Conservation of surface and ground water in a Western watershed experiencing rapid loss of irrigated agricultural land to development

A proposal to the Integrated Research, Education, and Extension Competitive Grants Program—National Integrated Water Quality Program (NIWQP), U.S. Department of Agriculture, Cooperative State Research, Education, and Extension Service

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Project Summary

Rural watersheds throughout the West are experiencing rapid replacement of irrigated agricultural land with suburban, exurban, and resort development, resulting in increased water demand and alteration of traditional irrigation practices. Furthermore, changes in water withdrawal, conveyance and use have altered ground-surface water interactions, exacerbating conflicts among users. To achieve NIWQP watershed-scale objectives to develop water conservation strategies, promote effectiveness of such strategies, and train the next generation of water professionals, we propose a research, extension, and education project in the Henry's Fork Snake River watershed that will 1) develop quantitative models of ground and surface water use and flow pathways under historic, current, and anticipated future water/land use scenarios; 2) identify socioeconomic and physical mechanisms that will encourage water conservation and efficient water management on developed lands; 3) prepare and distribute to decision-makers, planners, and stakeholders educational materials describing the watershed's hydrologic system and water conservation benefits and strategies; 4) facilitate development by the Henry's Fork Watershed Council of a water conservation and management strategy to increase water availability for agriculture while enhancing ecological benefits in key stream reaches; and 5) provide experiential training to an interdisciplinary team of environmental science graduate and undergraduate students. A model of surface and ground water flow will be constructed from existing hydrologic data and measurements of stream and canal gain/loss and will be calibrated to traditional irrigation management conditions. This model will be used to predict future conditions under hypothesized land/water-use scenarios. Decision-makers and stakeholders will be involved throughout the project to ensure that project outputs meet their information needs, are disseminated effectively, and contribute to development of stakeholder-driven conservation strategies.

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INTRODUCTION

Conflicts over water use in the arid and semi-arid Western United States date back to the 19th century. Early in the settlement of West, conflicts occurred over uses for mining and agriculture. The socioeconomic institutions that were developed to manage these conflicts include the prior appropriation doctrine, cooperative investment in water infrastructure, federal programs designed to develop the West's water resources, and government agencies charged with measuring, storing and delivering these resources (Reisner 1993, Fiege 1999). By the middle of the 20th century, irrigation became the dominant use of water in the West, accounting for over 90% of total water withdrawals and consumptive use in most rural watersheds. Although conflicts will always occur between junior and senior water rights holders in a prior appropriation system, traditional mechanisms of apportionment and delivery of surface water served agriculture well from the 1940s through the 1970s, in part because of a favorable combination of factors including low human population densities, relatively stable climate, and little demand for other uses. Since the late 1970s, however, these traditional water management practices have been unable to meet the needs of irrigation, let alone other uses, in the face of requirements for environmental flows (e.g., Kenney 1999), increases in ground-water withdrawal (e.g., Johnson et al. 1999), and changes in climate (e.g., Service 2004, Mote 2006). Currently, rapid population growth in the West is adding another significant challenge to water management through increased demand for water, conversion of irrigated land to suburban, exurban, and resort development, and alteration of traditional water management practices. We propose to address this emerging challenge to water allocation and management in the rural West.

Population Growth and Collaborative Watershed Management in the "New" West

Over the past three decades, the population of the rural West has increased substantially, as people seek a higher quality of life, which includes scenic beauty, access to public lands, and opportunities for outdoor recreation (Johnson and Rasker 1995, Riebsame et al. 1996, Rudzitis 1999, Frentz et al. 2004). Although a number of researchers have investigated the consequences of population growth to ecological processes and conservation (e.g., Theobald et al. 1996, Hansen et al. 2002, Gosnell et al. 2006), most of this work has focused on terrestrial ecosystems and landscape conservation rather than on aquatic ecosystems and water conservation. Conversely, most research into the ecological consequences of human use and management of water resources in the West has focused on the effects of dams and water withdrawal associated with traditional uses (e.g., Collier et al. 1996, Richter et al. 1997, Rood et al. 2003) and not on the effects of population expansion into irrigated regions. Concurrently, sociologists have investigated the theory that newcomers to rural areas place a higher value on environmental protection than do long-term residents and thus that "green migration" of new residents can result in greater support for conservation of natural resources in rural areas (e.g., Jones et al. 2003). In the West, discussion over the legitimacy of this theory has often been framed as the "cows versus condos" debate, in which the relative consequences to environmental quality are weighed between a traditional ranching/farming landscape and one dominated by exurban development, albeit one perhaps inhabited more environmentally enlightened residents (e.g., Wuerthner 1994, Knight et al. 1995). In at least some areas of the rural west (including the Teton Valley within the proposed study area of this project), long-time residents are actually more likely to support limits to population growth, maintenance of traditional land uses at the expense of economic growth, and protection of environmental quality than are newcomers (Smith and Krannich 2000). Preston (2005) has taken this observation a step further by likening immigration into the rural West to the fable of the charmed goose—people move to the rural West because of its natural amenities, but development associated with this immigration results in degradation of the very amenities attracting the new residents. Although natural amenities can include water and aquatic resources, this inclusion is often implicit rather than explicit, and theories of both sociological and ecological consequences of rapid population growth in the rural West have rarely been applied to effects on traditional irrigation systems and conservation of aquatic ecosystems.

Given the emphasis placed on effects of population growth on land use and terrestrial ecosystems, it is ironic that the social institutions generally considered most successful in addressing natural resource management conflicts in the West have grown up around water issues. Watershed councils and other collaborative, stakeholder-driven groups have proliferated in the rural West, providing alternatives to government decision-making in management of water resources (Kenney 1999, Lant 1999, Weber 2000). Success of watershed councils in implementing changes on the ground can be hampered by limited participation, lack of regulatory authority, and restricted funding availability (Griffin 1999), but such councils have generally been successful in facilitating collaboration and cooperation among water resource managers and stakeholders, including irrigators, government agencies, and fish and wildlife conservation interests (e.g., Van Kirk and Griffin 1997). It is likely that watersheds with well-established collaborative processes will be better equipped than those without such institutions to address the challenges to water management posed by rapid population growth. Addressing these challenges, however, will require successful incorporation into the collaborative process of new stakeholders such as developers, new residents, and county planners.

