Agricultural Water Management: Proceedings of a Workshop in Tunisia (Series: Strengthening Science-Based Decision Making in Developing Countries)

Laura Holliday, Editor, National Research Council

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STRENGTHENING SCIENCE-BASED DECISION MAKING IN DEVELOPING COUNTRIES

Agricultural Water Management

Proceedings of a Workshop in Tunisia

Laura Holliday, Editor

Science and Technology for Sustainability Program
Policy and Global Affairs

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PREFACE

During the 2002 World Summit on Sustainable Development (WSSD), the U.S. National Academies, the U.S. Environmental Protection Agency, and the American Chemistry Council announced a new initiative to facilitate better communication among scientists, policymakers, and other decision-makers so that scientific knowledge more effectively informs public policy and private sector decisions relating to sustainability in developing countries. More specifically, the goals of the initiative are:

- Foster improved understanding of the science and decision-making process, including national and local policy, industrial design and planning, and public choices;
- Establish dialogue in which decision-makers use science to inform their decisions and scientists consider the needs of decision-makers in their choice of research;
- Identify gaps between the needs of decision-makers and scientific research priorities and strategies for bridging these gaps, including ways to increase the professional connection between scientists and decision-makers, and;
- Share workshop results, via summaries and briefings, with a broader audience of scientists and decision-makers in the host country and internationally.

To achieve these objectives, the organizations involved (see list below) provided support for a series of "science in decision-making workshops" in developing countries on key issues of particular concern to the host country such as water and sanitation, persistent organic pollutants, and biodiversity. The workshops convene representatives from host country and U.S. scientific institutions, government, industry, non-governmental organizations, academic institutions, and other relevant organizations. Crosscutting themes addressed in the workshops include monitoring and data evaluation; elements of good science advice; facilitating the flow of scientific information; and the roles of institutions that link scientists and decision-makers.

Workshop topics are proposed by science organizations in developing countries. A steering committee established by the U.S. National Academies reviewed proposals and provided general oversight for the series. The workshop co-chairs– one from the respective developing country and one from the United States – designed each workshop, which were organized in a collaborative process involving the U.S. National Academies and one or more science organization from the partnering country.

The initiative involved the following organizations:

- U.S. National Academies
- Mexican Academy of Sciences
- Chinese Academy of Sciences
- TWAS, the Academy of Sciences for the Developing World
- InterAcademy Panel
- American Chemistry Council
- U.S. Environmental Protection Agency
- Scientific Committee on Programs of the Environment, China

- H. John Heinz Center for Science, Economics, and the Environment
- National Council for Science and the Environment
- State Environmental Protection Administration of China

The initiative's first workshop, "*Strengthening Science-Based Decision-Making for Sustainable Management of Ground Water in Mexico,*" was a joint workshop between the U.S. National Academies and the Mexican Academy of Sciences. It was held February 8-10, 2004, in Mérida, Mexico. The second workshop, "*Strengthening Science-Based Decision Making –Implementing the Stockholm Convention on Persistent Organic Pollutants"* was held June 8-10, 2004, in Beijing, China. The third workshop titled "Strengthening Science-Based Decision-Making for Agricultural Water Management." took place June 4-9, 2005, in Tunisia and is featured in this report.

The Tunisia workshop was co-chaired by Dr. Henry Vaux, Jr. of the University of California, Berkeley, and Dr. Sihem Benabdallah, of the Institut National de Recherche Scientifique et Technique in Tunisia. The meeting involved approximately 30 attendees from Tunisia, other Organization of the Islamic Conference (OIC) countries, and the United States, including decision-makers from both the public and private sectors, and scientists from relevant disciplines, such as agronomy, economics, and natural resource management. The overarching question considered at the workshop was: How can Tunisia and other countries in the region marshal their considerable bodies of scientific talent to address the problem of insufficient agricultural production caused by water scarcity? The workshop also addressed two major sub-issues related to food production. First, how can existing water supplies, including recycled waste water, be managed so as to optimize the domestic production of food and fiber? Second, what can the public and private sectors do to optimize production of high value agricultural products? Discussions of these issues included: information about scientific advances in irrigation; suggestions regarding communicating this information to the appropriate decision-makers; consideration of additional information that decision-makers need; and comments regarding what organizations are or should be involved in facilitating the flow of such information.

The workshop began in Tozeur with a field trip to observe Tunisian agriculture and agricultural management practices. The field trip participants, including almost all of the international and U.S. participants and several Tunisians, observed groundwater mining to produce dates, mangos, and other high-value crops; wastewater reuse experiments; oasis agriculture practices; erosion prevention systems; hothouse agriculture; and other agriculture and water management systems. Discussions at various sites revealed concerns about salinity, sustainability of the system (with groundwater levels declining rapidly), security implications of drawing down a shared aquifer, and the vulnerability to drought of the populations in the region.

The papers included in this volume were submitted by the participants to help frame these discussions. As such, many of the papers do not include the technical detail or exhaustive citations found in a scientific journal. The opinions expressed in the papers do not necessarily reflect the views of all workshop participants, their affiliated organizations, or the National Academies. The report does not contain consensus findings or recommendations from the workshop participants as a whole.

More information about the program "Strengthening Science-Based Decision-Making in Developing Countries" and about the Science and Technology for Sustainability Program is available online at *www.nationalacademies.org/sustainability*. This workshop proceedings is available online at *www.nap.edu*.

ACKNOWLEDGMENTS

We wish to express sincere thanks to the many individuals who played significant roles in guiding the initiative "Strengthening Science-Based Decision-Making in Developing Countries." The steering committee provided guidance on the initiative's goals; identified appropriate modes of operation; and reviewed all workshop proposals. Steering committee members include: Chairman Michael Clegg, University of California, Riverside; Thomas Lovejoy, H. John Heinz III Center for Science, Economics and the Environment; Whitney MacMillan, Cargill, Inc.; Perry McCarty, Stanford University; *Roger McClellan,* Chemical Industry Institute of Toxicology; and F. Sherwood Rowland, University of California, Irvine.

For the workshop featured in this proceedings "Strengthening Science-Based Decision Making for Agricultural Water Management" workshop co-chairs Dr. Sihem Benabdallah, Professor of Geochemistry Physics and Chemistry of Water at the National Institute of Scientific and Technical Research and Dr. Henry Vaux, Professor of Resource Economics and Associate Vice President Emeritus of the University of California, Berkeley were instrumental in designing the workshop agenda and ensuring productive discussions.

This publication was made possible by grants from the U.S. Department of State (State Department) and the U.S. Environmental Protection Agency (US EPA). The statements made and views expressed are solely the responsibility of the authors and do not represent the positions of the State Department, the US EPA, the U.S. National Academies, the National Institute of Scientific and Technical Research, or other organizations where the authors are employed.

This volume has been reviewed in draft form by several individuals chosen for their technical expertise, in accordance with procedures approved by the National Academies' Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in ensuring that the report is as sound as possible and meets institutional standards for quality. The review comments and original draft manuscript remain confidential to protect the integrity of the process.

We wish to thank the following individuals for their review of this volume: Randa Aboul-Hosn, United Nations Development Programme; Bernard Engel, Purdue University; Rita Maguire, ThinkAZ; Ayman Rabi, Palestinian Hydrology Group; and Moneef Zou'bi, Islamic-World Academy of Sciences.

Although the reviewers listed above have provided constructive comments and suggestions, they were not asked to endorse the content of the individual papers. Responsibility for the final content of the papers rests with the individual authors.

Special thanks are extended in recognition of the important contributions of the following National Academies staff: John Boright, Executive Director of the Office of International Affairs, who provided oversight for the initiative, and Derek Vollmer, who contributed to planning the workshop, as well as Kathleen McAllister and Laila Parker, who assisted in editing the report.

Laura Holliday, Editor

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OVERVIEW

Henry Vaux, Jr.
University of California, Berkeley

Intensifying water scarcity is now a global phenomenon. The water resources of many regions of the world are insufficient to meet the demands for food and fiber, municipal and industrial uses and environmental uses. Even countries that are relatively richly endowed with water may have to address regional or temporary water scarcity. Virtually no region or area of the world has water resources that are sufficient to meet demands in all times and regions. The arid and semi-arid regions of the world are experiencing the most intense water scarcity. Elsewhere it has been shown that science and the development of technology, including soft technologies, will be crucial in enabling countries and regions are or will be short of water to manage increasingly severe scarcity (Vaux and Jury, 2004).

North Africa and the Middle East are among the most water scarce regions and that scarcity will continue to intensify as populations grow and economies develop. Tunisia exemplifies the general scarcity problem faced by most countries in these regions. The indigenous water supplies of Tunisia amount to about 435 m^3 per person per year, roughly 25% of what is thought to be necessary to fully serve the water demands of each member of the population. This figure is typical of the countries of the Middle East and North Africa and will likely decline if the populations of these countries continue to grow. One of the major challenges of the future for these countries will be to manage intensifying water scarcity in ways that optimize the productivity of water and preserve and maintain environmental amenities to the greatest extent feasible.

Agriculture is the largest consumptive user of water throughout the world including in North Africa and the Middle East. The productivity of irrigated agriculture is significantly higher than the productivity of rainfed agriculture, particularly in arid and semi-arid regions. The consequence is that agricultural uses of water are very important in generating the food and fiber needed to serve the populations of the region. Nevertheless, the growth in competing demands means that efforts will have to be made to manage agricultural water in the most efficient ways possible. This volume contains the papers presented at a workshop held in Carthage, Tunisia in June, 2005 which was intended to address the use of science and scientific expertise in managing water resources of the region. The workshop was sponsored by the U.S. National Academy of Sciences, the Tunisian Ministry of Research, Science, Technology and Competency Development and the Tunisian National Institute of Scientific and Technology Research.

The overarching objective of the workshop was to focus on the question of how Tunisia and other countries in North Africa and the Middle East marshal their considerable scientific resources to address the problem of insufficient agricultural productivity due to water scarcity. Workshop participants focused on two related issues. First, how can Tunisia (and other countries) utilize their existing water supplies, including recycled wastewater, to optimize production of food and fiber? Second, how can Tunisia, other countries, develop the capacity for producing high valued crops for export in their warmer southern regions despite the lack of water in those regions? The answers to these questions depend on scientific advances in agronomy, water science and economics.

In considering the means of strengthening science based decision making the agenda was divided in to segments. One segment included general presentations on Science and Decision-Making, including the unique role of the Islamic World Academy of Sciences and the Academy of Science and Technology of Senegal. Another segment included presentations on science and water management and yet another examined specific water management issues in Tunisia. There was an extensive discussion of innovations in agricultural water management. One innovation which has significant potential for the region is the use of regulated deficit irrigation regimes on permanent crops which allow growers to produce high quality yields with very limited water supplies. In all of these presentations and in the related discussions participants recognized that there is much existing science waiting to be applied and utilized in the management of agricultural water. In addition, significant new scientific innovations are likely to be available to help growers everywhere utilize water in a highly productive and highly efficient fashion.

Many participants also recognized that the generation and availability of science alone is not sufficient for good agricultural water management. The science must be transferred to policy makers, water managers and water users. The workshop considered the questions of what constitutes good scientific advice from both the perspective of the scientist and the policy maker. Agricultural water users and managers provided perspectives on what constitutes good scientific advice. Water users also reported on how they had used science in their own endeavors. Finally, there were a number of presentations and discussions on how to link science with action. The structure of the program, the presentations, and the resulting discussions illustrated that while good science and the development of good science will be crucially important in resolving the water problems of Tunisia and its neighbors, communications of that science to a broad array of users, including policy makers, managers and growers will be at least as important.

The workshop was enriched by participants from many of the countries of North Africa and the Middle East. All participants engaged in the workshop discussions, bringing examples from their own situations to bear on the deliberations. It is the hope of the workshop sponsors and organizers that the presentations and deliberations of this workshop on strengthening science based decision making in agricultural water management will help in fashioning solutions to the significant water problems of North Africa and the Middle East.

Reaching-out to Decision-Makers on Science Matters: Islamic World Academy of Sciences as an example

Moneef Zou'bi
Director General
Islamic World Academy of Sciences

This overview paper addresses policy and decision-makers/politicians rather than scientists. As such, it highlights some of the major challenges that will be witnessed by humanity in the Twenty-First Century. The possible role that is/could be played by academies of sciences, and the Islamic World Academy of Sciences in particular, in realizing socioeconomic advancement through scientific and technological means, in their respective catchment areas, is also outlined.

NORTH-SOUTH DIVIDE

A Timeline

Divides between countries, regions, and civilizations have existed since the dawn of time. Socio-economic or development divides too have always existed between countries and regions. As long as 2000 years ago, the world was divided up into empires; the Persian and Roman empires, and to the east there was China. Islam was founded in Mecca around 610 AD. Within 150 years, the new Islamic state stretched from the Himalayas in the East to the Pyrenees in Europe. The Islamic civilisation bloomed between 750 and 1258 AD, in terms of science and technology output among other feats, with a South-North divide in terms of scientific advancement appearing between the Islamic state and the rest of the then world, especially Europe. The flow of knowledge and science through Muslim Spain to Europe (i.e. South-North) contributed to the renaissance in Europe that started around 1500.

That turning point marked the start of the slow decline of the scientific enterprise in the South. Two hundred years ago, the industrial revolution was underway in Europe, and yet another phase in the progress of science and technology in the world. The twentieth century was marked by three world wars: the First World War (1914-1918), the Second World War (1939- 1945), and the Third World War -the Cold War (1945-1990). The first two wars saw the defeat of a Western power, namely Germany, at the hands of a diverse alliance of powers, whilst the third saw the defeat of the Eastern Block at the hands of America and Europe (Figure 1).

FIGURE 1 A Proposed S&T 'Divide' Timeline.

The Contemporary Divide

The First World is made up mostly of the English-speaking world and Europe. Apart from Australia, most of the countries that belong to the economic or industrialized North actually lie north of the equator (World Bank Web Site).

The South is made up of the countries of South America, Africa, Middle East, South and South East Asia including China and India (Figure 2). Needless to say, most of the 57 Organization of the Islamic Conference (OIC) countries lie in the South.

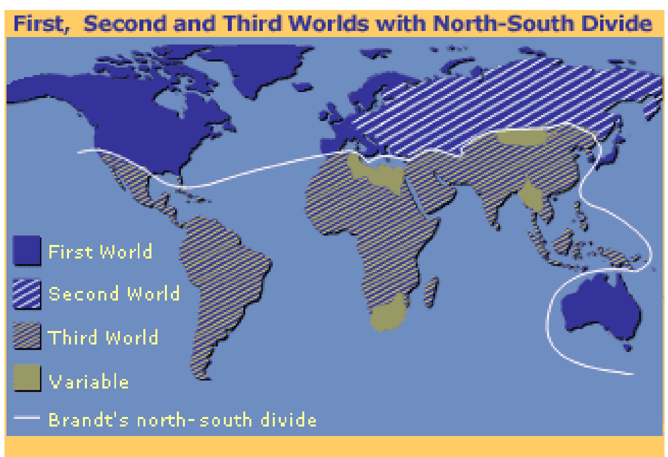

FIGURE 2 Brandt's North-South Divide, World Bank Web Site.[1]

[1] Willy Brandt was a 1971 Nobel Peace Prize Winner and the Chairman of the Independent Commission on International Development Issues in 1977. He was known for his commitment as an international spokesman for better North-South relations.

THE INTERNATIONAL S&T SYSTEM

Some of the landmarks/players

After the end of World War II, policy-makers in Europe and the US realized that science and technology (S&T) programs had had a profound impact on the outcome of the War, and wanted to put such benefits to civilian/societal benefit, as well as to stay ahead in the 20th Century's Third World War--The Cold War. The end of World War II also witnessed the creation of a number of international organizations founded to help with reconstruction activities after the war which left Europe almost completely destroyed, many countries bankrupt, and most of the countries of the South eager to gain political independence.

Apart from the United Nations and its various off-shoot organizations, a number of regional political groupings were founded. The Organization of the Islamic Conference (OIC) was, for example, launched in 1969 after the arson attack at the *Aqsa* Mosque in Jerusalem (Organization of the Islamic Conference).

Some of the players that were/are part of the international S&T system are:

1964: International Centre for Theoretical Nuclear Physics (ICTP), Trieste, Italy;
1981: Organization of the Islamic Conference Committee on Scientific and Technological Co-operation (COMSTECH), Pakistan;
1983: Third World Academy of Sciences (TWAS);
1986: Islamic Academy of Sciences (IAS), Amman, Jordan;

Other International Players

The United Nations, which was created in 1945, developed an elaborate set of organizations over the years, with science and technology forming part of the mandate of almost every UN body. The science and technology programs of UNESCO, UNDP, FAO, and WHO, form a large portion of international activities in S&T.

Academies of Sciences: General

Academies of sciences play a vital role as science advisors to the political leaderships of their "catchment areas," in both developed and developing countries. Worldwide, there exist around 90 national, regional and international academies of sciences according to the InterAcademy Panel, IAP, (InterAcademy Panel). However, despite the existence of many academies of sciences in the Islamic world, the understanding of the term 'academy of sciences' is still lacking. People's reaction is often nonchalant when the explanation is given that an academy of sciences is a Science *Policy Research Centre* or *Think Tank* where science and scientific issues are debated and studied. Put simply, an academy of sciences is the science advisor to the leadership in the catchment area in which it operates.

Academies of sciences are mostly national non-governmental agencies the aim of which is to provide advice to governments on science and technology matters. The Islamic Academy of

Sciences (IAS) came into being in 1986. The Summit Conference of the Organization of the Islamic Conference (OIC), which was held in Casablanca in 1984 approved the founding of the Academy, and mandated it as the *Think Tank* of OIC-member countries. The IAS was relaunched as the Islamic World Academy of Sciences in March 2005.

Is Science Useful?

Science remains the most successful means of knowledge creation (Clegg, 2003). The value of science and science capacity as a means to achieve socio-economic development and attain economic might has been proven beyond doubt, especially since the end of World War II. The rise of the economic power of the United States, Germany, Japan, and other OECD countries can be inextricably linked to S&T advancement.

Moreover, the rise of the Pacific Rim Tigers can also be attributed to scientific and technological advancement. Having said that, it is probably worthwhile to highlight some pointers as to how advancement in S&T has been achieved. In other words, the success of such countries may be credited to there:

- Their will to advance
- Education, education and education[*] (Blair, 1997)
- Building up their capacity including S&T capacity
- Implementation of sound S&T policies
- Increased funding
- Increased regional, North-South, South-South co-operation

Needless to say that science and scientific activities are probably the only sure means through which humanity can overcome its twenty first century challenges.

MAIN GLOBAL CHALLENGES AT THE TURN OF THE MILLENNIUM

What Are the Challenges?

The world, shaped as it is today by the progress in science and technology, is marked by the emergence of new, increasingly complex societal forms: a networked, self-managing society. This growing complexity is also a feature of the developing regions, where a series of problems have become increasingly acute: poverty; lack of access to drinking water to health care and to education; pollution; deforestation; desertification; exploitation of children; migration; armed conflict; illiteracy; isolation; marginalization and North-South disequilibria in the use of science and technological know-how, are all factors of instability that threaten the world.

[*] As stated by British Prime Minister Tony Blair in a British national elections campaign speech (1997).

The twenty first century will see problems of a magnitude not experienced by humankind in the past. Population growth is the main driver. Population growth invariably leads to food and water insecurity, an uncertain energy outlook, the spread of HIV/AIDS, as well as environmental degradation. Outlined below are challenges related to food and water that will face our world in the twenty-first century, including OIC-Member countries.

World Population

According to the Population Reference Bureau (2004), world population stands at over 6.134 billion at present (May 2004), with Asia's share mounting to 60% (Figure 3) (Population Reference Bureau, 2004). Population factors have an impact on many facets of life. The need for health care preoccupies the political leaders of the North whose populations are "aging," while the need for classrooms, employment opportunities, and housing, preoccupies the leaders of the countries of the South. The high-fertility countries in the Middle East and Africa with large proportions of young adults and children are examples. Populations of the North are relatively old.

A population's age structure affects how that population lives. Developing countries (of the South) have relatively young populations while most developed countries have old or "aging" populations. In many developing countries, 40 percent or more of the population is under age 15, while 4 percent is 65 or older. In all but a few developed countries, on the other hand, less than 25 percent of the population is under the age of 15 and more than 10 percent is 65 or older.

Countries of the South can implement joint programs to gradually limit the high rate of population increase in their countries. As many developing nations share the same religious and cultural heritage with their neighbors, they may be able to learn from each other's experiences in limiting population increase, as that is normally a factor adversely affecting economic growth.

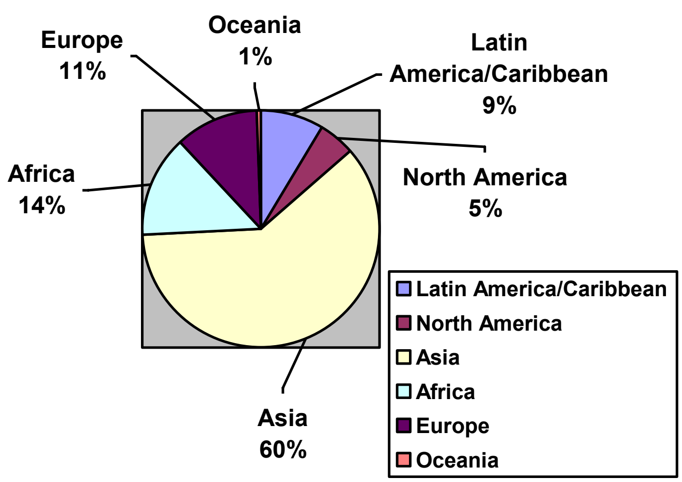

FIGURE 3 World Population, Population Reference Bureau, 2004.

The population of OIC-member countries is over 1,300 million. Populous OIC-member countries in Asia include: Indonesia, Bangladesh, Pakistan, Iran and Turkey. In Africa OIC countries include Nigeria, Egypt, Morocco, Sudan and Algeria.

Food Insecurity

Worldwide, the UN Food and Agriculture Organization (FAO) estimates that 842 million people were undernourished in 1999-2001. This includes 10 million in industrialized countries, 34 million in countries in transition and 798 million in developing countries. According to the FAO's annual report *The State of Food Insecurity in the World 2003,* hunger is on the rise again after falling steadily during the first half of the 1990s. FAO's latest estimates signal a setback in the war against hunger (FAO, 2003).

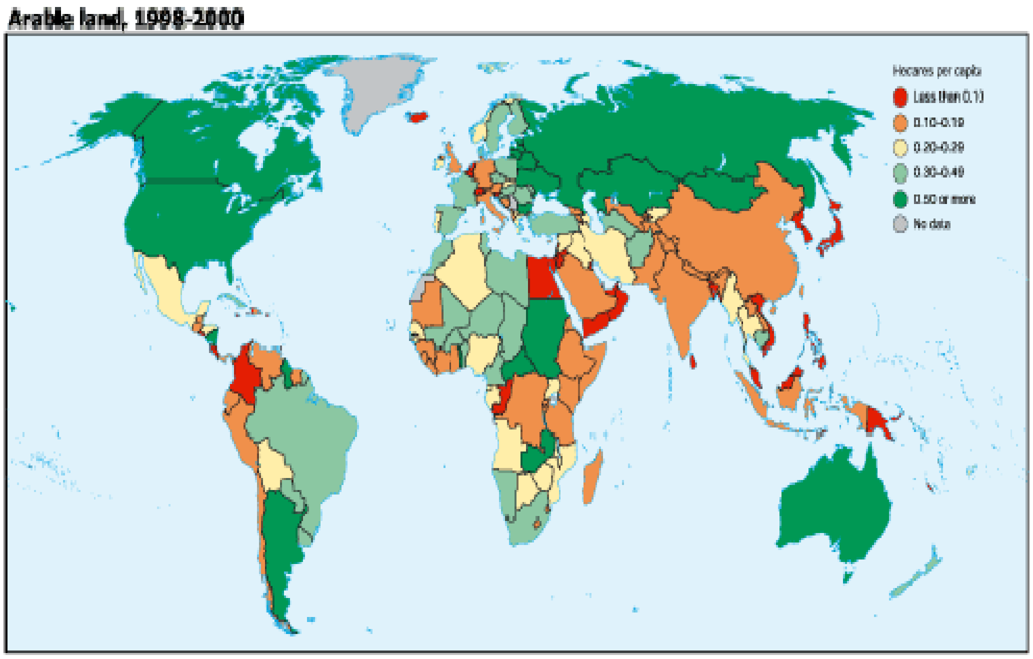

FIGURE 4 Arable Land, 1998-2000.

Figure 4 shows arable land ratios worldwide. It can be noted that in a number of OIC countries including Egypt, Jordan, the Palestinian National Authority (PNA), Yemen, Oman and Malaysia, the situation is critical.
Given the rate at which hunger has declined since 1990 on average, the World Food Summit goal of reducing the number of undernourished people by half by 2015 cannot be reached. The goal can, according to the FAO, only be reached if the recent trend of increasing numbers is reversed. Only 19 countries, including China, succeeded in reducing the number of undernourished throughout the 1990s, says the report. Twenty-two countries, including Bangladesh and Mozambique, succeeded in turning the tide against hunger. In 17 other countries; among them India, Indonesia, Nigeria, Pakistan and Sudan, however, the number of undernourished people, which had been falling, began to rise.

Water Scarcity

Many parts of the world suffer from water scarcity. This is not only due to the low rates of precipitation they receive, but also due to the increase in demand on water resources for domestic, agricultural and industrial uses. Central and northern China, northwest and southern India, parts of Pakistan, North Africa, the Middle East and the Arabian Peninsula as well as the Gulf states, are areas with serious water deficits.

Oil rich countries in the Middle East have adopted water desalination as the main means of supplementing their fresh water budgets, while other Middle Eastern countries such as Jordan, with no oil resources, are struggling to make ends meet. Jordan is one of the world's ten most poor in water resources.
Population growth, pollution and climate change, all accelerating, are likely to combine to produce a drastic decline in water supply in the coming decades, according to the World Water Development Report published in late 2003 (United Nations, 2003).

Faced with inertia at the leadership level and a world population not fully aware of the scale of the problem, the global water crisis will reach unprecedented heights in the years ahead, the report says, with growing per capita scarcity in many parts of the developing world. And that means hunger, disease and death.

A big difficulty with water is that, at least in the rich North, it is largely taken for granted. After all, it is the most widely occurring substance; whilst in the arid and semi-arid countries of the South, it is a matter of critical importance.

Regional co-operation in water matters is imperative if countries are to try to achieve some level of water security (Ergin, et al., 1994)

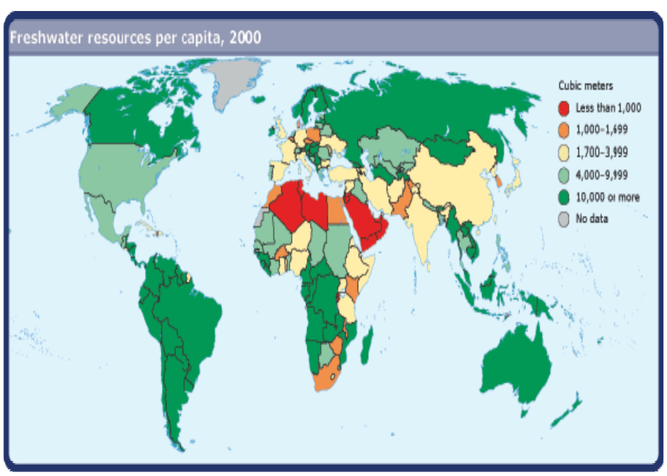

FIGURE 5 Freshwater resources per capita, 2000.

Figure 5 shows the freshwater resources map of the world in 2000. It shows how critical the water resources problem is in most Arab and many OIC countries. Only Indonesia and Malaysia (OIC countries) are *in the green* in terms of water resources.

OIC-COUNTRIES: PLAIN TRUTHS AND DIFFICULT CHOICES

OIC Countries' Difficulties in Brief

In most Organization of the Islamic Conference (OIC) Countries, expenditures on science R&D are low: estimated at less than 0.2%, in marked contrast to that in many European countries (Zou'bi, 2003). This low level of investment has also been highlighted in the first Arab Human Development Report published by the United Nations Development Program in 2002 (UNDP, 2002). The Report also reiterates that Internet penetration rates are also low; estimated at 0.6% (Zou'bi, 2001). Flowing from this low investment level, the science output is similarly very low. Only about 2% of the world's science citations originate from these countries and only about 1% of mainstream journal articles. Other statistics reinforce this analysis, with approximately 226 scientists/engineers per million population, in stark contrast to the approximately 7000 per million in Japan, for example.

In terms of university education, there are 550 universities in the 57 OIC-Member Countries, most of which are of low standard. This contrasts with the over 1000 universities in Japan. The science and technology budgets of all the 550 universities together amounts to only half of that of the National University of Singapore. Moreover, according to the 2004 study of the Institute of Higher Education, Shanghai Jiao Tong University, China, no university from any OIC country was ranked amongst the world's top 500 universities (2004).

The GDP statistics are equally sobering. The total GDP of 57 Islamic countries is less than half that of Germany and less than a quarter that of Japan.

The First Bottom Line: Global Challenges Are OIC Challenges

Notwithstanding some success stories, Organization of the Islamic Conference (OIC) countries faces an unprecedented socio-economic development challenge. It is imperative for the science community in these countries to reach out and convince the political leadership, as well as the public at large, of the value of science as a way to realize national development targets.

Academies of Sciences: The Heritage I

Some academies in the developing world – for example, in Brazil and Malaysia – owe their success to strong and sustained financial support from the government matched by the government's willingness to detach itself from influencing academy affairs. Such a strategy has allowed these academies to enjoy both adequate levels of funding and independence.

Academies prosper in such an open environment while governments benefit from the objective and unbiased advice they receive from expert institutions that they fund but not control.

In many OIC-countries today, academies are weak institutions. That, however, was not always the case. Indeed the Arab word, *majma*, meaning assembly, dates back to the 7th century. Moreover, Al-Ghazali's Nizamiyah Academy in Baghdad, catering to all fields of knowledge, including science, was one of the world's most renowned seats of learning at the turn of the first millennium. That is some 400 years before the creation of the West's first science academy, *Accademia Nazionale dei Lincei*, in Italy (Zou'bi, 2003).

A common feature of all the world's science academies is to seek economic and social advancements through wise application of science and technology. To fully realize this goal, academy representatives must get their message across to both public officials and the public at large.

The Second Bottom Line: The Heritage II

In the Islamic world, knowledge-based institutions, which date back to the earliest days of the Islamic religion, constituted one of the major defining elements of Muslim society during its 'golden age' – a time when Muslim culture dominated the world and stood at the forefront of progress and development. Put so laconically by no other than Carly Fiorina, CEO, Hewlett Packard, 2001, who said:

> "There was once a civilization that was the greatest in the world. A super-state that stretched from ocean to ocean. Within its dominion lived hundreds of millions of people, of different creeds and ethnic origins. This civilization was driven more than anything, by invention. Its architects designed buildings that defied gravity. Its mathematicians created the algebra and algorithms that would enable the building of computers, its doctors examined the human body, and found new cures for disease. Its astronomers looked into the heavens, named the stars, and paved the way for space travel and exploration. When other nations were afraid of ideas, this civilization thrived on them, and kept them alive. The civilization I'm talking about was the Islamic world from the year 800 to 1600" (Ergin and Zou'bi, 2002).

OIC-COUNTRIES OWN SCIENTIFIC DEVELOPMENT GOALS: VISION 1441

In October 2003, the Government of Malaysia as Chair of the Organization of the Islamic Conference (OIC) hosted the 10th OIC Summit in Putrajaya, Malaysia. The Summit was preceded by the OIC *Conference on Science and Technology for Industrial Development in Islamic Countries: Facing the Challenges of Globalisation,* which declared Vision 1441 and its objectives as the guiding principles in steering OIC-member countries' S&T efforts for the next two decades.

Vision 1441 (1441 is the Hijri year corresponding to the year 2020) encompasses three key S&T objectives (measurable targets) that OIC-member countries must try to achieve by that year, in their quest to realize socio-economic development. They are:

- To achieve 14 percent of the world's scientific output by the year 1441 H
- To achieve the ratio of 1441 RSEs (researchers, scientists and engineers) per million population by 1441 H
- To achieve investment in R&D of at least 1.4 percent of GDP

Vision 1441   *OIC member states are committed to become a community that values knowledge and is competent in utilizing and advancing S&T to enhance the socio-economic well being of the Ummah.*

Vision 1441 was then adopted by the 10th OIC Summit. Subsequent to that, a Task Force on Vision 1441 was formed by OIC Secretariat, in which the IAS is member. The Islamic World Academy of Sciences is committed to promoting Vision 1441, and contributing to the national strategies that may be derived from Vision 1441. Funding agencies, including the Islamic Development Bank, have expressed readiness to fund projects submitted by OIC-countries that are based on Vision 1441.

ISLAMIC WORLD ACADEMY OF SCIENCES (IAS)

Background

Science academies today have a critical role to play as a strong public voice for the promotion of both scientific excellence and science-based development. The glorious history of academies in the Islamic world has been largely lost to history. For nearly 1000 years now, the concept of an assembly of intellectuals or a fellowship of scientists dedicated to the advancement of knowledge within their societies has remained relatively obscure, even among the political elite.

In response to the need for an international organization that can play such a role and cater for the needs of the Islamic scientific community, the Islamic Academy of Sciences (IAS) came into being as a non-political, non-governmental organization that represents Muslim scientists from various parts of the world.

The establishment of the Academy was recommended by the OIC Standing Committee on Scientific and Technological Co-operation (COMSTECH), and approved by the Fourth Islamic Summit, Casablanca, 1984 (The Islamic Academy of Sciences, 1999). The Academy, which commenced its activities in 1986, is an independent body that enjoys international status comparable to learned bodies of similar nature in the world.

