Report 1:

Efficient Irrigation for Water Conservation

Water Task Force

College of Agriculture and Home Economics
Cooperative Extension Service
Agricultural Experiment Station

Efficient Irrigation for Water Conservation

Project Papers from the

Rio Grande Basin Initiative

A joint Texas A&M/New Mexico State University project
Administered in New Mexico by NMSU Water Task Force

Table of Contents

Introduction

Overview of Rio Grande Basin Initiative

The Rio Grande Basin Initiative is a joint Texas A&M University and New Mexico State University effort to improve water conservation through research and education of irrigation efficiency. It is funded by the Congress through the U.S. Department of Agriculture's Cooperative State Research, Extension and Education Service. The project is administered in Texas through the Texas Water Research Institute, and in New Mexico through the College of Agriculture and Home Economics' Water Task Force.

The Rio Grande Basin Initiative could not have come at a better time. As a result of regional drought, water distribution and use from the river is a growing matter of public scrutiny and litigation. Other issues, such as in-stream flow requirements, adjudication of water rights in southern New Mexico and increasing urban demands for water, make water availability even more critical.

The papers contained in this report are examples of the college's research efforts to improve agricultural and urban irrigation efficiency. What these papers do not clearly illustrate is the knowledge and commitment that these researchers are dedicating to finding and applying real solutions for very real problems facing New Mexico agriculture. The researchers and their Extension counterparts should all be commended for their contribution to the sustainability of agriculture in arid lands and for their service to NMSU.

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Irrigation District Studies

Efficient Irrigation for Water Conservation in the Rio Grande Basin

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Introduction

Irrigation efficiency is a quantitative term used to measure the effectiveness of irrigation water management. Irrigation efficiency has been studied extensively throughout the western United States (Doorenbos and Pruitt, 1977). There are various definitions for irrigation efficiency, but it generally can be defined as the amount of water available to plants divided by the total amount of water delivered to an irrigation unit. Improved irrigation efficiency can lead to reductions in water and energy consumption, more effective nutrient use and disease management, improved water quality and erosion control, as well as increased yields (Hansen et al., 1979; Garcia et al., 1999). Irrigation efficiency in the Rio Grande Basin's Elephant Butte Irrigation District has been the subject of research, although largely on a case-study basis (Deras, 1999; King, 1999; Samani and Al Khateeri, 2001). Research in the Mesilla Valley has found that on-farm irrigation efficiency (i.e. water used by the crop relative to water applied to the field) among the participating farms was relatively high (Samani and Al Khateeri, 2001). Mesilla Valley research also has shown that actual yields of commercial crops, such as alfalfa, chile and pecans, are considerably lower than potential production (Sammis et al., 1997; Samani and Al Khateeri, 2001).

While previous research has provided insight into irrigation practices in the Elephant Butte Irrigation District (EBID), this project's researchers are conducting the first systematic, wide-scale examination of EBID water application data at the field scale. These data only recently became available as a result of EBID's ongoing development of a comprehensive database, which encompasses a broad range of information.

Current State of Knowledge

This research project brings together technical engineering and socioeconomic issues. Literature relevant to this research covers a broad spectrum, including studies that deal with adoption of irrigation and conservation technology and agricultural structure. Selected literature is reviewed here. Caswell and Zilberman (1985, 1986) determined that the choice of irrigation technology in California's San Joaquin Valley was a function of water cost differentials, farm location, water sources, crops grown, well depth and land quality. One conclusion was that "modern" irrigation technologies (e.g., drip or sprinkler systems) are more likely to be adopted in locations with relatively low land quality and expensive water, while traditional surface irrigation technologies are more likely to be used in locations with heavy, leveled soils and cheap water.

Lichtenberg (1989) found that the adoption of center pivot technology in the northern High Plains was more likely on farms with lower productivity potentials. Shrestha and Gopalakrishnan (1993) examined the adoption of drip technology in Hawaii as a function of differentials in water use and yields, plantation location, soil types, temperatures and field gradients. The authors concluded that motivation for adopting drip irrigation originally was a concern for water conservation, which later changed to a desire for yield increases as growers became more experienced with drip technology.

Agricultural structure's effect on soil and water conservation behavior and on conservation technology adoption also has been investigated, with farm size often the structural variable of greatest interest. Farm structure is believed to influence conservation through actions and interactions of economics, technology, institutions and human resources (Tweeten, 1995). Camboni and Napier (1994) concluded that farm operators' decisions to adopt soil and water conservation practices primarily are motivated by economic incentives. These economic factors include profitability of the practice, cash flow, financial reserves and operator credit-worthiness (Tweeten, 1995). Numerous hypotheses have been advanced about the relationship of farm size to soil and water conservation practices. Large-scale farms often are believed to maximize short-run profits at the expense of the environment (Buttel et al., 1981). The theory that small-scale farmers are less likely to engage in soil and water conservation also has been advanced. Small-scale operators have higher costs per unit because they have fewer units over which to spread high fixed conservation information and machinery costs (Epplin and Tice, 1986). Small-scale farmers also may not be able to expend time or capital for conservation due to chronic farm income losses and full-time off-farm employment. According to Tweeten (1995), several studies have found no differences in conservation between large and small farms. However, when differences were found, results indicated better conservation practices on larger farms.

Harper and Eastman (1980) found that small-farm families in New Mexico tended to be motivated by factors other than profits or farm income. They concluded that the agricultural goals of small-scale farmers (defined as having less than $40,000 annually in gross agricultural sales) were dominated by the desire to maintain or improve the quality of life that results from their family's involvement in agriculture and the desire to avoid being forced out of agriculture.

Objectives and Outcomes

The objectives of this project are:

1. Identify the parameters that affect water needs, water use efficiency and economic returns from water in agriculture and municipal landscape use in southern New Mexico's Rio Grande Basin;
2. Develop tools that can be used to determine crop water needs and use in the area based on such factors as crop area, crop type, soil type, climate, irrigation methods, irrigation frequency, total farm size and farmer socioeconomic characteristics;
3. Develop tools that can be used to optimize water use in municipal landscaping and agriculture across the broad spectrum of farming operations in the region;
4. Develop tools to assess and optimize the process of water marketing; and
5. Develop tools for establishing strategies for optimum economic return from water.

The results of this research will be used to develop strategies and incentives and to provide Extension education to optimize the beneficial use of agricultural water use in southern New Mexico's Rio Grande Basin.

Conclusions

The overriding objective of this research is to identify the parameters that affect water needs, water use efficiency and economic returns from water in agriculture and municipal landscape use in southern New Mexico's Rio Grande Basin. The results of the research will be used to develop strategies for optimizing irrigation management and increasing irrigation efficiencies for a wide variety of farming operations. The project is receiving excellent cooperation from Elephant Butte Irrigation District personnel. The research is on schedule, relative to the calendar presented in the original proposal, and data collection and analyses are underway. Success of the project depends highly on future cooperation with EBID and individual irrigators.

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Irrigation Education and Training

Evaluation of User-Friendly Drip Irrigation/Mulch Systems for Urban and Small Farm Specialty Crop Production

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Introduction

Water has become a major issue for both rural and urban communities in New Mexico. Groundwater in the city of Albuquerque has been dropping at a rate of 1.3 to 2 feet per year (Uyttebrouck, 2000). Irrigation water for gardening in Santa Fe in 2000 was reduced to once a week. Gardeners and growers also are competing for water with endangered species like the silvery minnow (Soussan, 2000).

Gardening traditionally has been a means of supplementing the food security for many low-income people in New Mexico. New Mexico leads the nation with 15.1 percent of its residents experiencing food insecurity (Wattenbarger, 2000). Gardening also is popular with many affluent families, both as a source of fresh vegetables for better nutrition and as exercise for improved health. However, water usage for gardens and lawns can be substantial when using sprinklers. Water usage was found to double in midsummer versus midwinter in an Albuquerque home with two people using sprinklers for a backyard garden and lawn from 1999 to 2001 (City of Albuquerque, 2001).

Most small farms in New Mexico are irrigated by sprinkler, furrow or flood irrigation, all of which are relatively inefficient. Vegetable producers are very concerned about the potential water shortages for irrigation (Lamont, Jr., 1991). The days of unlimited water are rapidly passing, and more efficient irrigation methods must be evaluated and implemented.

Current State of Knowledge

Plastic mulches have been used by commercial vegetable growers since the early 1960s to help conserve soil moisture, control weeds, increase earliness, reduce fertilizer leaching, reduce soil compaction, reduce root pruning and increase growth of vegetables (Lamont, Jr., 1991). Black plastic mulch is the most popular. Most black plastic mulches (1.25 to 1.50 mil thick), however, break down in ultraviolet light when exposed to the sun. They also can become a major problem when growers try to remove them from the field in the fall, especially when buried edges remain intact. Most also are impervious to water to prevent drowning of crops in high rainfall areas.

Woven, black polypropylene mulch has been shown to help harvest rainfall New Mexico's dry climate, reducing water applications necessary to produce a crop (Dickerson, 2000). Incorporating an ultraviolet light inhibitor makes it reusable. Its durability also has been shown to help control noxious weeds like bindweed. Both characteristics make it ideal for organic certification programs.

Organic mulches help cool the soil, conserve soil moisture, reduce annual weed production and return nutrients to the soil through decomposition (Dickerson, 1996). Maximum control of the soil environment, including water conservation, can be obtained by using drip irrigation under either organic or plastic mulches (Lamont, Jr., 1991). Drip irrigation on crops can save as much as 80 percent of the water when compared with other irrigation techniques (Bogle and Hartz, 1986).

Although drip irrigation is one of the most efficient ways to irrigate, many gardeners are intimidated by the complexity and expense of most commercial systems. New battery-controlled timers and drip lines sold by most hardware outlets have, however, made this innovation more user friendly (Blume and Kayko, 1998).

The cost of installing a commercial drip irrigation system for growers can vary from \$700 to \$1,200 per acre (Wuertz, 2001). Expensive irrigation wells and even the problems associated with drilling new wells, especially in northern New Mexico, have discouraged many small-scale specialty crop growers from adopting drip irrigation. However, settling ponds for ditch water, combined with sand filters for small-scale drip irrigation systems, have become attractive alternatives for many small growers as a means of saving water.

Gardeners have many questions regarding "off-the-shelf" drip systems: Which timers are easiest to use? Which timers and drip systems are the most durable? Can I operate different drip lines at different times? Will salt build up in soils with long-term use of drip irrigation? Which systems are the most affordable? Growers want to observe existing on-farm drip systems in the field before investing in such systems.

Limited sites and personnel hamper the evaluation of drip lines, timers and mulches in the production of specialty crops at agricultural science centers along the Rio Grande Basin in New Mexico. Evaluating the same systems by trained master gardeners would reduce labor costs and expand the number of sites and crops that could be evaluated. Biweekly contact with all cooperators by one project investigator would provide continuity for the entire project. Diffusion of this information by trained master gardeners in contact with other gardeners, by news releases and Cooperative Extension Service publications would encourage widespread use of this technology and a reduction in water use.

There are several growers with drip systems in northern New Mexico. On-farm tours would allow growers to interact with these individuals to determine the pros and cons of such systems. The diffusion of this information through various mass media outlets would help other growers who are unable to attend tours.

Goal and Objectives

The ultimate goal of this project is to reduce water used in the production of vegetables, herbs and cut flowers in gardens and on small farms along the Rio Grande Basin in New Mexico. To achieve this goal, the project has a number of defined objectives:

1. Establish 16-19 Master Gardener drip irrigation/mulch demonstration projects and evaluate these projects for water application efficiency in the production of vegetables, herbs and cut flowers in seven counties along the Rio Grande Basin in New Mexico;
2. Evaluate various "off-the-shelf" battery timers used to control drip irrigation systems for "ease of use," "reliability" and "durability" over a three-year period at the above sites;
3. Evaluate three types of "off-the-shelf" drip irrigation lines in combination with various plastic and organic mulches to reduce water applied to the various crops at the above sites;
4. Train 500 master gardeners on the benefits of using drip irrigation and various mulches to produce vegetables, herbs and cut flowers.