Study Area

The upper Snake River basin, Idaho and Wyoming (Figure 1), provides an excellent geographic context within which to study the effects of population growth on water management in a landscape historically dominated by irrigated agriculture. In terms of total amount of water withdrawn, the upper Snake irrigation system is second within the U.S. only to California's Central Valley. The system includes nine major storage reservoirs with a combined capacity of over 4 million acre-feet. About 6.5 million acre-feet of surface water and 1 million acre-feet of ground water are withdrawn annually within the basin and applied to 2 million irrigated acres. The basin also contains world-renowned recreational trout fisheries and other scenic and recreational resources in and around Yellowstone and Grand Teton national parks. It is these resources— primarily those associated with the headwaters of the Snake River—that have fueled rapid population growth in the region. Within the upper Snake River basin, the Henry's Fork watershed (Figure 1) is ideal for a watershed-scale project aimed at developing water management strategies under conversion of traditionally irrigated agricultural land to development for three reasons: 1) it is experiencing rapid population growth on irrigated lands, 2) it supports some of the most unique and important fisheries, aquatic and wetland resources in the Greater Yellowstone Ecosystem (Van Kirk and Benjamin 2001, Van Kirk and Gamblin 2000, Noss et al. 2003), and 3) it has a watershed council with a 15-year record of success in facilitating collaborative water resource research and management. The Henry's Fork watershed is often cited as a model of innovation in natural resource management (e.g., Preston 2005). This high visibility, combined with the existence of well-developed collaborative institutions in the watershed, results in a high probability of not only achieving the goal of developing a water conservation strategy within the watershed but also of attaining the larger goal of extending methodology and results to other Western watersheds experiencing rapid population growth.

The 3,200-square mile Henry's Fork watershed is located in eastern Idaho and western Wyoming (Figure 1). About half of the watershed's area is federal land, including a portion of Yellowstone National Park. Elevations range from 4,500 feet at the southwest corner of the watershed to over 10,000 feet in the east. Major mountain ranges include the Teton, Big Hole, and Centennial ranges. These mountains are the oldest geologic formations in the watershed, which is otherwise dominated by volcanic features created between 4 million and about 600,000 years ago as the Yellowstone hot spot moved northeastward through the region (Hackett and Bonnichsen 1994). The Madison and Pitchstone plateaus (Figure 1) were formed by the most recent rhyolite eruptions of the hot spot and host large aquifers that discharge a nearly constant 450,000 acre-feet of water to the Henry's Fork upstream of Ashton (Whitehead 1978, Benjamin 2000).

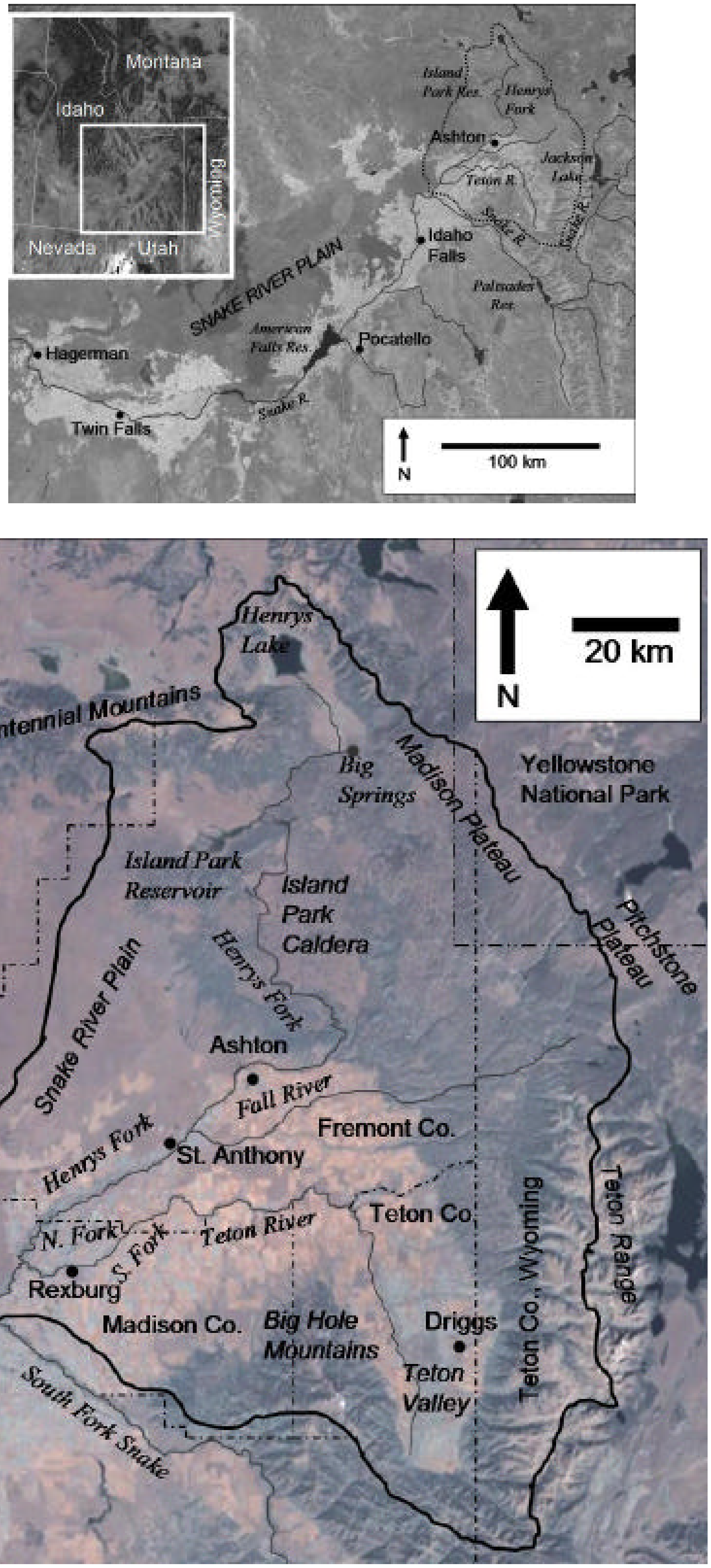

Figure 1. Location of Henry's Fork watershed within the upper Snake River basin (top), and watershed map (bottom). Light-colored areas in the top map represent irrigated lands.

Mean annual temperature and precipitation, respectively, range from about 42 °F and 12 inches at the lowest elevations to less than 33 °F and over 40 inches cm at the highest elevations. Precipitation is nearly uniformly distributed throughout the year at the lowest elevations but is characterized by a large early-winter peak at the higher elevations. The vast majority of discharge in the watershed's streams is derived from snowfall at elevations greater than 6,000 feet. The higher elevations of the Henry's Fork watershed lie in the Middle Rockies ecoregion; the lower elevations lie in the Snake River Basin/High Desert ecoregion (Omernik 1987). Prior to the development of cultivated agriculture in the watershed, elevations below 5,000 feet were primarily grassland and shrub steppes. Mixed conifer-aspen and spruce-fir forests occur at higher elevations, and alpine meadows are found at the highest elevations.