Mission and objectives

IAS's mission is to provide a dynamic institutional organization that can assist in the utilization of Science and Technology for the general development of Islamic countries and humanity (The Islamic Academy of Sciences, 1999). The main objectives of the IAS are to:

1. Serve as a consultative organization of the Muslim *Ummah* and institutions of member states of the Organization of the Islamic Conference (OIC), on matters related to science and technology
2. Initiate scientific and technological programs and related activities in science and technology, and to encourage co-operation among research groups in the various Islamic countries on projects of common interest

3. Encourage and promote research on major problems of importance facing Islamic countries and to identify future technologies of relevance for possible adoption and utilization
4. Formulate standards of scientific performance and attainment, and to award prizes and honors for outstanding scientific achievements to individuals and to centers of excellence in all science and technology disciplines

Role

The Academy has, since 1986, managed to achieve two primary objectives that form cornerstones in its mission to assist in the development effort within OIC-Member countries. As a policy-making body the Academy has been actively formulating and promoting science and technology policies that help countries streamline national development efforts. Secondly, the Academy has been able to directly implement important scientific programs that fall within its general mission, especially in the areas of the provision of experts to countries, publications, specialized training and information technology related activities (Figure 6).

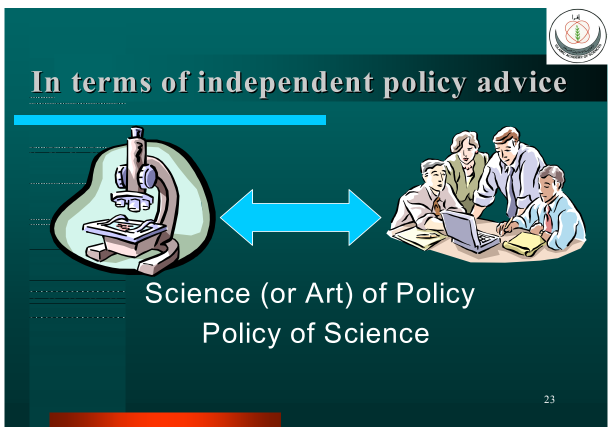

FIGURE 6 Science (or Art) of Policy/Policy of Science.

Activities: General

The IAS has gradually built itself as an action-oriented institution of the *Ummah* utilizing most of its resources for activities that accelerate the pace of development in OIC-member countries. The core objective of all such activities has been to promote the science and technology sector in OIC and developing countries

Operating on a year to year basis, the Academy has been promoting joint Islamic action through its specialized scientific conferences; publishing a series of Conference Proceedings (Policy Documents); journals; books; newsletters; and establishing a quality medical journal that is of an international standard. The Academy also undertook a number of quality training programs and built its own site on the Internet. Figure 7 below sums up most of the activities of the IAS.

FIGURE 7A Activities of the Islamic World Academy of Sciences I.

FIGURE 7B Activities of the Islamic World Academy of Sciences II.

International Co-Operation

Over the years, the Academy has built up scientific relations with a number of international non-governmental organizations, as well as governments throughout the world. These include:

- OIC Standing Committee for Scientific and Technological Co-operation (COMSTECH), Pakistan;
- The Islamic Development Bank (IDB), Saudi Arabia;
- The United Nations Educational, Scientific and Cultural Organization (UNESCO), Egypt and France;
- The Islamic Educational, Scientific and Cultural Organization (ISESCO), Morocco; and
- The Third World Academy of Sciences (TWAS), Italy.

These relations have helped the Academy to convene annual international conferences; each of which is held in a different country every year and supported by a number of international agencies. The host country normally provides local accommodation and hospitality for the participants while the Academy and the other co-sponsors pay the other expenses including the publishing of proceedings. The host country is also expected to contribute to the scientific content of the conference. The conferences aim to provide OIC heads of state with a scientific roadmap for their national development in the context of the discussed topic.

Medical Journal of the IAS

The *Journal of the Islamic World Academy of Sciences*, which first appeared in August 1988, is a quality publication comparable to international scientific journals. The Journal has established itself as a major scientific publication in the Islamic world and has been granted an ISS number (ISSN 1016-3360). It is a forum for publishing research from scientists and technologists in developing countries.

In order to strengthen the Journal, and in response to the large number of medical articles that are normally sent to it, the IAS Council requested the Chief Editor to re-launch the IAS Journal as a primarily medical publication catering to the needs of medical scientists in the Islamic world and beyond. The re-launch was successfully completed in 2000. In 2000, the electronic version of the Medical Journal of the Islamic World Academy of Sciences was launched (Medical Journal of the Islamic Academy of Sciences).

Conference Proceedings

In its efforts to disseminate scientific information, the Islamic World Academy of Sciences annually publishes the proceedings of the yearly conference it organizes; a process that was started with the publication of the proceedings of the Academy's Founding Conference. Such a process ensures that the papers that are presented at the conferences are made available to scientists and decision-makers that are concerned with Third world issues.

From 1988 to 1997, the Academy published seven books, which were the proceedings volumes of the annual Academy Conferences. During 2000, the Academy published the proceedings of its ninth Conference, *Science and Technology Education for Development in the Islamic World*, which was convened in Tehran, Iran during July 1999. That was followed by the proceedings book of the tenth Academy Conference, *Information Technology for Development in the Islamic World,* which was held in Tunisia in 2000. In 2004, the IAS published the proceedings volumes of its 2001 *Biotechnology* conference and its 2002 *Materials Science* conference (Figure 8).

FIGURE 8 Intelligent outreach.

FIGURE 9 The future.

International Outlook

A primary function of the Academy is to act as a Pan-Islamic affiliating body to the relevant international organizations. Muslim scholars can have a channel of communication, through the Academy, with many international academies of sciences and agencies. This helps the IAS to regularly identify specific international issues of importance and develop an understanding of the impact that such issues may have on countries of the South and the OIC in particular (Figure 9).

The IAS and Vision 1441

The Islamic World Academy of Sciences has, since it was founded in 1986, been lobbying for science and technology in decision-making circles, and has been energetically calling on OIC-Countries to develop and adopt long-term S&T policies. Moreover it has successfully attempted to secure all forms of support for the national science communities from the political leaderships in their countries. As the academy of sciences of the OIC, the IAS is keen to promote Vision 1441, and more importantly, to work to implement the strategies and secure the finances that OIC-Countries require to realize the targets stipulated in Vision 1441.

CONCLUSION

Realizing socio-economic development is the goal of governments and decision-makers. To convince decision-makers to pay more attention to and invest more in science and technology, lobbyists including academies of sciences and scientists must present a strong case for the positive impact of science and scientific advancement on society. They must provide historical and contemporary perspectives on how science can have a positive impact on the betterment of societies.

This paper does not address scientists or researchers. Rather, it is aimed at decision-makers and politicians in countries of both the South and the North. It aims to reiterate the value of science as a tool for development and advancement. It presents political decision-makers in both the North and the South with an overview of the problems the world is likely to face in the 21st century. It promulgates the adoption of the Millennium Development Goals and Vision 1441 as yardsticks for development.

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The Elements of Scientific Advice

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INTRODUCTION

With the passage of time, the substantive and contextual bases in which public policy must be made grow ever more complex. This is especially true of natural resources and natural resource policy. The explanation lies with the fact that as populations and economies have grown, the competitive pressures on natural resources have also grown. This has led, in turn, to levels of exploitation which either cannot be sustained or can be sustained only by using management systems which are based upon a clear and unequivocal understanding of how the underlying natural resource systems behave. The fact that there are limits to the resiliency of natural resource systems means that the management of such systems without adequate scientific underpinnings is inherently a high stakes gamble in which the entire system may be lost or its biological and economic productivity severely impaired (Houck, 2003).

The success of modern management systems for natural resources is almost always determined by the adequacy of the scientific understanding of those systems except in instances in which the policy maker simply rejects the underlying science in the interests of securing other objectives. To be effective, management strategies must be based upon and incorporate accurate information about the state of the system being managed and about the way that system will change over time both in the presence and absence of managerial manipulation. Several different types of scientific information are required. The first is a description of the current state of the system. The second would include a description of how the system varies over time and, more specifically, a characterization of the relationships between the descriptive parameters and all of the variables that cause those descriptive parameters to change. A third category of information derives from the second and includes information on how the system will respond and react to all manner of managerial interventions.

Good managers of natural resource systems are good appliers of science and scientific information. Thus, the successful manager of water systems has access to pertinent scientific information which characterizes the system to be managed and applies that information in making policy and managerial decisions related to how the water is managed. A water manager cannot usually be either a good manager or an effective manager if he or she does not have access to the pertinent scientific information. One of the obligations of scientists and the scientific community is to provide the needed scientific information to natural resource managers. This can be done either directly or through the development of scientific methodology which resource managers can then employ in developing their own scientific information. The latter strategy may be particularly attractive since it allows managers to tailor information development activities to the specifics of the particular system which they manage and the acquisition of the particular managerial information which they need.

As the purveyors of critical information which is needed to manage the world's resources sustainably to meet multiple objectives, scientists need to be clear on what constitutes adequate scientific advice. What are the elements of such advice and information? What principles should guide scientists in developing and rendering scientific advice? The remainder of this paper is devoted to a characterization and discussion of the elements of good scientific advice, particularly as it is applied to the management of water systems.

THE ELEMENTS OF GOOD SCIENTIFIC ADVICE: FIRST PRINCIPLES

Principle # 1: Frequently, scientists compromise their effectiveness and credibility by failing to distinguish among scientific information, scientific interpretation and policy value judgments. There is an understandable resentment among policy makers about scientists who behave as if their scientific backgrounds make them especially qualified to make policy value judgments. Policy value judgments are inherently non-scientific and scientists are no more qualified to make them than anyone else. In addition, scientists frequently compromise their effectiveness by failing to be clear about what is scientific fact and what is an interpretation of that fact. The first fundamental principle that should govern the development of good scientific advice can be stated as follows: It is crucial to distinguish between fact and what follows logically from fact, on the one hand, and interpretation of fact and value judgment on the other. This is not to say that scientists should be restrained from rendering interpretations of scientific fact and value judgments about the formulation policy. Rather it is to emphasize that scientists must make clear when their advice contains elements of interpretation or policy value judgments.

Principle # 2: There are at least three distinct dimensions of scientific advice which can be offered either independently or in conjunction with each other. These are: 1) existing scientific knowledge; 2) interpretations of existing scientific knowledge; and 3) methods for acquiring scientific knowledge. Existing scientific knowledge is comprised of information that is known with certainty, information that is known probabilistically and information that is uncertain or unknown[1]. It is rare that scientific information is known with complete certainty and there are circumstances in which information is unknowable with scientific certainty. In rendering scientific advice, it is thus important to inform the decision maker of the relative degree of risk[1] or uncertainty associated with specific pieces of knowledge so that risk and uncertainty can be accounted for in designing policies and management strategies. Similarly, interpretations of scientific information rest in part on what is known with certainty; what is characterized by risk and what is inherently unknowable and uncertain. Again, in making scientific interpretations, it is important that the scientists be very clear in describing the extent to which a given interpretation is based on hard knowledge and the extent to which it is based on probabilistic knowledge and/or judgments even where they are employed to reduce uncertainty.

There are other circumstances where scientific advice will not consist of scientific information at all but rather in the characterization and design of processes or methods for acquiring scientific information either on a one-time or on a continuing basis. Here again, reliability and accuracy are important characteristics of any system that generates scientific information. The task of the scientist in these situations is to provide knowledge not just about methods and processes for acquiring scientific information and their design but also to characterize *ex ante* the reliability of

[1]For purposes of this paper the term "risk" is used in situations which are described with a known set of probabilities and the term "uncertainty is used to describe situations in which information is unknown.

the system and the accuracy of the data which the system produces. This latter characterization is particularly important since frequently there are circumstance where the existing scientific state-of-the-art does not allow for the gathering of data and knowledge with complete certainty. A fundamental element for virtually all good scientific advice is that it characterizes accurately the extent to which the scientific knowledge in question is known with certainty; is known only probabilistically or is completely unknown (National Research Council, 1993).

These two principles are the fundamental principles that govern whether scientific advice is good or not. Advice based on the solidest and most comprehensive bodies of scientific knowledge will not be good if advisors do not clearly distinguish between facts and opinions. Similarly, good scientific advice must characterize scientific knowledge explicitly in terms of what is known with certainty; what is known with some attendant risk and what is not known or uncertain. Scientific advice will be severely compromised and even misleading where these two principles are not followed.

THE ELEMENTS OF GOOD SCIENTIFIC INFORMATION FOR WATER MANAGEMENT

In an ideal world, a water manager would wish to have comprehensive information. It is important to recognize that information is costly and the benefits of additional information will not be uniform. In the normal course of events, the marginal benefits of additional information will decline. Where this is so, the economically optimal amount of information will not normally be a completely robust and comprehensive set of information. In such instances, optimizing the amount of information will be economically efficient.

Optimizing Scientific Information: The totality of all of the scientific information that would be useful in managing water is substantial. While it would be helpful to have access to all such information, it is important to recognize that information is not costless. Consider, for example, the problem of protecting ground water from a possible leak in a toxic waste storage pit equipped with a clay liner. As shown in Table 1, the costs of a monitoring network rise exponentially as the probability of detection rises. The analysis based on this example shows also that the costs of a monitoring network and the probability of detecting a spill may depend critically on the shape of the spill or plume profile. The costs associated with uncertainty can be illustrated further by emphasizing that an optimally designed monitoring grid that will detect a radial spill with a probability of 0.9 will detect with a probability of only 0.23 if the spill turns out to be elliptical. These calculations were made assuming that the soil profile was homogeneous. Most substrates through which water and contaminates migrate are not homogeneous and this injects further uncertainty and raises still further the costs of acquiring adequate information (Vaux and Jury, 1985).

Probability Radial spill	# of sensors Elliptical spill	# of sensors
0.1	3	27
0.5	21	180
0.9	70	597

TABLE 1 Number of sensors required for different probabilities of detection with different spill profiles.

As a general rule, it will not be economically efficient to develop and gather a total or complete set of scientific information. In economics jargon, the marginal costs of gathering or developing the last bits of scientific information will outweigh the marginal benefits. (One exception will be instances in which toxic wastes threaten an aquifer and there is no alternative source of water supply.) In offering scientific advice it is important for scientists and managers alike to be clear on the fact that there is an optimal amount of scientific information (where the net benefits of the information are maximized) which will be less than a comprehensive set of information in most instances. Thus, one of the problems of formulating good scientific advice is to determine which pieces of scientific information are really important and beneficial and which are less important and less beneficial. Emphasis should always be placed to developing and communicating the most important and beneficial information first.

Dynamic versus Static Information: Water managers focus on both water quality and water quantity. Competent water management requires knowledge of how past and current actions will affect the future qualitative and quantitative conditions of the water system in question. The manager needs to be in a position to anticipate and react to future circumstances. This means that good scientific information on water will almost always be dynamic or time dependent. Such information is generated invariably with the aid of models. Models of varying types, include different sets of parameters, are accurate over specific ranges of conditions and vary in the degree of robustness with respect to different circumstances and parameter values.

Good scientific advice surrounding the adequacy of different water models will always include information on the appropriateness of the model for the circumstances in question; the estimates of the degree of accuracy, usually stated in terms of error bars; and a characterization of both the strengths and weaknesses of the model. In circumstances in which it is necessary to build new models data requirements may be extensive and the data expensive to acquire. Nevertheless, it is important to reiterate that the quality and accuracy of the model need to be made transparently clear.

Uncertainty and Adaptive Management: In many circumstances good scientific information upon which to base water management policies and schemes is simply not available. Yet there may be considerable urgency and need for management in order to protect the resource and to generate additional supplies of water in circumstances of scarcity. The prescription for such situations is adaptive management which entails flexible management regimes that can be altered and adapted as more experience with the system yields more information (Walters and Holling, 1992). The importance of adaptive management cannot be overemphasized. Data on water are lacking in many regions of the world even as the need for water management intensifies. Moreover, projected levels of population growth suggest that water management will need to become more pervasive if sufficient quantities are to be available to meet the drinking water and sanitation demands and grow the additional food needed to support more people.

The challenge here is to design a management regime which serves to protect the water and generate sustainable levels of exploitation in ways that also aid in determining experimentally the properties of the water system and its response to the manipulation of different management variables. It will rarely be true that the ideal experimental regime will be the same as a regime designed to accomplish the management objectives for the aquifer in question–even under uncertainty. The trick, then, is to design a management regime which balances the need for immediate management intervention and the need for scientific information. In most such circumstances, the scientist and the ground water manager will be required to exercise judgment jointly to design such a system. Here, good scientific advice will consist of knowing how to design an optimal experiment as well as knowing how to depart from that optimal experiment in ways that will allow management objectives to be achieved while at the same time ensuring that useful scientific data will be generated. The need to design water management regimes which are adaptive and yield useful scientific information relatively quickly represents a new and important area of endeavor for the water science community (Walters, 1986).

CONCLUSIONS

Successful water managers must be masters of many trades. The must be skilled policy analysts and imaginative devisers of policy. They need excellent communication and political skills. And, they must be good applied scientists. As water demands grow in response to population and economic growth throughout the world, water will need to be managed more intensively if new increments of demand are to be served. If water managers are to succeed in their ever more complex and ever more demanding endeavors they will need the best possible scientific knowledge and information.

In developing and communicating this scientific information research scientists must be mindful of two fundamental principles that govern good scientific advice irrespective of the kind of science involved. First, it is essential for scientists to be clear always about the distinction between scientific fact and value judgments. Scientific information consists of scientific fact and what logically follows from that fact. Interpretations of fact and value judgments should not be confused with scientific fact and scientists should be clear in labeling interpretation and value judgments for what they are. Second, there is hardly any certainty about anything. There is always a need for more scientific information and some phenomena are not completely knowable given the limitations of the scientific state of the art. In providing scientific information, scientists need to be clear to distinguish between what is known with certainty, what is known probabilistically and what is completely uncertain. The water manager deserves no less than to be advised when he or she is proceeding in realms where the science is inadequate or unavailable.

The particular elements of good scientific advice for the specific case of water management are three in number. First, it is important to recognize that scientific information is always costly. Rarely will it be economically justifiable to insist on complete information. Good scientific advice will focus on the most significant information and de-emphasize information which is less important or would be merely nice to have. Second, ground water is a dynamic resource whose condition changes with time depending upon environmental and managerial variables. Good scientific advice should be couched, where possible, in a dynamic framework. Third, and finally, too often there is little or no scientific information available. Here adaptive management in which the manager learns by doing will require solid scientific input and a careful balancing between the experimental needs and the objectives of the management regime.

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How can scientific research be more effectively integrated into public policy making?

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INTRODUCTION

If we agree that the issues involving water management are becoming increasingly complex, then it makes sense that more information, particularly accurate, thorough and objective information, will result in better decision-making. A question frequently asked in the scientific community is how can scientific knowledge more effectively be used to inform public policy and private sector decisions in water management?

It is clear that many of the research tools developed in academia are not fully utilized by policy-makers and water managers alike. There are at least three reasons for this: 1) the scientists who have developed them do not fully appreciate the institutional, economic and cultural constraints within which policy-makers operate; 2) policy-makers frequently are not aware that relevant scientific research is available to them; and, 3) there is a disconnect between the timeframes within which scientists/researchers and policy-makers operate.

Recently, there has been a concerted effort by universities to foster stronger relationships between the academic and public policy arenas. In Arizona, several programs have been initiated by the three state universities to actively seek input from natural resources managers in the "real world" as they develop their academic research agendas.[1]

Understanding the institutional, economic and cultural circumstances within which policy-makers develop and implement solutions.

The professional environments of scientists and policy-makers are very different. Most scientific research takes place within an academic environment where success is measured by the novelty of the research, its validity and acceptance by fellow academics. In contrast, political success is measured by election or appointment to office which requires policy-makers to answer to a variety of interest groups including stakeholders, constituents, the media, elected officials and the general public. Consequently, scientists and policy-makers are guided by different types of information. Figure 1 illustrates some of the key differences.

[1] ASU's International Institute for Sustainability funded by a National Science Foundation grant; Governor Napolitano recently proposed a "Virtual Water University" supported by research efforts at ASU, U of A and NAU; the newly opened Decision Theatre at ASU which will provide three dimensional analysis of urban growth issues.

Scientists	Policy-Makers
1. Objective facts	1. Subjective Values
2. Proof	2. Beliefs
3. Rational	3. Emotional
4. Measurements	4. Perceptions
5. Incremental Progress	5. Deadlines and Crises

FIGURE 1 Key Differences in Guidance between Policy Makers and Scientists. Bernabo, 1995.

While scientists must judge the quality of their research by its technical strengths, policy-makers must also consider the social acceptability and financial feasibility of a proposed solution to a problem. As a result, scientists can be frustrated when what appears to be the "correct" answer based on scientific values is overlooked for a more politically acceptable solution.

Furthermore, scientific development of useful products and services for water managers requires an understanding of the context in which the products and services will be used. A scientist, whose view is strongly influenced by the boundaries of his own experience, will fail to appreciate the practical needs of a water manager doing business in the "real" world. This disconnect results in a research product that is not useful, and therefore not used, by the water manager.

Most policy-makers, water managers included, operate within a "decision space." This is the range of realistic options available to a policy-maker or manager to resolve a particular problem. John Letey, Director of the Center for Water Resources at University of California – Riverside sums it up best, "Effective policies must be scientifically valid, economically viable, and socially acceptable" (Letey, 1999). Among their considerations is whether they have the legal authority to initiate a particular action and whether there is sufficient funding to finance the solution to the problem. In addition, water managers in the western United States must develop consensus among all the interested parties before taking any action or risk their actions being challenged in court. Most policy-makers and water managers operate within a highly complex environment constrained by numerous external factors. A successful scientific solution will need to take into consideration each of these external factors.

In order for information to be accepted by a policy-maker and his constituents, it must be credible. Fortunately, good scientific information requires thorough research and documentation which is consistent with the need for credibility. They will want to know who developed the information, why was it developed, did the funder of the research have a particular outcome in mind, and does any contrary research information exist?

It is also important for scientists to think about how accurate and credible the information being produced is compared to how accurate the policy-maker needs it to be in order to be useful. In the context of the type of information produced, how much risk and uncertainty is acceptable to practitioners? Do policy-makers in this area agree on the levels of risk that are acceptable?

And finally, the information must be better than the information available from other sources. It is important for academic researchers to be aware that they are in competition for a decision-maker's attention. Advocates on either side of an issue will be vying for their attention and ultimately, support. Thus, the information must directly and concisely address the decision-maker's questions. It must also be available to the decision-maker when he or she wants it; this may require a researcher to be flexible with his/her time and availability.

Communication and collaboration are the keys to successful relationships

"There are multiple facets to communication, some of which require common sense while others require concerted efforts to overcome barriers caused by different training and context"[2]. Often the biggest barrier to interaction between scientists and policy-makers is the lack of awareness of one another's existence. For example, despite the fact that significant research programs devoted to natural resource management exist at nearby universities, members of the Arizona Legislature rarely call upon them for advice. Legislation is introduced, committee hearings are scheduled and votes are taken, all with little or no input from the local scientific community. Why does this happen?

Many user groups, including legislators and government agency heads, either have no contact with universities or may not encourage researchers and academics to participate in or observe the decision-making process. In the international context there are numerous protocol and political considerations that affect the willingness to cooperate. However, universities can be excellent locations for developing new ideas and applications. Some successful examples of government and university collaborations include:

- **Watershed councils** and other local planning groups. Recently developed, watershed councils are focused on resolving environmental conflicts while improving land and water management. In California, for example, regional watershed councils have been established to address non-point source pollution from irrigated agricultural lands, identified as one of the nation's top water pollution problems (The Water Education Foundation, 2005). These councils can provide an early opportunity for scientists to engage stakeholders and decision-makers as solutions are considered.

- **Expanding the types of research** conducted by scientists to address the needs of local and state governments should be considered. Including policy-makers and other practitioners early in the design phase of research assures that the research is relevant to their particular concerns.

- **Partnerships** between government agencies, non-government organizations, academia, and stakeholders can be extremely fruitful. Through collaborative efforts by these groups, new relationships are established which can then become the standard approach to future problem solving. An example in the Lower Colorado Basin was the creation and implementation of the Multi-Species Habitat Conservation Plan. The federal government and the three Lower Basin states (Arizona, California, and Nevada) actively

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[2] "Connecting Science, Policy, and Decision-making: A handbook for Researchers and Science Agencies" by Katharine Jacobs, National Oceanic and Atmospheric Administration, 2001-2002 p 11.

engaged a broad range of scientists for nearly a decade to assist in the development of restoration projects in riparian, marsh and backwater habitats for 26 species of fish, birds, mammals and plants along the Colorado River from Hoover Dam to the Mexican border.

- **The Internet** is playing an increasingly important role in the dissemination of information. Designing scientific websites in consultation with potential users of the information can improve its utilization. Focusing on the kinds of information a policy-maker is interested in and describing how the data were developed, how it was intended to be used, and the current state of the science also improves its chances of utilization.

- **Arizona State University**, the second largest university in the U.S., based on student enrollment, has recently established the International Institute for Sustainability (IIS). It is a collaborative enterprise between scientists and users of scientific information specifically intended to bridge the gap between university-based research and public policy. The IIS brings together life, earth, and social scientists, engineers, and government and industry leaders to share knowledge and develop practical solutions to the environmental, economic, and social challenges of sustainable development in urban areas.

Unfortunately, policy-makers and water managers are not just looking for technical information; they are often looking for advice, which is inconsistent with the role of scientists. A scientist's desire to be precise about what they know and more importantly, what they do not know, conflicts with the need for a policy-maker or water manager to make a decision.

Policy-makers are interested in developing the best solution under the circumstances. They need to reach conclusions even when inadequate information is available, or there is conflicting information. This may mean that the loudest voice or the person with the greatest access may influence the outcome even though it is not the technically correct choice.

It is incumbent upon the scientist to find ways to meet the needs of the policy-maker and water manager, not the other way around. Longer-term forums like those listed above that provide opportunities for scientists and practitioners to interact can provide opportunities for the facts to be heard and fairly considered.

Appreciating the time constraints on policy-makers will improve the utility of scientific research.

The utility of information for policy-makers and water managers is directly related to the relevancy of the information and its timeliness. A frequently cited problem concerning the use of scientific research is that the information is not available when needed. Failure to provide information when it is needed may result in the information losing virtually all of its value to the decision-maker.

Policy-makers often operate in a world of crisis management. The crisis of the day, that is, the problem that demands an immediate response, gets their attention. When this occurs, a policy-maker will reach out to persons that are both knowledgeable about the crisis and are <u>immediately</u>

available. Rarely does a scientist meet both criteria. He or she has other demands on their time and cannot afford to be "waiting in the wings" for the next crisis that demands their skill set.

It may be more practical for a scientist to establish an on-going relationship with the committee staff or assistants of a decision-maker. There are a couple of reasons for this. First, the staff person will likely be made aware of the policy-maker's need for information to address a particular issue relevant to the scientist's expertise. Second, the staff person is more likely to have the time to meet with the scientist when the issue isn't acute but may become an issue in the future.

CONCLUSION

There are many opportunities to improve the utility of scientific research through developing new kinds of relationships with decision-makers. The key is developing an appreciation of the constraints and opportunities associated with working in the context of the "real" world, and establishing two-way flows of information with true engagement of decision-makers at one end of the flow, and the researchers at the other end. Expanded use of intermediaries and translators can enhance the flow of information where scientists and/or agencies do not engage directly with decision-makers. Additional suggestions for increased integration of science and decision-making include:

- developing and documenting cooperative demonstration projects
- facilitating long-term relationships and trust between scientists and decision-makers and their staff
- having people representing different backgrounds and perspectives in the same room when developing short and long-term research agendas

These efforts are important and necessary, and require both financial and institutional support. Evaluation of ways to improve the utility and communication of scientific research is itself a legitimate research objective that will significantly enhance the societal benefits of investments in science. An expanded focus on applied and adaptive scientific research is likely to result in increased interaction with policy-makers and water managers.

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The Academy of Science and Technology of Senegal: an instrument of action and advice to decision makers for the progress of the Nation.

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INTRODUCTION

It is widely acknowledged that science, technology and innovation are primary catalysts for the socio-economic development of a country. Natural resources and financial capital were the major determinants of development several decades ago but today knowledge and innovative capacity are the key factors stimulating competitiveness, economic growth, and sustainable development.

It is vital for every country to develop economic growth strategies based on knowledge and innovation. In order to successfully meet the challenges of globalization, African countries, in general, and Senegal, in particular, must place science and technology at the heart of their development policy.

The scholar Cheikh Anta Diop recognized the crucial role of knowledge, science and, specifically, for technology in any development policy. He reaffirmed this role in 1974 in Dakar, during the Third Biennial of the Association of East African Scientists: “Let us not forget that knowledge is the only force and the only richness here, and that to coin a phrase from the well-known Professor Lichnerowicz, one can say that the weight of every country is measured by the brains of its researchers and by its scientific bodies.”

As a developing country with a primarily agricultural economy, Senegal is confronted with limited human and material resources in scientific and technological fields, and therefore, has problems incorporating science and technology into its development policies.

The recognition that Senegal and other countries in the region need to better integrate science and technology in their economic development strategies was one motivation among many others that led to the creation of the Academy of Science and Technology of Senegal (ASTS). The integration of science and technology into economic, social, and cultural policies will ensure the well-being of these countries’ populations as they face the challenges of globalization.

History of the Academy of Science and Technology of Senegal

Senegal is home to a number of well-known scientists who contribute to the promotion of scientific excellence and who, in addition, are recognized authorities at both the national level and within international academic societies.

The Academy of Science and Technology of Senegal was created with the intention of capitalizing on this stock of human capital, essential to the scientific and technological advancement of Senegal. The General Assembly that constitutes the ASTS first met on

November 9, 1999. Governmental authorities had agreed to the creation of this institution, and they gave it an official recognition. Envisioned as an academic society and placed under the patronage of the President of the Republic of Senegal, the ASTS has as its mission assistance, consultation, advice, and expertise. The ASTS is currently the only Academy that exists in Senegal.

The opening of the ASTS took place on November 25, 1999, under the chairmanship of the Chief of State, and in the presence of members of the Government, the National Assembly and officials from the Third World Academy of Sciences (TWAS), the Third World Network of Scientific Organizations (TWNSO), and the African Organization for Science and Technology (AFRISTECH).

The annual opening ceremonies of the ASTS are often chaired by the President of Senegal, and include the participation of national and international political and scientific leaders. They are organized around a theme that is independently chosen by the Academy.

Mission of the ASTS

As an independent institution, the ASTS has the following principal objectives:

- to assist and advise the Senegalese State (government, public and private institutions) in the definition and implementation of national science and technology policy
- to initiate, recommend, and develop programs in the fields of science and technology
- to encourage scientific research, and to assist with the promotion and the use of the results of such research
- to bestow awards and recognition upon individuals who have made significant advances in their area
- to create job opportunities in science for young people and women
- to contribute to the development of a culture of science and to a closer connection between science and society

The Membership and Operation of the Academy of Science and Technology of Senegal

The ASTS is composed of permanent members, corresponding members, associate members, honorary members, and emeritus members. In 2005, the Academy had forty-four permanent members who were elected by a merit-based process, four associate members, and fifteen honorary members.

The ASTS is composed of the following deliberative bodies:

- The General Assembly, which includes regular members and associate members
- Sections that are chaired by a Vice President. The three main sections are: Science and Technology, Health Science, and Agricultural Science. A fourth section, Economics and Social Sciences, is in the process of being created. The current statutes allow for a maximum of twenty members in each section

- The Executive Office, which is composed of a President, three Vice Presidents (the Chairmen of the sections), a Permanent Secretary, an Assistant Secretary, a Treasurer, an Assistant Treasurer, four members of the Academy, and the immediate outgoing President

The ASTS is an institution that was created very recently, in 1999. While its young age could be a constraint at a practical level (budget, real estate), it also presents a challenge in terms of the composition of the institution and its function. Compared to more established academies, the ASTS is composed of members who are relatively young: thirty-three of the forty-four members are still active professionally (not retired).

Furthermore, in addition to their scientific activities, several members of the ASTS have had or still have significant political responsibilities: serving as ministers; advisers to the President of the Republic, the Prime Minister, or ministers of government; and deans of universities. These outside responsibilities, combined with the objectives and independence that are fundamental to the operation of the Academy, are likely to facilitate dialogue between Academy members and political decision makers. As a result, the scientific opinions that are produced by the Academy through studies (which are either requested by decision makers or initiated by the Academy itself) are generally respected by the political authorities who will then be able to take them into account at the time of a decision.

Activities of the Academy of Science and Technology of Senegal

Since its creation, the ASTS has carried out a number of activities to provide scientifically based advice to decision makers and to strengthen the contribution of science to sustainable development. These activities include: annual opening ceremonies, public lectures, scientific seminars, national and international conferences, studies and inquiries that are both requested and self-initiated, and scientific publications.

The annual opening ceremony is one of the Academy's most important events. It is chaired by the Head of State and held in the presence of the highest authorities in country, the media, and national and international ASTS guests. The theme of the ceremony is chosen by the Academy. The Academy then organizes preliminary reports for the topic. The principle conclusions and recommendations are read in the presence of the President of the Republic, who then responds to the Academy speech. Thus, the opening ceremony is a platform for the ASTS, a place for communication and dialogue between the nation and its decision makers on science and technology topics that are considered a priority by the Academy.

In 2003, the opening ceremony dealt with the topic "Development of Science and Technology Education in Senegal." The ASTS took advantage of this occasion to draw the attention of the Head of State to the fact that Senegal needs to implement educational policy in the area of science and technology education in order to create a place for Senegal in the knowledge society. Based on these recommendations, the Minister of Education has created a "National Steering Committee for the Development of Science and Technology Education," with the following objectives:

- to survey the current situation of science and technology education in Senegal for every level from pre-school to higher education
- to develop a national program for science and technology education
- to prepare a national seminar for discussing the above program
- to integrate the suggestions of the seminar with the program recommendations to be submitted to the Minister of Education
- to implement systems for evaluating the final program

This National Committee continues its work in this area, together with the ASTS.

The ASTS has also organized a scientific meeting on the topic of "Flood Management: The Case of the Town of Saint-Louis." Due to the recurring floods in Saint-Louis (a city located in northern Senegal, in the delta of the Senegal River), the ASTS decided to send a scientific expedition to Saint-Louis to study the issue. The President of the Republic, concerned about spring flooding in Saint-Louis, asked the ASTS to work with the Minister of Agriculture and Hydraulics and to make concrete recommendations on how to address the problem.