The project's expected outcome will be a greater understanding of the water-saving benefits of drip irrigation and various mulches producing vegetables, herbs and cut flowers. Information about drip irrigation and mulches will be made available to gardeners and growers through a number of publications and computer programs. Four publications will be released on mulches, drip irrigation systems for the backyard, small farm drip irrigation systems and water harvesting techniques. Two separate publications will be released on herb and cut flowers production. A PowerPoint presentation will be produced on drip irrigation/mulch techniques for both small-farm and backyard specialty crop production.

Conclusions

This project should result in increased awareness among gardeners about the benefits of using battery timers, drip lines and mulches for conserving water to produce vegetables, herbs and cut flowers. Small-scale specialty crop growers will be made aware of the benefits of less expensive commercial drip systems for conserving water to produce specialty crops.

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Institutional Incentives for Efficient Water Use

Institutional Barriers to Water Conservation in the Rio Grande Basin[1]

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Introduction

In recent years, legislation, administrative action and other measures have emerged that encourage private investments in increased water use efficiency to promote agricultural water conservation. The Rio Grande Basin of southern New Mexico and West Texas faces the same water scarcity problems as seen in various forms around the irrigated West. Growing cities and increased water demands for environmental use have prompted examination of measures that provide financial incentives for irrigators who reduce water used in agriculture, while maintaining the profitability of farming. Despite the growing total demand for water by all users, several institutional barriers may discourage irrigators from investing in measures to conserve water.

Objectives and Outcomes

This paper includes a brief review of the existing literature on existing organizations, laws, system operating procedures, and other institutions that could act as institutional barriers to agricultural water conservation. This review is part of a larger study to identify current legal and institutional barriers that block potentially economically viable investments made by irrigators in water conservation in the New Mexico-West Texas region of the Rio Grande Basin.

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[1] This white paper is a background document, which is designed to review existing literature and serve as a source of maintained hypotheses for an ongoing investigation into measures for reducing institutional barriers to agricultural water conservation in the Rio Grande Basin.

This study has three goals:

1. Identify policies, procedures and institutions that currently govern the use, distribution and trading of irrigation water;
2. Evaluate the range of policies, procedures and institutions that could govern efficiency improvements in the future use, distribution and trading of irrigation water; and
3. Formulate policies, procedures and institutions that could more efficiently and effectively govern the future use, distribution and trading of irrigation water. Accomplishing these objectives is expected to provide outcomes that produce several benefits to water users in the Rio Grande Basin, as well as to the general public.

Outcomes and related benefits include:

1. Reducing economic damages produced by drought in the face of increasing population and growing demands placed on water, including demands for endangered species habitat;
2. Reducing the cost of meeting new demands for water;
3. Smoothing water use transfers from agriculture to cities and endangered species while maintaining the viability and profitability of agriculture; and
4. Reducing the cost of assuring that all legal water right owners receive water apportionments.

Several potential existing institutional barriers to water conservation are discussed, along with possible measures for overcoming them. It is hoped that this review paper can serve as useful background material for ongoing research and Cooperative Extension Service activity to support investigations into measures that would promote agricultural water conservation in the Rio Grande Basin.[2]

Overview of Institutional Barriers to Water Conservation

Water Conservation Incentives

The ability to see an economic gain by shifting current water use to another user, sometimes called a water transfer, is an important incentive to promote conservation. People need to realize an economic gain from water conservation actions, such as carryover storage or reduced water application in agriculture, to have sufficient incentive to transfer water to other users. Both incentives and disincentives to actions that would promote water conservation are discussed.

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[2] A survey of agricultural producers is underway to identify current agricultural water use patterns in the Rio Grande Project below Elephant Butte Reservoir as well as potential economically feasible practices that could be adopted in the face of drought or new water marketing opportunities.

Lack of Clear Titles

In both New Mexico and Texas, a person or organization that must apply to a state administrative agency to obtain a valid water right, either through a new appropriation or a water transfer from another user. In both states, there is a constitutional requirement that the appropriator must show to the state's satisfaction that the water will be applied to beneficial use. In both states, within the Rio Grande Project, the water right permit is granted in perpetuity or until the land and/or water has been transferred to another user. After the permit is granted, the appropriator is required to put the water to beneficial use. Nevertheless, producers often express the fear that investments made in water conservation, such as changing irrigation technologies that reduce water applied or adopting new management techniques like irrigation scheduling, will result in the saved water being lost to the state or to the irrigation district, because of the presumption that the saved water was not used beneficially.

Water Transfer Barriers

Short-term water transfers through mechanisms like water banks could provide an economic incentive for agriculture to save water, especially in periods of drought or other shortages. Temporary water transfers, such as a one-season water rental or leasing arrangement, possibly through an arrangement similar to banking, could provide agricultural producers an incentive to reduce water use in agriculture.[3] The advantage of such a short-term transfer is the immediate infusion of cash into agriculture when the transfer takes place.

A water bank is a special form of a spot market organized and operated by a central banker, such as the state, a state-appointed water broker, irrigation districts or private companies. The bank, if established, is a mechanism for willing water right owners to lease water to the bank or renters, such as cities or an environmental group, on a short-term basis. The bank could acquire water in at least three ways: by paying farmers for water they would have used to irrigate their fields; by purchasing surplus water from local irrigation districts; or by paying farmers to use groundwater instead of surface water. A successful water bank experiment in California in the early 1990s taught several lessons: water markets, even when they are severely constrained and controlled, will work; water has a very high value for city and environmental buyers, and at a suitably high price there are likely to be many sellers; very large amounts of water can be found for the bank if money is put on the table; and third-party interests in water market transactions can be protected (Dziegielewski et al., 1993; California Department of Water Resources, 1990; Pratt, 1994).

Nevertheless, some Rio Grande Basin producers have expressed concern that these short-term transfers may be interpreted by water administrators or by the public as

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[3] Permanent transfers are even more attractive to municipal and industrial users, such as the city of El Paso; surface water treatment plants need a predictable and continuous water supply.

evidence of a nonbeneficial use of water. Furthermore, some producers may fear that the water right will be lost through a temporary transfer into a bank. This could occur because of unclear or unenforced legislation or poor communication by water administrators to producers. As a result, this important potential source of conservable water for use by others currently is unavailable.

Other barriers to water transfers include jurisdictional restrictions to water transfers across state lines, lack of adjudication of existing water rights, and lack of information about existing rules that permit transfers.

On-Farm Savings that Fail to Save Water for the Basin

Agricultural producers continue to adopt more technically efficient irrigation methods to produce higher net incomes through increased crop yields, increased efficiency in nutrient and chemical use, reduced labor costs and more efficient water use. One definition of on-farm irrigation efficiency is the ratio of water stored and depleted in the crop root zone for crop consumption to the total water diverted from the stream for irrigation. One method to increase on-farm efficiency, defined in this way, would be to encourage producers to apply water more consistently across fields, which enables crops to maintain, keep or increase their consumptive water use from reduced stream diversions.

Many policy makers believe that reduced diversions resulting from increased on-farm efficiency produce water savings that become available to meet other growing demands. Some states across the West are passing or are considering passing legislation that encourages producers to invest in improved on-farm irrigation technologies. However, this kind of legislation should be approached carefully, because many of these on-farm investments in greater irrigation efficiency can reduce the available water that would have been otherwise supplied through return flows to downstream appropriators (Huffaker et al., 2001; Huffaker and Whittlesey, 2000; Huffaker et al., 1998).

An on-farm investment that reduces water applied from the individual producer's view by X acre-feet in fact reduces downstream supplies by as much or more than X[4]. A policy measure that guards against this false water savings would encourage only those private investments in on-farm irrigation efficiency that do not decrease return flows relied on by downstream appropriators and instream users (Huffaker and Whittlesey, 2000). Return flows are not impaired only if the on-farm investment leads to reductions in the water consumed or irretrievably lost to the basin.

A California agricultural water conservation statute enacted in 1992 gives one example of legislation that provides the right incentives for saving water from the basin's view. This legislation grants irrigators who improve their efficiency (save water) a water right to only the net water conserved, which is measured as:

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[4] This counterintuitive result occurs because of reduced return flows. For example, a producer who switches from flood to drip irrigation, applies the crop's needed water by diverting X acre-feet less from the stream. However, this change in technology, while appearing to save water from the adopter's view, may reduce return flows by X, producing zero net water savings to the basin.

The reduction of the amount of water consumed or irretrievably lost in the process of satisfying beneficial uses which can be achieved either by improving the technology of the method for diverting, transporting, applying, reusing, salvaging or recovering water or by implementing other conservation methods. [California Water Code §105212(a) (West Supp. 1992)].

Because this statute is drafted to be consistent with real hydrology and is broad enough to account for hydrological systems in which a return flow is either present or lacking, the California legislation provides the correct incentives for water conservation.[5] By correct incentives, we mean incentives that encourage only those on-farm investments that save total water used in the basin. This guarantees that the on-farm water conservation investments made produce larger basinwide economic beneficial use of water, and do not merely redistribute the benefits and costs among irrigators along a given watercourse.

Barriers to Securing Rights to Conserved Water

One definition of water conservation is when the appropriator saves water that is otherwise irretrievably lost to the system.[6] Water is irretrievably lost to the system when it is depleted through uptake by plants, evaporation, runoff to saline groundwater basins or to aquifers too deep for economic use. Conserved water, according to this definition, is that use of a particular stream or other watercourse or supply source that is saved from loss and made available for current or future beneficial use.

For water to be conserved, the potential conserver must show that the conservation efforts will not damage other appropriators on the same watercourse, typically by reducing return flows (Glickstein et al., 1981). For example, a producer who intercepts his return flows from a field that would otherwise flow unimpeded to a downstream user fails to conserve water. This water saved would not otherwise be lost, since it takes water from another downstream appropriator.

There are many ways to conserve water. Concrete-lined canals or ditches, for example prevent water from seeping to uneconomical depths or to saline aquifers. Other ways include removing water-using weeds (phreatophyes) to decrease water lost to nonbeneficial uses or substituting water stored in surface reservoirs to shallow groundwater basins. Institutions that block producers from securing a water right to the water conserved in this way discourage investments in conservation.

Groundwater Substitution for Conserved Surface Water

Groundwater substitution occurs when irrigators respond to surface water price increases or shortages by reducing surface water demand and tapping instead into groundwater. An unfortunate side effect of this is that groundwater substitution can lead

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[5] If, however, demonstrating this conservation is too expensive, it may damage incentives to invest in conservation.

[6] Some states refer to this as "salvaged" water, i.e. water saved that takes no wet water from anybody else either currently or in the foreseeable future.

to actions that conserve one water resource at the expense of another to which it is hydrologically connected.

As a result of the interdependence between ground and surface water use, it is difficult to determine if a surface water pricing or conservation program promotes saved water from the view of the system. One water source is potentially conserved at the expense of the other. For this reason, the hydrologic and economic ease with which groundwater is substituted for surface water is important to understand and measure when discussing, designing or enacting policies that promote water conservation by agricultural producers.

What all this means for policy analysis is that the net result of surface water pricing, including marketing and conservation legislation or incentives, is an uncertain conservation policy tool, when groundwater is available as a close substitute for surface water. An effective conservation policy will account for the interaction between the two water sources and will attempt to encourage irrigators to manage the two water sources jointly (Schuck, 2001).

The Uncertain Duty of Water

Many Western states, including New Mexico, are adjudicating their streams, i.e. defining clear titles to the right to use water. A completely adjudicated stream system clearly defines all owners' rights to use water under all possible future hydrological conditions. Adjudication began in earnest in New Mexico's Lower Rio Grande in the late 1990s, with the first offers of adjudicated lands sent to landowners in 2000.