The Henry's Fork watershed consists of three U.S. Geological Survey (USGS) hydrologic cataloging units (Figure 2), Upper Henry's (17040202), Lower Henry's (17040203) and Teton (17040204). Mean annual water yield is 1.1 million acre-feet from the upper Henry's Fork, 0.9 million acre-feet from Falls River, and 0.7 million acre-feet from the Teton River. Of this, about 1.5 million acre-feet of surface water and 0.3 million acre-feet of ground water are withdrawn for irrigation, accounting for 99% of total water withdrawals in the watershed. About 0.7 million acre-feet returns to the surface water system, resulting in total annual discharge from the watershed of about 1.7 million acre-feet (Van Kirk, unpublished data). Irrigation water is stored in three reservoirs in the watershed, Island Park Reservoir (135,000 acre-feet), Henry's Lake (90,000 acre-feet), and Grassy Lake (15,000 acre-feet). A fourth storage reservoir was completed in 1975 on the Teton River northeast of Rexburg, but this dam failed on June 5, 1976, claiming 11 lives and causing significant property damage downstream. The earliest water rights in the watershed were claimed in 1879, when Mormon pioneers from Utah first settled in the Rexburg area (Van Kirk and Benjamin 2000). Water right priority dates become progressively younger with distance upstream from Rexburg, and nearly all water rights in the watershed are junior to those further downstream in the Snake River system. Irrigated land in the watershed totals about 275,000 acres, most of which is located in the lower third of the watershed and in Teton Valley. Primary irrigated crops are wheat, barley, seed potatoes, hay, and pasture.

The Henry's Fork watershed boundary coincides roughly with that encompassing the Idaho counties of Fremont, Madison and Teton (Figure 1). A small portion of Teton County, Wyoming, consisting mostly of national forest, national park, and wilderness, comprises the eastern edge of the watershed. In 2006, the three primary counties had a combined population of 51,600, which represented a 27% increase over the previous decade. Growth rates over this time period for Fremont, Madison, and Teton counties were 4.7%, 33.5% and 47.6%, respectively. In 2006, 436 new building permits were issued in Teton County alone, where the number of housing units had already increased 50% over the previous six years. Growth in Teton County is driven by its proximity to Jackson, Wyoming, and outdoor recreation opportunities and is comprised largely of resort and exurban development, nearly all of which is replacing irrigated land. By contrast, most of the growth in Madison County has been driven by expansion of Brigham Young University-Idaho into a four-year university and consists of suburban development into agricultural land. Fremont County is currently experiencing the initial phases of exurban and resort development similar to that which occurred in Teton County about 20 years ago. Although most of the resort development in Fremont County is occurring in

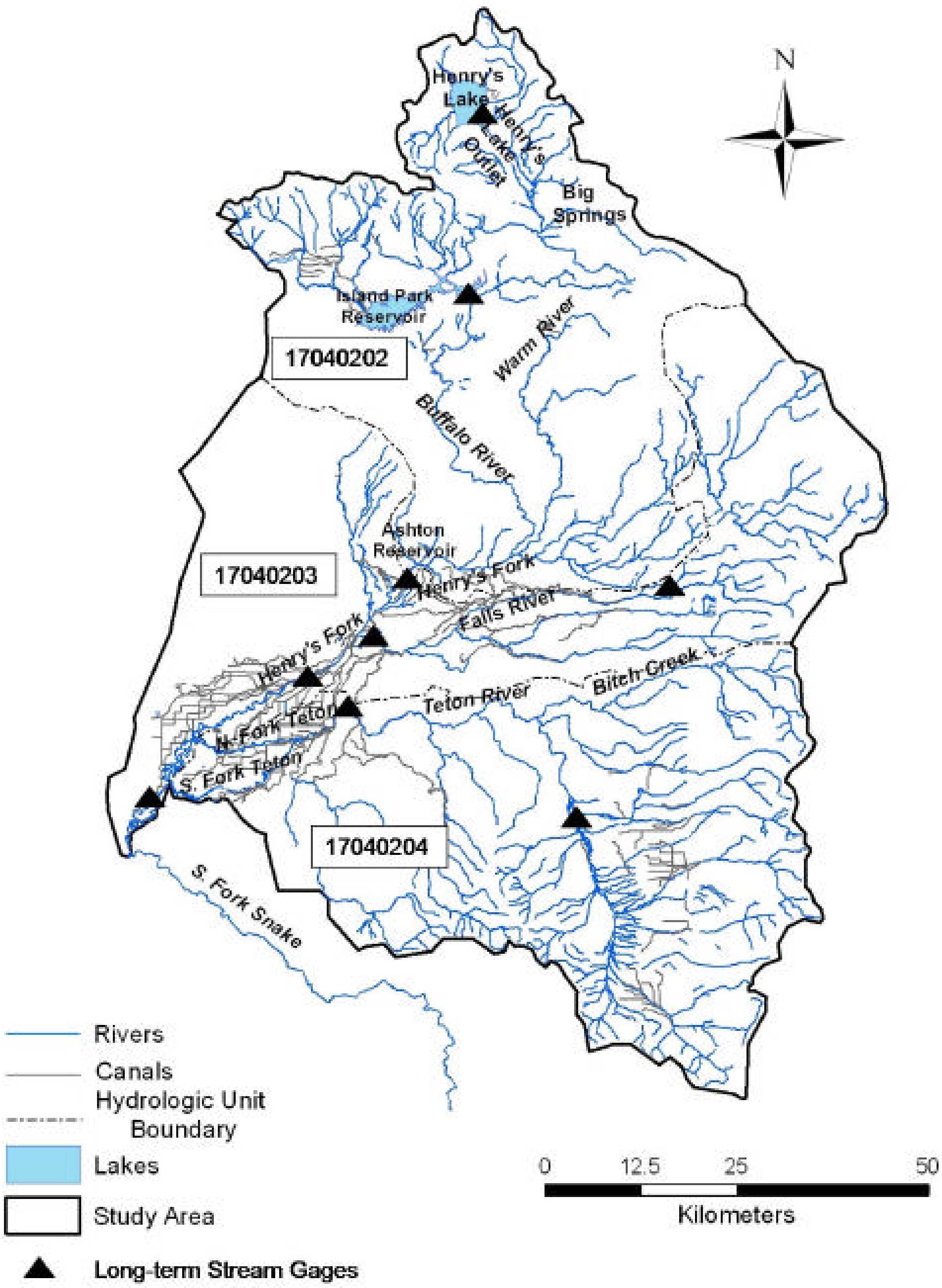

Figure 2. Hydrography of the Henry's Fork watershed.

Island Park, where the climate is too cold to support agriculture, exurban development in the Ashton area and suburban development north of Rexburg is beginning to encroach onto irrigated land. Economic trends in the watershed reflect a decrease in the importance of agriculture. In 1996, farming accounted for 11.5% of all jobs in the watershed; in 2005, this figure was 8%. Over the same time period, construction increased from 5.4% of all jobs to 8%. Farming currently supports about 2060 jobs in the watershed. Recreational fishing and boating on the Henry's Fork supports about 870 jobs, but if the Snake River immediately adjacent to the Henry's Fork watershed is included, this figure jumps to 2020 jobs (Loomis 2005, Loomis

2006). Thus at a regional scale, the economic importance of fishing and other river-related recreation is approaching that of agriculture.