The ASTS held a seminar about the flooding problem in April 2004, allowing a diverse body of individuals to focus on the problem. The seminar attendees included the President of the Republic; concerned ministers; international experts; and members of universities, local communities, and civil society. This seminar resulted in a "Plan of Action for Fighting Floods and for Urban Management," which was given to the Minister for Agriculture and Hydraulics by the President of the Academy.

The ASTS also organizes public lectures. These lectures are held on a monthly basis, and can be presented by members of the ASTS or by any member of the national or international scientific community. The lectures relate to topics agreed upon by the Academy and the presenters. The lectures are open to the public, to media, and to public and private institutions. Examples of past topics include:

- Political Science in Senegal: New Perspectives Offered by the Creation of the Academy of Science and Technology of Senegal
- Towards an Energy and Science Policy for the New Partnership for the Development of Africa (NEPAD)
- Public Health Policy in Senegal
- Mathematics: A Key for Development
- Reflections on the Use of Photovoltaic Solar Energy
- Can Agricultural Research Answer the Concerns of Agricultural Policy?
- Numerical Radiology: Luxury or Necessity for Senegal?
- Research: An Invaluable Tool for the Management of Fishery Resources
- The Introduction of New Communication and Information Technologies in West Africa

The ASTS also publishes studies. In 2004, the ASTS gave attention to biotechnologies and the potential they may have for sustainable development if applied to strategic sectors. The workshops on this topic resulted in a publication by the ASTS entitled, "Biotechnologies: Potentials, Stakes, and Prospects: The Case of Senegal." A document entitled "Plan of Action" is in preparation. This study will be delivered to the political authorities in the form of a national program for the development of biotechnologies.

International Cooperation

Due to the universality and rapid evolution of science and technology, it is necessary for the institutions that work for their application and advancement to cooperate. Conducting international relations is one of the most vital activities that the Academy carries out. It is important that the Academy establishes collaborative relationships through exchange of experiences, human resources, information, expertise, and/or through joint projects or scientific exhibitions.

An international dimension is strongly present in the activities of the ASTS. The 1999 inauguration by the President of the Republic was attended by representatives of academies of all continents and symbolized ASTS's collaborative relationship with international institutions that have similar values and objectives.

The ASTS is a member of several international networks, including:

- The Inter Academy Panel (IAP), a network of more than 90 academies worldwide. The ASTS is a member of the Executive Committee of the IAP and leads the Science and Education for Africa program;
- NASAC (Network of the Academies of Science of Africa), where the ASTS has been given the responsibility of establishing the Academies of Science in French-speaking Africa; and,
- NASIC (Network of the Academies of Science of the Member States of the Organization of the Islamic Conference).

The ASTS cooperates with academies of science and technology in many countries, including France, the United States, Canada, Italy, China, Kenya, and Uganda, as well as with international organizations such as the International Center for Development Research (IDRC) and the Agency for French-Language Universities (AUF). This cooperation is often framed by a signed agreement between the ASTS and these institutions.

In March 2005, with the support of the Inter Academy Panel and with the participation of the Network of the Academies of Science in Africa, the ASTS organized an international symposium on the development of a regional program for Science and Technology Education in Africa. The Senegal Ministry for Education strongly supported and actively participated in this symposium. As a result of this conference, the ASTS has been given the responsibility of coordinating a regional program to implement an "Inquiry Based Science Education" (IBSE) model at elementary schools in Senegal and other parts of Africa.

CONCLUSION

Above all, the Academy of Science and Technology of Senegal aims to be utilized by decision makers as an instrument of action and advice for the general progress of the nation. In order to better integrate science and technology in the process of sustainable development in Africa and, more specifically, in Senegal, it is essential that the Academy and its partners implement strategies to make knowledge and information available to the public and to decision makers at the time of policy decisions. For this reason, in 2005 the ASTS developed a strategic plan to fulfill its duty to public authorities, the private sector, and other stakeholders while also preserving its independence, transparency and scientific excellence.

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The Role of Science in Agricultural Water Management

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INTRODUCTION

Scientific methods provide credibility, consistency, and an impartial perspective on water management. Data and results of scientific analysis quantify the comparison of choices available to make complex decisions required to effectively use and protect an aquifer. The presentation is organized into the fundamental components of the water cycle and explains how this general scientific principle is applied to water management of a regional aquifer like the High Plains – Ogallala aquifer in western Kansas. Throughout the remainder of this paper the aquifer will be referred to simply as the Ogallala aquifer.

The Ogallala aquifer is a regional aquifer that supports agricultural production in western Kansas. The climate is semi-arid and requires irrigation to grow feed grain and forage for an established livestock feeding and meat processing industry. The area relies nearly exclusively on this industry for its economic future. Kansas has an established water management system in place to address the challenges of effectively using and protecting this vital ground water resource.

Geographic Setting of Kansas Water Resources

Kansas is in the center of the continental United States. It is a semi-arid short grass prairie with cropland in the west and semi-humid tall grass prairie savannah and cropland in the east. Winter wheat is a primary dryland crop in the west, and corn is a major irrigated crop in the west and a dryland crop in the east. Other row crops grown are alfalfa, grain sorghum and soybeans irrigated in the west and dryland in the east. Minor crops are sunflowers and recently cotton. Western Kansas has some of the largest beef processing facilities in the world. Tall grass prairies and cattle dominate central Kansas where shallow soils and steep topography prevent production of grain crops. The capital city is Topeka a city with a population of about 200,000. Kansas City and Wichita are the two metropolitan areas of the state and each exceed populations of about 600,000.

FIGURE 1 Geographic setting.

The annual precipitation varies from about 102 centimeters in the southeast to about 31 centimeters in the west. Water supplies for eastern Kansas come from the rivers and reservoirs that supply urban users. Most of the water use is for municipal and industrial use in the east. Some surface water is used for irrigation. The Arkansas River supplies some of the Wichita users but the river is nearly dry in the western half of the state.

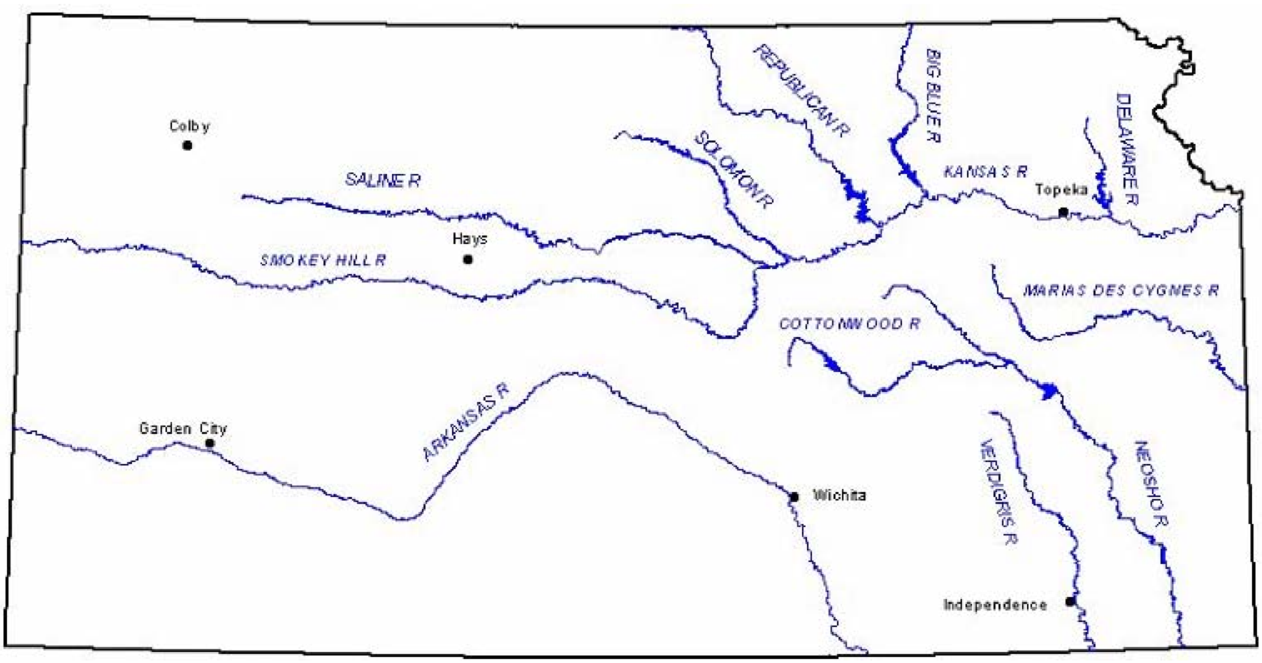

FIGURE 2 Major surface water supplies.

Western Kansas obtains most of its water from groundwater. The Ogallala aquifer is nearly the sole source of water for the western third of the state. It supports a vast rural agricultural area.

Nearly all the water use is for irrigation of crops for livestock feed. The groundwater resources for the central and east are some alluviums in general of limited extent along major streams that serve primarily municipal users and some irrigation.

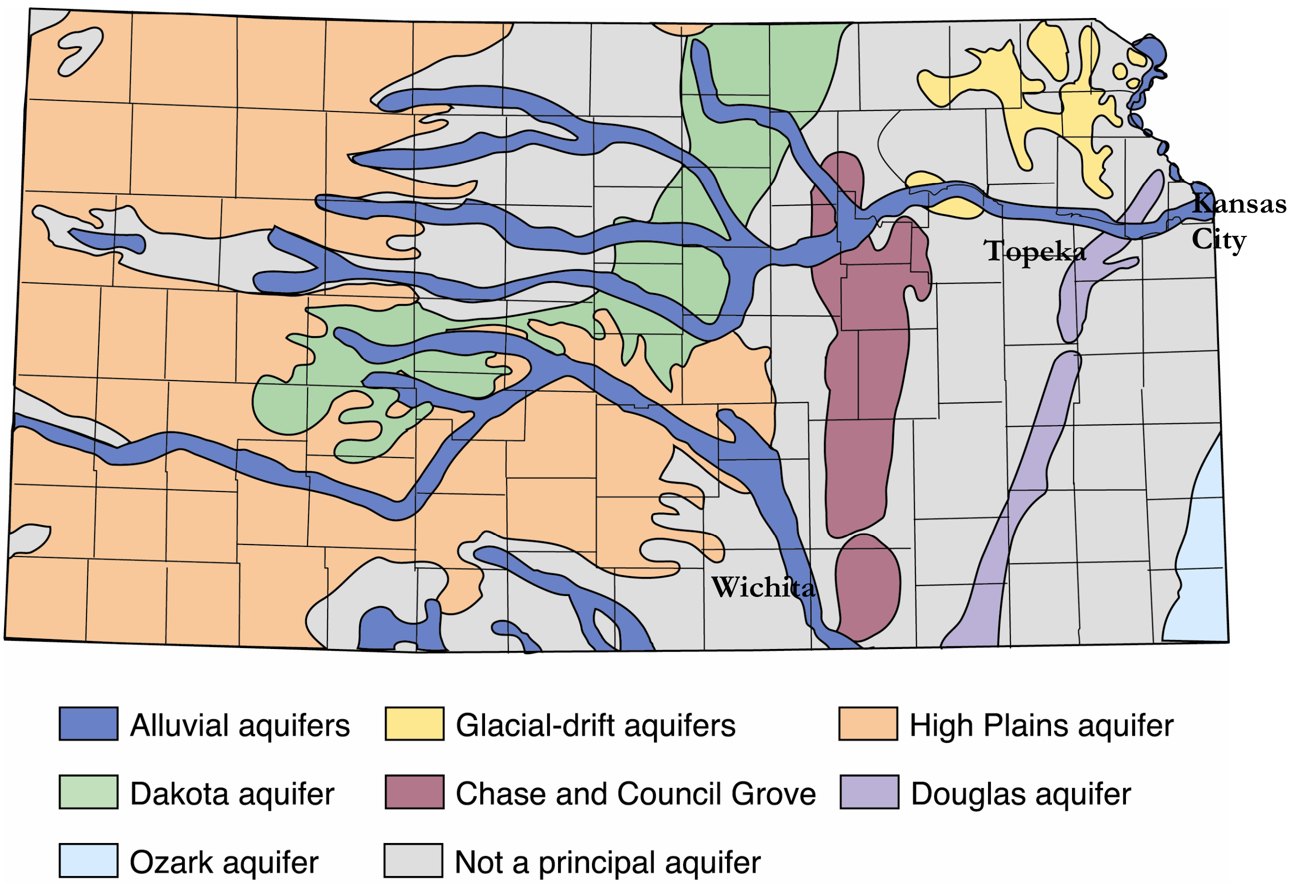

FIGURE 3 Primary aquifers.

Water Availability

The quantity of water in storage in an aquifer defines the extent of the aquifer's ability to sustain water use demands through variations in climatic conditions over time. Bedrock elevations throughout the Ogallala were determined and refined by the US Geological Survey and Kansas Geological Survey for the past more than 30 years. Estimates of the total water in storage in the Ogallala each year is obtained from annual water level measurements made at a network of wells distributed throughout the aquifer area (Laflen and Miller, 2004). The annual measurements are made in the winter season when wells have not pumped for several months. Records of the water levels are used to determine absolute changes in storage and saturated thickness and to define declining rates where the aquifer is depleting. Water level measurements are made by the Division of Water Resources, the State's water management agency, and the Kansas Geological Survey which is the earth science research organization for the state. The data base is maintained by the Kansas Geological Survey.

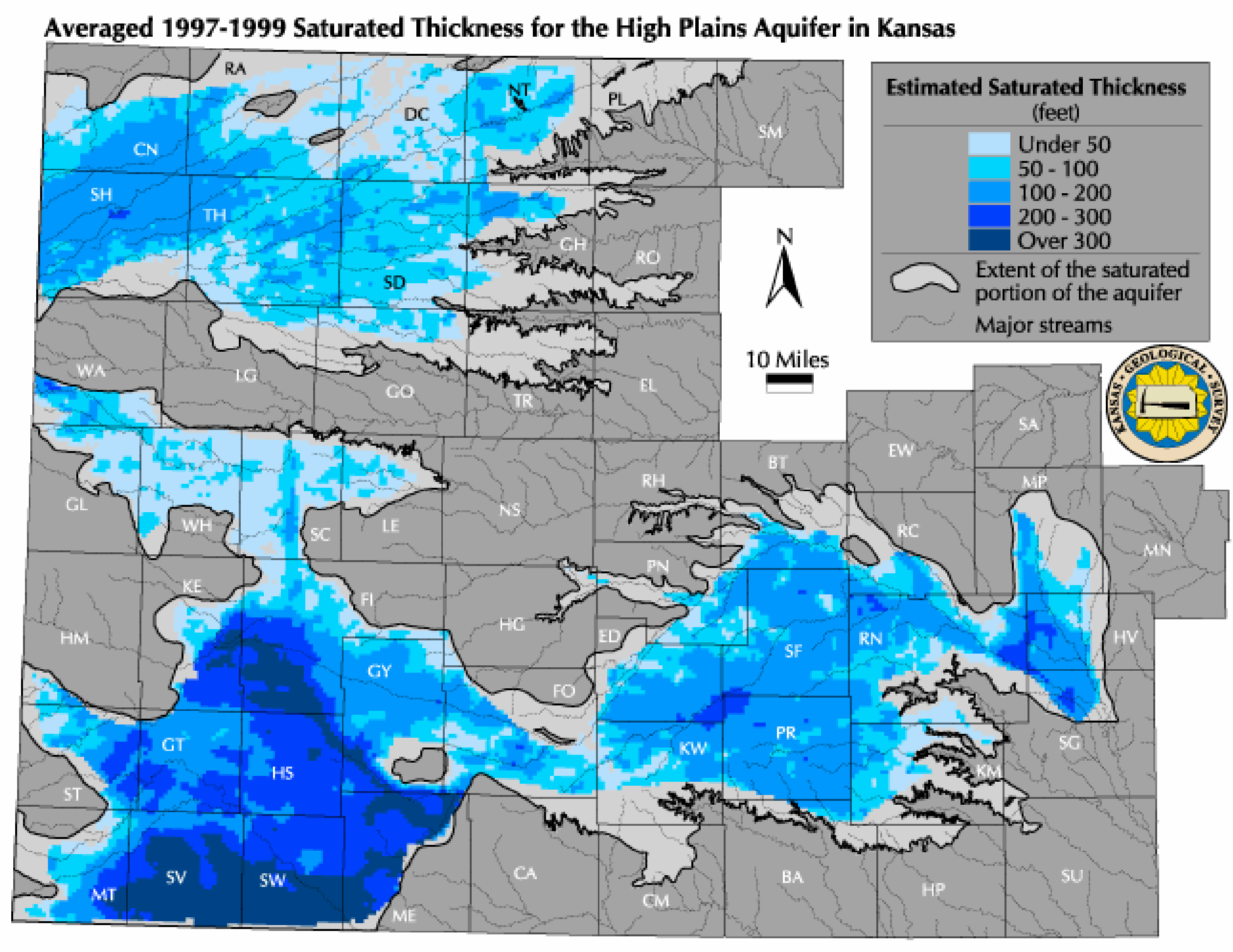

FIGURE 4 Averages 1997-199 Saturated Thickness of the High Plains Aquifer (Schloss, et al. 2000).

Annual natural recharge to the aquifer is the quantity of water that is sustainable over the long term. Long term average annual withdrawals that exceed this amount will result in depletion. To ensure a stable long term ground water supply, development ultimately must be limited by natural recharge. Mean annual recharge estimates have been made for the Ogallala aquifer by the U.S. Geological Survey (Hansen, 1991). The Kansas Division of Water Resources uses the estimates of natural recharge to define a term called safe yield in the law of the state. All new development within the state now must not exceed the safe yield, or natural recharge, in the area. The Ogallala is depleting at this time because the safe yield limit did not become law until after much of the development had already occurred. If depletion is to occur it must be planned and managed with the expectation that sometime in the future the development must return to within the limits of natural recharge.

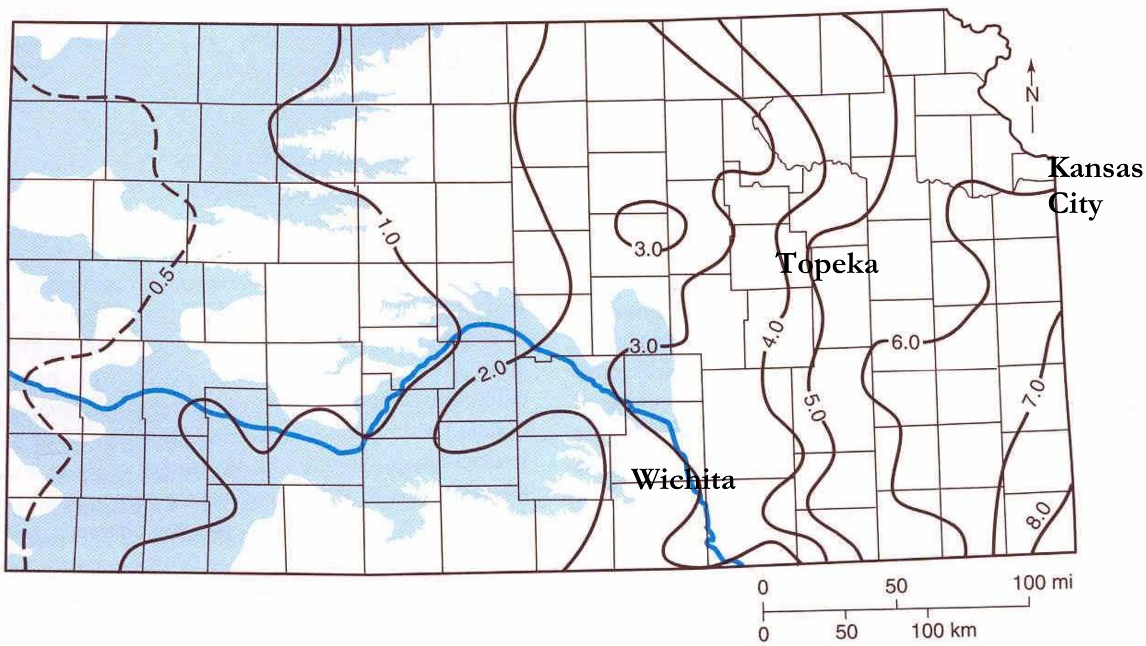

FIGURE 5 Mean annual natural recharge (Sophocleus, 2004).

Water Use

Crop demand must be satisfied by the application of irrigation water. Crop demand depends on the climatic conditions each season. Many energy balance equations have been developed that relate evapotranspiration of crops to measurable climatic variables such as temperature, wind, humidity, and solar radiation. Complex methods that apply equations that are assumed more accurate require the most sophisticated and costly climatic data (Natural Resource Conservation Service, 1993). Therefore some balance between the data collection requirements and accuracy must be reached for a practical approach to determining crop demand. There are long term climatic data sites in Kansas that are maintained by the National Weather Service and supplemented in some places by state operated stations.

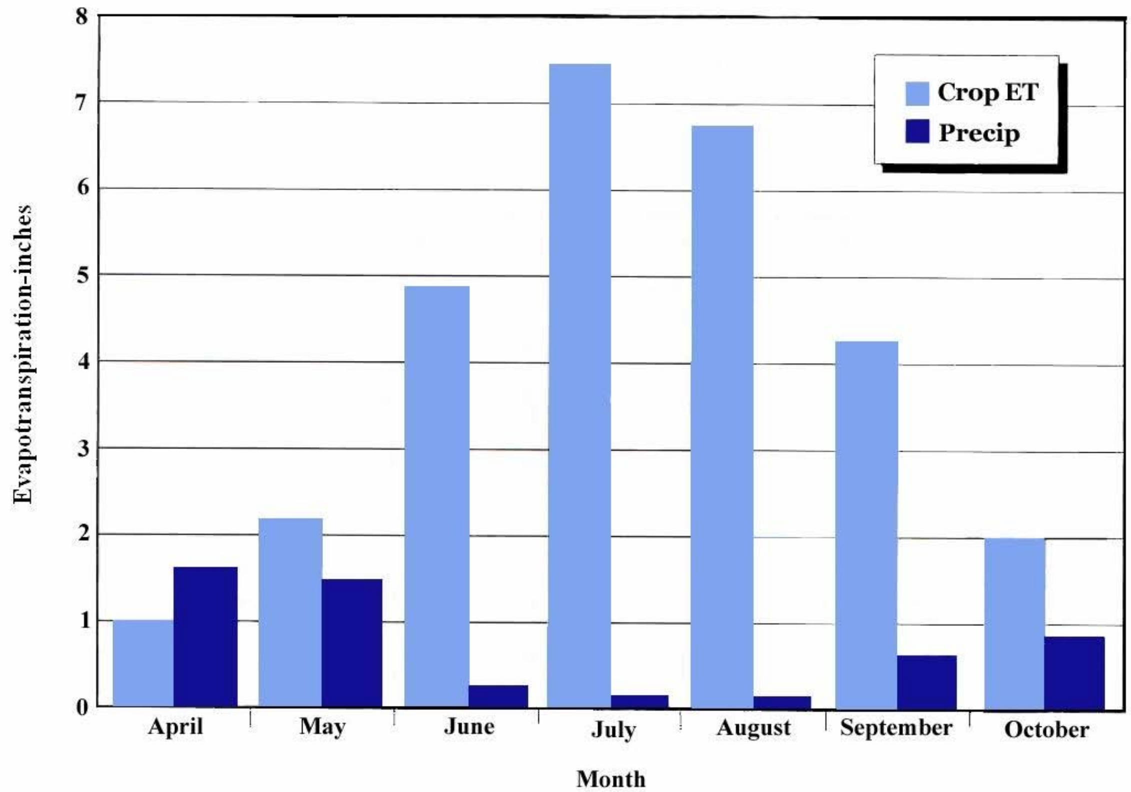

FIGURE 6 Crop demand (Natural Resource Conservation Service, 1997).

Withdrawals from the aquifer for irrigation must be managed to protect the aquifer and at the same time allow the greatest beneficial use. To ensure that an equitable quantity of water is available for each user the maximum reasonable quantity needed for irrigation is determined. This is based on a concept called net irrigation requirement. Net irrigation requirement is defined by law in Kansas as the average potential evapotranspiration of a given crop less the average available precipitation that can be recovered from the soil moisture storage. Each user is not authorized to use more water for irrigation than the net irrigation requirement which allows more users a share in the opportunity to benefit from a finite water source.

Irrigation water use varies with climatic conditions as water users pump water to meet the crop water demand or the net irrigation requirements. During some years, water use reaches the maximum allowable limits and other years it does not. Sometimes an individual user may choose not to plant an irrigated crop for a season. In Kansas, the typical reported use is less than 70% of the maximum allowable amount. Therefore the amount actually pumped must be monitored to determine the actual withdrawal from the aquifer. Flow meters are installed in the distribution lines from the pump to the distribution system. Meters are read at the beginning and end of the irrigation season or the year. Reporting water use on an annual basis is a requirement by Kansas law for each irrigation user. A user is fined if a report is returned after the required annual deadline for reporting. Water use information is used to project the demands and to determine the amount of pumping that will cause the aquifer to be depleted (Kansas Department of Agriculture, 2000). It also is used to determine if users have exceeded their maximum allowable quantity. The US Geological Survey includes the data from Kansas with other states to publish a national water use summary every five years (Hutson, et al. 2004).

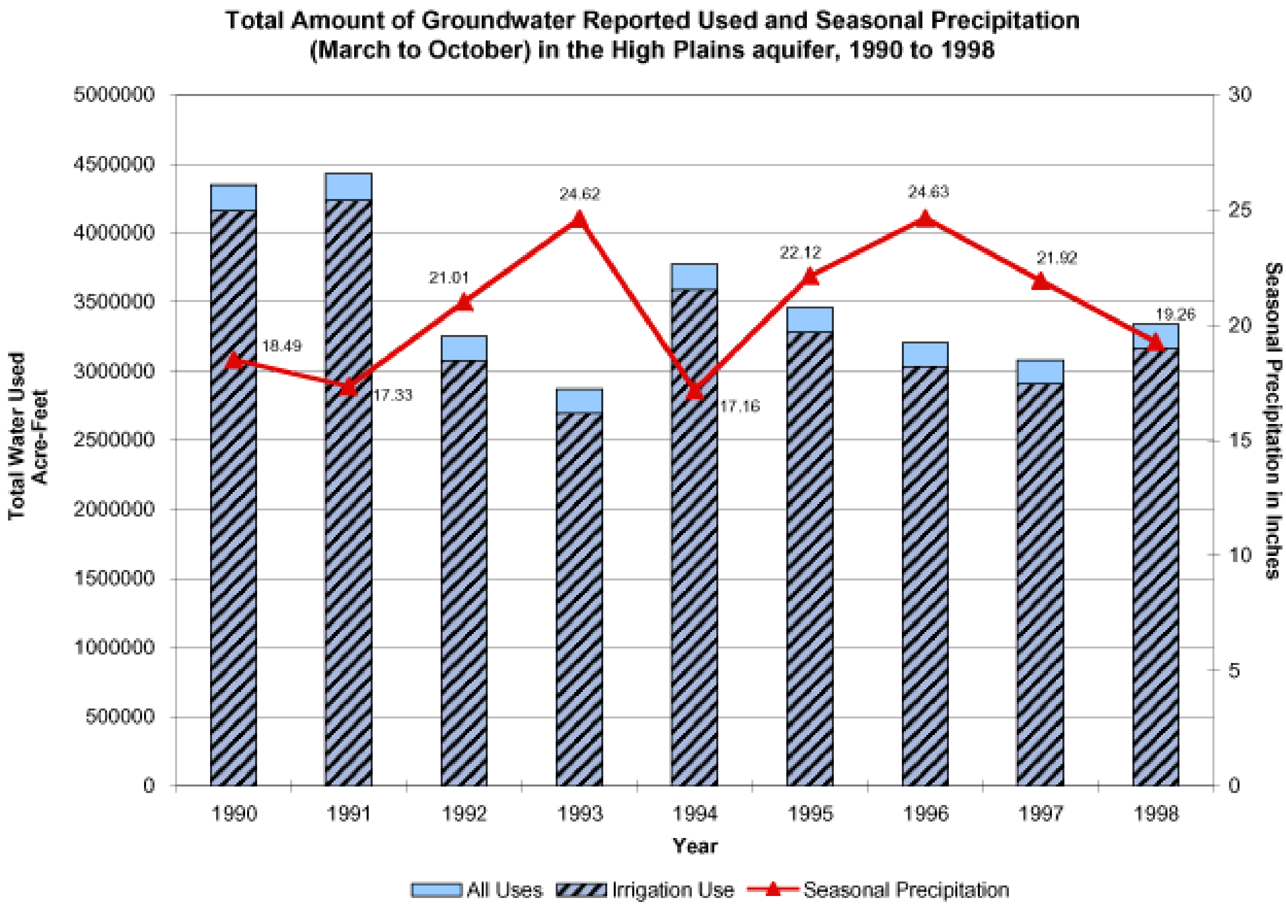

FIGURE 7 Annual water use and seasonal precipitation (Schloss, et al., 2000).

Protecting the Water Resource for the Future

Aquifer depletion is a challenge that is common to many areas. This is a challenge in the Ogallala as irrigation development far exceeded natural recharge before Kansas law put limits on irrigation. The area's economic success now relies on extensive withdrawals from the aquifer. It is essential that depletion be monitored so future use can be managed to use the remaining resource most effectively. Declines in groundwater levels have been determined from the data collected from the annual water level surveys described previously (Schloss, et al., 2000). One useful product from this data is a map of the percent change in saturated thickness that was prepared by the Kansas Geological Survey. It shows declining rates in areas where resources are consumed most rapidly.

Typically there is not an initial economic motivation to limit pumping to natural recharge in areas where the initial saturated thickness is ample, recharge is minimal and pumping is large. It may be more reasonable to manage the depletion by setting an allowable depletion rate that puts a limit on withdrawals that is an acceptable projection of the remaining saturated thickness at some time in the future. Through the past 25 years the allowable depletion in the Ogallala in southwest Kansas was to allow the saturated thickness to decrease by 40 % in 25 years but not to allow the aquifer thickness to become less than 12 meters. When the projected use of existing wells reached this limit, no new wells were allowed to be drilled in the Ogallala aquifer. In all of southwest Kansas, this limit has been reached or was exceeded before the limit was imposed. Now, no permits are being issued to drill new wells other than to replace existing wells. New water users must now acquire existing permits from willing sellers.

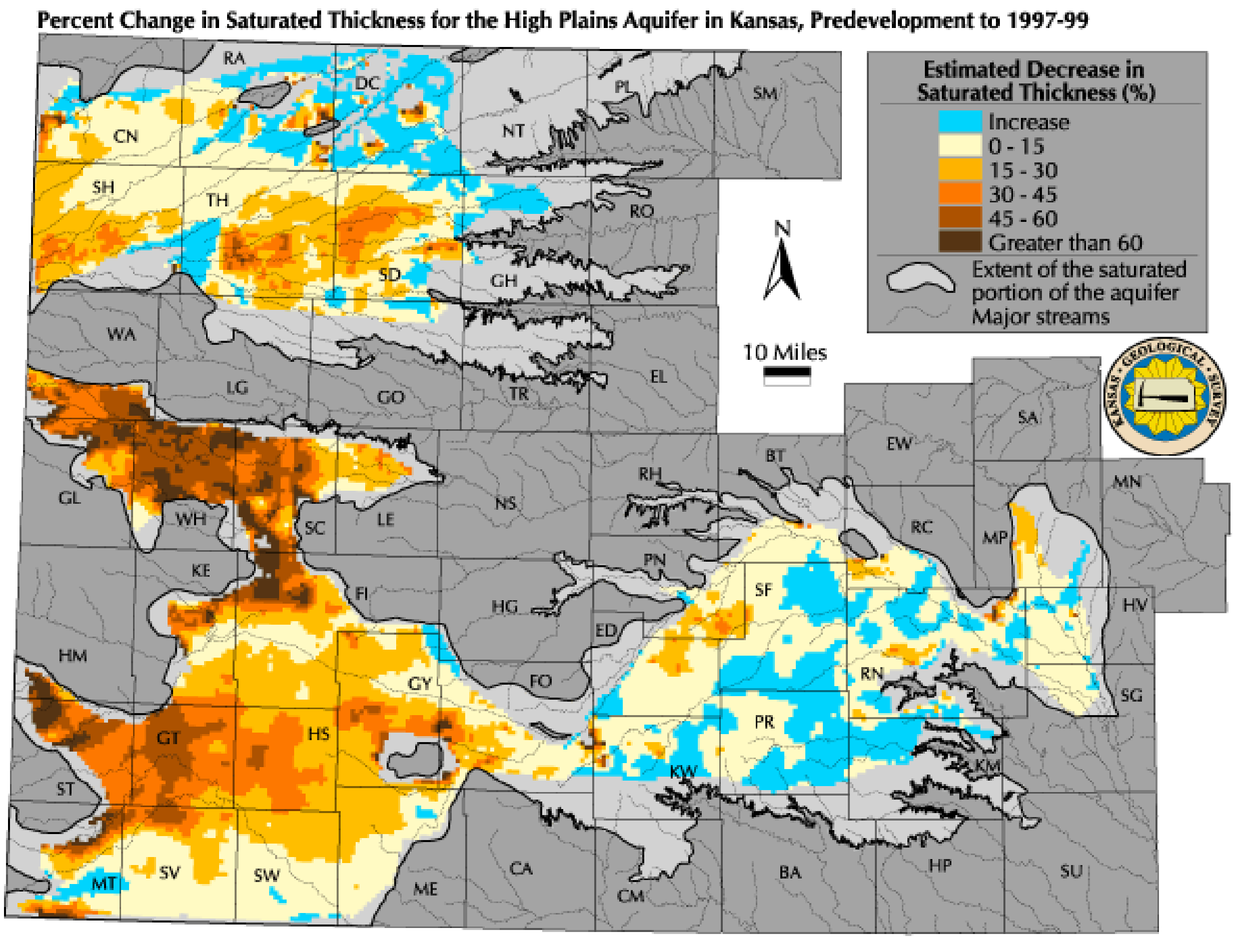

FIGURE 8 Percent change in saturated thickness (Schloss, et al., 2000).