Despite the considerable progress made on the adjudications, the "duty of water," i.e. the amount of water right assigned per acre, has yet to be established. There is considerable uncertainty over what the duty of water will be or how it will be established. Will all irrigators receive an equal amount of adjudicated water per acre, for example, 3 acre-feet per acre for every irrigator? Or will the offer vary with type of crop. For example, pecan growers could receive more water rights per acre than cotton growers because of the greater water applied historically per acre to pecan trees.[7] This uncertain duty of water prior to the completed adjudications may establish perverse incentives for water conservation: If there is widespread belief that producers who plant more water-using crops will get a larger adjudicated offer per acre, growers may have an incentive to plant crops or trees that use larger amounts of water solely to receive more water in the future.

Common Property Carryover Storage

Producers sometimes express an interest in seeing a policy that permits or encourages them to carry over and keep track of this year's unused water, which can be kept in a storage reservoir for use in a subsequent year. Rio Grande Project water users in southern

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[7] Tied to this is uncertainty of groundwater adjudication. The question centers on whether or not water rights offers will be defined on combined rights to surface and groundwater use. For New Mexico producers, groundwater is an important source of water during drought, but it also is used widely in normal years.

New Mexico and West Texas are discouraged from saving water in any given year and storing it at Elephant Butte Reservoir for later use.[8]

Three preventable losses occur when water is released from a reservoir and used for irrigation: part of the water is consumed by evaporation; a portion percolates to the aquifer; and the drainage water is sometimes damaged by salts or chemicals. If a system of carryover storage credits could be enacted with property rights assigned to those who reduce their current water use by fallowing land, adopting water-conserving irrigation technology or shifting to lower water-using crops, these losses could be reduced. In drought years, this saved water would be especially valuable.

The common property nature of the saved water in Rio Grande Project lands in combination with the historical 57 percent water allocation to New Mexico users and 43 percent to Texas users means that any water carried over this year is shared by everybody the next year. For example, suppose a Texas user reduces current use by 1,000 acre-feet and stores it behind Elephant Butte in hopes of receiving extra water the following year. The unevaporated part of the 1,000 acre-feet saved by the Texas user will accrue as 43 percent to the Texas user and 57 percent to New Mexico users. The fact that a well-defined, transferable and enforceable private property right is not earned in water carried over discourages people from conserving water.

Interstate Compact Constraints

The Rio Grande Compact and the 1906 U.S.-Mexico Treaty are the overriding mechanisms for allocating water to Colorado, New Mexico, Texas and the Republic of Mexico. The quantity of water allocated to each is set out clearly within the compact and treaty allocations with very little opportunity to trade water surpluses or shortfalls for cash or other considerations. The Rio Grande Compact[9] currently has no institution in place that would permit water users in Colorado or New Mexico to sell or rent surplus water to users below Elephant Butte Reservoir or to buy deficit water from these same users. If, for example, the Rio Grande Compact was amended to allow Colorado or New Mexico users to underdeliver to Elephant Butte in exchange for cash (buy water) or overdeliver to Elephant Butte Reservoir in exchange for cash (sell water), agricultural users in all three states may be encouraged by cash incentives to conserve water.

Mexico is allocated 60,000 acre-feet per year under the 1906 U.S.-Mexico treaty, an amount of water that is not normally subject to negotiation. If irrigators in southern

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[8] High evaporation, which causes considerable losses to water carried over, and limited reservoir storage space at Elephant Butte (meaning stored water may displace future inflows to the reservoir) are two reasons of why little carryover storage is seen.

[9] In the Rio Grande Basin above El Paso, Texas, water is managed to comply with the Rio Grande Compact. Colorado's water deliveries to New Mexico at the Colorado-New Mexico state line are a function of headwater flows produced by Colorado's snowpack runoff. All water not delivered to New Mexico is available for use by Colorado. Water that New Mexico delivers to Texas at Elephant Butte, measured at the gauging station below Elephant Butte, is a function of annual flows at the Otowi gauge above Santa Fe, excluding San Juan-Chama flows. So flows in New Mexico are delivered to the Elephant Butte gauge based on native flows at the Otowi gauge. In very wet years, when New Mexico does not have the capacity to use its full compact allocation, New Mexico may receive an annual credit of up to 200,000 acre-feet for its over delivery to Texas. In dry years, New Mexico may underdeliver to Texas by an amount not to exceed 150,000 acre-feet, and an annual debit is incurred in such cases. New Mexico, under the compact, may accrue total debits, offset by wet year credits, of up to a total of 200,000 acre-feet.

New Mexico or West Texas could sell or rent some of their unused water to Mexico in exchange for cash, the associated financial incentive may encourage them to invest in water conservation measures.

The Price of Water

Various institutions set both the price of water and the rules governing how water can be traded both within and outside agriculture. These institutions potentially have an important influence on water conservation. For example, each EBID member in New Mexico is charged $50 per acre per year for the right to use up to 2 acre-feet per acre, if there is enough water available at the reservoir. If some users conserve their 2 acre-feet allotment, each member still pays the $50. For this reason, the $50 charge is a district membership charge and not a price of water. Because any increase or decrease in water use between 0 and 2 acre-feet per acre results in the producers paying the same $50 price, the first 2 acre-feet per acre are effectively priced at zero.

EBID members also have the right to purchase additional water at $18 per acre-foot if the water is available, so the incremental price after two acre-feet is $18. If policies were instituted that allowed members to buy each acre-foot after two at $18, then rent any unused portion of it out at $100 or even $200 per acre-foot to a city or recreational or industrial buyer, there would be considerable financial incentive to invest in on-farm water conservation measures. However current water transfer practices do not permit trading of water outside agriculture. Thus, water is effectively locked into agriculture, which effectively discourages investments in water conservation and raises the price of water to city or environmental users.

Conclusions

The ability to realize an economic gain by shifting current water use to another user, sometimes called a water transfer, is an important incentive to promote conservation. Several barriers to water conservation were identified. These include lack of clear titles to water rights, barriers to water transfers, on-farm water savings that fail to save water for the basin, and barriers to securing rights to conserve water. Other barriers include the ease with which greater groundwater use can be substituted for reduced surface water, water's uncertain duty, the common property nature of carryover storage, interstate compact constraints, and water's low price, which locks water into agriculture.

One constructive measure to promote water-conserving decisions is to design institutions that remove barriers to informing water users about the opportunity cost of current water uses. Another is to enact laws and policies that guarantee that reduced upstream water use does not simply come at the expense of water taken from a downstream appropriator. Considerable differences in the value of water used in agriculture versus urban and environmental use create an opportunity for designing legal and pricing institutions that reduce barriers to market transfers and incentives that discourage conservation. Water that could be saved in agriculture is typically quite responsive to price changes. Owners or users of agricultural water rights could use this price sensitivity to their advantage by renting or leasing their water to cities or environmental users in periods of drought or other shortages with no change in water rights ownership. Without legislative action, perceptions by many farmers that all unused water may be lost pose a barrier to water conservation. Many users in New Mexico and West Texas fear that trading may not be considered a beneficial use. Where there is water infrastructure to store and move traded water, legislation that defines water trading to be a beneficial water use could remove this barrier to conservation.

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Urban Landscape and In-Home Water Conservation

Determining Landscape Choices, Plant Water Use and Minimum Irrigation Requirements in the Urban Environment

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Introduction

About 40 percent of the domestic water in desert states like New Mexico is used to irrigate managed landscapes. Because managed landscapes are highly visibly to the public, they are the first to be regulated for water use (Devitt et al., 1995). For these reasons, municipalities continue to aggressively legislate for and promote water conservation programs (Smith and St. Hilaire, 1999).

Water conservation legislation abounds throughout New Mexico. Several municipalities have passed water conservation ordinances, while many others have initiated long-term awareness campaigns on water conservation. Thus, sound scientific information about outdoor water conservation is needed to provide rationale for policy changes.

Current State of Knowledge

To be successful, water conservation programs must have long-term public awareness campaigns, meaningful educational programs and effective ordinances. For water conservation programs to be effective, public perception surveys must be commissioned to generate information that can guide those programs. In a public opinion survey of New Mexico residents, respondents were most concerned about quality drinking water quality, indoor water use and the rate at which ground water is being depleted (Brown et al., 2000). Although these respondents favored regulations that seek to conserve water, their least favored method of regulating water use was an increase in the water rates of households and businesses. Public perception surveys can determine consumer landscape preferences (Lohr and Bummer, 1992; Thayer, 1982), attitudes about water-conserving landscapes (Kuo et al., 1998; Zube et al., 1986) and plant selection factors important to landscape designers and landscape architects (Barton et al., 1998). For New Mexico, one area that has not been thoroughly surveyed is how consumers in the state decide to balance landscape preferences with water conservation issues.

Just as important as the public's perception of water conservation is the need for scientists to determine strategies to reduce urban water use in outdoor landscapes. The public is often unaware of the water needs of landscape plants and frequently overwaters them (Cotter and Croft, 1974). Current Cooperative Extension publications and lists of municipal ornamental plants do not give consumers meaningful information about how much water they need to apply to their ornamental plants (Smith and St. Hilaire, 1999). Thus, water use, minimum irrigation requirements and responses to reduced moisture regimes must be identified for plants used in New Mexico's outdoor landscapes.

Knowledge of plant water use allows irrigation planners to determine efficient irrigation schedules (Schuch and Burger, 1997). This will help to maintain aesthetically pleasing managed landscapes, while conserving New Mexico's scarce water resources. However, determining water use of plants grown in New Mexico's advective environment is a challenging scientific problem. Plant-water use values developed outside New Mexico often can't be applied to New Mexico's environment. Also, microclimate (Heilman et al., 1989; Vrecenak and Herrington, 1984) and plant size and maturity (Devitt et al., 1995) impact water use.

Of equal importance to knowing plant water use is information about the plants' minimum irrigation requirements. Drought tolerance traits might be more important than water use (Tipton, 1994). Research conducted in New Mexico's environment has identified drought tolerance traits of selected plant taxa (Balok and St. Hilaire, 2002). Clearly, horticulturists in New Mexico must identify more plant taxa that can flourish in landcape conditions common to the state's managed landscapes. Thus, simple and accurate techniques, such as lysimeter determined transpirational water use, need to be developed to predict plant water use reliably and to determine minimum irrigation requirements.

Project Objectives

The overall project goal is to provide the public with information about plant water use, irrigation requirements and the factors that influence consumers' decisions to adopt water-conserving landscapes. Specific project objectives are:

1. Identify the factors that affect consumers' decisions to adopt water-conserving urban landscapes;
2. Determine the water use of selected ornamental plants with potential for use in New Mexico's managed landscapes;
3. Determine the minimum irrigation requirements of selected ornamental plants in landscapes, such as Xeriscapes.

Expected Outcomes

Objective 1: For this objective, the proposed approach will be to use a public perception survey to determine the factors affecting consumers' choice of a landscape in a desert environment. A survey was initiated in the city of Las Cruces to determine the factors that affect consumers' decisions to adopt landscapes that might conserve water in an urban environment (Spinti and St. Hilaire, 2002). Preliminary survey results indicate that respondents had a favorable attitude toward landscapes that might conserve water but their actual landscape choice might be mitigated by several factors. For example, when asked about using plants in managed landscapes, 81percent of respondents agreed they would be willing to use desert plants in their front yards, but only 41percent reported that they had desert landscaping in their front yards. While only 10 percent of respondents chose a lawn as their favorite landscape element, 71 percent reported they had a lawn. Furthermore, 95 percent of respondents preferred landscapes that had unique and interesting features, regardless of how much water the landscape consumed. All the respondents had trees in their landscapes, and of these, 55 percent reported that trees were the most important landscape element. This information shows that the majority of respondents would be willing to try a landscape that conserves water if it contained trees and was well planned.

A larger survey of the city of Las Cruces is planned and the data will be published elsewhere. However, the information gathered from this study is expected to clarify consumer attitudes and landscape preferences. In addition, data from this study could be used to develop methods to encourage homeowners to accept change in their landscape, support the use of new plant species, and increase awareness of the savings that investment in an automatic watering system can confer. A major outcome of this study is to provide a framework of sound scientific data within which public policy makers and stakeholders in water conservation could operate. Changes in landscape preferences and landscape water use have the potential to save large amounts of residential and commercial water.