Previous and Ongoing Research and Management Activities

Van Kirk and Griffin (1997) have recorded the history of conflicts over water management and use in the Henry's Fork watershed, which included the formation of the Henry's Fork Watershed Council in 1993. The Council is a grassroots, community forum co-facilitated by the Fremont-Madison Irrigation District (FMID), representing about 1700 irrigators in the watershed, and the non-profit Henry's Fork Foundation (HFF), representing a roughly equal number of anglers and river conservationists. Concurrent with formation of the Watershed Council, HFF launched a research program aimed at providing the scientific knowledge needed to inform collaborative water resource management. The PD on this proposal served from 1994 to 1998 as the Foundation's first research director. Research conducted by HFF and its collaborators has included fisheries biology, aquatic ecology, human dimensions of natural resource management, and hydrology, and has been published in numerous regional, national and international journals. The PD co-edited a special issue of the *Intermountain Journal of Sciences* devoted to the aquatic resources of the watershed (Van Kirk and Zale 2000), which serves as standard reference material for new scientists and managers working in the watershed. Much of the research published in this and other journals was facilitated in part by the Watershed Council, and the results have been used to develop innovative water and aquatic resource conservation and management strategies in the watershed. In 2000, Friends of the Teton River (FTR), a sister organization to HFF, was founded to address water and aquatic resource issues specific to the Teton subwatershed. Both HFF and FTR have been nationally recognized for their collaborative, research-based approach to water management issues.

As a university faculty member, the PD has conducted several research projects in the watershed with funding from HFF, FTR, the Watershed Council and other governmental and non-governmental organizations. These projects analyzed anthropogenic alteration of hydrologic regimes throughout the watershed (e.g., Figure 3) for the purposes of identifying ecological consequences of such alteration and investigating relationships among hydrologic regimes and the basin's hydrogeology (Van Kirk and Burnett 2004, Van Kirk and Jenkins 2005, Bayrd 2006). The results of these investigations have formed the scientific basis for conservation and management efforts throughout the watershed, including the Henry's Fork Drought Management Plan that was mandated by federal legislation authorizing transfer of title of some irrigation infrastructure in the watershed from the federal government to FMID. One of the major outputs of these research efforts is a large database of calculated natural flows for every major stream in the watershed. These natural flow data are important not only because quantify the hydrologic regimes under which native aquatic and riparian species evolved but also because they quantify the watershed's inherent inflow to the water management system that supports irrigation, river-related recreation, and development. The PD is currently collaborating with University of Idaho researchers to develop models of surface-ground water interactions on the Snake River Plain, part of which lies in the Henry's Fork watershed.

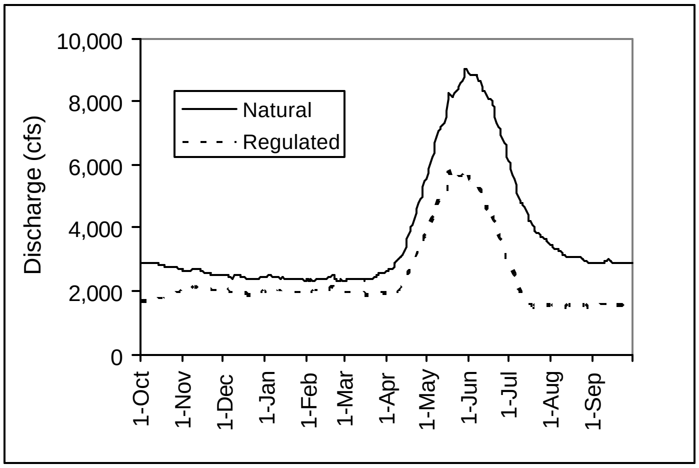

Figure 3. Mean natural and regulated flow in the Henry's Fork at Rexburg for the period 1972-2003. The cumulative difference between the two curves represents consumptive use of about 1,000,000 acre-feet of water in the watershed.

The Watershed Council, HFF, FTR, and other partners have facilitated numerous fisheries conservation and water quality improvement projects, including re-introduction of native fish, re-watering of dewatered stream reaches, and construction of fish passage facilities. In many cases, these projects have benefited irrigators through replacement of aging irrigation infrastructure and improvements in efficiency. Numerous such projects in the watershed have involved USDA funding and/or technical assistance through the Natural Resources Conservation Service (NRCS). An important water quality improvement project currently underway in the watershed is an effort to reduce high nitrogen concentrations in ground water near Ashton. The Idaho Department of Environmental Quality has designated the area as a ground water quality priority area. The NRCS has recently implemented a project to reduce fertilizer application rates in this area, and the PD currently serves with representatives from NRCS and other agencies on the local planning team tasked with developing nitrate management strategies. The watershed's nongovernmental organizations, particularly FTR, have complement science and restoration activities with comprehensive education and outreach programs that build collaborations and create a community of informed and engaged watershed stakeholders.

Project Team

For several years, the PD has been seeking a funding opportunity to address water conservation and management issues associated with population growth. Beginning in August 2008, the PD will begin a faculty position at Humboldt State University (HSU) in California, which has long been recognized for its outstanding programs in environmental engineering, mathematical modeling, and natural resource planning. This new position gives the PD the opportunity to assemble an interdisciplinary team of faculty with the expertise to successfully tackle a large interdisciplinary water resources project such as this. To ensure that project outputs meet the information needs of watershed stakeholders and decision-makers and are communicated appropriately to them, the academic component of the team will be complemented in the watershed by staff from HFF, FTR, and FMID. The project's senior personnel (Table 1) will supervise an interdisciplinary team of three graduate students and one undergraduate student both in the academic setting at HSU and in the watershed field setting.

Table 1. Project senior personnel (in alphabetical order)

Name	Title and affiliation	Expertise
J. Mark Baker	Asst. Prof. of Government and Politics, HSU	Community-based natural resource management, socioeconomics
Yvonne Everett	Assoc. Prof. of Natural Resources Planning, HSU	Natural resource planning, community-based management
Brad Finney	Prof. of Environmental Resources Engineering HSU	Surface and ground water hydrology, water resource management
Steve Steinberg	Assoc. Prof. GIS/Remote Sensing, Dir., Spatial Analysis Institute, HSU	Spatial Analysis, GIS applications in social sciences
Dale Swensen	Executive Director, Fremont-Madison Irrigation District	Irrigation management, co-facilitator of Henry's Fork Watershed Council
Steve Trafton	Executive Director, Henry's Fork Foundation	Fisheries conservation, co-facilitator of Henry's Fork Watershed Council
Rob Van Kirk	Assoc. Prof. of Statistics, HSU	Hydrologic modeling and data analysis, water resource management
Amy Verbeten	Education and Outreach Director, Friends of the Teton River	Experiential and environmental education

Stakeholder Involvement in Identifying Project Need

The PD spent the 2005-2006 academic year on sabbatical as a visiting scholar at the Idaho Water Resources Research Institute, with funding from the National Science Foundation. As part of this sabbatical, he organized and/or facilitated several meetings of the Henry's Fork Watershed Council devoted to socioeconomic change in the watershed and its effects on traditional land and water uses. These meetings drew large attendance from a variety of stakeholder groups, including county and city planners. Guest speakers included experts on socioeconomic issues in the region and irrigation managers who had experience with rapid development in their districts elsewhere in the state. Discussions at these and subsequent meetings identified three major issues that need to be addressed in order to develop water management and conservation strategies appropriate for the urbanizing landscape.