Development that allows depletion to occur means that in the future the aquifer will not produce adequate well yields to sustain the existing water uses. It is important to know when that time may occur to plan for alternate water management strategies. There are now areas within the Ogallala that have reached the point that well yield will no longer sustain the past water uses. A useful analysis to plan strategies for this challenge is the projected useable lifetime of the aquifer. This analysis combines a projection of past pumping rates, the saturated thickness, and aquifer characteristics. It presents the results in terms of time that all users can understand and interpret. The results of this analysis, for the Ogallala, show the geographic variability of the Ogallala and the areas where the time remaining to develop an alternate water management strategy is very short. Evaluation of alternative strategies must rely on more sophisticated projections that may require numerical modeling to define the outcome of management decisions (Lucky, et al., 1986).

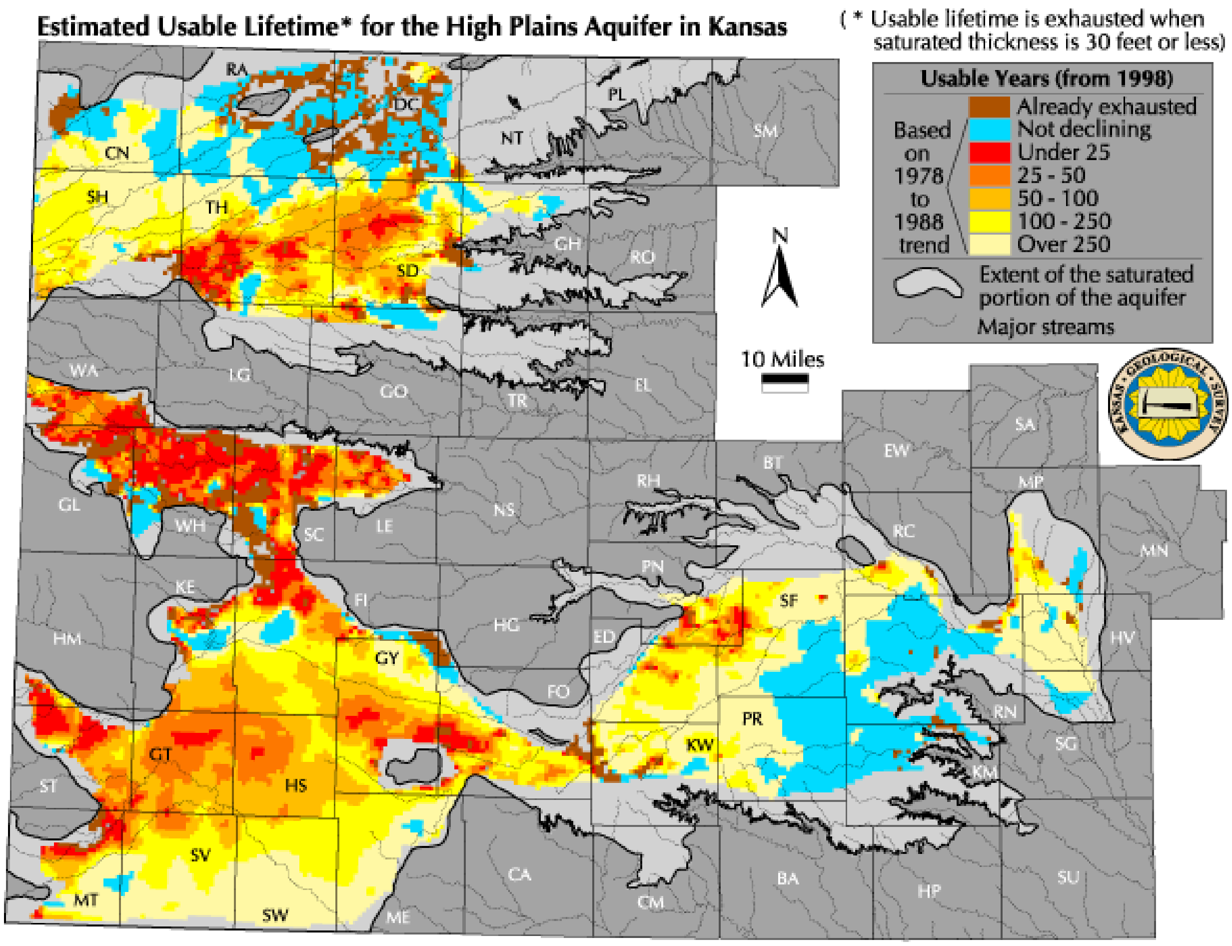

FIGURE 9 Projected useable life time (Schloss, et al., 2000).

Organizational Structure for Water Management

Effective water management in Kansas relies on a structured approach defined by state water law and associated rules and regulations. This structure is established, refined, and implemented by users working together through a series of organizations of farmers, local interest groups and ground water management districts. The State laws are developed through elected legislative representatives and administered by rules and regulations established by state agencies that work with local users and their representative groups (Huntzinger, 2005).

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Optimizing Irrigation for Agricultural Water Management: Scientific Principles

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Introduction

The basic principles of irrigation are quite simple. However, the practical application of these principles can provide complications. Crops are exposed to energy originating from the sun, and/or wind. Much of the energy is dissipated by evaporating water from leaf surfaces, which is commonly referred to as transpiration. Water may also be evaporated from the soil surface and the combination of evaporation from leaf and soil surfaces is evapotranspiration (ET). Water transpired from the leaf surface is replaced by extracting water from the soil and transporting it through the root and stem system.

The soil serves as a reservoir from which the plant extracts water to meet the demands of transpiration. The quantitative storage capacity depends on both the type of soil and the rooting depth of the crop plants. Soil texture and structure which result in large pore sizes, have lower storage capacity than soils with smaller pore sizes. More deeply rooted crops have a higher storage capacity as compared to shallow rooted crops. Irrigation is the practice of recharging the storage capacity that has been depleted by ET when natural precipitation is not adequate to meet the ET demands. The time to irrigate is usually before the soil is too dry for water to be extracted by the plant at a rate to meet the transpiration rate. If the rate of water movement to the leaf surface is less than the rate of transpiration, the plant responds by closing stomata to reduce the water loss. Carbon dioxide (CO_2) used for plant photosynthesis enters the plant through these same stomata. Therefore, closure of the stomata reduces water loss but also reduces CO_2 intake and therefore reduces the rate of photosynthesis. Thus the plant has a dual mechanism for protecting itself under a limited water supply. It reduces transpiration, thus attempting to maintain turgidity. At the same time it reduces photosynthesis, which would otherwise increase plant surface area causing greater interception of energy and more transpiration.

Numerous studies have reported that total dry matter production in plants is linearly related to ET. This observed result is consistent with the mechanism that the plant uses to protect itself against inadequate water. However, the part of some crops that is sold is not linearly related to total dry matter production. For these crops the marketed product might be achieved or possibly increased by allowing the soil to dry to a level reducing transpiration at specific time periods. Dr. Goldhamer will present the application of this concept.

The combination of a soil and crop rooting system that has a low storage capacity dictates the use of smaller quantity, more frequent irrigations; whereas a larger storage capacity allows less frequent though higher quantity irrigations.

All irrigation waters contain some dissolved salts. Plants transpire pure water causing the soil solution to become concentrated with salts as transpiration proceeds. Because of this effect, occasionally irrigation must not only recharge the storage capacity, but additional water may be necessary to leach excessive salts from the root zone. The concentration of salts in the irrigation water and the crop tolerance to salinity dictate the amount of leaching. Irrigation management entails consideration of salinity as well as water content in the root zone.

Water Application Technology

A canal, well, or pond may serve as the irrigation water supply. A means of transferring the water from the source to the root zone must be designed. Irrigation systems can be broadly characterized as being pressurized or nonpressurized. Pressurized systems are those in which water is delivered through a pipe under pressure and discharged by one of a variety of different outlet designs including sprinkler heads and drip emitters. Nonpressurized systems are those in which water is delivered and allowed to flow across the field. Various configurations for flow across the field such as furrows or basin borders are possible. All irrigation systems deliver water to the soil surface from which it must infiltrate into the soil to recharge the soil-root storage capacity. The infiltration rate therefore becomes an important factor in irrigation management.

Nonpressurized irrigation systems deliver water in a manner that causes free-standing water on the soil surface. The following description of water infiltration into soils applies for the case of free-standing water on the soil surface and is therefore appropriate for nonpressurized irrigation systems.

The infiltration rate decreases with time and approaches a constant steady state rate as depicted in Figure 1. The soil water content at the time of water application affects the initial infiltration rate. The initial infiltration rate is more rapid for a dry as compared to a wetter soil. The infiltration rate is largely controlled by the soil pore size with the most rapid infiltration occurring with soils with large pores. Therefore, different soils have different infiltration rates. Furthermore, the infiltration rate of a given soil can be modified by tillage operations. For example, a soil that is plowed and tilled to produce a seedbed at the beginning of the season has high infiltration rates. However, the process of wetting the soil causes the soil aggregates to disperse and become more compact and thus the infiltration rate for many soils decreases with successive irrigations after tillage. Modification of irrigation management during the growing season to accommodate changes in soil infiltration characteristics is very difficult to program.

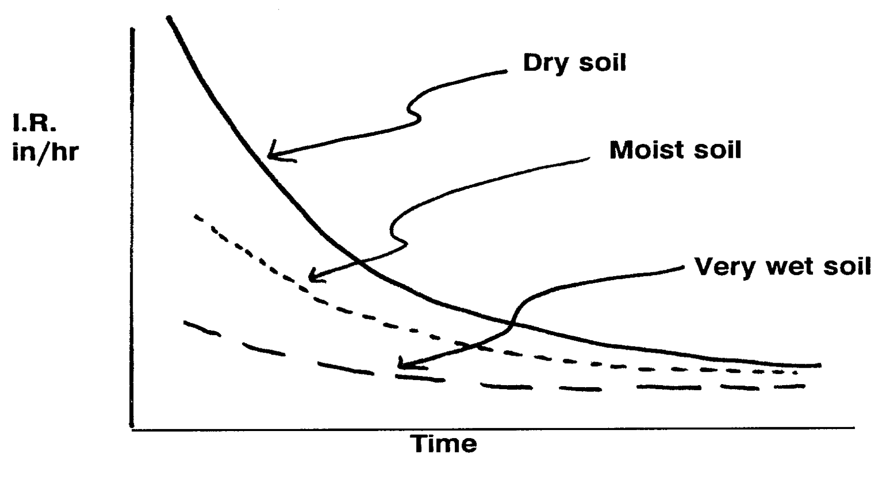

FIGURE 1 The relationship between infiltration rate (I.R.) and time for a soil and different initial degrees of wetness.

Water cannot infiltrate the soil at a rate greater than which it is applied. Pressurized irrigation systems can be designed to deliver water to the soil surface at a prescribed rate. A well-designed system would not deliver the water to the soil surface at a rate more rapid than it can infiltrate. Therefore, runoff from the field can be avoided with pressurized systems. Furthermore consideration can be given to the changes in infiltration rate during the season and designed not to surpass the infiltration rate at any time during the growing season.

Pressurized systems have the advantage of having complete control on the amount of water applied and infiltrated by valves. Conversely, the amount of water that infiltrates the soil and potentially available for crop production for nonpressurized systems is partially dependent on soil characteristics. Although the irrigator has some design and control features for nonpressurized systems such as length of furrow, rate of water discharge, and time (duration) of water application; the quantitative control is limited. Runoff from the field is usually an unavoidable condition for nonpressurized systems. Water must be maintained on the soil surface at the lower end of the field to allow adequate infiltration. During that period of time, water is flowing off the field.

Irrigation uniformity adds complexity to irrigation management. A uniform irrigation is one in which the same amount of water infiltrates the soil at all points in the field. Most frequently the amount of water that infiltrates into the soil is variable for different parts of the field. Nonuniform irrigation creates a dilemma. If irrigation is programmed to restore the storage capacity in the parts of the field that receive the most water, the other parts of the field will be under irrigated, causing yield reduction in those under-irrigated areas. Conversely, if irrigation is programmed to recharge the storage capacity zones with the lowest infiltration rate, the other parts of the field will be excessively irrigated, leading to unrecoverable water loss to deep percolation. Uniformity of irrigation therefore is one of the most critical factors affecting irrigation management.

Properly designed and maintained pressurized systems can deliver water very uniformly across the field. However, if water is emitted into the air, such as through sprinkler systems, the wind currents can greatly disturb the distribution of the water. Therefore, although sprinkler systems can be designed to be very uniform, wind can cause a very nonuniform distribution. Pressurized systems that do not spray water into the air, such as drip systems, allow for very uniform irrigation.

Nonpressurized irrigation systems have two sources of nonuniformity. First, water is on the soil for a longer period of time at the top than the lower end of the field. This provides the opportunity for more water to infiltrate at the top end as compared to the lower end of the field. This nonuniformity is referred to as opportunity time nonuniformity. Variability of soil infiltration rate across the field due to textural or structural differences also leads to nonuniform infiltration across the field. The total nonuniformity is a combination of the opportunity and soil variability.

Accurate measurement of irrigation uniformity is important in developing the optimal management scheme for a given irrigation system. Unfortunately, measurement of uniformity is complex. Uniformity of sprinkler systems is measured by distributing containers throughout a collection area and measuring the amount of water collected in each container. The data are then statistically analyzed for variability. The numerical result depends on the size of the container. Using large containers will result in a high uniformity value than using smaller containers under the same conditions. Thus, the value is already recognized as being somewhat subjective based on the measuring technique. Even a drip system of soil water is high at the location adjacent to the emitter and the amount of water between the emitters is very low. Nevertheless, depending on the type of plant, the plant root system can integrate different parts of the root zone and effectively even things out. This factor raises an additional point concerning uniformity. The plant root system can accommodate uneven water distribution and can extract more water where the soil water content is high. A tree with a large root system can accommodate considerable nonuniformity of the water application under the canopy. A shallow rooted vegetable crop would be more highly impacted by the same distribution.

The nonuniformity for surface systems is determined by measuring the rate of advance of water down the furrow, and then inserting these numbers into equations developed to compute the nonuniformity associated with opportunity time. These measurements do not include the nonuniformity associated with soil variability, which can be considerable. Therefore, the numerical values for furrow systems are overestimates of the true uniformity.

As long as the measurement procedure for a given irrigation system is consistently used, the comparative uniformity of different fields with that particular system can be determined. In other words, the uniformity from one sprinkler system can be compared to a different sprinkler system. However, it is not appropriate to compare a uniformity coefficient that has been measured for a furrow system to a sprinkler system.

With all the factors considered, the drip system has better uniformity than a sprinkler system, which is better than a nonpressurized system. However, the costs for the systems are in the reverse order. The improved performance from a drip system may not justify the cost for the drip system. Furthermore, pressurized systems require an energy supply that may not always be present in the field.

Water Use Efficiency and Water Conservation: Definitions

Water use efficiency and water conservation are commonly used terms applied to irrigated agriculture. However, confusion and misunderstanding can arise because these terms have multiple definitions. Water use efficiency is calculated by a ratio of terms which is then multiplied times a hundred to report the efficiency as a percentage. Different measurements may be used in the ratio resulting in different numbers and yet all may be referred to as water use efficiency. For example, water use efficiency can be defined as a ratio of beneficial water use to the applied water (AW) to the field. However, beneficial use sometimes is defined as ET and at other times it is ET plus the amount of water required for leaching salts from the root zone. Some individuals include all of the water delivered to the field as AW, whereas others might only consider the infiltrated water that would be available for crop use. For example, in a surface irrigated system, the runoff may be considered as part of the AW, or it may be subtracted from the AW. Obviously different numbers result for different combinations of these terms. Furthermore the computations can be made on different area sizes. For example the ratio can be calculated for a field, the total farm, or the total basin. Different numbers result depending on which is selected. Possibly the biggest problem however is the common belief that a higher efficiency number is always better than a lower number. Any number less than 100 percent is considered to have some degree of inefficiency. As will be discussed later in this paper, this is not usually the case.

Water conservation, likewise, is subject to different definitions. One definition is to use less water. This can be accomplished by various means, each with a specific consequence. A farmer can use less water by not growing a crop. Or, a farmer can grow a crop and apply a small amount of water resulting in very low crop production. Farmers can also grow a crop for high production and either eliminate runoff or capture runoff and use it as part of the irrigation supply.

The main point is that in using these terms, the definition must be clearly specified and the consequences of the action properly evaluated. A further complication is that all of the definitions are based on water quantity without reference to water quality and water quality cannot be ignored in a management scheme.

A distinction between water use and water consumption is required to properly assess water conservation practices. Water consumption is water that is lost for future use. For example, ET is water consumption. It is water that is lost and not available until it is returned again in the form of precipitation, usually at a different location. For a nonpressurized irrigation system with runoff from the field, part of the water is consumed through ET and part is used but runs off and is available for other uses. Water that percolates beyond the root zone might be consumed or used depending upon the fate of that water. If the water migrates to groundwater or a stream, it is still available for use and therefore not consumed. Conversely, if it migrates to a location where it cannot be retrieved, it should be considered as consumed.

Crop-Water Production Functions

Agricultural production is a business operation and irrigation management can be evaluated in context of the business. The goal of any business is to maximize profits. Maximizing profits can include sustaining the business through a period when profits are not possible and generating growth in anticipation of future profits. Therefore, one definition of optimal irrigation management is that management which maximizes profits.

Water is an input to the production system. The functional relationship between crop yield that is marketed and AW must be known for the economic analysis. Only water that infiltrates into the soil has an opportunity to contribute to crop production. The water running off the field cannot contribute to crop production so the crop-water production function can only be based on the amount of infiltrated water (IW). The runoff water has economic implications that must be accounted for separately.

The uniformity of irrigation significantly affects the crop-water production function. The relationship between cotton lint yield and IW for various irrigation uniformities for climatic conditions of the San Joaquin Valley of California is presented in Figure 2. The uniformity is characterized by the Christensen's Uniformity Coefficiency (CUC), where a value of 100 represents perfectly uniform irrigation and decreasing values of CUC represent increasing nonuniformity. Also depicted in Figure 2 is the amount of water percolating below the root zone for the various CUC and IW amounts. Considering the uniform irrigation first, crop yields increased with increasing amount of IW until a maximum yield is achieved and additional AW does not contribute to more production. When the irrigation is nonuniform, more average water must be infiltrated to get the highest yields. For a given amount of IW, the yield decreases as the irrigation uniformity decreases.

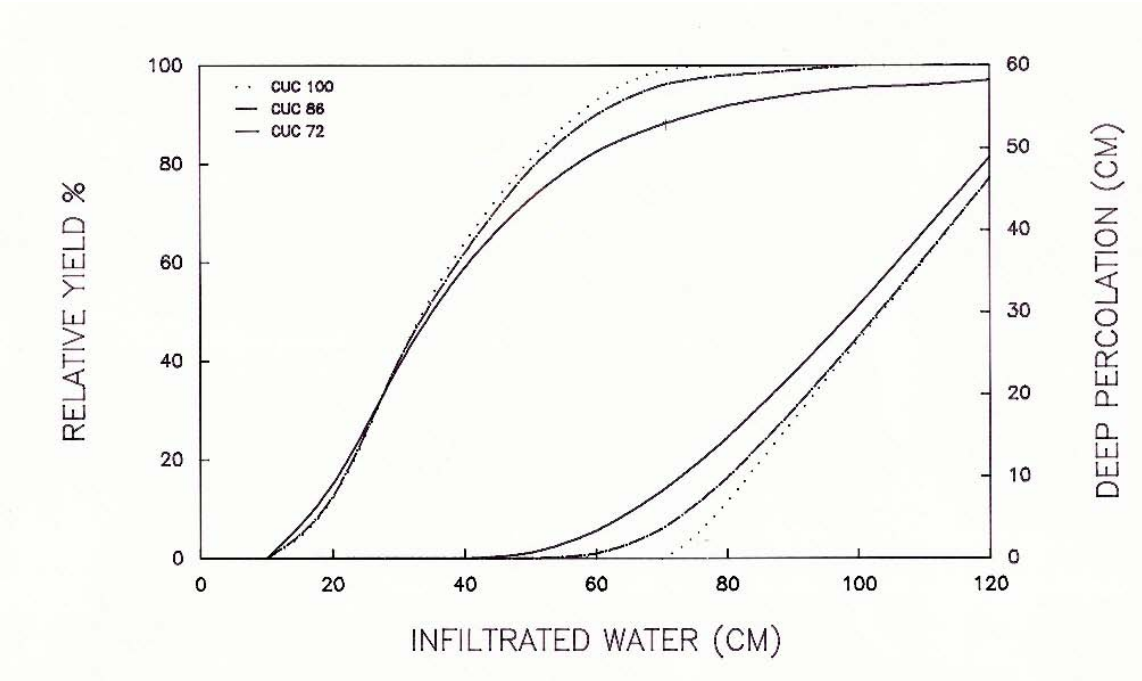

FIGURE 2 The relationships between relative yield and deep percolation to the amount of infiltrated water for three levels of Christensen's Uniformity Coefficient.

Under uniform irrigation no deep percolation occurs until water has been applied to reach the maximum yield. In other words, all of the water is used by the crop. After maximum yield has been achieved, any additional AW goes directly to deep percolation. In contrast for nonuniform irrigation, some deep percolation occurs before a maximum yield is achieved. This is a consequence of some parts of the field having more water than necessary for maximum crop yield and other parts of the field having less water than required. In all cases increasing IW increases the amount of deep percolation. For a nonuniform irrigation there is a trade-off between irrigating for high crop yield and low deep water percolation.

The salinity of irrigation water is another factor that affects the crop water production function. The salts in the irrigation water become concentrated through evapotranspiration and therefore some water must be applied to leach the excess salts from the root zone. The amount of water to be applied, however, depends on the salinity level of the irrigation water and the crop sensitivity to salinity.

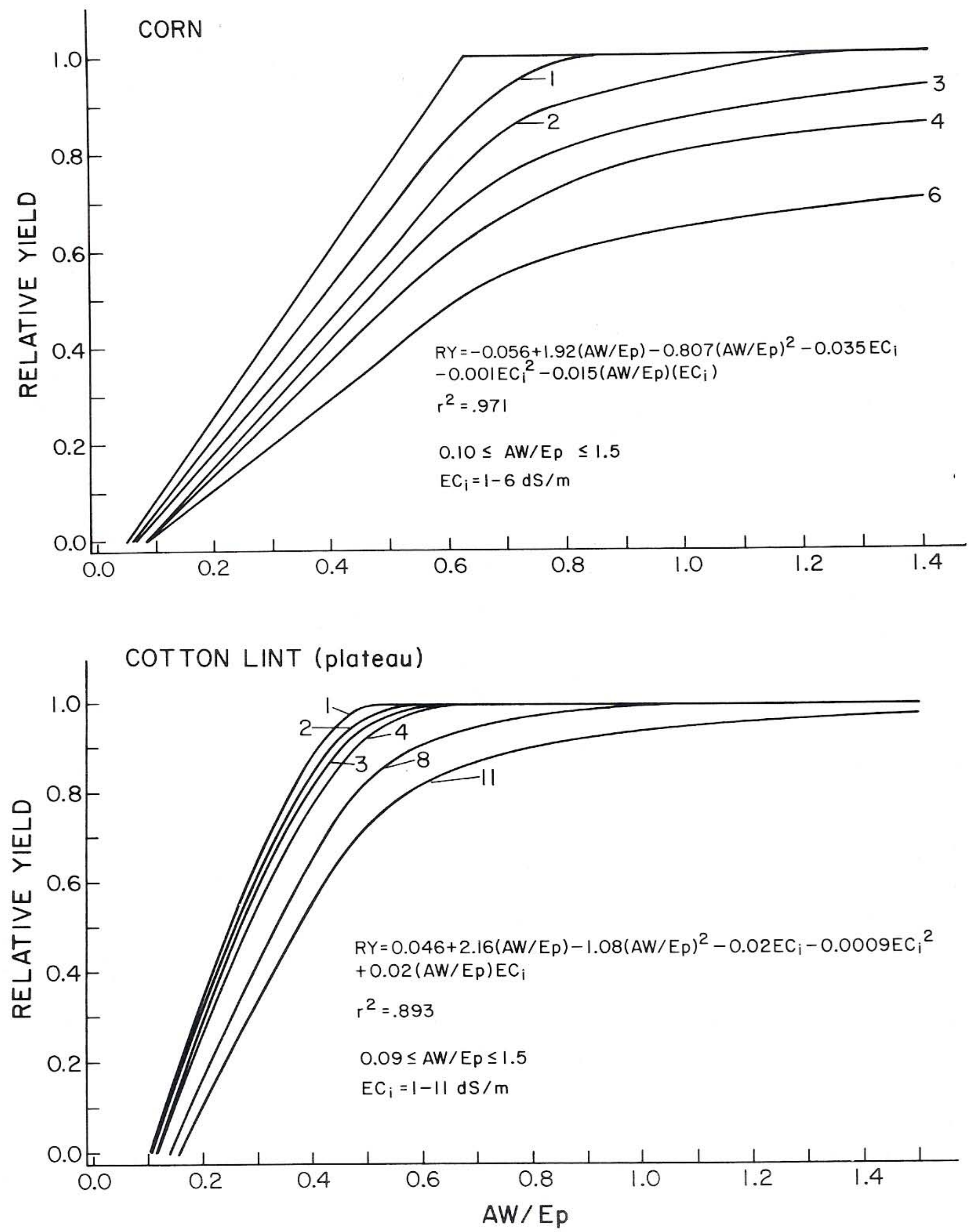

FIGURE 3 The relative yield of corn and cotton as a function of applied water (AW) scaled by pan evaporation (Ep) for waters of different salinities. The number on each curve represents the irrigation water salinity in dS/m.

Letey et al. (1985) developed a model to compute the relationship between relative crop yield and the seasonal applied water for crops with different tolerances to salinity. The crop-water production functions are presented in Figure 3 for corn, which is a salt sensitive crop, and for cotton lint, which is a salt tolerant crop. The applied water (AW) assumes that all of the water infiltrates and E_P is the pan evaporation. The ratio AW/E_P may be used to facilitate comparison between different climatic zones with different E_P values. The relationships for wheat are presented in Figure 4.

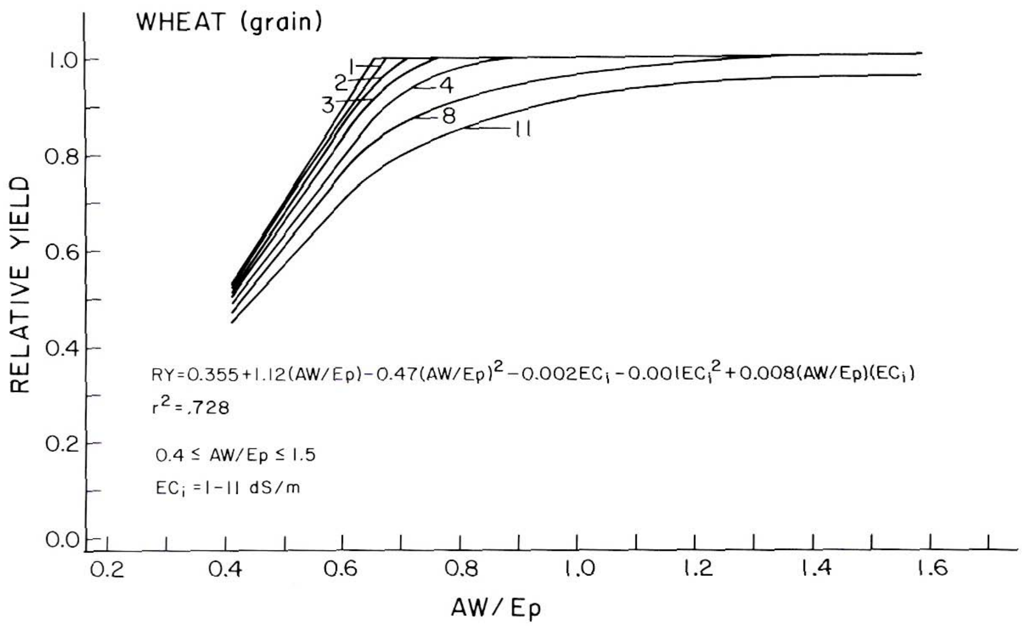

FIGURE 4 The relative yield of wheat as a function of applied water (AW) scaled by pan evaporation (Ep) for waters of different salinities. The number on each curve represents the irrigation water salinity in dS/m.

Note as the salinity of the irrigation water increases, more water must be applied to get the same yield. Irrigation water salinity may reach a level where maximum yield cannot be achieved regardless of the amount of water applied. Larger differences in yield for a given amount of AW or larger differences in AW for a given yield occur for the salt sensitive corn than the salt tolerant cotton. Indeed for cotton, irrigation water salinities up to 4 dS/m require relatively small amounts of additional water to achieve the maximum yields. Note that wheat is salt tolerant and the relationships are similar to those of cotton.

All of the curves depicted in Figures 3 and 4 assume that the irrigation is uniform. Nonuniform irrigation would modify the results in a manner as depicted in Figure 2. In other words, increasing nonuniformity would cause each of the curves in Figure 3 to be lower for a given water application.

Economic Irrigation Efficiency

Because of deficiencies in the traditional water use efficiencies, as stated above, a different criterion must be used to characterize the optimal irrigation management. Since agriculture production is a business operation, maximizing economic irrigation efficiency would be an appropriate goal. Economic irrigation efficiency is defined at the farm level as the irrigation management that maximizes profits. In a broader context economic irrigation efficiency could be defined as irrigation management that maximizes net social benefits. The difference between the two definitions is the result of externalities. An externality arises when some of the costs or benefits of irrigation agriculture accrue to society as a whole and the costs (as reflected in market prices) are not borne by the farmers or the consumers of their products. Externalities can be positive or negative. An example of a positive externality occurs when water purchased by a farmer runs off his farm and serves some beneficial societal use. However, if the water is polluted it can impose a cost to society and create a negative externality.

The crop-water production functions as depicted in Figures 2, 3 and 4 can be converted to benefit curves by multiplying the yield by the market price for the crop. Such curves are depicted in Figure 5 as a hypothetical case representing two irrigation uniformities. The total benefit (TB) in $ ha^{-1} for a given IW is higher for the more uniform (TB1) than the less uniform irrigation (TB2). The total cost of water (TC) is also depicted in Figure 5 where the price of water for case 1 (TC1) is greater than for case 2 (TC2).

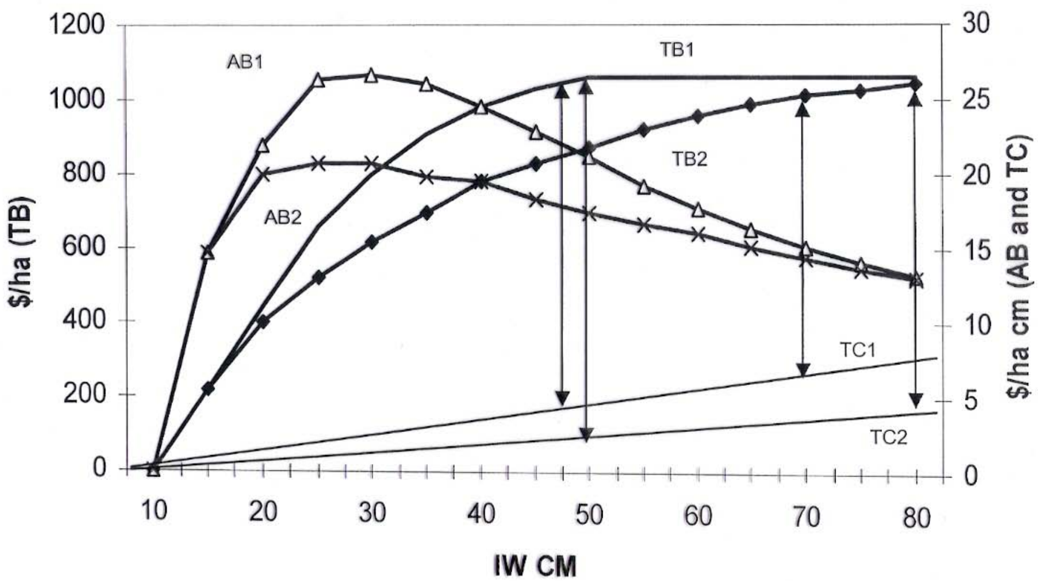

FIGURE 5 The total benefit (TB) and average benefit (AB) as a function of infiltrated water (IW) for two levels of irrigation uniformity, when irrigation uniformity is more uniform for case 1 than case 2. Also presented is the total cost for water (TC) as a function of IW when the cost for water is higher for case 1 than case 2. The arrows represent IW that maximize profits.

The highest profit is achieved where the differences between TB and TC is the greatest. These points are identified by arrows in Figure 5. Some general conclusions can be derived from the information depicted in Figure 5. The economically optimal (profit maximizing) level of IW depends on the shape of the crop-water production function and the price of the water. Improving the uniformity of irrigation results in a decrease in the value of IW that achieves economic efficiency. Also raising the price of water lowers the value of IW that achieves economic efficiency. Raising the price of water has a greater effect on decreasing the economically efficient IW value under the nonuniform irrigation system as compared to the more uniform irrigation system. Indeed raising the price of water had relatively little effect on changing the economically efficient level of IW for the most uniform system.

A shift in irrigation technology or management to achieve more uniform irrigation usually imposes a cost. The increased cost may not be offset by the increased benefits associated with improved irrigation uniformity to justify the investment. This factor must be evaluated on a case by cases basis.

The average benefit (AB) as a function of IW is also depicted in Figure 5 for the two irrigation uniformities. AB is calculated as TB divided by IW and has the units of \$ (ha cm)$^{-1}$. AB is the average dollar return per hectare-centimeter of IW. Note that the maximum AB value occurs at a lower IW value than the economically optimal quantity. Even though the average return decreases, the cost for additional irrigation water is exceeded by additional return associated with an incremental increase in water. Economically optimal input is at the point where the marginal benefit equals the marginal costs. The marginal benefit is defined as the benefit associated with the next incremental increase in input and likewise the marginal cost is the increase in cost associated with the next incremental input. The marginal benefit is the slope of the TB curve and the marginal cost is the slope of the TC curve depicted in Figure 5. Note in Figure 5 that the slope of the TB curve equals the slope of the TC curve for the optimal irrigation as indicated by the arrows.

