assess performance of alternative ecosystem restoration/maintenance approaches. Estimate social welfare generated by sport-fishing. 2020: Share results through meetings with resource managers, professional conferences, and journal articles. Sea of Cortez project, 2015/16: Identify physical-economic relationships and stakeholder characteristics for inclusion in experimental design. 2017/18: Design, test, run laboratory economic experiments. 2019: Share research results through a white-paper for stakeholders, journal article, and presentations at a workshop for policymakers.

Mil.3.2 In 2015/16: Identify and summarize relevant water laws, policies, institutions for case-study Midwestern states. 2017/18: Compare Midwest water institutions to those in western US and to economic theory; identify Midwestern institutions' relative strengths and weaknesses. 2019: Draft a report for relevant stakeholders.

Mil.3.3 In 2014: Conduct a literature review; identify and meet with stakeholders; identify distribution of benefits/costs under current Columbia River Treaty; define characteristics of the renegotiation setting (e.g., relevant parties and economic conditions); develop a game theoretic model that reflects these. 2015/16: Integrate into the model any new developments in the renegotiation process; analyze alternative renegotiation strategies, characterize outcomes, and estimate distributions of benefits/costs. 2017: Present findings through stakeholder meetings, professional conference, and journal article. Timing and nature of certain activities depend on developments during the CRT renegotiation process.

Projected Participation

Please see the completed Appendix E, available at <http://nimss.umd.edu/homepages/outlineAppE.cfm?trackID=16396>.

Outreach Plan

W2190 members have a strong record of reaching out to stakeholders and policymakers to gather input about research needs, and discuss research findings and their practical implications. As described earlier under “Related, Current and Previous Work,” past outreach efforts have included a publicly -available web-based decision tool, a professional training module, several one-page research factsheets, a free public symposium, a workshop for policymakers which generated several news articles, and 59 extension bulletins, popular press articles, and reports targeted to stakeholder groups. W2190 members have also reached academic and research audiences through a long list of journal articles and professional presentations.

W3190 members intend to continue this rich tradition of actively engaging stakeholders, policymakers, academics and fellow researchers. As described above, in the Methods section, W3190 members will organize and host meetings with local stakeholders and policymakers to gather background information, exchange ideas, meet potential collaborators, and eventually discuss practical implications of our research results. Meetings may involve formal presentations, panel discussions, informal/interactive surveys, and may generate additional outreach opportunities through local news stories. W3190 members will also organize and host a free public symposium in conjunction with a future annual meeting. The event will be modeled after the successful symposium held in conjunction with our annual meeting in Riverside, California in 2012. Other outreach efforts will result in extension bulletins and presentations, popular press articles in regional magazines and newspapers, policy briefs, white-papers, factsheets, and technical reports to stakeholder groups. Many projects will involve training and mentoring graduate students, and in some cases undergraduate students, which constitutes outreach to future water resource scientists and managers.

W3190 members will continue to publish peer-reviewed articles in disciplinary and interdisciplinary journals. To highlight the group’s diverse portfolio of water-related research, we will pursue a special issue in a relevant outlet (e.g., Journal of Natural Resources Policy Research) during years 4 & 5 of the project. Members will also present individual research projects’ findings at relevant professional conferences. Opportunities also exist to organize a special session on “Challenges and Innovations in Water Management and Policy” at the Heartland Environmental and Resource Economics Workshop (an annual conference held at the University of Illinois, Urbana-Champaign) or an annual meeting of the Western Agricultural Economics Association or University Council on Water Resources.

Organization/Governance

W3190 will be governed by an executive committee, which will consist of a Chair, Vice-Chair and Secretary. Each year, at the annual meeting, project participants will elect a new Secretary. The Secretary’s responsibilities will include: providing input about the proposed organization of the next annual meeting; corresponding with W3190 members about the meeting; soliciting state reports from members in the weeks leading up to the annual meeting; compiling state reports and providing an electronic copy to participants during the annual meeting; taking notes during the annual meeting; and providing input on the annual (or final) report after the annual meeting

concludes. The Secretary will then be promoted to serve as Vice-Chair for one year. The Vice-Chair's responsibilities will include helping the Chair organize and prepare for the annual meeting, and drafting the annual report for the executive committee to review. The Vice-Chair will then be promoted to serve as Chair for one year. The Chair is responsible for organizing the next annual meeting, and revising and submitting the annual (or final) report. At times, the executive committee may choose to organize ad-hoc sub committees for various purposes, such as proposal writing, special annual meeting events (e.g., field trips), etc.

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