Objective 2: To determine the water use of selected ornamental plants with potential for use in New Mexico's managed landscapes, data will be collected gravimetrically in conditions that simulate outdoor landscapes. To simulate the plants' natural edaphic environment, a belowground container system will be used. A relatively simple and inexpensive system will be engineered to determine plant evaporative water use. Recently, the water use of Mexican elder plants (*Sambucus mexicana*) was determined (Feser et al., 2002). Previous reports have identified the performance of some Southwestern tree taxa exposed to reduced moisture regimes (Balok and St. Hilaire, 2002) or have identified plant taxa that merit more use in urban landscapes (St. Hilaire, 2001). These data, together with more data gathered on additional species and at different seasons, will provide comprehensive information about plants that potentially will survive and thrive in New Mexico's managed landscapes. Landscape irrigators will be able to more accurately determine irrigation schedules once plant water use is known. Planners and developers will know plant water use and will be better able to judge water requirements for planned green spaces.

Objective 3: To determine the minimum irrigation requirements of selected ornamental plants in landscapes, plants will be subjected to watering schedules that show reductions in the amount of moisture applied to plants. Plant performance will be assessed through physiological measurements and qualitative ratings of the aesthetic traits. Data on plants' minimum irrigation requirements can help extension personnel recommend irrigation regimens for landscapes. The nursery industry may use this information to modify plant selection to better reflect the plants materials that will survive on a thrifty irrigation budget. In addition to providing Extension personnel and the nursery industry with information about plants' irrigation needs, lower labor costs, lower irrigation expenditures and a diminished potential for environmental contamination are possible benefits.

Conclusions

In summary, scientific information about landscape water use has the potential to provide a framework for policy decisions that affect landscape water conservation. For New Mexico, three areas that directly affect urban water use—how consumers in the state decide to balance landscape preferences with water conservation issues, water use of plants in managed landscapes, and minimum irrigation requirements for ornamental plants—require further research. However, developing information for these research areas is challenging because of New Mexico's unique environment. Preliminary information reveals that many respondents would install a water-conserving landscape, if it contained trees and was well planned. Data on water use and minimum irrigation of ornamental plants could help the nursery industry modify plant selection to match the environments in which these plants are likely to be installed. In addition, Extension personnel will be provided with scientific data on the plants' irrigation needs. Additional benefits from this research include lower labor and irrigation costs, and, of course, conservation of New Mexico's scarce water resources.

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Effect of Subirrigation and Soil Amendments on Water Consumption, Irrigation Efficiency and Turfgrass Quality

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Introduction

Due to rapid population growth and urban development in the United States, current water allocations coupled with expected future demands might soon exceed the supply required to satisfy present per capita, water-use rates. During water shortages, priority is given to water uses that are deemed more essential to human society. As a result, growing attention is focused on the amount of water used to irrigate landscape and recreational areas, such as home lawns, parks, golf courses and athletic fields. The rapid urban development rate has led to increased demands for landscape irrigation of newly developed residential and commercial areas, as well as to the proliferation of recreational areas, such as golf courses and athletic fields.

Irrigating these areas accounts for a large percentage of total urban water use. In southern California, for example, it is estimated that residential urban outdoor water demand in the region exceeded agricultural sector demand in 1990 by 60 percent and was estimated to exceed agricultural sector demand the following year by 100 percent (UCRTRAC, 1999). In New Mexico, based on green fees and golf memberships alone, turfgrass is the No. 2 cash crop in the state after alfalfa, generating $100 million per year, based on a conservative estimate. These landscape areas and recreational facilities will experience increasing pressure from government to conserve water and use the most efficient available irrigation method (Connolly, 2001).

Current State of Knowledge

Due to the high intensity of play and low cutting height of these recreational turf areas, additional irrigation is needed during the vegetative period, especially when natural precipitation is insufficient. Despite its low efficiency in distributing water to the plant stand, sprinkler irrigation has been the accepted practice for irrigating lawns since Joseph Smith patented the first swiveling lawn sprinkler in 1894 (Connolly, 2001). Sprinkler overlap, wind drift and evaporation losses during the irrigation process all contribute to water losses that increase overall water consumption and/or decrease plant stand quality. Subirrigation systems that apply water laterally to the root zone from perforated tiles or emitters buried either close to the surface or just below the normal root penetration from beneath the surface (subsurface drip irrigation or subground irrigation) potentially can save substantial quantities of irrigation water compared with sprinkler systems. Many agricultural studies have demonstrated improved water-use efficiency and crop productivity through subirrigation. These studies showed increased yields in tomatoes, cotton, sweet corn, cantaloupes, alfalfa and other crops, without increasing applied water (Connolly, 2001). Although the benefits of subsurface irrigation's benefits have been studied extensively in agriculture, subsurface irrigation has received very little acceptance or attention for turf irrigation, despite strong evidence of its potential water savings. Stroud (1987) and Chevallier et al. (1981) reported water savings of up to 50 percent when using subirrigation, and Leinauer (1998) reported a 90-percent reduction of water used for irrigation on subground-irrigated turf plots compared with sprinkler-irrigated plots. In addition to water savings, other advantages of subirrigation systems include improved distribution uniformity (no runoff or puddling), uninterrupted use of the turf area during irrigation, and energy savings due to lower operating pressure. Research also confirms that subground irrigation results in a significant reduction in water pollution, a pressing environmental concern because of less potential for erosion and leaching of nutrients and other contaminants (Connolly, 2001). Despite data demonstrating potential benefits of subirrigation systems, the technology still has a long way to go to find market acceptance. One argument against using subirrigation is that emitter spacing and depth is extremely difficult to determine, especially in sloping areas. Other reasons for irrigation's limited success subsurface include the relatively high installation cost, difficulty in monitoring underground systems and lack of urgency for water conservation.

Another factor contributing to the high water demands of these high-traffic, low-cut grass stands is the nature of the root zone mixes used to construct the areas. These areas, which include athletic fields and golf course greens and tees, usually are built with sandy root zone mixes that have low water holding-capacity. The United States Golf Association (USGA) introduced specifications for the properties of root zone mixes for turfgrass areas four decades ago (Hummel, 1993). These recommendations have become the standard in root zone construction. Since 1960, thousands of tees, putting greens and athletic fields have been built in accordance with these guidelines. To provide optimum soil conditions for turfgrass growth, these specifications use a stratified, coarse-textured, sandy root zone: a medium- to coarse-textured sandy root zone is placed on top of a gravel blanket. Because of this coarse texture, the root zones provide high air-filled porosity but lack adequate water retention. To increase water-holding capacity, root zones usually are amended with peat. To date, peat is the only recommended organic amendment for root zone construction. However, during recent years, peat has become increasingly scarce, as bogs become more restricted for harvesting peat. Alternative inorganic or organic amendments will need to be considered in the future.

Objectives and Outcomes

In order to determine how best to conserve irrigation water, it is imperative that the irrigation methods be tested rigorously and compared, and that soil amendments aimed at retaining water be assessed as well. In this project, we propose to compare the effects of three irrigation methods (sprinkler, subsurface drip and subground) and different root zone materials (sand, sand/peat mix and sand/urea-formaldehyde polymer) on water use, turf performance and quality, soil physical properties, water movement and soil gas composition in sloping and flat areas of a 51,000-square feet research turf area seeded with creeping bentgrass.

The objectives are as follows:
1. Study the effects of irrigation system type on irrigation water consumption, turf quality and drought resistance in flat and sloping areas;
2. Study the long-term effects of irrigation systems and root zone type on turf quality;
3. Study the effects of irrigation system type on turf establishment;
4. Study the effects of different soil amendments on turf grow-in and turf quality during the establishment stage; and
5. Study the long-term effects of irrigation systems and soil amendment type on changes in soil physical and chemical properties in root zones.

This study will provide valuable information about strategies for conserving water when growing and irrigating turfgrass areas. The research results will be made available in a variety of ways. The results will be published in appropriate trade journals, conference proceedings and peer-reviewed journals. Progress reports also will be published on the university's Web page. Press releases and fact sheets about using subirrigation in turf will be distributed by the university's Cooperative Extension Service. The research site will be open to the public on field days, which will include an onsite presentation of the research project. Finally, the research plots will be used to host workshops on irrigation education and efficient water use and to demonstrate, in tangible terms, water conservation's economic benefits.

Conclusions

Because of the increasing pressure to conserve water in this country, it is imperative that efforts be made to determine the most efficient irrigation method as well as to use readily available and cost-effective soil amendments to produce high-quality turfgrass with as little water consumption as possible. This project will address these issues and should provide answers and strategies to minimize water consumption in tufgrass irrigation.

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Science, Technology, Urban Agriculture, Research and Demonstration Sites (STUARDS)

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Introduction

One of the most important resources in the arid Southwest, and particularly in New Mexico, is water. It also is one of the scarcest. Consequently, planners are faced with conserving, preserving and managing this resource for the future. Water resource challenges are being addressed and met by several initiatives at New Mexico State University (NMSU).

The goal of this project is twofold: to design and establish a Science, Technology, Urban Agriculture, Research and Demonstration Site (STUARDS); and to provide this design to the NMSU Water Planning Committee. The primary objective is to develop a plan and funding proposal to establish a research and demonstration site (STUARDS) in an area located on unoccupied land in the eastern portion of the NMSU main campus adjacent to I-25. The purpose of the site would be to allow research and demonstration in urban horticulture, floriculture, irrigation technology, fisheries and wildlife and water reuse and conservation. Much of this site is undeveloped. Only a portion currently is used for special events parking, which has caused dust and weed control problems. All of the area under consideration has high visibility and easy access. Also, the STUARDS project will document future water needs for this portion of the main campus update to the university water plan. A key component of the water plan is documentation of the university's research and extension water resource needs for the future (a 40-year plan is used).

University domestic, geothermal, research, Extension and economic development water needs are driven by a number of factors. For example, student enrollment and the university's response to accommodate student body needs drive much of the domestic water requirements on the main campus. However, faculty members drive future research and Extension activities as they develop programs. The approach used by the Water Planning Committee is, therefore, to canvas university departments and their faculty to identify and incorporate these plans. Many of these plans do not envision significant water use needs beyond normal laboratory needs. Others, however, envision activities that would require significant water needs to develop agricultural, riparian, irrigation technology, water conservation, and geothermal research and demonstration projects. The project described below addresses a focused effort to enhance the university's agricultural research and Extension activities for urban horticulture, floriculture, irrigation technology, riparian and water reuse and conservation.

The importance of this proposal is demonstrated by the high priority assigned to land and water-use planning by the NMSU Regents, the high priority for developing the described area by the Office of Facilities and Services (OFS), the increasing importance to New Mexico of the urban horticulture industry, and the goals and objectives of the Efficient Irrigation for Water Conservation in the Rio Grande Basin Initiative.

Currently, agricultural research in Las Cruces is conducted at two off-campus research facilities (Fabian Garcia Research Center and the Leyendecker Plant Science Research Center). In both cases, these centers were developed as research tools, mainly for irrigation research, variety development and disease control research[1]. Currently, demonstration activities at these sites are coordinated primarily by individual researchers and include an annual onion field day at Fabian Garcia and a pecan workshop at Fabian Garcia and, occasionally, at Leyendecker. The chile research programs occasionally have field days at these facilities[2]. Establishing STUARDS will bring agricultural research and demonstration activities back to the central NMSU campus. This would expand the scope of demonstration beyond the current activities that are held at the off-campus facilities. Proximity to Interstate 25 and high visibility provides the research and demonstration site with a significant increase in public access and visibility.

The east campus area described in the plan has very little vegetative cover, and the Office of Facilities and Services staff is currently seeking ways to not only control dust and weeds but also to continue using part of the area for special events parking. Their interest could include planting native turf grasses that would be used for parking and other ornamentals for shade. Establishing these plants would provide defacto demonstration by exposure to special event attendees.