1. **Decreases in ground water tables.** As a result of conversion from flood to sprinkler irrigation practices and increased pumping of ground water that occurred during the 1970s throughout the West, the amount of water recharged to unconfined aquifers in irrigated regions has declined dramatically since its peak in the 1950s and 1960s (Whitehead 1994, Johnson et al. 1999, Miller et al. 2003). While this conversion resulted in increased "efficiency" (e.g., Venn et al. 2004), the largely unintended result of this efficiency has been a steady decrease in water tables over the past several decades (Figure 4). These declines, in turn, result in increased pumping costs for ground-water users and decreased return flow to streams. Although this problem has been largely created by the water management community itself, and some may argue that high water tables experienced during the 1950s and 1960s were maintained at artificially high levels that are not sustainable today, development threatens to make this problem even worse. Even under sprinkler irrigation, seepage from typical canal systems averages about 35% (Wytzes 1980, Battikhi and Abu-Hammad 1994, Venn 2004), and this recharge is

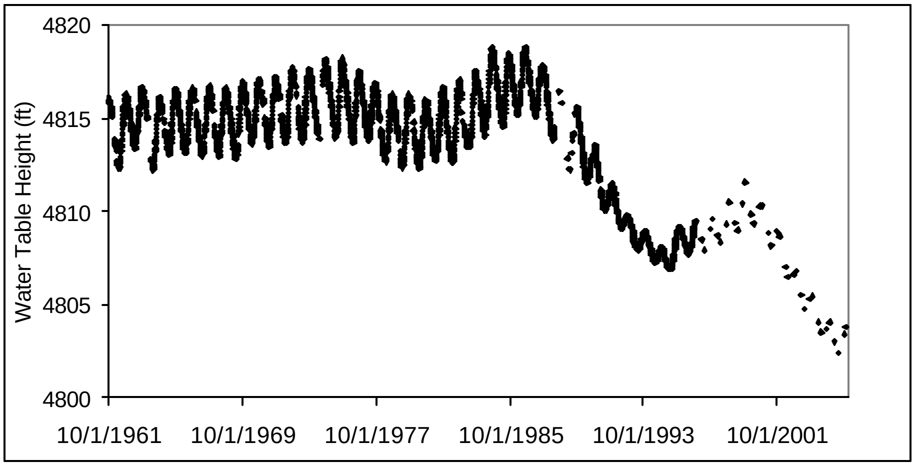

Figure 4. Water table height in a well located in the southwestern part of the Henry's Fork watershed. Note the strong seasonal periodicity resulting from recharge during irrigation season and the steady decline following conversion to sprinkler irrigation.

important to maintaining ground water resources in irrigated landscapes. Loss of irrigated land to development could further reduce recharge incidental to irrigation (e.g., Kettle et al. 2007), especially if development results in replacement of ditch and canal systems with pipelines. Among numerous proposed physical and regulatory solutions to the problem of declining water tables in Idaho is the concept of crediting irrigators for return flow instead of simply charging them for the total amount withdrawn. There is thus great interest on the part of irrigators, including FMID, in quantifying return flow and accounting for both surface and ground water within an irrigation system. Furthermore, a quantitative model of surface and ground water flow in the watershed has been identified as an important research need to inform development of nitrate management strategies in the Ashton ground water quality priority area.

2. **Theoretical water savings from urbanization.** Because domestic use, even with reasonable allocation for lawn and landscape irrigation, requires much less water per acre than is traditionally applied for irrigation, there is the potential for a large amount of water to be saved in an urbanizing landscape. In many if not most cases of resort and exurban development, the replacement of irrigated land with development occurs in headwater areas, where water rights are junior in priority to those downstream. Hence, such "saved water" could supply increased flows for aquatic and riparian ecosystems as it is delivered through natural stream channels to irrigators with more senior rights. Furthermore, if one buys into the "condos" side of the cows versus condos debate, new residents may have an interest in conserving water if the savings can be applied to ecological restoration and fisheries enhancement. However, these theoretical savings have not materialized, and it is not clear what the sociological, economic, and physical factors are that act to prevent or encourage such water savings.
3. **Challenges to managing irrigation conveyance systems in an urbanizing landscape.** Although most irrigation water is currently applied with pressurized sprinkler systems, almost all conveyance occurs in an intricate system of canals and ditches. These systems require a great deal of cooperation and coordination among users and watermasters to ensure that each user takes only his allocated right, leaving an adequate amount to reach

users further down the system. These cooperative systems were developed over a century ago when a typical ditch or canal company may have consisted of only a dozen users, each of which irrigated large acreages with relatively large amounts of water. With subdivision of this land, the number of users on such a ditch system can easily increase by a factor of ten and the amount allocated to each user reduced by this factor. The obvious challenge of managing cooperative systems with large numbers of users is made even more challenging because the new users are not experienced with irrigation. Typical problems include difficulties in accessing and maintaining irrigation infrastructure and users diverting more than their allocated amount. Other problems occur when water rights are not sold with land or are purchased by third parties who neither own land in the subdivision nor intend to use the rights for irrigation of cropland.

OBJECTIVES

The research objectives of the proposed project follow from the stakeholder observations described above. Extension objectives follow from the widespread observation among those involved in collaborative watershed management that it is effective only when scientific information is communicated to stakeholders and decision-makers in a meaningful way, and stakeholders remain involved throughout the process of converting research into policy and management (e.g., Grigg 1999). Furthermore, it is critical to the future evolution and success of collaborative water resource research and management that the next generation of water scientists and managers are trained in a collaborative, interdisciplinary atmosphere, thus motivating our educational objective.

Research Objectives

1. Develop quantitative models of ground and surface water flow pathways and use under historic, current, and anticipated future water/land use scenarios.

2. Identify economic, regulatory, and physical mechanisms that will a) encourage water conservation and b) facilitate efficient water management on developed lands.

Extension Objectives

3. Prepare and distribute to decision-makers, planners, and stakeholders educational materials describing the watershed's hydrologic system and water conservation benefits and strategies.

4. Facilitate development by the Henry's Fork Watershed Council of a water conservation and management strategy to increase water availability for agriculture while enhancing ecological benefits in key stream reaches.

Education Objective

5. Provide experiential training to an interdisciplinary team of environmental science graduate and undergraduate students.