The shape of the AB curves in Figure 5 is identical to the shape of the ratio of yield (Y) to infiltrated water (IW). This ratio (Y/IW) is a common definition of water use efficiency. Note that the IW that achieves maximum water use efficiency by this definition is not the IW that is economically efficient. Irrigating to achieve the maximum commonly defined water use efficiency results is a significant reduction in yield. Clearly maximizing water use efficiency by this traditional definition leads to results that are not the most economically beneficial. Therefore, as stated above, increasing the water use efficiency may not be a positive goal.

A shift in production function from less uniform to more uniform irrigation does result in higher water use efficiency for a given value of IW. Therefore increasing the numerical value of water use efficiency by a change in management that entails a change in production function is positive. However, it is not necessarily economical. It is not obvious that the shift in production function from the less uniform to the more uniform irrigation is economically efficient. The main conclusion is that generalizations cannot be made, and each situation has to be thoroughly evaluated from a production and economic consideration.

Irrigation Scheduling

Irrigation scheduling refers to the time, duration, and quantity of an irrigation. Although crop water production functions as depicted in the figures provide the scientific and economic basis for optimizing irrigation, farmers do not have such complete detailed information available to guide their irrigation management. Nevertheless, the general principles still apply. Since the purpose of irrigation is to replace the water lost from the storage zone between irrigations, knowing the amount of ET that has occurred since the last irrigation is important. Alternatively, the farmer could monitor the soil water content as a function of time to determine when the soil is sufficiently dry to warrant recharge. Therefore, a method of monitoring either ET or the change in soil water content is required for irrigation scheduling.

Climatic conditions drive ET, therefore monitoring the potential ET by an evaporation pan or from other climatological data. In California several weather stations have been established throughout the state to form a California Irrigation Management Information System (CIMIS). Farmers with computer systems can get daily information from the weather station located nearest to their farms.

The climatological data identify the potential ET. The crop ET is not always equal to the potential ET. For example, during the early part of the season for annual row crops, the plant is small, and the crop ET is much less than the potential ET. As the crop grows and the canopy cover increases, the crop ET approaches potential ET. Thus, to estimate crop ET the potential ET is multiplied by a crop coefficient (Kc), which must be empirically determined for each crop as a function of time. Studies have established the crop coefficients for several crops in California. Results from these studies can be used to guide irrigation management. Nevertheless, the study results are not absolute and the farmer must use judgment and make observations in the field to be sure that his irrigation is appropriate.

Monitoring the soil water content as a function of time requires instrumentation. The neutron probe can be used to measure the water content in the soil profile, but this method is labor intensive. It requires the installation of neutron probe access tubes and then measurements on some predetermined schedule. Other instruments such as tensiometers can be installed at various depths and require reading on a timely basis. Some of the instruments have electrical signals that can be connected to a recorder for continuous monitoring with minimal labor input. Soil moisture monitoring requires capital investment and then some level of operational expense.

Policy Issues Related to Irrigated Agriculture

Water Pricing

One belief, particularly in the United States, is that agricultural irrigation water is under priced and that if the cost for water was increased, it would induce the farmers to improve their irrigation management. A decrease in the optimal IW as a cost for water increases can be observed in Figure 5. However, based on the shape of the crop-water production function, cost of the water, and the sale price of the crop, the decrease in optimal IW may be relatively small.

The effect of cotton and water prices on the optimal AW and the gross returns net of water cost to the farmer were calculated for a measured crop-water production function for cotton grown in the San Joaquin Valley of California. In this case it was assumed that all of the AW infiltrated and there was zero runoff. The results are summarized in Table 1. Note that increasing the water price or decreasing the cotton price decreased the optimal value of AW. However, the differences in optimal AW are very small and the main effect was in reducing the profitability of growing the crop to the farmer. Indeed the computed differences in optimal AW are smaller than the degree of precision that the farmer has in controlling AW.

TABLE 1 Effect of cotton sale price and water price on the economically optimal water application and gross monetary returns net water costs (GR).

Cotton Prices $/kg	Water Prices $/cubic meters	Optimal AW centimeters	GR $/ ha
0.32	59,207	84.1	0.031
0.32	118,414	80	0.025
0.23	59,207	82.6	0.021
0.32	250,398	71	0.001

The computations reported in Table 1 are based on no runoff from the field. If the farmer had runoff from the field, the increase in water price could provide an incentive for reducing or eliminating runoff from the field. But in this case, since the runoff from the field is useful for other societal benefits, very little is gained from a societal water availability point of view. The main effect of raising water prices is to decrease farmer profitability or more likely to induce a shift in the crop to be grown. Relatively little is to be achieved in a net societal water savings.

Improving Irrigation Efficiency

A common belief is that if agriculture increased the water use efficiency, more water would be available for societal use. Discussion of this matter is complicated by the several definitions of water use efficiency. However, some general statements can be made. First, for common irrigation practices, an efficiency value of 100 percent by any traditional definition is not the economically efficient practice. Therefore, increasing the efficiency number may or may not serve a positive economic effect.

The pertinent scientific fact is that the purpose for AW is to meet the ET demands of the crop. Except in special cases, decreasing the crop ET also decreases the yield. Any AW in excess of ET is still potentially available for societal use. For example, water that runs off of a field or farm has some societal use depending upon the locale. The water that percolates below the root zone has to be evaluated on a case-by-case basis as to its availability for societal use. Reduction of AW or deep percolation in most cases will reduce the amount of water available for societal use. These statements are based on water quantity without consideration of water quality. Water quality must be considered as a significant factor but may have relatively little effect on total societal water availability.

Water resource managers who are considering increasing irrigation efficiency as a major policy approach to increasing water supplies to meet future demands may be over estimating the potential increase in water supply. In some cases, the over estimates can be large.

Using Crop-Water Production Functions

Traditionally, agricultural management concepts have been based on achieving maximum yields. Crop production research was directed towards determining the treatment that provided maximum yield rather than establishing crop-water production functions. The leaching requirement concept was established for irrigating with saline waters. The leaching requirement is defined as the leaching that results in maximum yield. A common approach to specify the amount of irrigation water to apply for nonuniform systems is as follows. The distribution of water application across the field is measured. The average of the lowest one-fourth of the numbers is divided by the average of all of the numbers. This results in a number less than 1 that is then divided into the average to determine the amount of water to be delivered to the field. This approach is to achieve maximum yield throughout the field. Focus on maximum yield can obscure the vision to other alternatives for irrigation management. Production functions reported in this paper will be used to illustrate this point.

The effects of irrigation uniformity are depicted in Figure 2. Maximum yield for a uniform system can be achieved with 70 cm of IW. The distribution of numbers that resulted in the CUC of 86 were such that the lowest one fourth averaged 31.3 and the total average was 40. Dividing 31.3 by 40 and then dividing that number into 70 results in 90. Therefore using a common irrigation prescribing procedure, an IW of 90 cm would be prescribed.

Note that the difference in yield for the CUC equal 86 curve between 70 and 90 cm of IW is very small compared to the increase in water application.

For the case of CUC equal to 72, irrigating to achieve the maximum yield that can be achieved with a uniform irrigation is not practical. However, a very large water application would be prescribed using the standard procedure. Slightly less than 90 percent maximum yield is achieved with 70 cm of IW. However, the rate of increase in yield with increasing values of IW is not great.

The second example will be related to saline irrigation water using the production functions depicted in Figures 3 and 4. Maximum yields of salt tolerant cotton and wheat can be achieved with an irrigation water of 4 dS/m by applying very little more water than used for nonsaline water. In this case the leaching requirement concept to achieve maximum yield is appropriate. However, what can be overlooked is the opportunity to save "fresh" water if a very saline water supply is available. For example, assume that a saline water of 8 dS/m was available. Irrigating either wheat or cotton with this water would be questionable. However, blending this water with nonsaline water to create a water of 4 dS/m is feasible and "saves" a large fraction of the nonsaline water that would otherwise be used to irrigate these crops. This conclusion would not be obvious if one only used the leaching requirement index. Like in all cases, more widespread implication of doing this must be evaluated. As a general rule, the opportunity to use very saline water to irrigate economic salt tolerant crops must be considered.

Using Water for its Highest Monetary Value

Economists suggest that water should be used for its highest monetary value. For example, the analysis summarized in Table 1 indicates that raising the price of water induces a small amount of water application reduction, but a significantly large reduction in farmer profits. If the price of water is raised, the farmer's option usually is to switch to a higher value crop. One might argue that this is an economically efficient management option for water.

Water marketing is proposed as an option for stimulating transfer of water from agriculture to urban uses or from lower value to higher value uses. The urban dweller and industry can afford to pay more for water than many farming operations. This option is considered in light of an increasing human population that is living in urban areas.

Moving water to irrigate higher valued crops has one serious potential consequence. The foods that feed the masses of population are the lower valued crops. If the trend for agricultural production throughout the world was towards the higher valued crops, this could have potentially serious consequences on the ability to feed the human population.

Analyses of water necessary to meet increased urban human populations is usually done by calculating the water use by an urban dweller and multiplying that by the increased number of people. In one regard this may be an overestimate of the water required. Except for watering gardens and lawns where the water is consumed through ET, most of the urban water demand is using rather than consuming water. In other words, the water has been used and can be treated and reused.

However, this analytical approach seriously underestimates the true urban water demand. The amount of water required to grow the crops that feed the people living in the city is almost always overlooked. An estimate of the water required to produce various foods in California was done. Using these data a daily total of 2680 liters were used to produce the food in a 2200-calorie menu suggested by the USDA Food Nutrition and Consumer Service. For comparison, a typical urban home in California uses about 473 liters per day. Of the total water therefore required for the livelihood of an urban dweller, 85 percent of the water was used to produce the food. Strictly by coincidence, in California approximately 85 percent of the developed water is devoted to irrigation agriculture and 15 percent to the cities.

The main point is that a major water need for an urban dweller is that which is used to produce the food that sustains them. Based on this fact, there should never be a competition between urban and agricultural uses of water. Almost all of the water consumed by agriculture is to provide for the necessities of the city dweller. Therefore, one of the major long-range concerns related to water supply is that of supplying the food for the increased human population. Rather than managing water to maximize the monetary benefit per unit of water, it might be more appropriate to maximize the food calorie production per unit of water. This criterion may ultimately be more valid in achieving a goal of feeding the peoples of the world.

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Linking Agricultural Water Management and Scientifically-Based Decision Making

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As it was stated in the paper entitled "Agricultural Drought Management in Iran", published in the proceedings of Iranian-American Workshop on "Water Conservation, Reuse and Recycling", and held in December 2002 in Tunis, Tunisia, the main source of water in Iran is precipitation in the form of rain (70%) and snow (30%). Normally it amounts to 252 mm or 413 billion cubic meters (bcm) annually.

At present, the population of Iran is more than 68 million. About 4.5 bcm of water is for drinking, 1.5 bcm is allocated for industries and mines, and 82.5 bcm is used to irrigate approximately 8.4 million hectares of agricultural land (orchards and field crops). About 1.4 million hectares (ha) of these areas are managed by modern irrigation and drainage networks, 6.7 million ha by means of traditional conventional irrigation systems (furrow, border, flooding), and less than 0.3 million ha are under pressurized systems (sprinkle and trickle irrigation).

Some of the water problems include:

- Declining groundwater levels (≈ 1 m/year) in arid regions, which depend on groundwater resources for agriculture, industrial activities, and urban water supply. Overall, 60% of these activities depend on groundwater sources.

- Deforestation in the north, west and central mountainous areas.

- Floods and drought occur more frequently than before. Heavy damages and economic losses result from these phenomena.

- Conversion of high-value agricultural lands by urban dwellers, especially the lands which are close to rivers or fresh water resources.

- The irrigation and drainage networks of some constructed dams have not been built or completed after decades.

- Immigration of rural people to towns and cities and leaving agricultural activities behind.

- Increases in soil and water salinity.

- Low efficiency in irrigation systems (33% for surface, 65% for sprinkle and 85% for drip systems). More than 90% of the lands are irrigated with conventional surface systems.

- Many large dams (capacity range of 1-7000 million cubic meters) were built during the last 25 years to supply agriculture and drinking needs. These dams have adverse environmental effects. Few scientists were involved in making construction decisions.

- Attaining self-sufficiency in major agronomic crops puts pressure on water resources. The Ministry of Agriculture has been successful in attaining self-sufficiency in wheat in 2005. What is the price of this self-sufficiency as the "virtual water" concept is concerned?

- Lack of farmers' participation in decisions related to water management.

Some of the frequently asked questions in the scientific community (Iranian universities and research institutes) in respect to water management are:

1. How can scientific knowledge and research results be more effectively distributed especially to farmers who are the main users of water resources, in their water consumption and management decisions?
2. How can policy makers be convinced to apply certain scientific findings in the society?
3. How can new sources of funds be found to work out new ideas?
4. How can the disconnections among scientists, policy makers and water authorities be alleviated?

These questions are intensified in the third world as the type of water problems, views of the public, level of people's education and knowledge of the laws, public requests, and institutional and economic situation are different from developed countries.

The following steps are proposed to overcome some of the problems listed above, to find practical solutions, and to foster better relationships and collaboration between scientific communities and policy makers, water managers, and farmers. These steps are very important and necessary:

- Differences in the context of activities and efforts should be understood. Scientists live in academic environments full of students and other colleagues, while policy makers are practicing in governmental offices face to face with the people having real problems who seek quick solutions to their problems.

- Scientists, policy makers, water managers, and farmers often are living in their own thoughts and are not aware of the existence of the others. For example, despite the fact that hundreds of universities and research institutes exist in big cities, farmers still use conventional thousands-year old irrigation or agronomic systems to grow agricultural crops with low water use efficiency. Or, many parliament members or water managers either have no contact with universities or may not encourage the university members to observe decision-making processes and give scientific advices. Closer relationships and collaboration between these parties is recommended.

- The timeframes and constraints are different for scientists and policy makers. Scientists are not in hurry to find results of their research. They should be able to verify the originality of their research findings. Policy makers and water managers are confronted with hundreds of real-time problems, which must have proper solutions as soon as possible. They must respond to the voters. Farmers need water at the beginning the growing season and cannot wait longer. Understanding these differences helps all sides to find the optimum solution to the problems at the best time.

- Local integrated water resources councils or planning groups, with participation from representatives of all sectors, may be established to resolve local or regional water problems and conflicts. An example of this kind of council is the "Water Council" found in most of the provinces of Iran. This council includes the governor general of the province, representatives from the regional water authority, water and wastewater company, the municipality, the department of environment, agricultural organizations, local universities, water research institutes, the department of meteorology, management and planning organizations, and some others. This committee is very active during drought and flood periods.

- Scientists should focus more on conducting applied research for solving the problems of local farmers and water managers and consider integrating these practitioners in the early design of research activities. Here, most of the researchers and scientists find the research ideas more or less on their own ingenuity or reading papers. Farmers don't convey their problems directly to the scientists. Lack of farmers' associations impedes the understanding of problems and solutions.

- New technologies, like the internet and satellite programs, should be used to propagate and disseminate the results of research findings and to help set research priorities. This would eliminate the need for frequent meetings of busy people.

- The extension services should be strengthened with the help of properly educated intermediaries to disseminate research findings and to expand the flow of information. This would remove some of the barriers between the three parties involved in water use and management. Presently, extension services are under the supervision of Ministry of Agriculture. They do whatever they can to convey the latest research results, but there is no direct connection with the university system.

These efforts are quite important and need the support of universities, state water authorities, planning and budget organizations, for financial backup, and agricultural organizations. Evaluations should be done to allow for further refinements and adjustments to the activities.

One might ask: who is going to organize these activities and who is going to support them financially? Is it the task of universities or ministries of energy and agriculture? Do the governors of the provinces orient and conduct the activities? Etc.

I think there should be multi-participatory committees, listening to different views and making decisions as practicable as possible. The stimulus should come from policy makers and politicians because they are the ones responsible for resolving everyday problems and are the arms of the government. One fact should be brought up---politicians, policy makers, and water managers are usually university-educated people with BS or MSc. level degrees. Rarely, do you find someone with PhD degree. Time is so important for them that they wish they could work more than 24 hours a day. This might be a good reason for not looking at new papers, new journals or books. Listening to experts who have up to date information is important.

Regulated Deficit Irrigation in Trees and Vines

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Introduction

Irrigated agriculture is the primary user of water in much of the world, commonly using 70% more of developed water supplies. Irrigation water may be used consumptively in crop transpiration or evaporation from soil; a process termed evapotranspiration (ET), and may have other sinks such as deep percolation or tailwater runoff. As in the urban and industrial sectors, irrigated agriculture has been steadily improving the efficiency of water use for decades. More efficient irrigation systems and improved irrigation management practices that reduce tail water and apply water with high uniformity, thus minimizing percolation, are being widely adopted.

However, tailwater and deep percolation are usually not true water losses. Tailwater is normally collected and reused elsewhere on a grower's acreage. Unless it moves to a salty, perched water table or flows to the ocean, water "lost" to deep percolation can be pumped and reused. Thus, one field's or grower's loss is another field's or grower's source of supply.

On the other hand, any reductions in consumptive use (ET) result in the net saving of water to the basin in question. Thus, it's important to explore the potential of reducing ET in irrigated agriculture. Research done on soil evaporation (E) indicates that the potential for reducing E in the intensive agriculture of California is small in most situations. One exception is the few early years of orchard crops. Buried drip irrigation in mature crops can reduce E by 5-10% (Bonachela at al., 2001) but is very expensive to install and maintain (Camp, 1998). Transpiration (T) is by far the largest component of ET and is where we need to focus our objective of reducing ET.

It has been known for many decades that when T is decreased by water deficits, crop production is also reduced below its maximum potential (Hsiao, 1973; Bradford and Hsiao, 1982). This is because the processes of carbon assimilation and T take place through the stomata, the microscopic pores in the leaves of plants that are responsible for gas exchange. As water stress is imposed, the stomata close and that reduces both water loss and carbon uptake and thus, productivity. Indeed, preventing water stress forms the basis for most of the water budget irrigation scheduling programs that exist today, including CIMIS. Does that mean that there is no opportunity to reduce T in irrigated agriculture?

This goal of reducing transpiration by stressing the plant has been extensively researched in the past for field and row crops but has been shown to reduce yields and also water productivity (crop yield per unit of water used) in most herbaceous crops. However, numerous studies the past 15-20 years in California, Australia, Spain and Israel (Chalmers et al., 1981; Mitchell et al., 1986; Caspari et al., 1994; Lampinen et al., 1995; Naor, 2000; Naor et al., 2001; Teviotdale et al., 2001; Girona, 2002; Moriana et al., 2003; Goldhamer et al., 2002) have shown that regulated deficit irrigation (RDI) can reduce consumptive use in tree crops and vines without reducing grower profits, and in some cases, even increasing grower profits. A recent review on irrigation of fruit trees has highlighted the potential of using various forms of deficit irrigation in the water management of orchard and vineyards (Fereres et al., 2003).

Regulated Deficit Irrigation

We define regulated deficit irrigation (RDI) as a regime that purposely stresses the trees or vines at specific developmental stages of the crop such that there is little, if any, negative impact on the yield of marketable product and/or profits. The water stress is normally imposed at stages of the season when reproductive growth is relatively low. The water stress results in lower tree water status, partial stomatal closure, which reduces ET (Fig. 1). The objective of RDI is to maintain or increase farm profits while reducing the consumptive use of water.

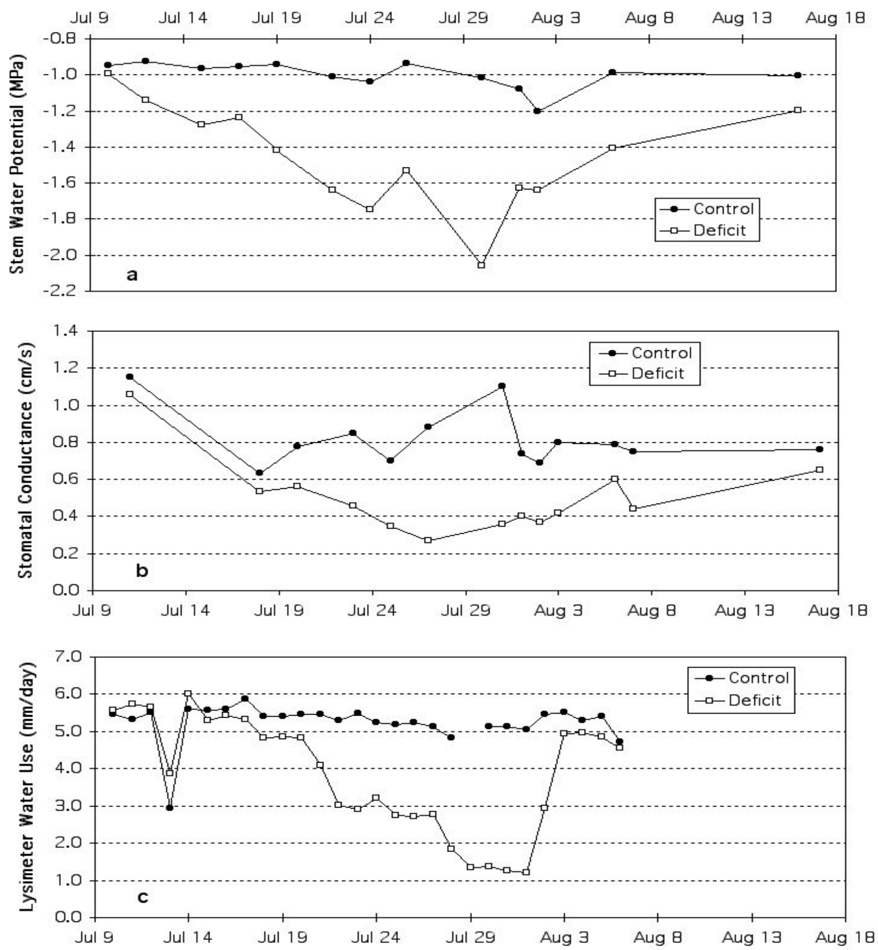

FIGURE 1 Impact of progressively more severe deficit irrigation from July 10 to August 1 on a) midday stem water potential, 2) midday stomatal conductance, and 3) ET of mature peach. Control was fully irrigated. Deficit trees returned to full irrigation on August 2. Adapted from Goldhamer et al. (1999), Fereres et al. (1999), and Mata et al. (1999).

Crop-Specific RDI Opportunities

Citrus

Recent research on the mature navel orange, "Frost Nucellar" has shown that early season stress improves harvest fruit quality by reducing peel creasing (Goldhamer and Salinas, 2000). This resulted in a higher percentage of the fruit graded as Fancy (high value) and a lower percentage as Juice (low value). Fruit drop and fruit load were not negatively affected. Figures 1 and 2 show mean data from the final three years of a four year study involving 14 RDI regimes and a fully irrigated Control. Note that due primarily to slightly reduced individual fruit weight, the relationship between gross yield (kg/ha) and applied water is fairly linear (Fig. 2). On the other hand, there is no relationship between gross revenue ($US/ha) and applied water (Fig. 3). Thus, total grower revenue was higher under many of the RDI regimes (those that imposed stress early in the season) while applied water (and consumptive use) were reduced.

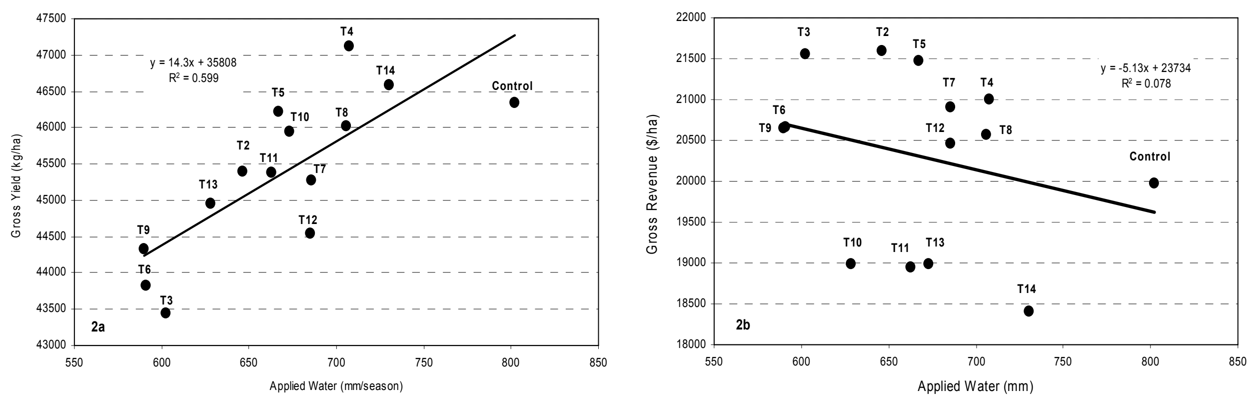

FIGURE 2 Mean data from the final three years of a four year study in the San Joaquin Valley of California of mature navel orange tree ('Frost Nucellar') response to 14 RDI regimes compared with a fully irrigated Control showing a) gross yield versus applied water, and b) gross revenue versus applied water. Adapted from Goldhamer and Salinas (2000).

Another issue in late harvest citrus is excessively large fruit and granulation. Goldhamer and Salinas (unpublished data) found that granulation can be significantly reduced using RDI (Table 1). Additionally, some RDI regimes shifted the fruit size distribution toward smaller, more valuable fruit. While this had a modest impact on gross yield (Fig. 3a), it resulted in higher grower revenue, water productivity, and revenue productivity (Figs. 3b, 3c, and 3d, respectively).

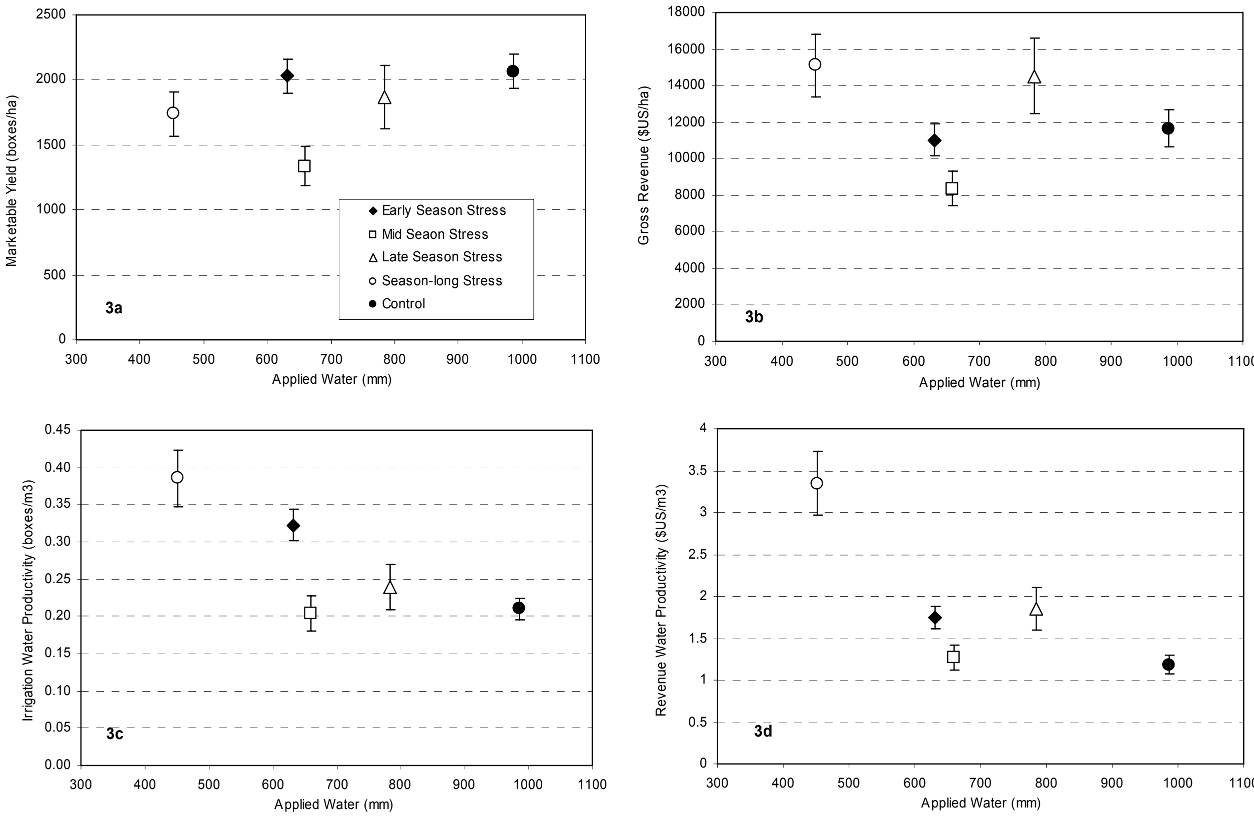

FIGURE 3 Mean data from the first two years of a study in the San Joaquin Valley of California involving four RDI regimes on mature late harvest navels ('Lane Late') compared with a fully irrigated Control showing applied water versus a) marketable yield, b) gross revenue, c) irrigation water productivity, and d) revenue water productivity. Unpublished data from Goldhamer and Salinas. Vertical bars are ± one standard error of the mean.

TABLE 1 Fruit granulation (drying of the pulp) measured at harvest in the first year of a study in the San Joaquin Valley of California involving four RDI regimes on mature late harvest navels ('Lane Late') compared with a fully irrigated Control. Unpublished data from Goldhamer and Salinas.

Irrigation Treatment	Small Sizes 88+113+138+163 Granulation	Medium Sizes 56+72 Granulation	Large Sizes 48 Granulation	Extra Large sizes 24+36+40 Granulation
	------------------------------ (%) ------------------------------			
T1; early summer stress	1.2 a*	4.3 a	6.6 ab	13.9 ab
T2; mid summer stress	2.6 ab	6.5 ab	9.6 b	15.5 ab
T3; late summer-fall stress	4.4 ab	14.0 c	15.4 c	22.2 bc
T4; continuous stress	1.1 a	2.2 a	3.2 a	8.8 a
T3; fully irrigated Control	5.8 b	10.5 bc	21.4 d	30.7c

Pistachio

Mature pistachio trees have the potential to transpire water at an extremely rapid rate (Goldhamer et al., 1985). While pistachio trees are extremely drought tolerant, they are able to withstand severe stress (Goldhamer et al., 1984). Pistachio production involves many more yield components than the other nut crops and each of these yield components can be negatively influenced by water stress. However, the unique fruit development pattern of pistachio nuts provides a period where the tree is relatively tolerant of stress: just after full shell size has been attained until the onset of rapid kernel growth. We refer to this as Stage 2 growth and it normally occurs from Mid May thru early July in the southern San Joaquin Valley of California. Goldhamer and Beede (2004) reported that irrigation at 50% of potential ET during this period can occur without negative impacts on production and a significant increase in irrigation water productivity (kg/m3; Table 2).

TABLE 2 Mean data from the final two years of a four year study in the San Joaquin Valley of California of water deprivation (shown as 0%) during fruit growth stages and the most successful RDI regime (irrigation at 50% ET during stage 2 and 25% ET post harvest) compared with a near fully irrigated Control.

Irrigation Treatment	Yield Dry Split Nuts (kg/ha)	Irrigation Water Productivity (kg/m3)
0% Stage 1	3170 d	0.407 bc
0% Stage 2	2510 bc	0.408 bc
0% Stage 3	1140 a	0.287 a
0% Post harvest	2750 bcd	0.344 ab
50% Stage 2; 25% PH	3070 cd	0.469 c
Control	3040 cd	0.361 ab

Additionally, Goldhamer and Beede (2004) found that mild to moderate stress from leafout to full shell size (Stage 1) can significantly improve shell splitting which can sometimes be a major problem for growers. Closed shell nuts are worth much less than split nuts. The downside of Stage 1 stress is that it can reduce nut size. Nevertheless, Goldhamer and Beede (unpublished data) showed that Stage 1 stress can reduce closed shell production by about 50% relative to fully irrigated trees (Table 3). Similar results were obtained when Stage 1 stress was coupled with Stage 2 stress. This treatment reduced applied water by almost 30% and significantly increased irrigation water productivity.

TABLE 3 Mean data from the first two years of a study at Parlier, CA involving two RDI regimes (T1; stress during stage 1, and T2; stress during both stages 1 and 2) compared with a fully irrigated Control on two pistachio scion cultivars.

Rootstock	Irrigation Treatment	Harvested Dry Split Nut Weights (g)	Harvested Fresh Closed Shell Nuts (% by No.)	Applied Water Productivity (kg/m3)
Atlantica	T1	1.14 a*	15.3 a	0.267 ab
	T2	1.13 a	15.3 a	0.324 a
	Control	1.23 b	28.7 b	0.229 b
PG1	T1	1.17 a*	17.9 a	0.355 ab
	T2	1.19 a	16.3 a	0.426 a
	Control	1.25 b	34.8 b	0.305 b

Almonds

Smaller kernels translate into both lower yield (assuming no impact on fruit load) and less valuable kernels as processor prices are related to kernel size. There are approximately 5% differences in kernel value for each of the five or so kernel size categories. Most of the RDI work to date that imposed preharvest stress in almonds reduced harvest kernel size (Goldhamer and Viveros, 2000; Girona et al., 1993a; Goldhamer, 1997; Torrecillas et al., 1989). The magnitude of the size reductions was related to the magnitude of the stress. On the other hand, Shackel (2002) and Romero et al. (2004) found no significant reduction in fruit weight with preharvest stress. Most of the published studies report that RDI can be imposed without negatively impacting fruit load if the stress is biased to preharvest. Even though individual fruit size was reduced regardless of the preharvest RDI imposed, Goldhamer and Viveros (2000) found significant improvement in irrigation water productivity in most of RDI regimes.