Objectives

The goal of this project is to assist the water committee by developing a plan to establish a Science, Technology, Urban Agriculture, Research Demonstration Site (STUARDS) for irrigation efficiency studies, demonstration and outreach at the main campus. The objectives include:

1. Establishing and implementing a Planning Committee to assist the water committee and to provide oversight to the STUARDS study process;
2. Conducting a series of planning meetings with relevant faculty and other NMSU personnel to gather basic information about needs relevant to establishing the STUARDS project;
3. Developing action plans and a set of strategies to implement and establish the STUARDS project;
4. Developing a funding proposal to submit to selected agencies for infrastructure and site development of the STUARDS project in 2002.

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[1] Conversation with Rich Phillips, project manager, March 6, 2002.

[2] Conversation with Dr. Jim Fowler, superintendent Fabian Garcia and Leyendecker research centers, March 8, 2002.

Approach and Methods

A STUARDS planning committee was formed and includes Dr. I. Miley Gonzalez, interim vice provost for research; Karl Wood, director WRRI; Bobby Creel, associate director, WRRI; Phil King, Civil and Agricultural Engineering; Tom Bagwell, Agricultural Economics and Agricultural Business; Bernd Leinauer, Extension Plant Sciences; Rolston St. Hilaire, Agronomy and Horticulture; Geno Picchioni, Agronomy and Horticulture; and Terrell Baker, Extension Animal Resources.

The planning committee has coordinated this effort closely with the ongoing effort of the water committee and the Office of Facilities and Services to determine what research is needed to address the goals and objectives of the initiative, such as selecting crops and irrigation method(s) and determining location and size of plots, costs to implement the research, and staffing and water requirements. From these planning activities, a funding proposal will be prepared and submitted in 2002 by NMSU's Agricultural Experiment Station for construction of the STUARDS project.

NMSU Water Plan

Water planning has been an integral part of NMSU's activities virtually since its inception. This process was formalized in action taken by the president and Board of Regents. On March 6, 1987, NMSU's Water Planning Committee was formed. The committee's work was given official approval by the Board of Regents in a May 8, 1987 resolution, which directed the university to "continue its historic water planning endeavors by adopting a specific water plan for New Mexico State University enabling it in the future to meet all of its domestic, geothermal, agricultural, research and economic development needs."[3]

Land and water-use planning remains a high priority for the Board of Regents. The university water plan published in 1987 (Abernathy et al., 1987) is being updated. The update will incorporate development that has occurred over the past decade and items that were not addressed in the initial plan and rearticulate the university's water policy. These policy statements follow.

"A. Update the NMSU Water Plan to ensure, in the state adjudication, that NMSU has sufficient water to:
    1. Meet the needs of future campus growth.
    2. Allow NMSU to engage in all agricultural activities necessary to maintain its leadership in the areas of water use technology, conservation, recycling, geothermal.
    3. To support its economic development efforts.

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[3] NMSU Board of Regents, meeting minutes from May 8, 1987, Las Cruces, New Mexico.

B. Continue to provide water policy leadership in the Lower Rio Grande to ensure that the agricultural region in particular and the entire Lower Rio Grande watershed in general have access to water, both in quantity and quality, sufficient to meet the needs of future generations.
C. Provide support in the state adjudication on agricultural and related issues.
D. Maximize and protect NMSU's prebasin water rights."[4]

The water plan update is being conducted under the direction of Ben Woods, vice president for Facilities and Services, by a working committee that includes Bobby Creel and Karl Wood, Water Resources Research Institute; David Bollschweiler, Office of Facilities and Services; Owen Lockwood, retired and from the Physical Plant Department; Tom Bahr retired and from the WRRI; and Jim Witcher, Southwest Technology Development Institute. Karl Wood and Bobby Creel also are on the STUARDS committee.

Expected Outcomes

A series of proposed projects have been designed by committee faculty.

A. Greening a Campus Parking Area in the Southwest: Demonstrating the Effect of Irrigation on Water Use of Turf and Ornamentals

Bernd Leinauer, Assistant Professor, Extension Plant Sciences
Rolston St. Hilaire, Assistant Professor, Agronomy and Horticulture

Background

Due to rapid population growth and urban development, the demand for potable water in New Mexico and in the Southwest could soon exceed maximum supply. When water is in short supply, priority is given to uses that are deemed essential to human society. As a result, attention is growing on the amount of water used to irrigate landscape and recreational areas. However, landscape areas, including turf and ornamental plants, play a vital and important role in not only increasing the aesthetic appeal of urban areas but also in providing functional, recreational, environmental and economic value. Important functions of landscape areas include stabilizing soils and controlling wind and soil erosion around housing, schools and industrial developments. Landscaped areas reduce noise and air pollution and provide a moderate microclimate by preventing heat buildup. However, irrigating these areas accounts for a large percentage of total urban water use. Accordingly, water conservation plans, such as selecting low water-use plants, irrigating with effluent water or using an efficient irrigation system, have been or are being developed to ensure adequate supply of potable water in the future.

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[4] Briefing on Water Matters. Prepared for New Mexico State University, Board of Regents Meeting, Las Cruces, New Mexico, March 23, 2001. Law and Resource Planning Associates, Albuquerque, New Mexico.

Purpose

We propose to install research/demonstration fields at the parking area east of Aggie Memorial Stadium and Pan American Center. Plots can be laid out to compare different irrigation systems, root zones and soil amendments and low water-use turf species and ornamentals, while the area can still be used for event parking. These test plots could serve as demonstrations during field days and for Extension training. In addition, these fields could generate valuable data about teaching water conservation strategies. Findings could be published on NMSU's Web site.

B. Optimizing Fertilizer and Water Use in Greenhouses

Geno Picchioni, Assistant Professor, Agronomy and Horticulture

Background

Potential for environmental impact, most notably water quality degradation, is greater in greenhouse crops than in any other cropping system when potential chemical discharge is expressed per unit of land. The relationship between the natural climatic and edaphic habitat of floricultural crops and their behavior in a protected environment has been virtually ignored by floriculturists. NMSU's horticulture laboratory has shown that an appreciation for the crop's native habitat may be essential for optimizing nutrient and water management in the greenhouse (Picchioni et al., 2001). The potential to increase fertilizer and water application efficiency in greenhouse crop production through a better understanding of the crop's natural edaphic habitat appears to offer an attractive alternative to existing empirical research efforts that have met with significant barriers. Greenhouse production is a major part of the most rapidly expanding segment of New Mexico agriculture (ornamental crop production). But there is increasing concern about fertilizer nutrient runoff from greenhouse production. A likely response to public concern will be more stringent legislation governing use of fresh water and runoff of fertilizer nutrients from greenhouses, as has already occurred in California and Arizona. This response underlies the practical importance of this research to NMSU and the entire state of New Mexico.

Purpose

The purpose of this project is to develop a demonstration greenhouse site that shows or investigates ways to optimize greenhouse production and minimize environmental impact by optimizing use of water, fertilizers and other chemicals.

C. New Mexico State University Stream and Riparian Area Classroom and Laboratory

Terrell T. Baker, Assistant Professor, Extension Animal Resources
M. Karl Wood, Director, New Mexico Water Resources Research Institute

Background

Stream and riparian systems in the arid Southwest occupy less than 2 percent of the landscape, far less than their counterparts in other regions of the country. Largely due to their scarcity, the ecological and economic importance of these unique environments far outweigh their representation in the landscape. However, there remains a great deal to learn about these systems, their ecological significance and management strategies to effectively balance ecological integrity and economic productivity. A critical component of this educational process will be to educate the public about the importance of stream and riparian systems. Riparian vegetation typically has greater root masses than upland vegetation. High-density root masses stabilize stream banks and reduce stream-bank erosion. High root and stem densities also reduce the velocity of overbank floodwaters, which reduces erosion, improves water infiltration into the soil and traps sediments. These functions combine to increase residence time of water in a specific stream reach, decrease sediment export, raise the water table, build the riparian area and restore nutrients. Riparian areas can improve water quality significantly. Riparian vegetation also provides critical wildlife habitat. In addition to their ecological functions, riparian systems also represent significant value to humans through their recreational, aesthetic, and productive (i.e., agricultural) opportunities. Most of the controversy surrounding riparian systems in the Southwest today is the result of the different values placed on these systems by different groups of people.

Purpose

We propose to construct and install a stream corridor within the Tortugas Arroyo on the southeastern side of campus, south and east of the Pan American Center. We also propose to create a pond behind the existing dam south of the Tortugas Arroyo. We intend to use the pond to supply and receive water that will be used for the stream. The pond will serve the additional function of creating aquatic habitat for wildlife and educational purposes. It is anticipated that NMSU faculty will use both facilities for research purposes. This stream and riparian area classroom will contain educational facilities and be home to both guided and self-guided interpretive tours.

Water Requirements

We estimate that approximately 400 acre-feet of water will be required annually to operate the classroom.

D. Irrigation Development and Research Support.

J. Phillip King, P. E., Civil and Geological Engineering

Background

The research projects proposed in this document will require both the design of research-quality conventional irrigation systems and the development of innovative systems for irrigating under heavy vehicular traffic. NMSU has led New Mexico in developing drip irrigation practices for onions at the Fabian Garcia Research Center and for alfalfa at the Agricultural Science Center at Artesia. Drip irrigation shows great promise for use in highly controlled irrigation and chemigation applications, such as using water in greenhouses and reusing greenhouse effluent, and for precisely applying water for irrigation trials on a variety of crops. The research projects proposed here will require highly controlled systems, so that irrigation trials on actual landscape vegetation and trials in greenhouse water use and reuse can be conducted. These will use conventional hardware with more sophisticated controls and software, allowing measured delivery of irrigation rates ranging from full irrigation to minimum survival rates. In addition, using turf grass and other ornamental plants could rely on sprinklers, but high losses due to wind drift and lack of fine control over application for irrigation trials would compromise both the project's demonstration and research aspects. Irrigating with a sprinkler also would preclude using the parking lots immediately after irrigation. The high traffic associated with parking lots that host various sporting and cultural events, RV conventions and military vehicles makes conventional drip irrigation impractical for the turf areas, because soil compaction may damage the drip system or cause it to function improperly.

Purpose

This component will focus on the design and installation of a highly controlled irrigation system to support development of the eastern NMSU campus STUARDS project. The two major components of this task are:

1. To design and install a research-quality irrigation system to service the purposed projects—Optimizing Fertilizer and Water Use in Greenhouses, New Mexico State University Stream and Riparian Area Classroom and Laboratory, and Specialty Crops and Alfalfa Irrigation.
2. To develop high-efficiency subsurface drip irrigation laterals for use on high-traffic areas, such as the NMSU parking lots in the Greening a Campus Parking Area in the Southwest: Demonstrating the Effect of Irrigation on Water Use of Turf and Ornamentals project. High traffic drip irrigation systems also could be used for agricultural crops, such as alfalfa, where tractor and truck traffic must be delayed with surface or sprinkler systems until the field is adequately dry or oriented between drip lines with conventional drip systems.

E. Future project plans include alfalfa,[5] pecan and specialty crops.

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[5] According to Dave Bollschweiler, Office of Facility Services, NMSU currently spends approximately $110,000 per year on outside alfalfa hay purchases. This need could be met by alfalfa production at this site.

Environment, Ecology and Water Quality Protection

Irrigation Ditch Seepage Effects on Surface Water/ Groundwater Interaction along the Rio Grande Corridor

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Introduction

In New Mexico, an intricate link between surface water and groundwater has developed over 400 years (Rivera, 1998). Water from rivers is channeled through ditches and acequia irrigation canals to provide irrigation water (New Mexico State Engineer, 1997). Most projects that address irrigation ditch seepage have sought to convey water efficiently to fields by minimizing seepage losses, which are typically 25-50 percent (Yussuff et al., 1994). While water that seeps from any given ditch is lost for irrigation, the seepage water itself may perform many important functions. Directly adjacent to the ditch, seepage supports riparian vegetation with wildlife, grazing and amenity values (Johnson et al., 1977; Thomas et al., 1979; Hunter, 1990). Riparian vegetation supported by ditch seepage can regulate nitrogen flux to groundwater (Pinay et al., 1998). Ditch seepage may protect deep groundwater quality by transporting nutrients and salts from shallow groundwater into receiving surface water (Owens et al., 1991). In the corridor along the river, shallow groundwater may originate as seepage from ditch or river surface water (Fernald et al., 2001), providing elevated groundwater levels for domestic and agricultural wells. From the irrigators' standpoint, seepage that returns to the river represents return flow that is available for downstream diversion.