METHODS

Stakeholder Involvement

Because the project is designed to address issues identified by watershed stakeholders and decision-makers, they will be active participants throughout the project. Here we outline the major stakeholder groups that will be involved, the methods we will use to involve and engage each group, and the role of stakeholder involvement during each of the three years of the project. We have identified four major groups that we will engage during the project:

1. **"traditional" water users:** irrigators on working farms and ranches. Because most of these irrigators belong to FMID and/or to private canal companies, this group also includes these entities as organizations.
2. **"development-oriented" water users:** developers, property and resort managers, landscaping businesses, homeowners associations in new exurban developments, and new residents, whether full-time or part-year. Some municipalities have acquired surface water rights to ensure supplies for future expansion and are thus included in this group.
3. **"non-consumptive" users** of fish, wildlife and scenic resources, including fishing guides and outfitters, anglers, and organizations representing their interests.
4. **planners and decision-makers:** county and municipal planners, in addition to the more traditional state and federal management agencies such as the Idaho Department of Water Resources (IDWR) and the U.S. Bureau of Reclamation.

The traditional water users and management agencies and fish and wildlife conservation interests have been active participants in the Watershed Council since its inception. Thus, many representatives of this group will be involved via their participation in the Watershed Council. Although development-oriented users and county and municipal planners have occasionally participated in the Council, we cannot assume that they will be adequately included in the project through participation in the Watershed Council. We will rely heavily on FTR and HFF to help reach these stakeholders and decision-makers, as both organizations, particularly FTR, have developed collaborative relationships with a number of important members of these groups. Beginning with Watershed Council, small-group, or individual discussions with members of the four stakeholder/decision-maker groups with whom members of the project team have already established relationships, we will use a snowball method to identify other key members of these groups from whom to collect information. This method will result in a greater degree of trust and cooperation than blind sampling methods or large public meeting formats. Reaching stakeholders through introductions from known and trusted individuals will also help avoid placing students in potentially hostile situations.

Stakeholder/decision-maker participation in the project will occur in three phases, one for each year of the project. During the first year, we will pursue each of the three primary stakeholder-identified issues listed above by collecting more detailed information on stakeholder concerns and information needs. We are particularly interested in what types of information and data would be most helpful to them in making water management decisions and what future scenarios of land and water use they would like to see us analyze. We will devote two Watershed Council meetings during the first year to collecting this information and rely on FTR to help facilitate other outreach activities to recruit and engage groups that do not attend the Council meetings.

During the second year, we will use an adaptive approach to data analysis and model development by providing progress reports and examples of model output and requesting feedback on whether our outputs are likely to meet stakeholder needs. This phase may also include collection of additional data that can be used to analyze differences in perceptions about water conservation and management among the four stakeholder groups. We will devote one Council meeting, an all-day Council field tour and other activities as appropriate during the second year. During the third year we will deliver research results to stakeholders and decision-makers through a variety of mechanisms, including Watershed Council meetings and public educational forums such as FTR's monthly "water-wise" series.

Methodology by objective

Objective 1. Hydrologic model development. The hydrologic model will begin with the natural flow data already compiled by the PD. These data are in the form of estimated daily flow in every major headwater ground and surface water source in the watershed over a 30-year period. A time series model that generates 30-year synthetic stream flow sequences that have the same probability structure as the observed dataset will be used as inputs to the hydrologic model. The time series model includes a methodology recently developed by the PD that includes nonstationarity by utilizing Fourier analysis of variance components of the parent distribution. If desired, the means and variances can be altered to simulate potential changes in natural flow caused by climate change. Simulated stream inflow will then be subjected to storage, withdrawal and loss to ground water. The PD has already compiled daily storage and withdrawal data for every reservoir and canal in the watershed over the period 1972-2006, the majority of which has occurred during the "modern" period of reservoir management and sprinkler irrigation (Benjamin and Van Kirk 1999, Van Kirk and Burnett 2004, Van Kirk and Jenkins 2005). The PD has also compiled what storage and withdrawal data exist for years prior to 1972. Although not nearly as complete as the post-1972 set, these data will be adequate for estimation of withdrawal rates that occurred during flood irrigation. These two data sets will be sufficient to model withdrawal and storage under historic flood and current sprinkler irrigation conditions. Because storage, delivery and withdrawal rates are functions of both water supply and water rights seniority, the model will account for the general seniority of priority dates in the Henry's Fork watershed relative to those in the rest of the upper Snake River system (Benjamin and Van Kirk 1999).

Development of the hydrologic model will require estimates of stream and canal losses and gains. The PD has compiled stream channel loss data collected by IDWR in Teton Valley during the 1930s. Wytzes (1980) measured stream and canal losses in the lower part of the watershed during the late 1970s, and the USGS has estimated stream channel losses and gains in the Henry's Fork downstream of Ashton (Hortness and Vidmar 2003). After analyzing these data and hydrogeologic characteristics (Kilburn 1964, Nicklin 2003), we will calculate channel losses and gains from existing data where available and develop a sampling plan to collect measurements of canal and stream channel discharge in key reaches between existing stream gage stations. The PD's analysis to date suggests that key reaches in need of field measurement will include all streams and canals on highly conductive alluvial fans in Teton Valley, the lower Teton River, the Henry's Fork at Warm River, the Henry's Fork at numerous points between the gages at St. Anthony and Rexburg, and all of the large canals in the lower watershed. Flow measurements on small streams and canals will be made using a standard wading methodology. Those on larger canals will be made from bridges and other structures, and those on the larger rivers will be made from a boat.

Other information on ground-water flow characteristics will be obtained from well data available from IDWR databases and other existing sources. These data will be used to estimate ground water pumping rates. Analysis of stream loss/gains and the well data (e.g., Figure 4) will allow estimation of aquifer input-output relationships. Standard techniques (e.g., Ferris 1963, Manga 1997) will then be applied to these input-output relationships to estimate aquifer hydraulic conductivities. Once these are known, recharge from stream and canal losses and from snowmelt can be used as source terms in the partial differential equations governing transient ground-water flow. Additional source (e.g., recharge from flood irrigation) or sink (e.g., pumping) terms and modifications to canal and stream channel seepage rates under different hypothesized land and water use scenarios can then be added to model different conditions. Identification of current and anticipated future spatial patterns in land and water use will be facilitated by analysis of Geographic Information Systems data available from county planning offices and IDWR. Analytical and numerical solutions to the ground-water flow equations will then allow estimation of water table heights and discharge back to surface flow. The PD has developed and tested such models on scales ranging from individual streams to the entire Teton Valley (Van Kirk and Jenkins 2005), and these relatively simple, analytical models have proven to provide adequate prediction of stream flow under different water and land use scenarios (Figure 5). While it is expected that these simple models will have sufficient resolution to be applied to the other aquifers in the Henry's Fork watershed, a standard numerical ground-water flow package such as MODFLOW will also be used if the analytical models prove insufficient or intractable. Model outputs will consist of simulated stream flow at the major gage station locations and particular stream reaches important to maintenance of fishery and ecological values under natural (no water withdrawal), flood irrigation, sprinkler irrigation, and potential future land and water use conditions (e.g., conversion of all agricultural land in Teton Valley to development with and without water conservation measures). We will provide water managers and stakeholders with a useful computational tool and supporting data that they can use to calculate the effects of various management strategies on surface and ground water flow in the watershed.