Peach

The pioneering RDI work in fruit trees was conducted on late harvest peaches (Chalmers et al., 1981). Since the fruit has a double sigmoid development pattern, where a rapid growth first stage is followed by a slower growth second stage, which, in turn, is followed by a rapid growth third stage, the theory was that stress can be imposed during Stage 2 of fruit growth. Researchers in Australia found that with this approach, there was no significant reduction in harvest fruit size, unwanted vegetative growth was reduced (presumably less pruning required), and consumptive use was less (Chalmers et al., 1981). There was no increase in fruit drop. However, we in California and others in Europe have been unable to reproduce these results in late harvest peaches; we usually observe a slight reduction in harvest fruit size (Girona et al., 1993b; Goldhamer et al., 2002; Girona, 2002). While these size reductions may not be statistically significant relative to fully irrigated trees, the fact that fruit value is so closely tied to fruit size results in significant loss of grower revenue.

This is not the case with early harvest peaches; those harvested in late May-early July (Larson et al., 1988; Johnson et al., 1992). The RDI regimes impose stress only following harvest. Since fresh peach production includes early season thinning of the crop to a desired number, any impact of the previous year's stress on fruit load is negated. However, stress in late August-mid September has been found to increase the percentage of fruit "doubles;" two fruit in varying degrees of completeness attached to one stem (Johnson et al., 1992). This fruit is worthless and can be removed in the thinning process. However, it requires the thinning personnel to be more watchful, thereby slowing down their work. The fruit double problem can be largely avoided by reintroducing full irrigation in the late August-mid September period.

Wine Grapes

There is unanimity of opinion that water stress in grapes can improve the quality of the wine produced (Goodwin and Jerie, 1992). In fact, irrigation of wine grapes was against the law until recently in some European countries. While it was recognized that irrigation could increase yields, there was a fear that wine quality would also be reduced. Now it's recognized that irrigation is required to maximize both production (yield) and grower profit. However, there is no agreement on the extent of the stress required to produce the maximum amount of fruit of the best quality for wine making.

It's been thought that the main objective of RDI in wine grapes is to produce a berry that is smaller than when fully irrigated; thus increasing the ratio of skin to pulp (Kennedy et al., 2002; Prichard, 2003). The constituents of the skin are thought to have the primary influence on wine quality. However, reducing berry size also reduces yield, assuming the same fruit load. Some believe that it's not necessary to impose stresses severe enough to reduce berry size in order to produce higher quality wine; that stress-related chemical changes in the fruit are primarily responsible (Matthews et al., 1990). However, there is universal agreement that reduced vegetative growth and thus, smaller canopies, improves grape color by allowing more sunlight to penetrate into the canopies.

Most agree that optimal RDI in wine grapes involves stress prior to veraison (berry color change). Early season stress is usually imposed by delaying irrigation until a desired level of stress occurs in the vines (Prichard, 2003). The triggers used to identify when enough stress has occurred vary. One approach uses plant water stress measured with a pressure chamber; the other is based on irrigating at certain fractions of ET (Prichard, 2003).

Grower Adoption of RDI and Likely Consumptive Use Reductions

We believe that growers are motivated by two primary forces: profit and regulation. If growers believe that a new technology or approach to irrigation will increase their profits, adoption is much more likely. Purposely imposing stress with RDI is considered a risk by most growers and the rewards must balance this risk. Water cost savings may not be considered as reward enough for adopting RDI. We believe that in the future, it's likely that growers will be compensated for actually reducing consumptive use by agencies that supply water. The scenario is that agencies that meet the growing demand from the urban sector due to an expanding population and environmental sectors will offer to pay growers for water that they currently apply to crops.

Growers will be forced to consider whether the highest profit will be achieved by having their plants consume the water or selling it. If growers recognize that 200-300 mm can be saved using RDI without negatively impacting production and this water can add to their profit by being used elsewhere, RDI adoption is likely. We are not implying that all "saved" water will be sold. To the contrary, the growers will decide how they can better use this water by planting more land, for example.

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The Water Resources and Water Management Regimes in Tunisia

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INTRODUCTION

Tunisia is located in North Africa, on the border of the Mediterranean. Covering 162,155 km², it is characterized by a temperate climate in the north, with mild rainy winters and hot summers, and a desert type of climate in the south. It has a population of 9.84 million growing at a rate of 1.08% per year (INS, 2003). About 65% of the population is urban, residing primarily on the coast. Tunisia is classified among the least water resources endowed countries in the Mediterranean basin.

The history of Tunisia reveals how the scarcity of water resource forced its inhabitants to deal with its unequal distribution within the country. As early as 130 B.C., the Roman Emperor Adrian constructed a temple of water and a huge aqueduct to transfer water over 123 kilometers from a spring located in the region of Zaghouan to the city of Carthage. In the early eighth century, the Arabic Dynasty of Aghlabides transferred groundwater and stored it in big basins to supply the new founded town of Kairouan. This concern for water still persists since it is required for development in all social and economic sectors.

This paper is intended to provide an overview of the current water situation in Tunisia by presenting its water potential with a focus on its regime and spatial variability, water demand trends for the different economic sectors, the choices made to manage the water balance deficits, and the various problems and challenges faced in managing this resource.

WATER RESOURCES

Rainfall and surface water potential

Surface water resources in Tunisia are characterized by problems of quantity and quality. These resources are limited because of the semi-arid to arid climate found in most of the country, with episodic droughts, and a natural deterioration of water quality because of the salty types of rocks found within the country.

Tunisia receives on average 230 mm/year of rainfall; that is 36 billion cubic meters (bcm) of rainfall. However, this volume varies between 11bcm during a drought year and 90 bcm during a very wet year.

The variability of the climate under the Mediterranean influence in the north and under the Saharan influence in the south make rainfall at the same time scarce and unequally distributed in space and time. The annual precipitation is on average 594 mm in the north, 289 mm in the center and only about 150 mm in the south. The ratio between the highest observed values and the lowest observed values of precipitation vary from 4.4 in the north to 15.8 in the south, illustrating the temporal irregularity and variability of rainfall. The decade beginning in 1990 had 4 dry years, one very wet year (1995 -96), three relatively wet years and two average rainy years. In the southern part of the country, this decade was rather a dry one.

Rainfall information has been collected and stored since 1900. Over the last decade, records show that Tunisia experienced 12 important flood periods alternated with 17 dry periods. Droughts appear two to three times every 10 years and can last two, three or even four successive years.

Surface water resources are estimated at 2700 million cubic meters (Mcm) distributed per year over three natural areas distinguished by their climatic and hydrological conditions as well as by rather homogeneous geomorphologic and geological aspects.

The north provides relatively regular contributions evaluated to 2190 Mcm, thus representing 82% of the total surface water potential while covering only 16% of the country. The center part, covering 22% of the area, is characterized by irregular resources. It provides 12% of the total surface water potential. The southern part of the country which accounts for approximately 62% of the total area is the poorest in surface water, providing very irregular resources evaluated at 190 Mcm which represents 6% of the country's total potential of water.

The quality of surface water, evaluated by its degree of salinity, varies according to the origin of the resource. Considering that a salinity of less than 1.5g/l is acceptable, then approximately 72% of the surface resources may be considered of good quality. Water quality also varies across the country with 82% of the water resources in the north considered good quality, 48% of that in the center and only 3% in the south.

These inequalities in quantities and quality make water management more difficult and explain the need to transfer surface water from the north to the Sahel and the south in order to improve the drinking water supply and insure equity between regions.

Groundwater potential

The groundwater resource is estimated at 2000 Mcm, confined within 212 shallow aquifers containing 719 Mcm and 267 deep aquifers. It is estimated that 650 Mcm of this resource, located mainly in the south, is nonrenewable.

Like surface water, groundwater is characterized by unequal allocation and variable quality in terms of salinity. Groundwater is distributed as follows:

- The north has 55% of the shallow groundwater resources and only 18% of the deep groundwater resources
- The center provides 30% of the shallow resources and 24% of the deep resources
- The south provides 15% of the shallow resources and has 58% of the deep resources.

Good quality groundwater is found in only 8% of shallow water and 20% of deep aquifers. If one accepts that salty water up to 3g/l can be used in the agricultural sector and for the production of drinking water, then approximately 36% of groundwater resources are not suited for these two sectors which are in increasing demand.

Another phenomenon, which highly affects the quality of water, is drought. In periods of drought, the salinity of the water stored in shallow aquifers can reach 3.5 g/l due to overdraft as resources are drawn down for both drinking and irrigation.

Total water resources potential

Water resources in Tunisia are estimated at 4700 Mcm including 650 Mcm of nonrenewable resources or 13.8% of the total water resources. Groundwater resources represent 42.5% of the total potential. Thus, the per capita endowment is at about 450 Mcm per year. This ratio will reach 315 Mcm per capita per year in 2030. This ratio is higher in other Mediterranean countries such as Morocco with a ratio of about 1083 or Algeria, with a ratio of 655.

WATER DEMAND

The main water uses are irrigation, tourism, industry and drinking water, totaling a combined annual volume of 2528 Mcm.

The demand for irrigation is 2115 Mcm, or 84% of the total allowances, making agriculture by far the largest water consumer. For this reason, considerable efforts have been made through several reforms to set prices for water, to develop water saving programs and to encourage water saving technologies by establishing financial incentives and by penalizing waste, to actively involve users in water management through setting collective interest groups, and finally to value non conventional water by reusing the treated sewage water.

In addition, the demand for water for the domestic, tourist and industrial needs continues to increase. Drinking water demand was estimated at 290 Mcm in 1996 and is projected to reach 491 Mcm by the year 2030. The water demand for industry is also projected to almost double between 1996 and 2030 going from 104 Mcm to 203 Mcm.

With 1298 km of mostly sandy shorelines, the tourist sector has seen a tremendous increase over the last decade. The number of hotel beds increased from about 150,000 in 1996 to 214,319 for the year 2002 within 777 hotels (ONTT; 2004). Water demand in this sector was estimated at 19 Mcm in 1996 and is projected to reach 41 Mcm in 2030.

Further, there is a significant spatial variability in water demand. Water consumption is greatest on the coastal areas whereas water resources are primarily found in the north and eastern interior of the country. Nearly two thirds of the population is located on the low plains of the Mediterranean coast. One third of the manufacturing industries are located around Tunis, with the remaining being spread between the north and the southern part of the coastline. The richest and most fertile soils are located in the north where the coastal plains and valleys are used to produce wheat, barley, tomatoes, vegetables and grapes and in the Cap Bon peninsula, which produces oranges.

This situation requires the transfer of water from centers of production; mainly from the northern part where the surface water resources are available to the centers of demand, mainly located in the coastline.

WATER BALANCE

Meeting the increasing demand for water while accounting for the space and time imbalance of water quantity and quality makes water scarcity one of the most urgent problems of the country.

From the information given above, it can be easily derived that the water balance will be negative in the near future. The projected volumes for the year 2030 show a strong water stress warning by comparing exploitable water volume of 2732 Mcm to the water demand volume of 2760 Mcm. The use of the reclaimed water becomes necessary to fill the water deficit of 389Mcm.

The exploitation index of renewable resources, the degree to which renewable natural water is exploited, and the vulnerability of the country as regards cyclical shortages is estimated at 57 % for the period of 1990 to 1997 (Blue Plan, 2000). Above 50%, this index reveals high pressure on renewable fresh water resources and indicates the need for rationalizing the management of water uses and demands. It highlights the need for Tunisia to adjust policy on water availability and demand.

WATER MASTER PLAN FUTURE STRATEGY

Faced with a water deficit with respect to the mobilized resources, the strategic choice was to move from increasing water production to demand management by financial means, water pricing, new techniques, legal and institutional mechanisms.

The Tunisian national strategy centers around three major points:

1. **The management of the demand**: a question of preserving the resource, ensuring economic efficiency, and preserving social equity by a good water distribution
2. **The integrated management of the resources**: the use of groundwater during periods of drought, the recharge of groundwater to face problems of overdraft and degradation, and the use of treated waste water and brackish water
3. **Resource and environmental protection**: quantitative conservation through reinforcement and improvement of water capture and storage, qualitative conservation of water resources and ecosystems through pollution reduction, monitoring, and cost evaluation

With regard to demand management, some reduction targets were set as objectives for the year 2010: 30% for agriculture by improving of the systems of irrigation, replacing some of the hydraulic structures and modernization of the distribution network; 20% for industry by recycling, improving the production processes and the introduction of clean technologies; and 27% for drinking water by the use of modern equipment.

With regard to integrated water management and protection of the resource, the goals were as follows:

- Make use of reclaimed water in the agriculture and industrial sectors
- Evaluate groundwater recharge potential
- Desalinate brackish groundwater for drinking
- Promote the use of agriculture species tolerant to salinity and hydraulic stress
- Protect water bodies from pollution

In order to ensure equality of water distribution, improve drinking water quality and set up a short and long term strategy for water storage, transfer and economical management of the various interconnected catchments, the Ministry of Agriculture invested in devising a digital master plan to simulate and compare water resource needs for the different sectors to the available water for different time horizons. The model is based on the introduction of projected cases of production and usages. Thus, the simulation can take into account several criterion to determine the water balance: (1) the demand development perspective by considering several trends for each sector of demand, (2) the initial storage in dams and the available resources in groundwater, (3) the type of the hydrologic year defined by the manager as being average dry or wet, (4) the possibility of mixing water with different salinity coming from different water bodies, (5) planning horizon and time step simulation.

The almost 10,000 types of simulated scenarios lead to the development of regional water balance maps indicating regional shortages and deficits. Further, this tool was used as a decision support system to plan for the construction of the remaining dams and the additional mobilization infrastructures in order to prevent water shortages until the year 2030.

ADDITIONAL CHALLENGES

Tunisia will shortly be confronted with the problem of a water deficit between its consumptive uses and its water productivity. Conscious of this problem, managers and policy makers are giving particular attention to improvements in water supply and mobilization programs, to enhancements in water productivity with an integrated management perspective, to promotion of treated sewage water and its development, and to controlling the different economic sectors of water demand and protecting the available resources from losses and pollution.

The transfer of water, intended to correct spatial distribution variations and to reduce the gap between resources and demand by giving priority to drinking water, will reach its limits by the year 2030. The rate of mobilized water will reach 95% in the year 2011.

To ensure sustainable socio-economic development, the current action plans need to be continued and others need to be initiated. Several general challenges need to be faced:

- More attention is needed to develop integrated water and quality management approaches taking into account both surface and groundwater and through the use of adapted modeling and sophisticated decision making tools. It is not a question any more of taking into account water production and its quality in the two compartments independently (surface water, groundwater), but rather the quantitative and qualitative aspects of each of these compartments should be integrated. Conjunctive management of groundwater and surface water is being used in dealing with urban water demand in drought periods. This experience should also be extended to the wet years and applied to agricultural water demand.

- Given the specific characteristics of rainfall and its periodicity, the development of new ways of flood management, through appropriate water and soil conservation or recharge techniques, will allow for additional storage. Real time management could also add to a better management scheme and additional resources.

- The use of reclaimed water will contribute significantly to the Tunisian water balance. The development of this source of water requires a specific action plan. The planning and management of this resource will be based on real demand rather than on a bulk volume of available water. Pilot projects in different activity sectors such as agriculture and industry are still needed to assess the technical, economic and financial feasibility. Applied research is needed to further study the potential negative impacts on the environment and public health.

- Agriculture is the largest water consumptive center of use. Therefore, any opportunity for water conservation in this sector will help preserve significant water resources. Reducing the distribution losses within the irrigation and drinking network is among the priorities of the water saving program. Yet, more attention should be paid to the local soil and plant characteristics. Understanding the vulnerability of soils and plant to salinity and to hydraulic stress could translate into improvement in soil moisture conditions, adequate drainage systems design, reduction in water intake and optimal farm environment.

- Protecting the hydraulic structures and water reservoirs from sediment buildup will be a continuing challenge. A ten year water and conservation program was established with the objective of recovering additional water resources and protecting large reservoirs from rapid silting and losing their valuable storage capacity. The Tunisian program is based on the construction of 1000 hill-dams, 200 mountain dams and the reforestation in the watershed behind the major reservoirs.

- Technical research should play an important part in these pressing issues: finding the appropriate agriculture techniques to confront water scarcity and poor water quality; evaluating the real potential and vulnerability of aquifers and their possibility of recharge; finding alternative sources of water storage and supply; and defining the real potential and limits of reclaimed water.

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Water in Tunisia: A National Perspective

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Introduction

Water resources in Tunisia are characterized by scarcity and a pronounced irregularity. By adopting an integrated strategy for the use of water based on scientific and technical studies, Tunisia has been able to develop a complex and diverse water infrastructure allowing the country to mobilize and exploit available water resources. At the same time, Tunisia has put in place systems and legislation to assure access to drinking water for the majority of the urban and rural population and to provide supplies for agricultural irrigation, as well as the industrial and tourism sectors.

Exploitation of conventional water resources is very advanced and it is expected that water demand, driven by population increases and improvements in living standards could reach its maximum around the year 2030. Aware of this problem, Tunisia has decided to enact a strategy to develop its water resources. This strategy is based on the judicious allocation of a limited and costly resource and the management of the country's growing demand for water. Effective management of water resources depends on continual monitoring and control as well as the implementation of reforms in the water sector.

These reforms have permitted Tunisia:

- To encourage the valuation of water resources and to fight waste and mismanagement in pricing water for drinking, irrigation systems, and urban demands gradually bringing the price of water closer to its real economic value
- To develop a system for water conservation in the drinking water and irrigated water sectors using technical instruments and financial incentives
- To encourage primary users to form cooperatives that help to control costs and assure greater efficiency in the use of water

Despite the scarcity of water resources, Tunisia has adopted a water policy that has permitted:

- The development of conventional and non-conventional water resources and better control of demand in all socioeconomic sectors based on an integrated and flexible plan
- The development of a system of irrigation zones allowing the country to maintain a stable, growing and sustainable agricultural system
- Minimization of the negative effects of the dry climate on the users
- Assurance of an equitable division of water resources for all regions in Tunisia allowing the majority of inhabitants adequate water resources

Thanks to the use of water policies and innovative reforms in the water sector, Tunisia has been able to assure food security and improve the quality of life in the urban, rural and Saharan zones while satisfying the needs of the industry and tourism sectors and still respecting, as much as possible, ecosystem limits.

Development of Water Resources in Tunisia

Aware of the problems engendered by charging for water, Tunisia has developed voluntary policies to support the control and the valuing of water resources. Considerable efforts have been deployed to develop all water resources using a variety of means (dams, collinear dams, collinear lakes, emission of sewage waters, desalination, drills, surface wells, treatment of used water, recharging water tables). Several geographic zones are connected by a system of regional canals and locks.

During the last ten years (1990-2000), a strategy was devised and implemented to provide integrated control of potential water sources. The cost of this ten year strategy approached two billion dollars. Modeling has been used to demonstrate the working of several water systems in place. This modeling simulates all possible resources and system demands. The simulation model illustrates potential conflicts caused by the need to satisfy water demands and suggests the appropriate timing of activities to provide additional water resources.

In 2003, Tunisia had 27 dams, 180 collinear dams, 600 collinear lakes, and more than 4000 deep wells and 150,000 surface wells exploiting 86% of total conventional water resources. These proposed projects will permit the development of 90% of conventional water resources by the year 2010. In order to increase the water potential in the country, the use of non-conventional water resources, such as treated waste-water and desalinated briny water, is being encouraged. At the same time, the exploitation of water resources is being managed by better allocating the scarce resource. In addition, the protection of coastal aquifers against the intrusion of salt water is reinforced by regulations.

In summary, the exploitation of conventional water resources in Tunisia is very advanced. It is projected that total water demand, due to population increases and increases in living standards, should reach its limit by the year 2030. Conscious of this problem, Tunisia is engaged in formulating a strategy to more fully develop its water resources and to meet the demands of the various socio-economic sectors. The strategy focuses on demand management and integrated planning systems. The cost of developing additional water sources continues to grow. Management, maintenance and system improvements require substantial investments, effective management and technological improvements. The management and exploitation of hydraulic systems in Tunisia must withstand the scrutiny of users who demand more and better performance at minimum risk. Therefore, public and private management must adapt to the new structures and the users must adjust to the need to make prices reflect new system costs.

Use of Water Resources

Irrigation constitutes the largest consumer of water in Tunisia, using 80% of the total water potential in the country. In 2003, agricultural land accounted for about 370,000 hectares. The phreatic water levels irrigated over 150, 000 hectares, while the deep levels irrigated over 70,000 hectares, for a total of 220,000 hectares. Dams irrigated 130,000 hectares, treated wastewater served to irrigate 7,000 hectares, and the rest is irrigated partly from pumping directly from temporary water sources and partly from natural sources.

The volume of water used for irrigation is estimated at 2,100 million m^3 (cubic meters), with average consumption per hectare of approximately 5500 m^3/year. Consumption reaches 20,000 m^3/hectare/year in the oasis in the South and is on average about 4000 m^3/hectare/year in the North. The amount of irrigated land is expected to reach 400,000 hectares in 2010. Irrigation supports 55% of total agricultural production and 25% of export crops and only represents 7% of usable agricultural lands.

In 2003, 260,000 hectares (70% of the total irrigated land) was equipped with water conservation systems including drip irrigation, sprinklers, pipes and watertight channels. The remaining 100,000 hectares are programmed to be equipped around 2010. A group of collectives (AICs) manage 135,000 hectares of irrigated lands. These associations are responsible for the maintenance of the irrigation network and the distribution of water to their members. Drinking water in metropolitan areas is managed by a national company that distributes 350 million m^3 per year to meet the needs of 1.5 million subscribers. The volume is expected to increase to 450 million m^3 by 2030. In rural areas, the administration of the drinking water distribution system is handled by cooperative associations (AIC).

Conflicts between various water users will become more acute in the future. There will be pressure on the agricultural irrigation sector to transfer water to the urban, industrial and tourist sectors; the agricultural sector will need to compensate by strengthening water conservation efforts and water efficiency programs. The small traditional farmer will have problems despite government subsidies which may only postpone their economic failure.

Management of the Extremes: Drought and Flooding

Drought is a current and periodic phenomenon in Tunisia, and it is taken into account in all the plans and development programs. Drought can cover one or more regions while being seasonal or annual and it can last two or three successive years. In the last decade, Tunisia has succeeded in overcoming many of the difficulties associated with drought due to strong water management programs, irrigation controls, and a set of effective socio-economic policies.

A practical guide for managing the effects of drought, written in 1999, is based on historic experience in Tunisia as well as on contemporary experiences at the national and international levels. This tool alerts the different institutions concerned with drought to take all necessary precautions and actions to mitigate the effects of drought and to minimize disruptions in the economy. The principal objective of the strategy is to protect vital resources--- water, livestock, orchards, roadways, and forests--- in order to assure drinking water and to support agriculture. Tunisia also experiences exceptional flooding, where water quantities can quadruple. Hydraulic infrastructures limit damage and make use of surpluses. Surpluses are used to refill different water tables.

Reuse of Treated Wastewaters

Since 1960, Tunisia has engaged in studies and demonstration of the re-use of treated wastewater. Currently, 7000 hectares, planted primarily with orchards and for livestock feed, use treated water for irrigation consistent with national law. With expanded urban development and land development, the volume of treated wastewater used is expected to grow to 450 million m^3 in 2030, equivalent to 10% of the total conventional resources of the country, permitting the irrigation of 100,000 hectares.

Thus, recourse to treated wastewaters, in areas where demand is highest and quantities are limited, will be encouraged to respond to increasing demand in the irrigation and industrial sectors. In addition, it is important to point out a pilot program to recharge water tables, which is taking place in the Cap Bon region, to assess the usefulness and the acceptance of wastewater extension and use. The use of treated wastewaters from large urban cities like Tunis, Sousse, and Sfax requires large storage capacity and transfer from these centers to areas with resources of lesser quality. The reuse of treated wastewaters in irrigation takes place with strict controls and sanitary procedures consistent with established norms.

Recharging Subterranean Aquifers

Management that integrates groundwater and surface water resources by artificial recharging from surface water resources during surplus periods is an important component of the country's water management plan. Seventy million m^3 were artificially recharged in 1996 and the volume will increase to more than 200 million m^3 per year by 2030. Water will be diverted from barges and hillside reserves. Given the irregularity of surface water availability, ground water must be used to meet needs during dry years. Excess surface water during wet years is then used for artificial recharging of the aquifers that have been overexploited in dry years, thus avoiding negative effects on the aquifer and degraded water quality. In this area, Tunisia has gained a rich technical experience in a program that consists of recharging zones where underground water resources are over exploited with excesses from zones where surface water resources are plentiful. The cost of recharging is high. Water users appreciate and understand the value that recharging offers and are willing to pay the cost.

Limiting Siltation in Dams

Tunisia is characterized by an arid climate, with varied relief, light vegetative cover and torrential rains. It suffers from soil erosion, which results in dam- clogging mudslides at a rate of 0.008/year. Monitoring of potential mudslides near dams regularly takes place. The sloping basins are continuously protected to minimize siltation and to extend the dam's useful life. The degradation of soils in the sloping basins varies between 0.3 and 2 mm per year. Programs to conserve water and reforest areas near dams will extend the life of these facilities. The observed results on various reservoirs in use have permitted the evaluation of the lifespan of each reservoir.

Desalination of Briny Waters and of Seawater

Tunisia has briny water tables, situated essentially in the south of the country. Reverse osmosis has given this potential water source increased value by making it available for drinking water. Total desalination capacity for drinking water is about 80,000 m^3 per day. The desalination of seawater offers a long-term alternative source of drinking water which could contribute as much as 50 million m^3 in 2030. Thus, desalination of briny and sea waters constitutes an alternative that is more and more attractive as a source of drinking water in areas where water supplies are limited and do not meet standards, notably in the center and the south of the country.

Four important desalination plants operate in Tunisia: Kerkennah (1983), 3300 m^3/day; Gabes (1995), 22,510 m^3 per day; and two stations in Jerba-Zarzis (1999), 12,000 m^3 per day each. Sixty smaller plants serve the industrial sector. In addition, the water law was extended in 2002 to permit private industry to produce and distribute desalinized waters in tourist and industrial zones when natural water is insufficient. Investments in this sector are encouraged by a set of specific subsidies.

Water Pricing

The water pricing system in Tunisia is progressive, charging by quarterly consumption, and incorporating a fee for sanitation. The first quarter is considered necessary to meet basic human needs with consumption not surpassing 20 m^3 per quarter. The last quarter considers consumption surpassing 150 m^3 per quarter. The cost of a cubic meter of the last quarter represents 6 times the cost of a cubic meter of the first quarter. The price of drinking water is uniform throughout the country and is not seen as an obstacle to development. Drinking water charges allow for the recovery of operating and maintenance costs as well as capital investment in hydraulic systems.

Irrigation water use is subsidized by about 30%. Charges cover the cost of utilization and maintenance. Equipment renovation and the largest 50 repairs of the infrastructure are covered by the State. Reforms in the irrigation sector will be put in place and strengthened over the next few years to help alleviate the cost of the function and maintenance of irrigated lands, to encourage conservation and maintain the value of irrigated waters. Progressive pricing is used to manage demand. It prolongs the terms of investment, encourages water conservation and prevents waste. Studies conducted on progressive pricing have shown the sensitivity of users to changes in the price of water explaining the decrease in relative demand observed during the last years. The reaction of large consumers is particularly important as a tool for dampening demand. For small consumers, the response to price changes is weak because water is a basic need.

Rural Drinking Water

Meeting the drinking water needs of rural residents is a political imperative for Tunisia, especially in disadvantaged areas. Demand will reach 60 million m^3 in 2030. Access to water in rural areas increased from 31% in 1987 to 82% in 2003, following efforts to improve conditions of life in this area. The objective of the national program is to increase coverage to 90% in 2006 with minimum coverage of 80%. When this objective is met, the cost per serviced inhabitant will increase from 400 dinars to 600 dinars to provide service to extremely dispersed residents. Individual wells, which are a well-established tradition in Tunisia, will be encouraged across the country. The maintenance of wells is controlled by the health services. The rural population is expected to stabilize between 3.2 and 3.5 million of which 825,000 will still need to be serviced in 2020. For the most dispersed population, private and mechanical cisterns are encouraged. Increased rural drinking water consumption has led to the creation of sanitation and resource protection programs. The construction of latrines, septic systems and wells will be encouraged and will improve hygiene conditions for 80% of the rural population. Source water protection is the responsibility of the health service. The management and maintenance of water infrastructure is carried out by 1500 cooperatives.

Reforms in the Legislation and Administration of Water

While exploring new water resources, Tunisia has already broached several reforms in the water sector that led to the introduction of demand management policies. Government officials in Tunisia have been involved in water related activities since September 25, 1885, when the first water decree was issued. The government's role in the water sector was confirmed by the decrees of 1933, and 1936, which were then replaced by the 1975 water code, which has been updated every time the technical or economic conditions demanded it.

Before reaching its full water potential, Tunisia instituted an important change in the management of its water resources. This change is based on the allocation of a limited resource and the management of its growing demand. The administration of water resources in Tunisia relies on the continuous monitoring of water resources - surface water, subterranean water, treated water, and the development of technical tools that help with decision-making (for example, the propagation of vineyards, the reduction of water levels, the recharging of aquifers, desalination, the intrusion of sea water, etc.) The administration of water in Tunisia has required several successive reforms, whose objectives were:

- To encourage the valuation of water resources and to fight against all types of waste and corruption created by pricing systems adapted to the drinking water and irrigation sectors
- To develop a program of water conservation in the drinking water and irrigation sectors by monitoring and controlling consumption
- To encourage the participation of users in the management of collectives to control and improve efficiency
- To give value to non-conventional water resources by reuse of treated wastewaters in agriculture and desalination of briny waters for drinking water needs.
- To protect the quality of the resources against pollution using a widespread purification program
- To adopt water and soil conservation programs to reduce erosion and to increase aquifer recharge

These reforms have been discussed for a long time at many levels and in concert with the beneficiaries. The reforms introduced by the water code of 1975 included several actions to encourage water conservation and protect water resources. In 2001, new reforms were introduced classifying water as a national resource that everyone must preserve, protect, and use in a lasting manner to satisfy the needs of citizens and the economy. The largest consumers are obliged to audit their use periodically (more than 5 million m^3 per year in agriculture, more than 1000 m^3 per year in the urban sector and 5000 m^3 per year in the industrial sector). Consumption quotas are imposed during periods of scarcity. The development of non-conventional water sources (desalination and treatment of wastewater) is encouraged, allowing individuals to produce water and distribute it for their own consumption.

Management and Equity

In Tunisia, investments in the water sector are designed to assure an equitable distribution of water resources. Small water projects (surface wells, hill lakes, hill dams, diffusion projects) are found in practically all the country. This explains the maximum cost of high mobilization from phreatic water levels (100%). In addition, the transfer of water and the interconnection of basins due to the North Water Plan Director's project have permitted better division of water resources across the regions of the country.

Delays in improving access to drinking water in rural areas were overcome during the last few years, as service increased from 30% in 1986 to 82% in 2003. The pricing of drinking water assures an equitable allocation between the different levels of consumption. In fact, the transfer between sections is estimated at 20 million dinars per year. Thus the benefits of the country's water infrastructure are shared among all the regions of the country and most of the citizens.

Management of Water Resources and the Integrity of Ecosystems

Assessments are carried out to identify needed actions that will safeguard the integrity of ecosystems and biological diversity. Ecosystems in dry countries are very sensitive and fragile. Monitoring of water levels, control of exploitation, and the establishment of protected areas all help to limit overexploitation and salt water intrusion. Impact studies of dams have led to the identification of mitigation measures to safeguard the hydro-geological and ecological equilibrium for upstream and downstream waters.

Protection of vital ecosystems will have growing priority with increased water use.
It is evident that in the dry countryside, mitigation measures are difficult to design and costly to implement. Mitigation measures must be carefully evaluated to improve complementary interventions and to avoid irreversible degradation. The participation of multidisciplinary research teams with the universities is highly encouraged in Tunisia as a means to identify approaches that will lead to more sustainable development.

Water Resource Development

The determination of the capacity of a resource depends in large part on a firm understanding of its specific potential. Thus, careful evaluation of the resource is essential in water development projects. In Tunisia, the General Directorate of Water Resources is responsible for the evaluation of groundwater and surface water resources. It is also responsible for assessing the potential water resources. It manages a network of measuring stations (pluviometric stations, hydrological stations, piezometric stations) covering all the lakes of the country, as well as an information center and tools for the study, simulation and analysis of aquifers and river beds of Tunisia. Existing studies allow for the planning, execution and the management of projects. The limited capacity of the resource is fixed based on these evaluative studies.

Thus, in order to maintain existing oases and allow for the creation of new oases in the south, capacity limits were established for the two major underground aquifers in Tunisia, the Complexe Terminale and the Continental Intercalaire (CI). The latter, CI, is one of the largest aquifers in the world, covering 600,000 km^2 beneath Tunisia, Algeria, and Libya. As a result of this regulation, withdrawal quotas have been determined for existing oases (0.7-1.0 L/s) and surface area quotas were established for new oases. The limited capacity of each phreatic water level limits the number of exploitable wells. If the limited capacity is reached, a suspension or safeguard decree is issued. The quota for allocation from large dams to each beneficiary is fixed. During dry spells, allocations between drinking water and irrigation are managed by the Minister of Agriculture. However, note that the limited capacity is exceeded in some local limited zones. These cases are very instructive because they show the breadth of negative effects when the limited capacity is exceeded in coastal aquifers.

Management of Demand and Integrated Planning

The increased exploitation of natural resources in response to demand growth can only lead to disequilibrium. This disequilibrium constitutes a severe constraint for economic and social development and can lead to decreases in living standards and the loss of productive systems. In order to manage the situation, preventative actions must be taken to diminish the severity of the disequilibrium. In Tunisia, data relative to the availability of water and to the use of water resources is sufficient and therefore action may be taken in the management of this disequilibrium. Furthermore, extraction in Tunisia does not yet surpass the renewable resources except in some very limited and circumscribed zones. The global situation is not yet disturbing and will not be during the next 20 years according to the elaborated prospective study, "Economy of Water 2000." In Tunisia, 84% of water resources are used by agriculture. The demand for water in medium and large urban centers is rising on average 2.5% per year. Improvement of agricultural efficiency will lead to the engagement of additional resources beyond newly mobilized resources in the future.