Current State of Knowledge

Traditionally, surface water and groundwater were treated separately. But it is now becoming recognized that management of one affects the other (Winter et al., 1998). Research since the 1980s has revealed that in many streams, there is significant interaction between stream water and the water in alluvial aquifers (Bencala and Walters, 1983; Dahm and Valett, 1996). This interaction in many cases is characterized as hyporheic flow, in which surface water enters the stream bed and banks, follows shallow groundwater flow paths, and reemerges to surface water downstream (Harvey and Wagner, 2000). Large percentages of total stream flow can enter and leave hyporheic flow paths, even in large rivers (Fernald et al., 2001; Laenen and Bencala, 2001).

The ecological and water quality effects of hyporheic flow and surface water-groundwater exchange are significant in streams with porous substrates. Surface-subsurface exchange creates habitat for benthic macroinvertebrates (Grimm, 1996; Brunke and Gonser, 1997). Exchange across the streambed can result in microbially mediated chemical transformation of carbon, nitrogen, phosphorus and other nutrients (Wondzell and Swanson, 1996; Mullholand et al., 1997). Exchange between surface water and groundwater can have important effects on water quality, both in the stream and in the alluvial aquifer. Of great interest in agricultural landscapes is the ability of surface water-groundwater exchange to create conditions for denitrification and to remove nitrate from surface water and groundwater (Pinay and Decamps, 1988; Sjodin et al., 1997; Hinkle et al., 2001). This exchange acts as a natural water filtering process (Fernald et al., 2000). Most investigations of surface water-groundwater exchange have occurred on streams (Morrice et al., 1997; Packman and Bencala, 2000). Few efforts have addressed the multiple functions of seepage from irrigation ditches, which are important sources of surface water that interact with groundwater.

The interactions between surface water and groundwater are changing as ditches are lined to increase conveyance efficiency. Lining ditches reduces seepage which in turn affects ecological and water quality processes that rely on ditch seepage. In locations where seepage rates are high from unlined ditches, lining ditches to improve conveyance efficiency may create local groundwater shortfalls. Less seepage may reduce riparian habitat with its wildlife, recreation and amenity values. At the same time, evapotranspiration from riparian vegetation along the ditches may represent significant water use. Reduced seepage may lead to poorer quality shallow groundwater. If lining enables irrigators to consume more water entering a ditch, and there is less seepage and return flow, lining the ditch may affect timing and amount of river flow downstream.

Throughout New Mexico and the southwestern United States, there is increasing demand and competition for scarce water resources. It is widely known that water seeps out of irrigation ditches and recharges shallow groundwater in the corridor of land between irrigation ditches and the river. Acequia associations cite the benefits of seepage from acequias, but few data exist to quantify the seepage functions. Irrigators and water management entities would like to account for return flow from ditch seepage, but they lack data to guide decision-making. Very simply, there are not many data to characterize hydrologic and water quality functions of ditch seepage. Broader, science-based knowledge of surface water-groundwater interactions is needed to better manage water resources in agricultural landscapes.

Research Objectives

To inform and improve ditch and acequia management, this study seeks to fill an important knowledge shortfall and quantify the hydrologic and water-quality interactions between irrigation ditch seepage, shallow groundwater and river flow along the Rio Grande.

This project seeks to determine hydrologic processes at three scales. At the smallest scale adjacent to the ditches, we will determine the amount of seepage from lined and unlined ditches. At the intermediate scale, which is the central focus of this project, we will determine the seepage effects on shallow groundwater level and flow direction. At the intermediate scale, we also will obtain initial estimates of groundwater flow rates, study water quality effects of ditch seepage, and assess riparian vegetation dependence on ditch and river seepage. This project will provide the foundation for addressing the third and largest scale along entire reaches of the river through study of interactions between groundwater and all surface water, including irrigation ditches, drainage ditches and the main river. Water quality effects will be studied at the same three spatial scales. Particular attention will be paid to seepage directly adjacent to ditch and river surface water and the effects of this seepage on local shallow groundwater quality.

Specific research objectives include:

1. Quantify seepage rates from irrigation ditches and the river into shallow groundwater;
2. Determine shallow groundwater flow path directions along the Rio Grande corridor;
3. Quantify effects of irrigation ditch seepage and river seepage on shallow groundwater water table elevation;
4. Compare seepage rates from lined and unlined ditches; and
5. Determine seepage effects on shallow groundwater quality focusing on nitrogen and specific conductance.

Extension and Educational Objectives

Acequia associations and irrigation districts faced with demands for more precise management of irrigation water require better understanding of hydrologic processes in the irrigated river corridor. The immediate target audience for extension of research results will be acequia and ditch associations. Other groups involved in water management, such as resource agencies, local governments and special interest groups, also will benefit from more precise knowledge of surface water-groundwater interactions.

The wider group of land and water users along river corridors will be an important Extension audience.

Specific Extension objectives include:

1. Provide quantification of seepage rates from lined and unlined ditches to acequia and ditch associations;
2. Provide assessment of ditch and river seepage effects on flow, water quality and riparian habitat to the wider audience of river corridor land and water users; and
3. Establish demonstration research projects that are easily accessible to a wide audience.

The educational objectives of this project are twofold. First, the project will provide students recent data to illustrate processes of surface water-groundwater interaction and issues in water management. Second, the sites will serve as outdoor laboratories. The research sites will be used for labs in undergraduate and graduate level watershed management courses and are being considered for a future short course on surface water-groundwater interactions.

Outcomes

This study will provide important information for developing water conservation plans and managing ditches and acequias along the Rio Grande. It will provide results from research at sites along the Rio Grande in northern, central and southern New Mexico. It will show how ditch and river seepages affect groundwater levels, provide estimates of the amount of water that returns to the main river from the ditches, and show how seepage affects well water availability and water quality. This study will relate groundwater levels to riparian habitat and estimate riparian vegetation evapotranspiration. Study benefits extend beyond irrigators and will be useful to multiple stakeholders interested in riparian areas, water quality, ecosystem function and watershed management. Study results also will provide the impetus for assessing larger implications of surface water-groundwater interactions, extending from the headwaters to the mouth of the Rio Grande.

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Agricultural Irrigation Systems and Conservation of Native Fishes: Issues in the Rio Grande Valley of New Mexico

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Introduction

Human population growth in the arid Southwest is a source of increasing stress on water supplies that vary with precipitation from near adequate to scarce. As water supplies grow tighter with population growth, native aquatic species become threatened with extinction. For traditional agricultural use of lands, this can mean giving up water to save a species (Adams and Cho, 1998). In the arid and semiarid lands of the Southwest where farms and cities are concentrated along rivers, farmland that loses a right to irrigation water eventually becomes more valuable for high-density, urban developments, which further exacerbates the stress on the water supply and the cascading impacts to native species (Jackson et al., 2001).

Irrigation has a long history in the Rio Grande Valley of New Mexico that extends back to the 1400s (Scurlock, 1998). The first small-scale irrigation networks constructed by Native Americans led to a sizeable acreage under cultivation by the late 1500s. Perhaps as much as 30,000 acres were irrigated by pueblo residents (Scurlock, 1998). The Spanish introduced ditch irrigation to New Mexico in the early 1600s. It has been estimated that as much as 125,000 acres of farmland were under irrigation in the middle Rio Grande Valley between Cochiti and San Marcial by 1848. Presently, there are approximately 57,000 acres under irrigation in the middle Rio Grande Valley (Clark, 1987; Wozniak, 1987).

Cities and industries in New Mexico's Rio Grande corridor have grown from a rich history of agricultural success. However, as New Mexico's population has increased, native floral and faunal communities have undergone significant changes (Gehlbach and Miller, 1961). Of the 24 fish species that were native in the middle Rio Grande Valley, 14 have been extirpated (Sublette et al., 1990). Reasons for the loss of these species include river fragmentation into discrete regions by dams, river water consumptive depletions, flood control with levees (Junk et al., 1989), flow regulation, biological production impairment (Hildrew, 1996), and the introduction of nonnative species (Ong et al., 1991; Schramm and Piper, 1995; Lang and Altenbach, 1994; Hatch et al., 1998).

This paper summarizes issues in the Rio Grande Valley with respect to native fish occurrence and conservation. We summarize these issues for two native species, Rio Grande silvery minnow (*Hybognathus amarus*) and Rio Grande cutthroat trout (*Oncorhynchus clarki virginalis*).

Current State of Knowledge

Along the main channel of the Rio Grande, the Rio Grande silvery minnow (*Hybognathus amarus*) has been extirpated from the lower reaches of the Rio Grande main channel (Sublette et al., 1990), but it still occurs upstream of Elephant Butte Lake the headwaters to Cochiti Dam. Because of its endangered status, efforts to conserve the species have focused attention on consumptive water uses including irrigated agriculture. Irrigation diversions have been blamed in recent years for drying the river channel; further fragmenting the river into upper reaches that are inaccessible to native fish occurring in lower reaches; and entraining eggs, larvae and adults native fishes into irrigation ditches (USFWS, 1999; Scheidegger and Bain, 1995).

In higher elevation tributaries to the Rio Grande, declining of native fish populations also have occurred. The Rio Grande cutthroat trout (*Oncorhynchus clarki virginalis*) was a member of a native fish community that included longnose dace (*Rhinichthys cataractae*), flathead chub (*Platygobio gracilis*), fathead minnow (*Pimephales promelas*), Rio Grande chub (*Gila pandora*) and Rio Grande sucker (*Catostomus plebeius*). At higher elevations, such as a spruce-fir ecotype, the less diverse native fish community included Rio Grande cutthroat trout, Rio Grande sucker and Rio Grande chub. Natural resource extraction, the nonnative fish introductions and river fragmentation by dams and diversions have contributed to the confinement of the Rio Grande cutthroat trout to isolated headwaters. It is rare to find an intact native fish community in New Mexico's mountain streams (Calamusso and Rinne, 1996; Calamusso, 1996).

Recently, the U.S. Fish and Wildlife Service has initiated a "status review" for Rio Grande cutthroat trout. Because of its apparent elevated risk of extirpation and because of the increasing rarity of native fish communities, our project will study how acequia diversion structures can act as migration barriers to protect native Rio Grande cutthroat trout populations and other members of its native fish community (Stumpff and Cooper, 1996; USFWS, 2001; Paroz et al., 2002).

Agricultural irrigation affects the conservation of native fishes directly or indirectly in a number of ways. Issues of relevance include: upstream fish passage past diversion structures (Papanicolaou and Maxwell, 2000), river flow depletions in times of drought (U. S. Senate, 1898), entrainment of eggs, larvae and adult fish into irrigation ditches, water quality from agricultural drainage and irrigation return flows (Ong et al., 1991) and quality of habitat provided by agricultural drains (Lang and Altenbach, 1994).

In Upstream Passage: Under the "drift paradox" (Hershey et al., 1993), extinction is inevitable when downstream drift is the only transport process (Speirs and Gurney, 2001). In recent years, about 70 percent of the Rio Grande silvery minnow population has been located downstream of the San Acacia Diversion Weir (USFWS, 1999, 2001), in approximately the lower one-third of the middle Rio Grande Valley. It is believed that San Acacia diversion dam is a barrier to upstream movement that causes the bulk of the minnow population to be located downstream. With the Rio Grande silvery minnow being a pelagic spawner, passive downstream transport of embryos and larvae is possible up to the time when they can swim sufficiently. Hatching occurs in two or three days, depending on water temperature, and swimming ability is developed about three days after hatching (Platania and Altenbach, 1998). If minnows downstream of San Acacia diversion are to be relocated upstream of the barrier, as is called for in the recovery plan, how likely is it that offspring from the relocated minnows will drift passively past the diversion or be entrained into the Socorro Main Canal?