Objective 2. Identification of water conservation and management mechanisms. Based on information needs and challenges identified by stakeholders and decision-makers in phase one of the stakeholder involvement, we will investigate potential physical, economic, regulatory, and social mechanisms that could be applied in the watershed to promote water conservation and efficient management on developed lands. Examples of physical mechanisms could include water-saving landscaping methods and new infrastructure appropriate to irrigation systems with large numbers of users. Economic and regulatory mechanisms could include water banking, water rights transfers, and market-based approaches (e.g., Aylward et al. 2005, Ward et al. 2007). Social mechanisms may be as simple as education of new residents or as complicated as creation of a modern, exurban version of the cooperative canal and ditch companies that were instrumental in building and operating irrigation systems in the 19th century. Identification of conservation and management mechanisms will require research in the primary and gray literature and continued stakeholder involvement as part of phase two. This second phase of interviews with stakeholders, decision-makers, planners and water managers will be used to

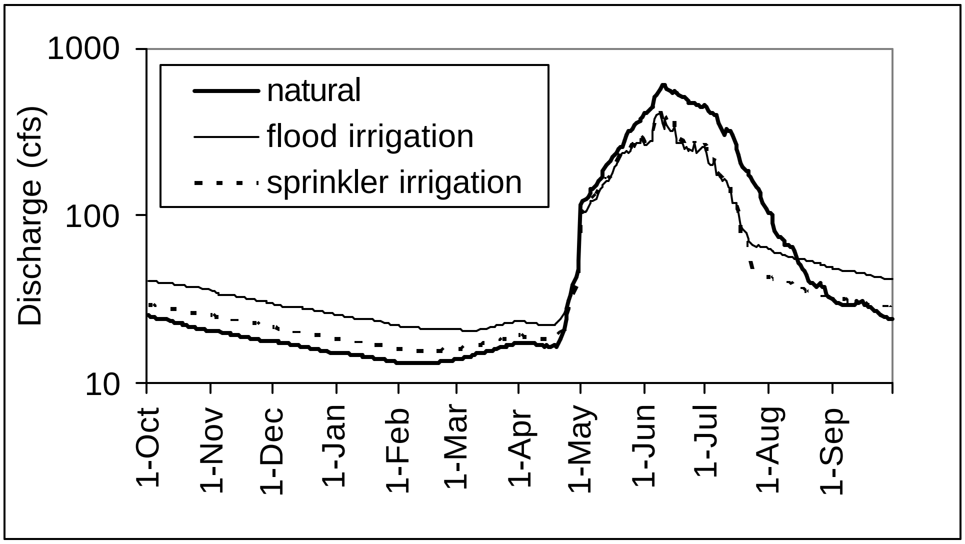

Figure 5. Simulated 30-year mean discharge from Teton Creek into the Teton River under natural, flood irrigation, and sprinkler irrigation conditions.

provide insight into factors that prevent or encourage water conservation in developed areas. These additional interviews will be especially important in developing innovative responses to the social and institutional changes canal companies face as they attempt to maintain water distribution systems, resolve conflicts among and between traditional and development-related water users, and maintain the integrity of the traditional irrigation institutions under conditions of rapid socioeconomic change. Friends of the Teton River has developed relationships both with traditional irrigators in the watershed and with other organizations involved in developing socioeconomic and regulatory water conservation and management mechanisms elsewhere in the west, and information from these organizations will also be useful in meeting this objective.

Objective 3. Preparation and dissemination of educational materials. Driven by information gathered from stakeholders and decision-makers in phases one and two, we will develop and disseminate educational and informational materials summarizing our research findings in formats appropriate to each stakeholder group as part of phase three. Some of this information will focus on steps individual landowners can take to conserve water and help ensure efficient management of existing irrigation systems. Other information aimed at the development-oriented user group will include explanation of the basic hydrology of the watershed as well as the physical and biological connections between their own use of water and maintenance of ecological values associated with streams and rivers. Information targeting county and municipal planners will include estimates of water availability to support continued development and predicted effects of future development on water supplies. Dissemination methods will include public presentations, informational brochures and web site content, and reports and data in formats useful to planners and managers. During this phase, we will continue to employ the snowball approach to reaching key stakeholders and decision-makers so that our information extension reaches the largest audience possible. We will also utilize an adaptive approach to developing and disseminating information as we receive feedback from key informants on what methods are most effective at reaching members of each stakeholder group.

Objective 4. Development of water conservation and management strategy. During the third year of the project, we will devote three Watershed Council meetings to development of this strategy. Although we know that not all stakeholders and decision-makers regularly attend Council meetings, we will attempt to increase participation at these meetings through additional advertising and direct communication with non-Council participants we encounter during the first two phases of stakeholder involvement. The first two of these meetings will be held during the spring of year three to identify and agree upon and outline and key components of the strategy. The Council's consensus-based Watershed Integrity Review and Evaluation (WIRE) process (Weber 2000) will be used to develop this outline. During the summer, when the Council does not meet regularly, members of the project team will write a strategy document based on this outline. In the fall of the final project year, the Council will review the document using its WIRE criteria, hopefully reaching consensus to endorse the document in some form.

Objective 5. Experiential training to an interdisciplinary team of students. An interdisciplinary team of three master's students and one undergraduate student will carry out most of the work of the project, under the supervision of the project's key personnel. All three of the graduate students will receive full support (tuition/fees and stipend) for five academic semesters, and will work on an hourly basis in the watershed for two summers. The time frame of five semesters plus two full summers is generally longer than required for most master's degree programs, but the work involved in this project is somewhat larger than that usually expected of master's students. Additionally, we want the students to spend two summers in the watershed as possible in order to gain as much interdisciplinary and applied experience as possible. Additional funding will be available to support graduate student travel to present their work at professional meetings and conferences. Each student's master's degree program, advisor(s), and project involvement is given here.

a. Environmental Systems, Environmental Resources Engineering Option. Thesis advisor: Finney. Research will focus on the physical aspects of the hydrologic model, including field measurement of canal and stream gains/losses, estimation of aquifer properties, and compilation and analysis of existing water and land use data.
b. Environmental Systems, Mathematical Modeling Option. Thesis advisor: Van Kirk. Research will focus on the mathematical aspects of the hydrologic model, including statistical analysis of data, generation of stochastic hydrologic inputs, and solution of ground-water flow equations. The two Environmental Systems students will work together, especially in the field.
c. Natural Resources Planning and Interpretation (NRPI). Thesis advisors: Everett and Baker. Research will focus on the socioeconomic aspects of the project, including gathering information from the four stakeholder groups, analyzing differences in attitudes toward water conservation and management among these groups, elucidating socioeconomic impediments to water conservation on developed land, and identifying mechanisms that will promote water conservation and efficient water management in the developing landscape.