The interconnection of large networks of aqueducts in different regions of the country improves the capacity of the system to compensate for deficits in one area with excesses in others. This means of managing allows a better balancing of supply and demand. In the future, balancing supply and demand will depend more on the rational management of demand, because development of new resources (dams, recharging of aquifers, recycling water, desalination of water) will be more difficult and costly. The management of water demand in Tunisia has taken several forms. It has been considered a part of the master plan of water use and implemented in the development of projects with the introduction of a quota and restrictive technological tools (capacity of pumping stations, limits on building in tourist and industrial zones, surfaces of irrigation zones). However, the almost-urban escapes this planning, perhaps because the dynamic programs of rural development have limited scope. In Tunisia, the use of water changes in the urban and agricultural domains has helped to better manage demand and to better set value to the resource. In addition, public information campaigns have made citizens more conscious of this resource and of the need to better protect it.

Demand management, as demonstrated in the case of Tunis and in irrigated areas, has proven effective and is likely to become more and more necessary to rationalize the use of water resources and to assure their long term availability. Demand management has been supported by judicial tools. Thus, the water code of 1975 permits central and regional public services to manage the resource by issuing authorization, establishing zones of safeguard and of interdiction, and controlling the management of water sources. In Tunisia, the coverage of the country was determined by the Regional Master Plans, integrating the homogeneous hydrographic basins: North, Central and South. Furthermore, regional master plans for rural drinking water covering each administrative unit have been established and have helped to improve access to safe water in rural areas. All the water development projects have been carried out, are being carried out or will be within the framework of these master plans, of which several are currently being completed.

Long Term Strategy for Water Management

To manage the water sector, Tunisia has developed a long term action plan. This plan allows the country to estimate water use 20 years in advance. This action plan, in addition to demand management programs, defines measures that permit technology to preserve, protect and conserve water resources and to develop new conventional and non-conventional resources.

Tunisia has conducted studies of the water sector, with a time horizon set at 2030. Several technical and socio-economical studies have been undertaken so the country may develop action plans and interventions to meet evolving water needs, allowing economic and social growth.

CONCLUSION

Thanks to the adoption of rational and modern management of its water resources, Tunisia, despite the scarcity of its water resource, has been able to develop its agricultural and economic sectors linked to the water resource in a sustainable manner. In the long-term future, all residents in both the cities and villages will have access to drinking water. Agriculture, which consumes 80% of natural water resources, has adopted a modern distribution system using water conservation and water reuse, attaining 20% artifical recharge in response to water and soil conservation projects, dams, and collinear lakes. The strategy of water resource mobilization and use constitutes an essential component of the economic and social development of Tunisia.

This strategy assures the security of food supplies, improves the quality of urban, rural and Saharian life and assures water supplies in the industrial and tourist sectors, while respecting the limited capacities of the ecosystems. It guarantees the continuity of exploitation of the resource while encouraging a larger participation of users in its management. This strategy integrates the management of surface and ground water resources as well as natural and non-conventional resources; and has set in place a mechanism of the optimization of water use through the efficiency of use, water conservation, reduction of loss and waste and the protection of water sources.

Participatory Irrigation Management: A Case Study from Turkey

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In 1993, State Hydraulic Works (DSI), the main agency responsible for large scale water works initiated a program to transfer management responsibilities to users, with support of government and World Bank. With the transfer of operation, maintenance and management responsibilities, financial responsibility for routine O&M expenses were also taken from the state. This amount can now be allocated toward state irrigation investments (ERDOGAN, F. C. 2003). Water Use Associations (WUAs) manage 91% of irrigation systems constructed by DSI. Performance indicators such as irrigation ratio, irrigation efficiency, collection rate of fees and others are now better than before the transfer programs. Although the transfer program has encouraged good management, operation, and maintenance of irrigation systems, some problems have been seen regarding administrative, legal and managerial aspects of WUAs. Judicial problems are currently among the key problems, especially in the GAP (South Eastern Anatolian Project) region. In addition to those problems, political and coordination issues need to be solved. Some problems which are common in almost all Mediterranean countries include weak coordination among institutions dealing with irrigated agriculture and few qualified technical staff, major constraints to sustainable water resources management.

Another problem is the inappropriate use of technologies that result in inefficient irrigation and maintenance systems (KORUKÇU, A, 2003). In order to achieve efficient coordination and management of irrigation, committees at the regional level should be established to set priorities for irrigation investments considering local conditions while ensuring the full participation of users. The committees could serve as a kind of bridge to convey problems from the ground to decision makers and provide feedback and support to the WUAs in the process.

Participation of farmers should be considered the most essential factor for better management of irrigation systems. Although, substantial efforts are given to participation during the transfer process, participation should be encouraged earlier in order to create ownership among farmers. At the present time the participation of farmers starts with completion of construction. Training of farmers on management, operation and maintenance should be carried out before the transfer process.

INTRODUCTION

Projects for the development of water and land resources are still the most important investment projects in Turkey. In order to obtain optimum yield from irrigation projects, appropriate planning, design, management, operation and maintenance are essential. Greater socio-economic development is possible by taking measures to increase the value of irrigation investments and for high quality and profitable production (OZKALDI, A., et al, 2003). Since water and land resources are limited, most of the effort should focus on efficiency. Although Turkey has a significant potential to develop water and land resources as compared with some other Mediterranean countries, there are important financial, physical and socio-economical constraints. Irrigation projects are costly to construct and require funds for operation, management and maintenance to achieve the goals and maximize agricultural benefits from irrigation.

Irrigation Development

There are two main agencies responsible for irrigation investments the DSI and the General Directorate of Rural Services (GDRS)). The responsibilities of this Directorate have been transferred to the Ministry of Agriculture and to governors where DSI is responsible for water resources with discharges larger than 500l/s. GDRS is responsible for discharges of less than 500l/s. DSI is in charge of the development of soil and water resources and putting these resources into use and for public benefit. DSI plans, designs, and constructs irrigation systems, and also defines general principles and policies for irrigation management. DSI either takes direct responsibility for irrigation management units or transfers the responsibility to other organizations. GDRS deals with land reform, on farm development projects such as drinking water and roads and transfers its irrigation system responsibilities to cooperatives. The irrigation area developed by the two agencies until 2003 is presented in table 1. As it is seen from the table, the biggest portion of irrigated area, 2,340,197 ha, has been developed by DSI where GDRS has developed 1,002,238 ha of land.

TABLE 1 Irrigation Development (01.01.2003), DSİ 2003

DSI	2 340 197
GDRS	1 002 238
Farmers and others	1.000.000
Total irrigated area	4 342 435

Administrative Structure of Water Use Associations (WUAs)

Since WUAs manage the biggest portion of irrigation areas (91% of the area developed by DSI is managed by WUAs), it is important to understand their organizational structure in relation to other organizations. WUA consists of several villages. DSI identifies WUA boundaries and prompts village administrators to apply by preparing the WUA statute in a standard DSI format and submitting it to the General Directorate of Local Administrations of the Ministry of Interior. WUA can make amendments in the statute by taking decision to the council. The Council (Figure 1), typically with 30 to 50 members, consists of mayors and village administrators (Muhtar) as 'natural members' and a number of 'selected members' depending on the service area. The Board committee typically has seven members. The General Secretary and Accountant are Board members, and the remainder are elected as Council members for a year. The Chairman is elected for one to four years term. DSI is an observer member during the election of chairmen.

The key actor is the General Secretary, as he is responsible for technical implementation and management of WUAs' projects. He is the second person in terms of ranking positions. He is expected to communicate with other institutions and organizations. One of the most important problems is the weak link among extension services, decision makers, and the final users in water management. There is need for institutionalization among all these stakeholders so that the problems can be transmitted to the decision makers through WUAs when they occur at the farmers' level, since the WUAs are the closest organization to farmers and work together with farmers on daily duties.

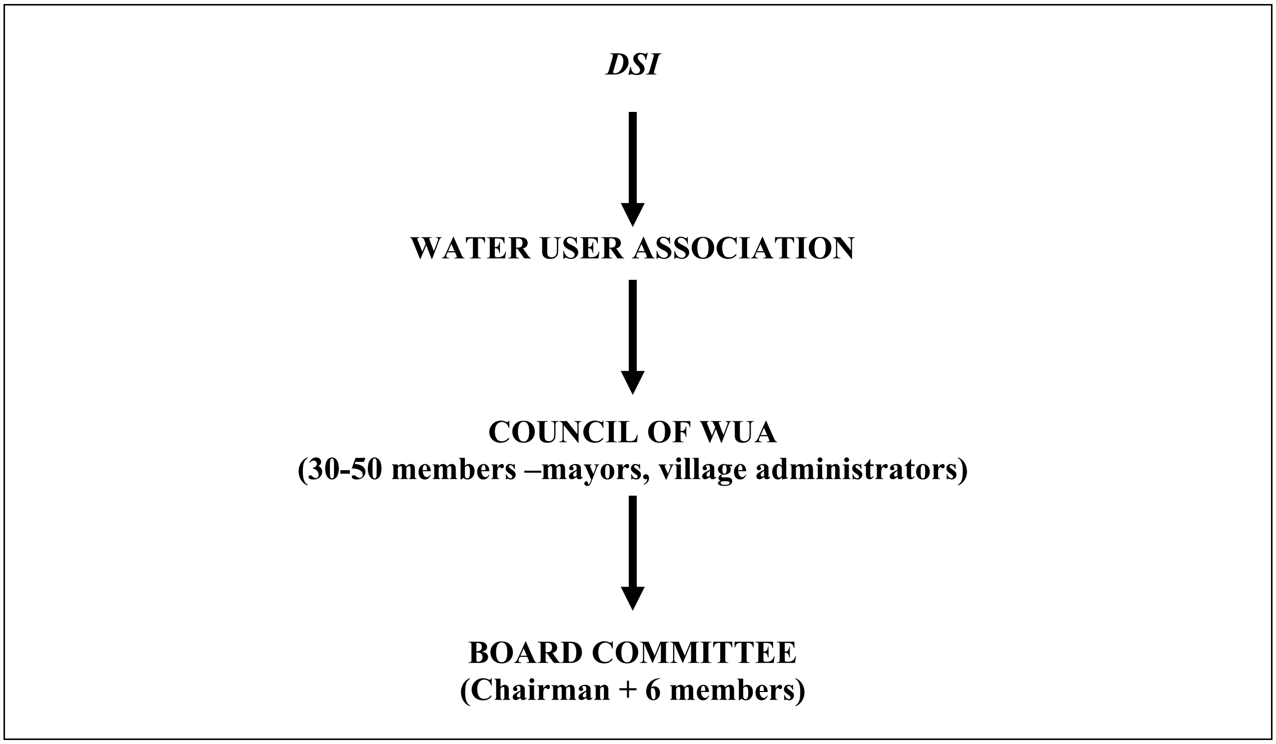

FIGURE 1 Water User Association.

Some Problems of WUAs

The main problem after transfer is inequitable water distribution for the first years. As WUAs get more experience, this problem decreases year by year. Inequitable water distribution occurs due to water shortages, mistakes made assessing crop water requirements, the impact of powerful big land owners, a tendency of chairmen to favor their relatives and mismanagement and inadequate maintenance work. WUAs in the western part of the country work more efficiently than some WUAs in the other parts of the country. The success of WUAs depends mostly on the chairman's management capacity. If the chairman is educated and has managerial skills, the WUAs work smoothly even when they have old irrigation facilities.

WUAs' staff needs training especially on water distribution and irrigation plans. Although they have some experience on these issues, they do not know some of the technical aspects of irrigation as in the case of Harran Plain. General Secretaries and water distribution technicians are very experienced in water distribution and regulating water in canals, but often they do not understand crop water needs at the beginning of season. Their entire water request depends on the size of the irrigated area not on crop patterns, thus they do not have true records regarding to water distribution. They measure water only when there are conflicts with DSI on allocated water and need to check with WUA from main canals which are under responsibility of DSI.

WUAs do not have monitoring systems that reveal problems and can improve planning for the future. They have records on budgetary issues and collection of water fees, but they do not have a management information system that can be used as database.

Inefficient use of water at the farm level is another problem. WUAs can not intervene with farm level activities as the nearest organization to farmers. The limited capacity of WUAs does not allow them to provide direct support to farmers at on farm level although some WUAs have written in their statute that they will support farmers in agronomic and crop protection issues. WUAs can be supported by providing staff that are available when needed, from governmental institutions. Thus, WUA can play a bridging role between farmers and institutions. In this regard WUAs can have an agricultural “extension unit” constituted within WUA office building.

Farmer participation in the transfer process is enhanced somewhere at the beginning of the establishment of WUA. Towards the end of the construction’s completion works, there is little time before irrigation. Although DSI puts most of its efforts on establishing of WUA rather then providing farmer participation in earlier stages before implementation, in some cases DSI contracts with construction companies for training of WUA staff on operation and management of irrigation systems, especially in pumping systems.

Most WUAs who have taken on responsibility for the management of new irrigation schemes do not adequately deal with system maintenance. They do not allocate the 30% of their budget to maintenance as is suggested in the statute. Instead they allocate something like 0.5-1.5% (BEYRIBEY; M, et al, 2003). They should be required to establish the operational and maintenance units within their framework.

Future Perspectives

Irrigation investments are carried out very slowly due to limited budgets. All investment costs are compensated by DSI at the present time. Since the government has budget constraints and can not allocate more money for investments, beneficiaries should share a small part of the cost after they take over the responsibilities of irrigation. They can collect this share together with water fees. The share compensated by beneficiaries could then be transferred to construction works.

There is no common solution for all regions. Each region may have different problems, different circumstances, and social structures. A national committee for each region should be formed to play a coordinating role between the national government and beneficiaries so that problems can be directed to the appropriate institutions and government. Agency participation of beneficiaries will be easier through national committees. Coordination is always a problem among related institutions and WUAs, as well as other organizations. It is also a problem in institutions that deal with irrigation issues. For instance, land consolidation and on farm development should parallel irrigation project implementation. GDRS having responsibility for on farm development and land consolidation may not have a sufficient budget to perform the work while DSI may have enough funds to continue construction work. Thus, farm development work may be completed long after irrigation systems are finished. In this case, irrigation efficiency becomes a serious problem.

Training of WUA staff remains an important issue not only for water distribution but also for irrigation at the farm level. Most training activities for WUA staff focus on water distribution purposes. Since WUA staff is among the closest people to farmers, they should be trained on irrigation at the farm level and on agronomic aspects. DSI could remain the trainer of WUAs for irrigation planning and O&M activities. The agronomic aspects are generally neglected.

DSI should lead the establishment of the federations of WUAs to manage the main canals. Management of the main canals is still hard work and may not be carried out by DSI. DSI should gradually move away from management of the main canals.

CONCLUSION

Turkey has been involved in participatory irrigation management activities for more than ten years. WUAs have gained experience in the management, operation and maintenance of irrigation systems. Now, they are faced with "second generation problems" stemming from legal and political constraints. In terms of water distribution and collection of water fees, WUAs do not have serious problems because WUA staffs have become more skillful and capable. Although it will not solve all the problems, the draft law for WUAs should be enacted as soon as possible.

Areas to be transferred should cover large areas that may not be more economical to manage. WUAs having responsibility for small areas with many farmers may not be able to cope with conflicts among farmers. Water fees are estimated based on an area principle, so that as the area gets smaller the income of the WUA gets smaller, and at some points that income may not meet expenditures. The biggest portion of WUAs' income comes from water fees (85%). The rest comes from member fees, fines and penalties. The last three items are not collected regularly, thus all WUA incomes generally come from water fees. As the service area increases the income increases.

Water pricing should be estimated in realistic ways and approved by the WUA councils. The WUA budget does not represent the real costs of WUAs (UNVER, O, Gupta, R, K 2002). At the present time, WUAs consider water fees of neighboring WUAs in their estimates so that they do not exceed the amount identified by neighbors; hoping to avoid farmers' complaints and allowing the reelection of the chairman. Thus, water fees often remain far below the real amount. Therefore, some WUAs are faced with budgetary problems. The estimated amount by WUAs should be ratified by DSI in order to have realistic prices.

Despite all of these constraints, Turkish experiences in participatory irrigation management can be a model for some countries. DSI has achieved the transfer activities without increasing the number of staff; in fact it has had a decreasing number of staff.

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Putting Science Into Action: From Washington State Community-based Outreach To National Programming In Washington DC

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Each time you pick up a newspaper, issues surrounding the availability, distribution and use of water are highlighted, often headlined. From explosive regional conflicts between urban demands and rural control, to the needs of endangered species versus traditional irrigated agriculture, to small town America's mining of groundwater supplies, U.S. citizens are regularly reminded that the nation's water supply is not limitless.

Globally, freshwater demands have tripled since 1950, while water supplies remain fixed. Demand is expected to double by 2035, leaving 48 percent of the world's population (2.4 to 3.4 billion people) living in water-stressed environments by 2025 (Pereira et al. 2002). Securing water to meet this growing demand has involved the improvement and construction of storage facilities and greater reliance on groundwater resources—both unsustainable over the long-term. Continued rapid growth of domestic and industrial water uses, growing recognition of the environmental demands for water, and the high cost of developing new water resources threaten the availability of irrigation water to meet growing food demands. A crucial question in the U.S. is whether water availability for irrigation—together with feasible production growth in rainfed areas—will provide enough food to meet growing demands and ultimately improve national and global food security. Simply put, do we continue to grow our own food?

> "The use to which we, as a society, put our water will come under increasing scrutiny and intensifying management as we move in to the 21st century. We will have to stretch our understanding, and apply our wisdom ever more creatively if our aspirations for the growth and development of our society are not to be constrained as a result of limited water resources." (South Africa's Water Policy quoted in NCSE 2004).

The World Water Council World Water Vision Commission Report (World Water Council 1998) suggested two approaches to water resource sustainability (i.e., bringing water supplies in line with demand): 1) improve technologies to provide "new" sources of freshwater such as desalination and/or inter-basin transfers—both fraught with environmental consequences and technical limits (Glennon 2005), and 2) provide greater efficiencies in water management and conservation. Both will be required to help provide equitable water distribution among all demands. In the U.S., the National Council for Science and the Environment (2004) developed nine major recommendations to enhance sustainability of global water resources. These recommendations promote developing new technologies for sustainable water management, closing the gap between science and policy in water resources, and integrating social and natural science efforts on sustainable water resources management.

The recommendations also highlight the need for education and outreach for sustainable water management. Education needs to extend to all levels (K-12 and post secondary) and include improved communication between the science community, the public, and decision makers. Both reports emphasize behavioral change towards water uses, and adoption of new and existing conservation technologies as a means to solving current and future water demands. "Water conservation and efficiency are the greatest untapped sources of water in this nation – cheaper, cleaner, and more politically acceptable than any other alternative" (Gleick 2003). Protection and improvement of water resources through technology adoption and behavioral change often require efforts of outreach educators that go well beyond being purveyors of knowledge.

This paper focuses on the changing philosophy of outreach education in water resources science and management expanding from knowledge delivery towards greater behavior change and adoption—the result of outcome-based logic modeling pervasive throughout U.S. government agencies and the land-grant university based Cooperative Extension Service (CES). To promote these expanded outreach efforts, we need to acknowledge existing knowledge gaps regarding (Rosengrant et al., 2002):

- The effects of shifting regional water use patterns on communities and ecosystems and uncertainty about the impacts on water supply from improved land treatment and ecosystem management;
- Identification of appropriate incentives such as agricultural water pricing reform that protects farmers against capricious changes in water allocation, ensures that they benefit from water conservation efforts, and provides a basis for water trading among farmers and across sectors;
- The ineffective and protracted dissemination of research to the farm;
- Unknown decision-making processes and a general lack of integrated decision support systems that plague appropriate water use at the farm level

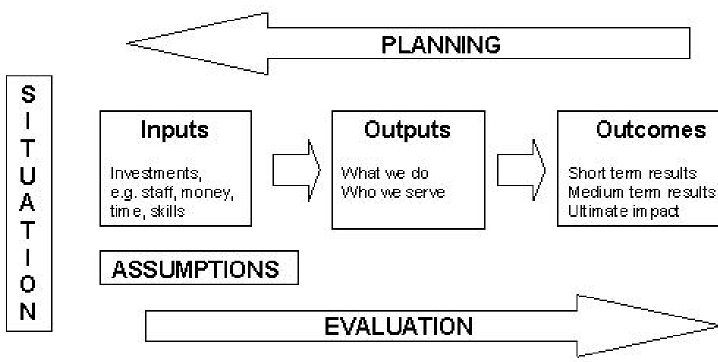

FIGURE 1 Agricultural Water Logic Model, McMaster University Health Sciences Library, Ontario, Canada, 2004.

In response to the need for greater research, education and outreach, the U.S. Department of Agriculture Cooperative State Research, Education and Extension Service (USDA CSREES) launched an initiative in 2004 entitled *Agricultural Water Logic Model* courtesy of McMaster University Health Sciences Library, Ontario, Canada (Dobrowolski and O'Neill, 2005). Agricultural water security maximizes the efficiency of water use by farmers, ranchers, rural and urbanizing communities, thus ensuring that water volumes are allocated for per capita domestic water consumption, ecosystem services, recreation and aesthetics while meeting the needs of food and fiber production. It requires an economic and social context, with a goal of sustainable agriculture—high yields coupled with well-being and water efficient farming that retains water volumes for ecosystem services and recreation. The initiative articulates agriculture in the urban environment through the linkage of urban farm-based irrigation and water reuse technologies. Part of the agricultural water security initiative focuses on the development of water saving practices typically at less cost and with far greater effectiveness than achieved by efforts to increase supplies. If engineering ingenuity is occasionally devoted to increasing water conservation, rather than focused on water supply augmentation, the returns could be extremely large. Some municipalities in the U.S. have found that $1 invested in watershed protection can save up to nearly $200 in new water treatment facilities (Johnson et al., 2001). The adoption of these new water saving technologies at the farm and householder level requires more than just "laying out the facts."

Vast amounts of educational materials exist for improving water conservation and water management, though much of this information requires adaptation to local watershed conditions. Some of these outreach concepts that are in place or need adaptation to other communities include:

1. Outreach to farmers, ranchers, and rural communities towards *adoption* of greater use of recycled water and crop substitution;
2. Place-based education—eliminating sub-tropical lifestyles and the farming of low water efficient crops in desert climates
3. Educating water managers in both rural and urban communities, as impacts of water supply will be disproportionately felt by lower income families;
4. Educating landscapers in rural, urban, and urbanizing areas on the use of drought tolerant trees, shrubs, and turf, reduced turf and lawn areas, use of drip irrigation and reuse of irrigation water;
5. Educating residential pool designers on development of pools that serve the recreational need and minimize water losses;
6. Educating the public (adults) using *adoption-outreach* techniques to promote behavioral change in the way rural and urban households and farms use or think of water efficient plants and other xeriscaping, low water use fixtures and appliances, efficient irrigation devices, water conserving practices and impervious surfaces. Techniques may include public service ads, incorporation of water supply reports as part of local weather reports, or campaigns to adopt water conserving toilets and showers; and
7. Educating the public (youth) by incorporating water conservation into the basic curriculum and creating "waterwise" school programs (Dobrowolski and O'Neill, 2005).

Adoption-outreach, the effort to turn value free and socially-neutral water knowledge and technology into behavioral change, is a significant challenge for outreach educators today. Adoption-outreach requires an expansion of knowledge and behavior through several stages that include a lack of issue awareness or denial, through non-committal issue acceptance, critical reflection on the issue with careful planning of potential actions, visible attitude change, and finally sustained behavior change (Prochaska and Velicer, 1997). Adoption-outreach moves people towards changing behaviors by providing appropriate and necessary information to the audience or stakeholders. It also creates and implements a shared vision of the nature of the problem and helps stakeholders to recognize that the chosen solution is correct. Adoption-outreach builds a sense of community and individual entitlement towards the quality of water resources. It reduces individual behaviors that prevent action, e.g., rationalizing destructive behaviors and denial, and it acknowledges the difficulty of implementation of practices.

Outreach educators must assist value-motivated citizens or politicians in deciding to what extent they make use of water conservation and use tools that have been generated by science and technology. Water concepts and methodologies developed by scientists cannot be viewed as "a siren's song," as suggested by Zoebel (2002), *complicating* the choices that farmers, decision-makers and citizens must make about what is economical and what is the wise use of agricultural inputs and rural resources. Farmers are now using many of the detailed methods for measurement and analysis that reductionist science has developed, as they seek integrative and dynamic understanding of physical and biological processes in agriculture. Maximization of both yields and water use efficiency has less meaning for farmers—the overall farm capital and labor must be maximized, rather than any single input like water use.

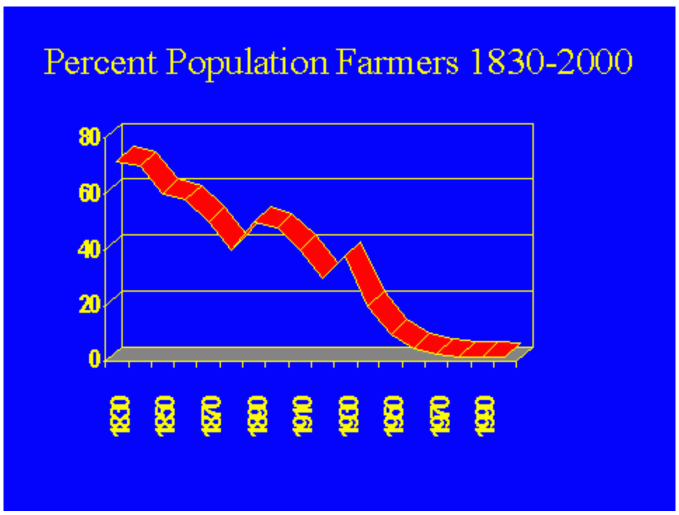

FIGURE 2 Stam and Dixon, 2002.

The number of farms and farmers continue to decline—altering the time-honored rural audiences for cooperative extension and similar outreach programs. Larger farms, corporate farms and an expansion of the number of smaller farms close to urban markets must shift the traditional emphasis on rural communities and agriculture to a linked system of rural, urban, and urbanizing communities and activities that influence water availability for all uses (Stam and Dixon, 2002). Reluctance of farmers and householders to grasp these water conservation opportunities often relate to relative input costs such as inexpensive or "free" water for both farm and urban users, urbanizing and rural landscape irrigation; conserved irrigation water that is difficult to lend, lease or sell leading to greater total consumption (Huffaker and Whittlesey, 2003); or the householder's inability to see the need or the risk.

Key questions for CES outreach educators working with adoption-outreach include:

> How does the CES effectively work to bring science to decision makers, producers and the public? And how does science benefit from the knowledge brought back from outreach professionals? It's supposed to be a two-way street—but does it really work? What about the credibility of outreach professionals in the eyes of research scientists?

And the credibility of research scientists in terms of their knowledge of state and national needs?

Some insights are required to understand the effectiveness of the present outreach process to promote adoption and behavioral change. Often, we cannot understand why our scientific discoveries and new technologies are not implemented or addressed (to both on-the–ground and administrative decision makers). We feel very deeply that as scientifically trained outreach educators, if we just provide these people with the facts, they would do the right thing, there wouldn't be a problem, we could have a rational discussion, and they would reach the right conclusion—and everything would be fine (Hallman, 2005). Defining the problem as an 'educational deficit' leads inexorably to the one true solution—we must be purveyors of knowledge and *educate people.* The concept of educational deficit is captured by the Education Deficit Model (EDM) and is really seductive to analytical people; given the same assumptions and data, there can be only be a restricted set of conclusions and actions. EDM deals with the formal contents of water knowledge and the methods and processes of water science and technology, but it neglects the context—institutional embedding, investment, organization and control (Wynne 1992). However, there exists abundant evidence from behavioral research that the correlation between knowledge and action rarely exceeds 0.20 (Hallman et al., 2004). New information is often twisted in ways to support existing beliefs, decisions, and actions; people know the 'facts' about smoking and continue to smoke, know that diet influences obesity and continue to be overweight. Marketing evidence shows little response to knowledge of the facts towards a purchase—when was the last time we were swayed by advertising or labeling (Wasink 2003, Hallman, 2005)?

A lack of knowledge is only one of several barriers limiting progress towards behavioral change (McKenzie-Mohr, 2000). Barriers to progress towards pro-social behavior can involve a lack of motivation, prerequisite knowledge and skills required for a specific action, little expectation of success or impact, habit or routine, nonexistent supporting attitudes and public policy, community norms that result in inconsistent behaviors in public versus in private, few mechanisms for social pressure or disapproval, missing or unknown economic incentives and inappropriate cultural models that block or inhibit the understanding of cause and effect among others. What alters people's behaviors may be more closely tied to perceived risk rather than the information an outreach professional might provide. There are often large discrepancies between the risks experts worry about (e.g., a global water crisis) and those lay people are most concerned about. The perception of a given risk is amplified by what psychologists call "outrage factors," which can make people feel that even small risks are unacceptable (Hallman et al., 1995). People select risks to worry about according to the norms of their social situation rather than responding to more objective hazards (Sturgis and Allum, 2004). Perceptions of technological risks are related to certain types of world views or the holding of certain core beliefs and values (e.g., environmentalism).

Within these concepts there appears to be little relationship between perception of risk and the degree of understanding of water issues. It has been suggested that what is important to understanding water issues is not the ability to memorize a collection of facts, but an appreciation for the place water science and technology fits into one's life experiences and the level of trust that can be placed on water experts and institutions (Jasonoff, 2000, Lewenstein, 2003). A stumbling block to a shared vision for water use in agriculture is that few Americans are close to agriculture or share a vision of the importance of water to food production. If they are asked to sacrifice certain lifestyle benefits (e.g., large and lush green lawnscapes, water features), they need to know the nature of the sacrifice, alternatives available, whether the sacrifice is equitable across the group of stakeholders, and whether there exists a belief that they can carry out and maintain the action. Rewards received for sacrificing must satisfy the individual, satisfy society's needs, and be equitably distributed (Hallman, 2005).

To produce a water literate citizenry that can effectively participate in public debate about water, and hold government agencies accountable for national/regional/local program objectives and the implementation pace of water policy is a challenge to outreach professionals and scientists (Sturgis and Allum, 2004). We must develop a CES-led integrated program for adoption-outreach of water technologies – achieving true behavioral change among farmers, ranchers, and citizens, where the full value of water is appreciated, and the risks to water supplies from mismanagement, population growth and changing weather patterns are understood (O'Neill and Dobrowolski, 2005). It is important to recognize that multiple sources of directly relevant, problem-solving information are available to farmers, householders, and decision-makers.

If cooperative extension is to compete, our information must be easier to use, quickly implemented, unique, and trustworthy. Acceptance into the stakeholder "circle of trust" requires careful listening, transparency in our actions, and clarity in our statements. Outreach professionals will need to survive hard times—stakeholder criticism, repeated requests for explanation, and character tests towards building capital in credibility. Personal commitment to stakeholder issues and a significant time investment are necessitated. Time is required to understand and be sensitive to cultural and language differences. A torrent of information exists, particularly on the internet, and often stakeholders are overwhelmed and do not understand how to take action. Issues arise about the authenticity of the data and stakeholders often are confronted with source skepticism. Outreach educators can buffer attitudes and antagonism by good, honest, replicated science and outreach—with outcomes driving the process, i.e., logic model based.

Delivering water management technology and know-how from agriculture (e.g., irrigation technology, plant substitution and adaptation, water reuse) into the urban, urbanizing, and rural residential environment will require new outreach efforts that closely follow the model implemented by food science researchers and extension educators to counteract obesity. Results should help to provide water managers and policy makers with options and tools that lead to behavioral change and a reduction in social conflict. Our strategy for water availability research and education must involve the social aspects of water—human perceptions, behavior, and understanding; and our technologies should create new opportunities without creating new problems. Water availability problems that garner immediate attention are those that affect individuals or groups personally, where recognition and knowledge of the problem exists and how long the affect lingers. Making additional sources of water available by wastewater reuse is particularly vulnerable to public perception. "Found" water from wastewater reuse directly links water availability with human health, e.g., public concern over reuse water applied to school yards and parks. A sociological rather than technological toolkit would more appropriately integrate human reactions to water reclamation and reuse in project design.

Important action items for research, education, and extension that incorporate the social dimensions of agricultural water security include:

- Design researchable metrics to evaluate adoption-outreach outcomes or performance-based measures of outcome,
- Develop applied research or technology to overcome knowledge gaps that constrain adoption-outreach of water conservation and reuse,
- Identify the socio-economic drivers of behavior change and how to evaluate the linearity and non-linearity of science and social feedback loops related to behavior change,
- Elucidate the mismatches that exist between actual and perceived risk of water availability or water-borne hazards,
- Consider two-stage funding, one stage for trust development, stakeholder and issue identification and refinement, the second for implementation and evaluation.

How do we begin to address these issues? First, research scientists must recognize the efficacy of a partnership with outreach professionals through targeted, integrated funding. Currently, USDA-CSREES funds several integrated programs in the National Integrated Water Quality Program to improve the quality of our Nation's surface water and groundwater resources through requiring integration of research, education, and extension activities (http://www.csrees.usda.gov/fo/fundview.cfm?fonum=1134). Concomitantly, outreach professionals and decision-making stakeholders need to provide feedback to scientists building powerful, responsive partnerships that are more effective with controversial issues. Partnership teams must focus on shaping solution-driven research and applications projects and their use of a balanced membership from the science/technology, outreach, development, and environmental protection communities.

Extension and research personnel need to be active, locally recognized and trusted. New delivery mechanisms and evaluation tools based on adoption-outreach need to be part of program outcomes. Opportunities must be continued and expanded to allow outreach professionals to bring a local perspective to national level programming and policy making that is issue-based or agency-focused, e.g., the Intergovernmental Personnel Agreement (IPA) Mobility Agreement. The purpose of the Intergovernmental Personnel Act (IPA) mobility program is to allow temporary assignment of employees between federal agencies and state, local and Indian tribal governments, institutions of higher education and other eligible organizations. The IPA often is used to strengthen the management capabilities of federal agencies or other eligible organizations, assist the transfer and use of new technologies and approaches to solving governmental problems, facilitate an effective means of involving state and local officials in developing and implementing federal policies and programs, and provide program and developmental experience to enhance the IPA’s regular job performance. A 2005 IPA agreement between USDA-CSREES and James Dobrowolski resulted in significant progress towards implementation of the agriculture water security initiative.