For Rio Grande cutthroat trout, prevention of upstream migration of nonnative fishes is desirable (Calamusso and Rinne, 1996). Our preliminary work suggests that acequia diversion structures protect at least four populations of Rio Grande cutthroat trout in the Rio Grande Basin, including Alamitos Creek, Rito Angostura, Rito Resumidero and Rito de la Presa. If these acequia diversions protect native trout populations, are there notable features that could be used in other areas?

Depletions: The Programmatic Biological Opinion for Rio Grande silvery minnow calls for the U.S. Bureau of Reclamation to maintain water in the middle Rio Grande throughout the year. It is not clear if this requirement could lead to closure of irrigation diversions in the Middle Rio Grande Conservancy District during times of drought (DuMars and Nunn, 1993). Since most of the agricultural drains in the district contain water throughout the year, it is prudent to determine if the drains could support silvery minnow or other native species. If so, they might be used as temporary refugia during drought conditions, enabling irrigation activities to continue.

Entrainment: The Rio Grande silvery minnow is believed to spawn near the water river's surface, a behavior known as pelagic spawning. Within a half hour or so, the eggs swell by absorbing water and they become semibuoyant (Platania and Altenbach, 1998). This buoyancy enables the eggs to drift downstream until some time after hatching when the larval minnows are able to swim. During this time, the embryonic minnows are susceptible to being diverted into irrigation canals. It is unknown whether larval minnows can find their way out of the irrigation system, although there are many locations in the Middle Rio Grande Conservancy District where unused irrigation water empties into drains.

Entrainment of larval fish into water diversions has received considerable attention by researchers, especially those associated with cooling water intakes to electrical generation stations and with irrigation diversions (e.g. Harvey, 1987; Adams and Cho, 1998; Papanicolaou and Maxwell, 2000). Significant questions include: At what density are Rio Grande silvery minnows entrained into the Middle Rio Grande Conservancy District's irrigation system? If minnows are found to be entrained into the irrigation system, do some of them escape into drains where they have access to the Low Flow Conveyance Channel? Are there simple ways to remove entrained fish from irrigation canals and return them to the river?

Adult fish also can be entrained into irrigation canals and ditches. During July and August 1993, Lang and Altenbach (1994) sampled fish from 74 sites in the Middle Rio Grande Conservancy District from Cochiti Dam to the Bosque del Apache National Wildlife Refuge, including the Low Flow Conveyance Canal. A total of 12,570 fish were collected representing 27 species. Ten native species were collected from the irrigation system, included gizzard shad (*Dorosoma cepedianum*), red shiner (*Cyprinella lutrensis*), Rio Grande chub, Rio Grande silvery minnow, fathead minnow, flathead chub, longnose dace, river carpsucker (*Carpiodes carpio*), smallmouth buffalo (*Ictiobus bubalus*) and bluegill (*Lepomis macrochirus*). Native fishes constituted more than 60 percent of all the fish collected from the irrigation system; red shiners and fathead minnows were far more common than the other native species. Less than 2 percent of the native fish were Rio Grande silvery minnows.

Lang and Altenbach (1994) also sampled drains within the Middle Rio Grande Conservancy District. They found 20 species of fish, of which eight were native. It is unknown whether the composition of fish populations in the drains remains stable year-round.

Water quality: In some regions, irrigation return flows associated with drains have been shown to have elevated levels of dissolved metals, pesticides, and herbicides. A study on the water in drains entering Bosque del Apache National Wildlife Refuge from the Middle Rio Grande Conservancy District found little water quality impairment (Ong et al., 1991).

Habitat quality: Lang and Altenbach (1994) found that conditions were sufficient for the reproduction of many of the introduced nonnative species. Young-of-the-year sunfishes were found commonly in the drainage returns leading to the Rio Grande, while young-of-the-year catfishes were very common in irrigation channels. The seasonal flows in many irrigation channels were thought to prevent most fish from establishing stable populations within the system. The relatively stable flows in perennial systems were thought to be more conducive to establishing fish species within them, and it was observed that abundance and species richness were higher in these segments than in those with ephemeral flows.

Lang and Altenbach (1994) found no evidence to support Rio Grande silvery minnow reproduction in the irrigation district. No eggs, larvae or gravid females were collected. The majority of specimens caught were young-of-the-year individuals found in the Belen Division, which were thought to have been entrained in the system as eggs or larvae. They then would have developed and dispersed throughout the irrigation system. It was not known to what extent this phenomenon might have played a role in the presence of Rio Grande silvery minnows in the irrigation systems. Lang and Altenbach speculated that the diversity of fish populations within the entire conservancy district might be due to repeated introductions from mainstem impoundments and other sources, rather than from stable breeding populations. It was judged that the irrigation system could not provide a long-term refuge for fish, due to low habitat diversity and seasonal flows within the system. We hypothesize that drains might provide short-term refuge for Rio Grande silvery minnow and that conditions might be engineered to stimulate spawning in the drains.

Objectives and Expected Outcomes

Our project seeks ways to balance human uses of natural resources so that native species can be conserved, while retaining agricultural and other uses of water and allied resources. Compromise solutions that conserve native species and human social values, including vital agricultural interests, provide several benefits. First, it is widely held that "species of fish, wildlife and plants are of an esthetic, ecological, educational, historical, recreational and scientific value to the nation and its people" (Endangered Species Act, 1973). Second, traditional agricultural enterprises provide significant resources to human populations.

Project objectives include:

1. Determine the aquatic biodiversity supported by the system of agricultural irrigation delivery ditches and drains in the Middle Rio Grande Valley and assess the feasibility of irrigation drains serving as refugia for Rio Grande silvery minnow; and
2. Identify the effectiveness of acequia diversion structures as migration barriers that protect populations of Rio Grande cutthroat trout, Rio Grande sucker and Rio Grande chub.

Conveyance channels for agricultural water could contribute positively to conservation in several ways (Mueller and Liston, 1994). First, production of genetically fit individuals is important in species conservation. Agricultural drains could provide an alternative rearing environment that is more naturalized than confinement in a building and more capable of producing vigorous fish. Second, the more locations at which an endangered species can be sustained, the lower the probability that the species will go extinct in the short term. Securing additional populations in agricultural drains could lower the overall risk of extinction. Third, drains may provide a better energetic food base than the Rio Grande, because the river through canalization with levees, has been disconnected from its floodplain. As a result, the river has lost significant organic inputs from the bosque forest of cottonwoods and willows. Biological production in the river would be expected to be impaired, because rivers are typically heterotrophic and their food webs depend on allochthonous inputs of organic matter. Fourth, lateral connectance between drains and the adjacent river could mimic historical conditions where a meandering river channel had periodic flood pulse connections to oxbows and levee lakes that would have provided native fish habitat.

Conclusions

Compromise solutions to native species conservation should be sought that will preserve important social and economic contributions from irrigated agriculture. We believe our studies will provide an important perspective in the conservation of native fishes. The many miles of drains within the Middle Rio Grande Conservancy District suggest that serious attention should be given to their potential utility as refugia for native species. Conservation and recovery plans will be improved when they provide water for both farmers and fish.

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Identification and Detection of Problem and Noxious Weeds on Irrigation Canals will Lead to Effective Weed Management Programs and Increase Water for Irrigation

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Introduction

The Elephant Butte Irrigation District (EBID), which maintains more than 300 miles of canals, laterals and drains, delivers irrigation water within the EBID boundary that includes rural and urban users. EBID is primarily a gravity flow system with containment and delivery in the form of compacted earthen canals and laterals and return flows through open cut drains. The irrigation season generally runs from February through October each year (anonymous, 1995). Irrigation water is distributed through two canal and lateral types: intermittent facilities that hold water only when someone is irrigating from the canal or lateral, and continuous facilities that hold water throughout the irrigation season. Drainage ditches hold water intermittently throughout the season, depending on irrigation overflow and rainfall.

The Rio Grande becomes more saline as the water moves through the system (Levings et al., 1998). In addition, soils of pecan fields along the middle Rio Grande Basin in southern New Mexico were found to be somewhat saline (Picchioni et al., 2000). The water salinity along southern New Mexico's irrigation canals has not been assessed. However, an increase in irrigation water salinity as it moves through the canal system has been documented for other river systems of the southwestern United States (U.S. Salinity Lab Staff, 1954). As the quality of the water varies from one end of the canal system to the other, the soil salinity and vegetation may reflect those changes.

Vegetation found along each of these systems may vary due to differences in soil characteristics, including texture, organic matter, salinity and moisture content and other environmental factors. Some of the plant species that have been observed in the canals and ditches in Doña Ana County include Johnsongrass, Palmer amaranth, yellow nutsedge, barnyardgrass, junglerice, Russian thistle, horsetail (*Equisitum*), common lambsquarters, common bermudagrass, saltcedar (a class C noxious weed) and Siberian elm. In addition, a new infestation of camelthorn, a class A noxious weed in New Mexico, recently has been identified along the Rio Grande system. All of these species are problems in cropland, urban landscapes and riparian areas. The ubiquitous nature of weeds throughout the urban and rural areas of New Mexico, including the canal and ditch banks, reduces the water available for irrigation. This affects both rural and urban users. Weeds compete with desired vegetation for water and cause producers and urban managers to increase water consumption in order to maintain their desired vegetation.

Therefore, improvement in weed detection and management in urban and rural areas is needed to reduce demand on water resources. In addition, assessing the dominant vegetation and soil characterization along the canal system will help us determine if vegetation can be used as an irrigation water quality indicator.

Current State of Knowledge

Many problem weeds that occur on the canals have the potential to use excessive quantities of water through extensive root systems and high transpiration rates. The amount of water used varies among plant species due to differences in root characteristics and distribution in the soil (Radosevich et al., 1997). Many weeds are known to be "water wasters" (Patterson, 1995). These plants are less sensitive to the amount of available water and they transpire or use a great deal of water each day. The presence of plants on canal banks that have extensive root systems and /or transpire continually will reduce the amount of water available for irrigation. Weeds present in the canals and ditches also can obstruct water flow (personal observation DiTomaso, 1998), increasing infiltration and evaporation of the standing water and further reducing irrigation efficiency. In addition, soil conditions, such as salinity, may favor certain weed species. For example, Kochia commonly is found in saline soils (Ross and Lembi, 1999).

EBID has three maintenance stations—Hatch, Las Cruces and Chamberino—that are responsible for the district's weed control. They use mowing and herbicides to control the weeds along the canals and roadways. Herbicides use generally is limited to spot treatments in areas away from the canal. This practice has increased the infestation of certain weeds, such as *Equisitum,* which are not affected by most herbicides. EBID mows each section of the canal system roughly every 6 weeks during the irrigation season. However, some annual weeds can emerge and produce seeds in less than 6 weeks (Aldrich and Kremer, 1997). Often the mowing deposits the mature seed into the canal system. In addition, during the winter when no water is present in the canals, many people deposit and burn Russian thistle plants and other vegetation in the canals. This practice leaves weed seed to be flushed away at the beginning of the following irrigation season.

The weed seed produced on canal banks and deposited in canals moves into farmland and urban landscapes via irrigation water. Kelley and Bruns (1975) sampled irrigation laterals in Washington's Yakima Valley for weed seeds and found between 77 and 137 plant species present in the irrigation water. The weeds that move onto fields also reduce irrigation efficiency, because weed infested crops and landscapes require additional water. These weeds must be managed, resulting in additional herbicide use and cultivation that will impact water quality if the sediment or herbicide moves into air and bodies of water.

Geographic Information Systems (GIS), Global Positioning Systems (GPS) and remotely sensed data are rapidly becoming vital tools for extrapolating point-source information to local and regional scales. GPS and GIS used to document noxious weeds infestations to assist in targeting the infestation area and the extent of the population.