During the project's second summer, a recent bachelor's degree recipient in NRPI with particular skills and interest in interpretation will be hired to work under the supervision of Amy Verbeten, FTR's Education and Outreach Director. This student will assist in development of education and outreach materials that will be disseminated during the project's final year. The development activities conducted by this student will include phase-two stakeholder involvement to help identify the most effective types of outreach for each stakeholder group.

During their summer field seasons, the students will be integrated into the well-established seasonal programs of HFF and FTR, which will give the students on this project the opportunity to interact with other students, interns and seasonal employees working on a variety of related projects including fisheries biology, habitat restoration, hydrology, stream ecology and human dimensions. This integration will include sharing seasonal housing and work space with other students. During the course of their field work, the students will interact with people in a variety of agencies and organizations. Students will be encouraged to occasionally assist each other with field work, an arrangement that promotes a great deal of camaraderie and interdisciplinary experience among the students. The students will also attend various education and outreach activities during their time in the watershed. During their second summer, the students, with appropriate supervision, will design and lead the Watershed Council's annual field trip.

Project Deliverables

In addition to information shared with stakeholders and decision-makers through the Watershed Council, other formal meetings and presentations, and informal communication, the project will produce, at a minimum, the following tangible products.

1. Three master's theses
2. Computational tool for modeling watershed hydrology
3. Education/outreach informational materials in brochure and web formats
4. Water conservation and management strategy document
5. Four articles submitted to peer-reviewed journals: one to specialized journals in the field of each master's thesis (e.g., *Irrigation and Drainage Engineering ASCE*, *Water Resources Research, Society and Natural Resources*, respectively) and one to *Journal of the American Water Resources Association*, an interdisciplinary journal.
6. Presentations by students and faculty at professional meetings and conferences.

Potential Pitfalls and Limitations

Based on the PD's previous experience with projects such as this, the most common problems encountered involve reluctance on the part of watershed stakeholders and decision-makers to attend meetings and provide information. Some of this reluctance is caused by time constraints; for example, Watershed Council meetings are held on Tuesdays from 8 a.m. to noon, when many would-be participants simply cannot attend. We will attempt to overcome this problem by reaching out to stakeholders through other mechanisms. In other cases, reluctance to provide information results from distrust of motivation for collection of the information. We hope that our snowball scheme for identifying stakeholders, beginning with those with whom we already have established relationships, will minimize this problem. Field work always presents logistical challenges, including problems and delays in obtaining access to canals and streams on private land, difficulty with stream flow measurements during high water conditions, and equipment challenges. Problems with access to canals in the lower watershed should be minimized by the participation of FMID in the project. In Teton Valley, FTR serves as the IDWR-designated watermaster and so has authority to access canals and streams and measure flow. In case of a high flow year, runoff is usually finished by mid-July, still leaving at least four weeks of field season during which to measure stream flows. The planning of two field season for data collection allows us a second field season for collection of data we were unable to obtain during the first season.

Limitations inherent to the methodology will be reflected primarily in accuracy of stream and canal gain/loss and aquifer property estimates. Ideally, these quantities would be estimated from long time series of data with a high resolution in both space and time. Where such time series data exist (e.g., at long-term stream gaging stations and monitored wells), we will obtain better estimates than in locations where we will, at best, be able to make one measurement per week over one or two 12-week field seasons. Thus, at the stream or canal reach scale, our estimates may be relatively poor and unable to capture temporal variability. However, at larger spatial scales (e.g., between long-term gage stations or at the confluence of major streams), we will be able to calculate relatively accurate estimates of these quantities. Our hydrologic model will be constructed and analyzed at the same spatial scale at which the data are collected to avoid the possibility of spurious output resulting from an attempt to force more resolution from the model than the data inherently support.

Project Evaluation

The project will be evaluated by its success in: 1) providing decision-makers and stakeholders with an understandable model of the watershed's hydrology and a useful tool to evaluate the impact of various water management practices, including water conservation, on the water cycling in the basin; and 2) facilitating development of a management strategy by the Watershed Council. At the end of the project, we will devote Watershed Council meeting time to evaluation of the project using the WIRE criteria.

TASKS AND TIMETABLE

The project will take place during calendar years 2009, 2010, and 2011. We plan to begin graduate student support in spring semester 2009 and have all of the theses finished by spring of 2011. However, if a student cannot begin coursework until fall 2009, that student will still be able to work the first two summers in the field and graduate in fall 2011. Faculty workload on the project is weighted toward the third year, when primary tasks will include submitting papers for publication, delivering products to the stakeholders, speaking at meetings and conferences, and writing the water conservation strategy document. Major tasks, by semester and year, are summarized in Table 2.

Table 2. Major project tasks and responsibilities.

Year	Spring semester	Summer	Fall semester
2009	•Recruit students (faculty) •Design field sampling programs (faculty and students) •Hold 2 Watershed Council meetings to gather stakeholder input (Swensen, Trafton) •Design plan to reach non-Council participant stakeholders (Verbeten)	•Convene entire project team in study area to initiate field work and meet with key stakeholders/decision-makers (whole team) •Collect hydrologic data (environmental systems students and Van Kirk) •Collect Phase 1 stakeholder input, targeting non-Council participants (NRPI student and Verbeten) •Begin investigation of water conservation strategies (NRPI student and Verbeten)	•Analyze field data (faculty and students) •Compile spatial data (students, Steinberg) •Begin hydrologic model development (environmental systems students, Finney, Van Kirk) •Continue investigation of water conservation strategies (NRPI student)
2010	•Continue data analysis •Analyze spatial data to support model development •Continue hydrologic model development •Continue investigation of water conservation strategies •Hold 1 Watershed Council meeting to update stakeholders and obtain adaptive (Phase 2) input (Swensen, Trafton)	•Collect additional field data as needed (students, Van Kirk, Verbeten) •Continue data analysis and model development •Continue Phase 2 stakeholder input (NRPI student and Verbeten) •Design and lead Council field trip (students, Verbeten, Trafton, Van Kirk) •Develop educational and outreach materials (Verbeten and undergraduate student)	•Apply hydrologic model to future scenarios (environmental systems students, Finney, Van Kirk) •Integrate hydrologic model results with water conservation strategies (all students and faculty) •Develop tools and products to communicate results for stakeholders (all) •Give presentations at professional meetings and conferences (all)
2011	•Hold 2 Watershed Council meetings to deliver results (Phase 3) and outline conservation strategy (Verbeten, Swensen, Trafton) •Students finish theses •Continue presentations at professional meetings and conferences (all)	•Continue Phase 3 stakeholder involvement, including dissemination of educational materials and presentation of public talks (Verbeten, Trafton, Van Kirk) •Submit papers for publication (all) •Finalize water conservation strategy document (all) •Continue presentations at professional meetings and conferences (all)	•Hold 1 Council meeting to consider final strategy document and evaluate project through WIRE process (Trafton, Swensen, Van Kirk) •Complete presentation and publication of results

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