Remotely sensed data, including multispectral and hyperspectral satellite images and aerial photographs, offer an inexpensive way to obtain information about vegetative cover and environmental conditions over wide areas. GPS technology provides spatial reference of remotely sensed and field collected data. GIS is used to map and statistically analyze several layers of spatially referenced information and expand the application of a simulation model over a geographical region to make use of the inherent spatial quality of the data. Spectroradiometers that measure the reflectance signature of plants in the visible and near infrared wavelength range have been successfully used to quantify characteristic reflectance signatures of plants for use in interpreting remotely sensed data.

Project Objectives and Expected Outcomes

The long-term goal of this project is to manage vegetation more effectively and sustainably to save water and maintain water quality. To accomplish this, we must first assess the characteristics of the canal system with respect to dominant vegetation and soils. This information will be mapped using GIS technology. Therefore, the objectives of this three-year project are to identify the major weeds growing on canals, laterals and to sublaterals; to determine if weed cover or species is related to soil characteristics; and determine the relative amount of water used by the predominant plant species.

Objective 1: To identify the predominant vegetation and soil characteristics on irrigation canals.

We will target the canal system maintained by EBID that begins at the Leasburg Dam, continues through the Mesilla Valley and ends south of the Mesilla Dam. By surveying the entire system, we can assess the dominant vegetation and soil characteristics as water is reused throughout the canal system. We will be able to determine if vegetation and soil salinity are affected by distance from the original source or by canal size. Our initial surveys will be conducted during the height of the irrigation season in order to sample and identify the plants during their maximum growth period.

The irrigation canal system will be surveyed systematically to identify the dominant plant species. We will focus our survey initially to ask three general questions. First, we want to know if percent weed cover on the canal is related to the species of weeds that are present. Second, we will determine whether texture, organic matter, pH, SAR or salinity of the soil along the canal is related to the percent weed cover or the predominant species. The third initial question is whether we can use aerial photographs and/or hyperspectral images to differentiate the weed species present on the canal banks. We will adjust the questions we ask in the research, based on the results of the first year of the survey.

GIS provides a practical, well-established framework for data management; map generation; and visual, graphic output. The system, including GIS, maps and remote-sensing data, will be practical and easy to update for growers, irrigation system managers and natural resource agencies. These tools will be essential for cataloging the soil characteristics and the weed species that are present, for determining if new, invasive species are threatening the area, and for evaluating precision weed management along the irrigation canal system.

Objective 2: To determine the relative water use of the major plant species.

This research to identify the species that use the greatest amount of water will be accomplished with greenhouse experiments. In addition, spectral reflectance characteristics of the plants will be determined over the experimental period using a handheld spectroradiometer. This information will supplement the information gathered in the field studies conducted under objective 1.

Conclusions

Once we identify the major species of weeds that grow along the irrigation canals and determine which species use the greatest amount of water, we can then develop cost-effective management strategies. The most economical approach to dealing with such a large problem is to identify the problem and target the weeds that are most destructive. In addition, information regarding soil salinity changes along the canals will allow us to develop testable hypotheses about soil and water quality. Using GPS to locate the weeds and other site characteristics and GIS to map the information in relation to canal location and other factors will provide a practical, easy-to-update information system about the irrigation canals. As it is gathered, this information will be relayed to EBID, growers and the urban population.

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Basin-Wide Hydrology, Salinity Modeling and Technology

Development of Decision Support Tools for Water Conservation in the Rio Grande Valley: Remote Sensing in Irrigation Management

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Introduction

Irrigation of agricultural crops is the largest consumer of fresh water. It has been estimated that approximately 70 percent of all water used each year produces 30 to 40 percent of the world's food crops on 17 percent of all arable land (Seckler et al., 1998). As water scarcity becomes more acute and competition for fresh water intensifies, better irrigation management will be required to achieve greater efficiency in using this valuable resource. To improve water use efficiency, it will be necessary to have information about crop and environmental conditions on scales ranging from farm fields to entire water basins. Computer models and decision support systems will become important tools in water allocation for agriculture and municipalities. Evapotranspiration (ET) is a key component of the water budget and information about the evapotranspiration of crops is important for developing of models and optimal agricultural water management. Accurate measurement of consumptive water use by irrigated crops can be obtained at specific sites with micrometeorlogical eddy covariance techniques, but determination of evapotranspiration on a regional scale requires extrapolation of this point data over large areas where environmental and crop conditions may be very different. Geographic Information Systems (GIS), Global Positioning Systems (GPS) and remotely sensed data are rapidly becoming vital tools for extrapolating models to local and regional scales. Remotely sensed data, including multispectral and hyperspectral satellite images and aerial photographs, offer an inexpensive way to obtain information on crop and environmental conditions over wide areas. GPS technology provides the spatial reference of remotely sensed and field collected data. GIS can be used to map and statistically analyze several layers of spatially referenced information and expand the application of a simulation model over a geographical region to make use of the data's inherent spatial quality. GIS provides a practical, well-established framework to handle data, run models, and provide user-friendly outputs for irrigation managers.

Current State of Knowledge

Remotely sensed data is capable of identifying "previsual" stress symptoms in plant canopies and can be used to detect canopy water stress (Carter, 1993; Riggs and Running 1991; Shibayayama et. al., 1993). It also can be used to forecast crop yield and growth parameters (Thenkabail, et. al., 1994; Rasmussen, 1997) and to identify unfavorable growth conditions in plant canopies simultaneously with physiologic measurements (Carter and Miller, 1994). Table 1 shows several biophysical parameters that can be measured or estimated by satellite and aerial remote-sensing techniques and the processes with which these parameters are associated. These processes play a vital role in understanding water use and in irrigation management.

Table 1. Biophysical crop parameters retrievable from remote-sensing measurement and their association with irrigation management (Bastiaanssen, 1998).

Crop Parameter	Process	Purpose
Vegetation cover	Chorophyll development, soil and canopy fluxes	Irrigation area
Leaf area index	Biomass, minimum canopy resistance, heat fluxes	Yield, water use, water needs
Photosynthetically active radiation	Photosynthesis	Yield
Surface roughness	Aerodynamic resistance	Water use, water needs
Surface albedo	Net radiation	Water use, water needs
Thermal infrared surface emissivity	Net radiation	Water use, water needs
Surface temperature	Net radiation, surface resistance	Water use
Surface resistance	Soil moisture and salinity	Water use
Crop coefficients	Grass evapotranspiration	Water needs
Transpiration coefficients	Potential soil and crop evaporation	Water use, water needs
Crop yield	Accumulated biomass	Production

Most of these parameters are determined by the reflectance characteristics of the plant or surface using multispectral or hyperspectral sensors. These sensors can be carried on aircraft and are on satellites that continually orbit the globe. This information is becoming more readily available and offers some new possibilities in water resource management and irrigation scheduling. Table 2 shows estimates of the accuracy that can be obtained for the remotely sensed biophysical parameters and shows the level of additional ground truth information and verification from ground-based measurement needed to calculate the parameter. Parameters, such as vegetation cover and leaf area index, need no additional information and give very good estimates. Other parameters, such as crop coefficients, need high levels of additional ground truth data for even moderate estimates.

Table 2. Derivations of biophysical parameters from remote sensing that are useful for irrigation management (Bastiaanssen, 1998).

Parameter	Accuracy	Need for Field Data
Vegetation cover	High	None
Leaf area index	Good	None
Photosynthetically active radiation	Good	None
Surface roughness momentum	High	None
Surface roughness heat	Low	High
Surface albedo	Good	Low
Thermal infrared surface emissivity	Good	None
Surface temperature	Good	Low
Surface resistance	Good	None
Crop coefficients: tabulated	Moderate	None
Crop coefficients: analytical	Moderate	High
Transpiration coefficients	Good	None

Data from aerial and satellite sensors, in combination with ground meteorological monitoring, can provide vital spatial and temporal information needed to drive real-time decision support tools for water management and irrigation scheduling. By combining remotely sensed biophysical and environmental parameters, it is possible to derive several parameters that directly relate to water use and irrigation management. Table 3 lists the water management parameters that can be derived from remotely sensed data and also shows estimates of the accuracy and level of additional ground truth information needed to calculate the parameters. These parameters can be used to development real-time, operational, decision support tools for use in irrigation management.

Table 3. Water management information that can be derived from remote-sensing data (Bastiaanssen 1998).

Parameter	Accuracy	Need for Field Data
Precipitation	Moderate	High
Surface runoff	Low	High
River discharge	Low	High
Potential evapotranspiration	Moderate to good	Low
Potential transpiration	Moderate	Low
Potential evaporation	Moderate	Low
Actual evapotranspiration	High	Low
Actual transpiration	Low	Moderate
Actual evaporation	Low	Moderate
Crop stress indicators	Good	Low
Crop yield	Good	Moderate
Relative yield	Moderate	Low
Topsoil moisture	Moderate	Moderate

Several models have been developed that combine remotely sensed data with ground-based meteorological data. For irrigation management, the main effort is in using remotely sensed data to estimate evapotranspiration. Remotely sensed data has proven to be a valuable tool in estimating evapotranspiration for regional water use and irrigation management. (Hatfield et al., 1984; Jackson et al., 1985; Reginato et al, 1985). An extensive review on the application of remotely sensed data to evapotranspiration can be found in the paper by Moran and Jackson (1991). The accuracy of evapotranspiration estimates by using remotely sensed data can be high. Caselles and Delegido (1987) applied a simple model, using only satellite temperature and albedo measurements, to estimate regional evapotranspiration for the Valentian Region in Spain. This model estimated regional evapotranspiration to an accuracy of 20 percent.

Sandholt at al. (1993) successfully calculated evapotranspiration of a test site using a combination of NOAA-AVHRR (Advanced Very High Resolution Radiometer) satellite data and meteorological observations. Raymond et al. (1989) used remote sensing data for Parker and Palo Verde Valleys in Arizona and California to measure regional evapotranspiration. The total consumptive water use calculated by conventional water budget methods compared with maps generated by remote-sensing data for Parker Valley was 392,100 acre-feet and 327,000 acre-feet. The in Palo Verde Valley study showed that the consumptive water use estimated from remote-sensing analysis was 165,191 acre-feet compared with 167,210 acre-feet from conventionally assessed crop maps. The Idaho Department of Water Resources (IDWR) currently is applying a more sophisticated approach, based on the SEBAL technique (Surface Energy Balance Algorithm for Land) developed by Bastiaanssen (1998) to estimate regional evapotranspiration for the Bear River system in Idaho.

Objectives

We propose to evaluate the feasibility of using remote-sensing data to model consumptive water use of irrigated crops (pecans, alfalfa, chile and cotton) and develop decision support tools for irrigation management in the Rio Grande Basin. This project will be multidisciplinary and include research and extension components. Evapotranspiration of crops under full and limited irrigation will be measured and the results correlated with estimates made using remotely sensed data. Remotely sensed data and data from the NMSU automated weather station network will then be used to estimate field and regional water consumptive use continuously in real time for use in water management.

Expected Outcomes

This project will provide both practical information and basic research results to form the foundation for efficient water management. Controlled field experiments will measure water use rates, net photosynthesis rates and plant stress of selected irrigated crops grown in southern New Mexico's Rio Grande valley. Continuous evapotranspiration and net photosynthesis rates will be measured, using micrometeorological "eddy covariance" techniques with fast response humidity, CO_2 and wind sensors mounted on towers above the crop canopies. The results will be correlated with estimates made using remotely sensed data. Remotely sensed data and data from the NMSU automated weather station network will then be used to estimate field and regional water consumptive use continuously in real-time for use in water management and water conservation planning. We will extrapolate our findings to model productivity and consumptive crop water use throughout southern New Mexico by using aerial and satellite remote-sensing information and GIS. The information would be made available to growers, crop consultants and irrigation managers through the Internet. The information generated will complement the existing irrigation management tools currently available through the New Mexico Climate Center.

Conclusion

Data from aerial and satellite sensors, in combination with ground meteorological monitoring, can provide vital spatial and temporal information to drive real-time decision support tools for water management and irrigation scheduling. These tools will be essential for evaluating precision irrigation techniques as land use changes and in times of limited water availability.

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