We are attempting to implement adoption-outreach with farmers facing mandatory adoption of riparian buffer technology on high value agricultural land to help preserve stocks of endangered salmon. Within the same year and after each policy decision, farmers with high value crops on small acreages were expected to install buffers with widths of 3 m (local requirement), then 10 m (local + federal requirement), followed by 65 m (after lawsuit against local authority) and now 0 m (decision appeal) with best management practices. An issue of this magnitude requires new and innovative tools. For example, the State of Washington adopted watershed analysis, structured a collaborative approach to developing a forest practices plan for a watershed based on a biological and physical inventory (Washington Forest Practices Board, 1997), and Water Resource Inventory Areas (WRIA, WDOE, 2003), administrative and planning boundaries, long before the US federal government claimed victory with watershed-level decision making.

This adoption-outreach effort is also targeted towards local residents and K-12 and college students. Beyond the development of traditional outreach educational materials such as written, visual and internet media for students, teachers, farmers, land management/regulatory staff and conservation groups, we focused our outreach activities to our broad clientele base in a manner that can be immediately used to make more informed decisions about farm management. A great deal of community input is required towards guiding project development, through numerous meetings with farmland owners, presentations to conservation groups and political officials, and meetings with local extension and education providers. Project credibility is further enhanced if clientele are given an opportunity to comment on the intent, scope and methods early in project implementation. Interactive web pages allowed viewers to send questions and comments directly to the science and outreach team. Trust was built by holding public field events before implementation and timed to correspond with important steps in the project to inform various clientele groups of the progress being made on the project, field reviews of the project by scientists and stakeholders, formal presentations to local decision makers, agricultural and environmental groups. It required 1.5 years to build the necessary trust and establish enough support to permit the project to go forward. Formal presentations were captured as streaming video and placed on our web site.

The research project provided opportunities across the K-12 through university continuum, in addition to train-the-trainer programs for extension and government agency personnel. We promoted the use of the experimental buffers for K-12 education by local schools (with landowner permission), and spent time with students and teachers in class and in the field. Cooperative collections of curricular materials are in continual development for use by K-12 educators in aspects of riparian ecology, groundwater and surface hydrology, water quality, soil science, and natural resource economics.

A local community college partnered with the project to train students for project field sampling and to develop and pilot-test a college-level riparian ecology curriculum. The course consists of modules that can be arranged for various audiences with different knowledge bases. This will allow the curriculum to be used at the college level for degree seeking students, workforce upgrade courses for non-degree seeking students or as community based information workshops to non-profit organizations, restoration groups, landowner associations, etc. The curriculum is a combination of web-based instruction material, PowerPoint presentations, and laboratory and field exercises. The varied format permits use in traditional classroom education, distance education, and daylong workshops. Because riparian areas are some of the most disturbed ecosystems in North America and are receiving significant attention from scientists and restoration groups, faculty are committed to this partnership.

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Protecting the Dead Sea Basin: The Position of Friends of the Earth Middle East on the Red Dead Conduit and the protection of River Jordan

Abdel Rahman Sultan
Friends of the Earth, Middle East

A Unique Ecosystem to the World

The Dead Sea

The Dead Sea basin is one of the world's unique ecosystems. The Dead Sea, a terminal lake, is the lowest place on earth and the saltiest large water body on the planet. Dead Sea waters are recognized for their medicinal and healing treatments. The area's complex geological form has created a spectacular landscape characterized by high mountain cliffs, deep canyons and green oasis. The springs that feed the green oasis attract unique biodiversity, in stark contrast to the desert surroundings. The Basin is a cradle of cultural heritage of utmost value to the three monotheistic religions of Islam, Judaism and Christianity. For all the above reasons the Dead Sea Basin is treasured by people the world over and is a major site of pilgrimage, tourism and industry.

The Jordan River

The Jordan River Valley is well known in local and international records as an area of remarkable natural, ecological, and cultural value, not only for the riparian parties, but also as a worldwide cultural and religious site. The valley was formed as part of the Great Rift Valley, a unique geophysical formation with a history of radioactivity and a reputation for wonderful bird watching. Diverse flora and fauna flank the winding curves of the Jordan River. The river itself is one of the most distinctive symbols of the land of the Bible and it figures prominently in the historical and cultural traditions of the region.

Existing Policies that Threaten the Basin

Dead Sea

Despite its uniqueness, there exists no integrated development plan for the Dead Sea Basin. The competing sectors, the mineral extraction industry, fresh water supply, tourism, local agriculture and urban development exploit the Dead Sea's resources without consideration of the area's natural carrying capacity. Due to present unsustainable development policies the Dead Sea is a living example of a 'tragedy of the commons.'

Over the last forty years, the Dead Sea water level has dropped by some 25 meters. The current yearly water level decline is over one meter. This is due to both water diversion upstream and industrial activities, which are responsible for 75% and 25% of the sea level decline respectively. With the disturbance of the water balance, a sinkhole phenomenon has developed with catastrophic impacts on development in the region. Sinkholes have damaged roads, parking areas, and tourist facilities. It is not possible to predict the location, scale and extent of new sinkholes, which pose real threats to people's lives and assets.

River Jordan

Despite its importance, the Lower River Jordan has been turned into little more than an open sewer. Sewage from all of the communities along the Jordan River Valley, Israeli, Jordanian and Palestinian, is untreated and directed towards the river. Fresh water coming from the Sea of Galilee and the Yarmouk River have been diverted or dammed so that the Jordan River's flow is today less then ten percent of its historic volume and that volume constitutes mostly sewage and diverted saline springs from the Sea of Galilee.

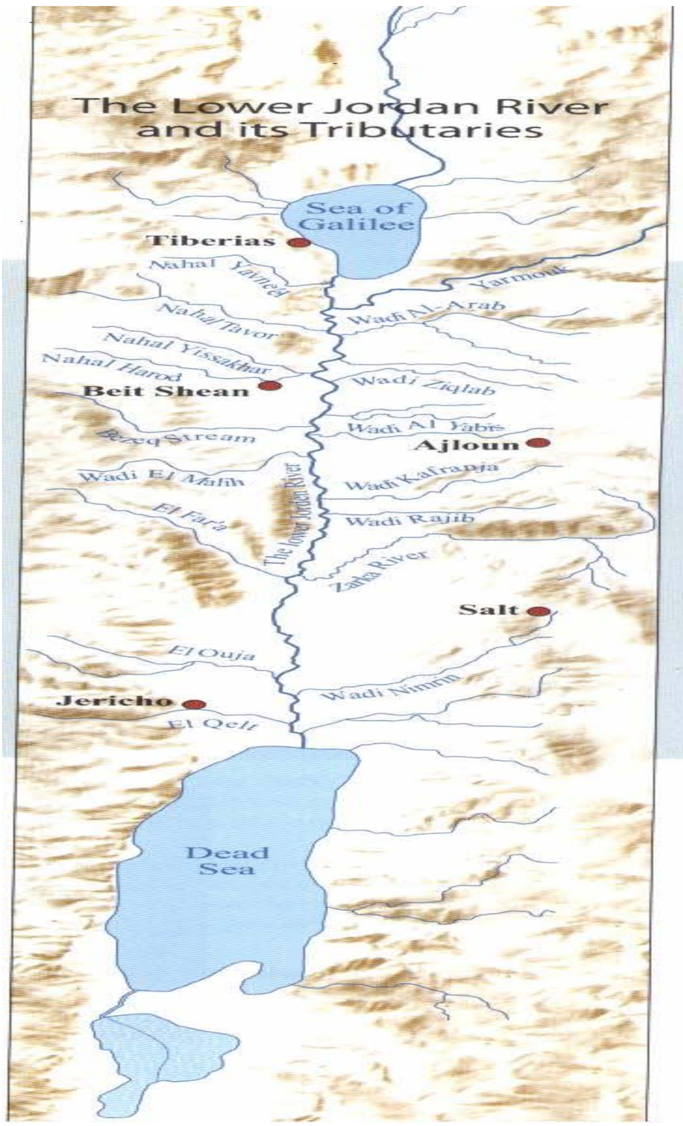

FIGURE 1 Map, Friends of the Earth, Middle East

The Call of the Governments of Jordan and Israel to Protect the Dead Sea

Friends of the Earth Middle East (FoEME) is seeking to conserve this unique trans-boundary ecosystem. In order to achieve this effort, FoEME desires to establish this area as a UNESCO World Heritage site and raise awareness about the area's uniqueness and challenges. The focus area of the project is the Lower Jordan River Valley, between the Sea of Galilee and the Dead Sea.

Friends of the Earth Middle East (FoEME) support the governments of Jordan and Israel for their call made during the Johannesburg Earth Summit 2002 to protect the Dead Sea. We congratulate our governments for recognizing that they are responsible for the environmental problems facing the Dead Sea and that they have the responsibility to solve these issues cooperatively prior to comprehensive peace in the region.

The plan as currently presented by the governments to build a conduit from the

Red Sea to the Dead Sea deals only with one problem facing the Dead Sea: the decline in water level. There is a need to broaden the issues involved in saving the Dead Sea to more than just the water level. Raising the water level will do little towards preserving the rich cultural heritage of the basin, nor in protecting the unique topography. Unsustainable tourism development with plans to build thousands of new hotel rooms along the ecologically sensitive corridors of the Dead Sea is threatening the cultural heritage of the area today. Raw sewage flowing from surrounding cities untreated into the Dead Sea is polluting ecosystems and threatening the tourism value of the Dead Sea as a natural spa and place of healing.

The proposed conduit raises many environmental questions related to the Dead Sea and Red Sea hydrology, water chemistry and impacts on the natural biota. The Red Sea-Dead Sea Canal (RDC) project components need careful and detailed investigation that involves sophisticated environmental modeling. The following are specific concerns that the proposed Red Sea - Dead Sea Conduit raises:

For the Dead Sea Basin

- The RDC could result in temporary and permanent changes on the hydrological balance of the Dead Sea Basin associated with the rise of the sea level.
- The resulting mixing in the composition of seawaters at the Dead Sea and the potential changes of its biology, chemistry, and physical stratification.

For the Araba Valley

- The vulnerability of the Wadi Araba (Arava valley) region to continuous leaks and/or accidental spill of seawater from the RDC.
- The environmental impact of the large-scale civil works involved in the construction of the RDC and its maintenance.

For the Gulf of Aqaba

- The likely impact of water flow disruption on the marine environment including the coral reef and sea grass meadows from the intake facility.
- Sediment movement around the entrance to the water intake canal and likely impact on marine life.
- The effect of the 11 km open canal in terms of potential humidity increase in the atmosphere and the comfort impact on the residents of Aqaba and Eilat as well as on the fauna and flora.

The Call of Friends of the Earth Middle East

In 1998, FoEME produced a concept document entitled: “Let the Dead Sea Live” that outlined a comprehensive plan to protect the Dead Sea. The concept document calls upon the government of Jordan, Israel and the Palestinian Authority to recognize the importance of listing the Dead Sea Basin as a Man and Biosphere (MAB) and World Heritage site. Since its publication, FoEME has led a campaign to bring the issue of the protection of the Dead Sea to the highest national, regional and international levels. Developing a regional integrated master plan involving Jordanians, Israelis and Palestinians under the framework of a UNESCO, Biosphere and World Heritage registration are immediate measures that could be taken by all three parties together.

Developing a management plan requires consideration of all the competing interests exploiting the Dead Sea region and balancing those interests according to the natural carrying capacity of the area. A study involving the true economic value of the resources that should be naturally available to the Dead Sea, including the fresh water currently being diverted needs to be undertaken. Alternative solutions should be reviewed including the possibility of increasing the flow of freshwater sources to the Dead Sea by limiting diversion from the River Jordan and promoting public and private water conservation.

Immediate actions are required to save the Dead Sea. If the RDC project is to be implemented water would still not be expected to reach the Dead Sea for another 10 years. The governments therefore need to put in place policy directives that will deal with the current crises and in so doing consider all possible alternatives and solutions.

FoEME calls on the World Bank to support the urgent need to protect the Dead Sea Basin

World Bank support however should be comprehensive to meet all the challenges that the Basin faces and advance a government policy document that would look into all the causes for present unsustainable practices and all their possible solutions. Measures should include short and long term planning considerations both national and regional. Planning should address all management elements and should include measures to improve the efficiency of the current water infrastructure in the region. Planning should investigate the current water uses and decide if these uses at present levels are sustainable. Civil society groups must be fully involved in all stages of this process, and where relevant independent third party experts should conduct assessments and evaluations.

Crossing the Jordan

With the support of UNESCO Amman office Friends of the Earth Middle East published a report entitled "Crossing the Jordan" in March 2005 to advance the rehabilitation of the lower Jordan River. The purpose of the release of the report was to place the issue of drying up of the River Jordan on the local and international agenda.

FoEME has produced a strategy to identify the common interests of the bordering Jordanian, Israeli, and Palestinian municipalities in rehabilitating the valley. The municipalities in the Valley agreed to create a mayors network for concrete action and cooperation.

The Goals *Next Step*

- To raise general public awareness as to the urgent need for rehabilitation of the River.
- To call on governments to act according to Annex IV of the Israel/Jordan Peace to rehabilitate the River.
- To call on governments to list the Lower Jordan River Valley with UNESCO's various mechanisms such as World Heritage, Man and Biosphere, etc. in order to promote sustainable development in the Lower Jordan River Valley.

FoEME's report "Crossing the Jordan" has identified two areas that can be described as 'core areas' in the north of the valley and in the south of the valley where there is a heavy concentration of nature reserves, national parks, proposed protected areas, important wetlands and important bird areas. The cultural sites include Prehistoric, Biblical, Greco-Roman, Early Christian and Byzantine, Crusader, and later Arab Muslims and Ottoman periods. FoEME proposes to advance recommendations that are divided into four themes: Ecological Rehabilitation, Eco-Tourism, Culture and Sustainable Agriculture, by first concentrating on the trans-boundary core areas in the north and south of the valley. FoEME prepared draft Action Plans for the two core areas identified. The action plan would involve further research, holding further discussions with all relevant stakeholders, obtaining appropriate technical assistance as required and the publication of a draft report on the development and protection needs of the cultural and natural sites in the two trans-boundary core areas.

March 8, 2005

FoEME Bakoora (Peace Island) Declaration for the Lower Jordan River Valley

Recognizing:

- The universal, natural, and cultural significance of the area
- That current practices are at the demise of natural and cultural values and at the expense of people's livelihoods
- That all peoples / riparians along the valley must share the benefits of the resources of the valley, and that in so doing the right balance must be struck with nature
- That sustainable tourism – along and/or crossing the Jordan - is the economic activity that can promote sustainable development and bring prosperity to the valley
- That the ecological rehabilitation of the River Jordan is a commitment made by the governments in the region on their signed peace treaties and/or agreements, and that now is the time to implement that commitment before damage done becomes irreversible
- That this necessitates the prevention of ongoing pollution and return of sufficient quantities of clean water flowing back to the Jordan River
- That appropriate UNESCO mechanisms are a strong basis for ecological rehabilitation of the river and valley
- That the three governments are called on to develop a coordinated and collaborative detailed action plan including extensive public participation that UNESCO and other donor states are asked to adopt and give technical and financial assistance towards implementation.

EcoPeace / Friends of the Earth Middle East (FoEME)

Friends of the Earth Middle East (FoEME) was established in 1994 under the name of EcoPeace. It is a non-governmental, non-profit environmental organization with the primary objective of promoting co-operative efforts to protect the shared environmental heritage of the Middle East. In so doing, it seeks to advance sustainable development and sustainable peace. FoEME has offices in Amman, Bethlehem, and Tel-Aviv.

Friends of the Earth Middle East is the only regional organization in the Middle East that brings Jordanian, Israeli and Palestinian environmentalists together for the promotion of sustainable development.

Training and Research Ideas for Water Management in the West Bank and Gaza

Abdelrahim Al-Asad
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And
Ayman Rabi
Palestinian Hydrology Group

Groundwater is the major water resource in the West Bank and Gaza. Estimates of annual groundwater replenishment from rainfall vary. However, the estimate of 679 mcm/year was officially agreed on under the Oslo Interim Peace Agreement for the West Bank in 1994. Meanwhile, the total renewable groundwater resources in Gaza are 46 mcm/ year (MOPIC, 1996).

Total water use in the West Bank and Gaza is estimated at nearly 266 mcm/year. Agriculture uses almost 70% of this total and the remaining 30% is being used for domestic uses, which also include commercial and industrial use.

For the past three decades, water management in the West Bank and Gaza was constrained by several political, technical and economic factors. Such constraints have adversely affected the overall performance of the water sector and resulted in creating a large gap between the services provided and the demand. The lack of investments in improving infrastructures (physical water losses reach 50% in some areas), the scattered nature of the water supply and management utilities with the absence of adequate rules and regulations and the absence of stakeholder participation in managing the supply has resulted in the deterioration of the entire water system.

A new water law has been published in the official newspaper on 5/9/2002. The Law #3 sets the major rules for the management of water resources and supplies in the Palestinian Areas. Section 7, article 25 of the law states that Regional Water Utilities (RWU) will be established, based on the desire of the local utilities and water user associations, to provide water and wastewater services for Palestinian communities. A special by-law will be established for this purpose. In the meantime, Section 11, article 41 states that local village and municipal councils, government bodies and NGOs continue to provide water and wastewater services until the RWUs are established.

Accordingly, local, municipal and village councils continue to manage the water supply and basic sanitation services in Palestine. Most of these councils lack adequate infrastructure, technical skills, and human and financial resource capacity. They cannot attain cost recovery and therefore are operating under deficits all year around.

In the mean time only a minor percentage of the produced wastewater effluent is being collected in the West Bank and Gaza and partially treated. The existing on-site sewage disposal in rural areas (almost 96% of households in the West Bank villages use cesspits) does not accommodate the vast increase in wastewater generated by the population. Thus, untreated sewage contaminates groundwater, wadi beds, and agricultural fields and this causes critical community and environmental health risks.

Such wastewater quantities have a good potential to be collected, treated and reused. It is considered one of the important alternative water sources. Yet, for cultural reasons, the Palestinian community doesn't accept this as a resource as of yet. Therefore, it is imperative to develop demonstration projects in order to prove the feasibility of such resources and demonstrate that the risks encountered with the use of treated wastewater are minimal when dealt with carefully.

Based on this argument, the issue of treated wastewater re-use is considered one of the key areas that need further development in the Palestinian Areas. Some technical capacity is needed and some new methodologies and approaches are also needed.

Despite the fact that there are some key institutions dealing with the subject, it still needs further development. The cooperation and coordination among them will further promote the issue and will lead to better results. Among the potential institutions are the Palestinian Hydrology Group (PHG), the Agricultural Engineers Association and the Ministry of Agriculture.

There is a clear need for further research on appropriate technology for wastewater collection and treatment in the rural areas. Such technology will help reduce investment costs and will lead to the adoption of decentralized sanitation as a means to reduce pollution from untreated wastewater, while creating an alternative source that can be utilized.

Having said that, there is also a clear need to build the capacity of technicians and operators who might potentially be needed to operate and maintain such systems. Currently, there is no such capacity at the operational level. PHG has established a Training Institute in order to build the capacity of such technicians. PHG is willing to cooperate with the other institutions in order to define the training needs and to design the appropriate training programs.

Furthermore, Water User Associations (WUA) need to be established as a mean to improve local irrigation water management and to increase its efficiency. The WUAs will potentially reflect the end users opinions and their participation. The decision makers and the other stakeholders will assist in promoting the good water governance. It is important that we develop appropriate methodology to set up and organize the WUAs. It is also important to look into the different experiences that exist elsewhere in the world and benefit from their experience.

Web-Based Ecological Decision Support System

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A reoccurring theme in the discussion of agriculture and food production in the coming century is sustainable development. This depends on integrated natural resource management with simultaneous optimization of agro-eco-production systems on economic, environmental, and social terms. Informatics and computer simulation models have become indispensable tools in dealing with diverse objectives in the decision making process. This paper describes our efforts in building a web-based ecological modeling system and implementation challenges. This overview illustrates the relevant technical platforms for state-of-the-art computing resources that can inform better management decisions.

Introduction

Accompanying the increasing globalization of world affairs, the prospect of food security and the environment has taken and will be at the center stage in the coming several decades. A quick survey of the current and projected situations regarding agriculture, population, and water resources has been published by the United Nation FAO.[1] It reveals an ominous combination of future high population, dwindling arable land, and increasing environmental pollution in most of the developing world. The prospect is more hopeful for developed countries where long-term, systematic research and extensive efforts to improve productivity and to mitigate negative environmental impacts have taken root. From across the globe, sustainable development is seen as a necessary trend that conserves land, water, and biodiversity.

In this paper, we will explore the use of computer simulation models and related information technologies that aid in the assessment, analysis, and management of agro-eco-production systems for improved productivity and fewer environmental hazards. Following an overview of the informatics and models used in natural resource management, we present a web-based hydrologic and hydraulic modeling package that is designed to bring the current generation of hydrologic models, which are utilized in most of the existing decision support systems, up to date. The features, potential usage, and future development of this web-based modeling system, in the larger context of the use of models in facilitating management, will be presented.

Informatics in Environmental and Natural Resources

Considering the highly variable nature of biological and environmental events and the need for using spatially explicit computer models in the decision making process, data must be collected from multiple locations, following carefully designed spatial patterns, and for extended periods of time. Such large volumes of data are typically stored in a relational database managed by one of the popular relational database management systems (RDBMS) such as Oracle, MySQL, MS-SQL Server, and ACCESS. The use of the internet has been revolutionizing all the main components of informatics in natural resource management. In a survey of the use of digital

[1] http://www.fao.org/documents/show_cdr.asp?url_file=/docrep/U8480E/U8480E0a.htm

media in managing and delivering information in the current electronic age, Wagner (2003) showed that the use of traditional desktop databases and CD-ROMs has been in decline during the past decades, while the use of World Wide Web (WWW) internet interfaced data collection and retrieval has seen exponential and continues to grow. The most common form of organizing and delivering spatial data using WWW is the linkage of a Web-based Geographical Information System (Web-GIS) and a backend relational database. Users with a web browser, can view, query, and manipulate the presented dataset to create a new dataset, or to access more information through a geo-referenced query delivered through the Web-GIS interface to the backend database. The Web-GIS mediated data retrieval and data organization greatly improved the usability of scientific data and research findings by decision-makers. The advantage of Web-GIS data portal is that it gives structure to the otherwise disaggregated collection of data and facts. In addition to the basic on-line GIS functions of search and overlay, it also provides statistical summaries and administrative functions. Web-GIS is seen as a way for promoting grassroots monitoring, data collection, and public involvement in environmental management. One example of such use of a web-based mapping program in river health monitoring and management is described by Graham et al. (2004). All stakeholders in the catchment of interest were provided with the opportunity to be involved in water sampling and data input into a web-based mapping and scoring system that calculates key indicators for pollution and can be used by management personnel for improved environmental management.

Natural resources and their management are intrinsically complex due to the dynamic balance and interactions among coexisting biotic agents and their abiotic environments within an ecosystem. Computer models have long been used for research on complex ecosystems, forming the basis for an integrated, system approach to management planning and implementation guidance. In an essay that discusses the future generation of ecological models for the purpose of environmental protection in natural resources management, Linthurst et al. (1999) outlined the direction of more advanced future modeling system developed in the form of a must-have list. The focus of the discussion was on modeling-mediated, watershed water quality control. The overall recommendations, which followed the ecological modeling research within the EPA's Office of Research and Development (ORD), were for: (1) a common software framework for ecological modeling to improve model(s) usability to aid in making management decisions and (2) further develop and improve watershed-scale (multi-scale) modeling to address more realistically the fate of multiple pollutants in multiple environmental media. For individual model improvement, the vision calls for the development of (1) "State-of-the-science process algorithms and component computational models with flexible scaling to provide problem-solving methodologies that are applicable at multiple geographic and temporal scales"; (2) "State-of-the-science atmospheric, terrestrial, aquatic, and biotic process models and stressors and effects models that predict real-world conditions and their incorporation into a common framework; (3) "Improved ability to interconnect one system with another system (e.g., the atmosphere and surface water ecosystems) and exchange information in between;" and (4) the linkage of ecological models to geographic information system (GIS) technology. To a large degree, the current generation of ecological models has become much more sophisticated than their predecessors in terms of dealing with coexisting biological species or pollutant agents and representation of underlying processes in hydrology, soil erosion, and nutrient cycling. However, dynamic temporal and spatial scaling of individual models is still a largely unaddressed issue. Yet, from the recommendations listed above, it is obvious that a collection of specialized models that each operates at its own optimized scale could form an integrated modeling system, which, when coupled with algorithms to interface across the disparate scales, could be a solution to this problem. Nonetheless, the current generation of ecosystem models is mostly landscape models that can be easily applied to the most common scale in the majority of real applications, i.e. watershed scale. Hence, the scaling issue isn't seen as urgent, at least for now. Noticeably, the above list of future developments didn't anticipate the increasingly important WWW platform for model development and, especially, deployment. The combination of Web-GIS and ecological modeling is becoming a trend for a future generation of modeling- mediated natural resources management. Such a trend is evidenced by more and more successful integration of Web-GIS and modeling in various natural resource management applications and by the ever more powerful computers and increasing household access to broadband internet connections. Specifically, the main use of GIS in ecological modeling is the explicit spatial representation of a management unit, which could be a field, catchment/watershed, basin, or region, in increasing order of geographic magnitude. A large proportion of the current generation of ecological models is field-based, focusing within the definitive horizontal limit of edge of field, and the vertical boundary of bottom of root zone. Therefore, problems arise with the process of scaling in attempting to project field based simulation to larger geographical areas where there is much more management diversity.

In dealing with the simulation of a biological community of plants and animals, traditional ecological models tend to assume spatial homogeneity over a large management unit (watershed or basin) at a given time. Current watershed or the larger basin scale models have adopted the grid cell system to represent the spatial diversity within these geo-management units. However, the interactions among the cell elements remain predominantly those of overland runoff and groundwater flow, and subsequently eroded sediment, nutrient, and other harmful chemicals. The interaction among biological agents across cells has not been adequately represented, making it difficult to predict the spatial and temporal distribution of plant or animal communities. This is evidenced in the work by Zhai et al. (2004) on the simulation of mixed pasture growth. In their work, a pasture was regarded as a management unit where multiple forage species grow in competition for light, water, and nutrient. The species were partitioned with resources based on their relative presence in the field (this is done based on leaf area index, LAI, or biomass). The method has proved to be quite effective in predicting growth of multiple perennial forage species in the pasture. However, it lacks the ability to simulate succession in the mixed pasture of forage species, especially annual species, and their spatial pattern. This leads to further difficulty in predicting realistic grazing animal intake on mixed pasture across a growing season, considering the commonly observed preferential grazing by ruminants.

The typical set up for a web-based DSS generally follows the so-called three-tier design. Tier 1 refers to presentation layers or client interface; tier 2 represents process manager or application logic; and tier 3 are the server resources such as databases, computer simulation models, and web-enabled GIS packages (Figure 1).

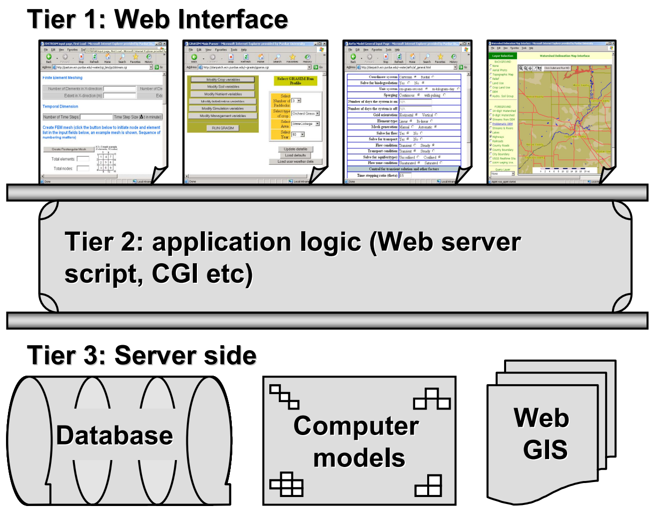

FIGURE 1 The 3-tier design for web-based modeling system.

Ecological models that are used to power various decision support systems should be continuously improved at the process level as new scientific understanding becomes available. For example, in an effort to adapt the EPIC model to the semiarid Northeast of Brazil, De Barros et al. (2005) further improved the EPIC model by incorporating the floral abortion effect due to dry spells in the season and devising better algorithms for resource partitioning among competing species.

In conclusion, there is a need to design a better approach to summarize various simulation results to form evaluation indices that are pertinent to the context of natural resource management projects, and at the same time are easy for stakeholders to understand. User interface design and model management in a web-based DSS directly impact the usability and adoption of these informatics- and model-based DSSs in real applications. Research such as that done by Xie (2003) on striking a balance between user friendliness and user control in an information retrieval system, and by Chiu et al. (2005) on the theoretical basis for designing better user interface for modeling systems, is needed to improve the applicability of the DSSs.

The Web-Based Ecological Modeling System

Our project aimed to create a centralized, web-based modeling environment where users can have access to hydrologic/hydraulic models and ecological models to facilitate the decision making process in projects related to runoff estimation, contaminated site remediation, reservoir siting, and pasture based production system management. All models have been under continuous development by our research group at the Department of Agricultural and Biological Engineering, Purdue University. The following models are currently included in the web-based modeling system:

- *Hydraulic/Hydrologic Models*
    - 2DSTREAM (2-Dimensional Surface Stream Flow Model). A finite-element-based overland flow model, 2DSTREAM was originally developed by Vieux et al. (1990a,b) and modified to account for dynamic time step for a one-dimensional

overland flow kinematic wave solution used in solving the uncoupled sets of overland flow (Jaber and Mohtar, 2002). Watershed input data such as nodal coordinates, elemental slopes, and roughness are read at the beginning of each run. The forcing function $r_e(x)$ is then calculated. Using the element and force vector information, the system of equations is built, updated, and solved for new flow depth (h) values. The model has been validated for different rainfall and slope conditions (Vieux et al., 1990; Jaber and Mohtar, 2002). http://pasture.ecn.purdue.edu/~water/2dstream/.

- SPARG/AIRFIX (Air Sparging and multiphase Solute Transport model). This model is developed as a practical, unsaturated flow and multiphase transport model that can be used for the design and operation of sparging and soil vapor extraction systems (Mohtar et al., 1996; Rahbeh and Mohtar, 2003). The model uses first order kinetics to represent the mass transfer of contaminants across aqueous, gaseous, solid, and NAPL phases. The theoretical basis of the model is based on the fact that soil particles are surrounded by water films which isolate the gaseous and non-aqueous phases. Therefore, the contaminant mass transfer can take place across the aqueous-solid (sorption/de-sorption), aqueous-gaseous (stripping), aqueous-NAPL (dissolution), and gaseous-NAPL (volatilization) interfaces. To simulate the air flow distribution, the model incorporates numerical code derived from the SPARG model developed by Mohtar et al. (1996) which is based on steady state unsaturated flow equations. http://pasture.ecn.purdue.edu/~water/airfix/.

- *Ecological Models*
  - SGRASIM (Silvopasture GRAzing Simulation Model) This model was built on the basis of the multi-species GRASIM model (Zhai et al., 2004a). The SGRASIM model explicitly models tree impact on understory forage growth in terms of light, rainfall interception, soil water, and nitrogen uptake/depletion. The model was field tested in an un-enhanced, mixed pasture under a black walnut tree canopy in Indiana, USA. The model simulated the multi-species forage growth in competition both under tree canopy and in open pasture. Soil water and nitrogen cycling are also explicitly modeled. Key components of the model have been field tested and are under continuous development to incorporate the latest research findings related to key processes in the pasture and grazing-based production systems. A prototype model is available for online application at http://pasture.ecn.purdue.edu/~grasim/ (Mohtar et al., 2000).

  - Water Harvest AHP: Water Harvesting Structure Siting/Impact analysis using the Analytical Hierarchy Protocol. Water harvesting, or rainfall collection, has been practiced at various scales in dry land and semiarid areas as a means to channel and store scarce rainfall for later use. The locations for water collecting structures are determined by a multitude of factors, which are not easily evaluated and often involve a compromise of interests. The Analytical Hierarchy Process (AHP) provides a systematic approach in conducting multi-criteria analysis and decision making. It allows for the comparison of alternatives based on the quantification of mostly qualitative characteristics of a given watershed/region. A Web-based GIS-hydrologic modeling system was designed to implement a spatial AHP process (El-Awar et al.,

2000) for selecting the most suitable and practical location for building water harvesting reservoirs. An online GIS digitizing tool helps users locate potential watershed, extract spatial data related to hydrologic characteristics to be used as input for hydrologic models, which in turn produces needed runoff estimates from sub watersheds, together with land use and land cover data and expert opinions to produce a single Reservoir Suitability Index (RSI). Ranking of RSI allows the quick determination of suitable locations. The prototype technology is available at http://pasture.ecn.purdue.edu/~water/wh/. Major features and potential application of the web-based tool is presented by Zhai et al. (2004b). http://pasture.ecn.purdue.edu/~water/wh/.

The overall design of the system is shown in Figure 2. It follows the general guidelines for web application design for a modeling system discussed previously (Figure 1). World Wide Web (WWW) interfaces have been constructed for SGRASIM, SPARG/AIRFIX, 2DSTREAM, and Water Harvest AHP. Model web interface was written in Dynamic HTML (dhtml) and server side processing is done with application specific CGI (common gateway interface) scripts written in Perl and C programming languages. To help user's applications using these web-based models, an online workshop is developed to provide users with modularized classes that combine presentation about model theories and hands-on modeling tutorials and exercises. Users can conduct self-paced education via the URL: http://pasture.ecn.purdue.edu/~water/workshops/, where online audio and video presentations and tutorials are available for free access.

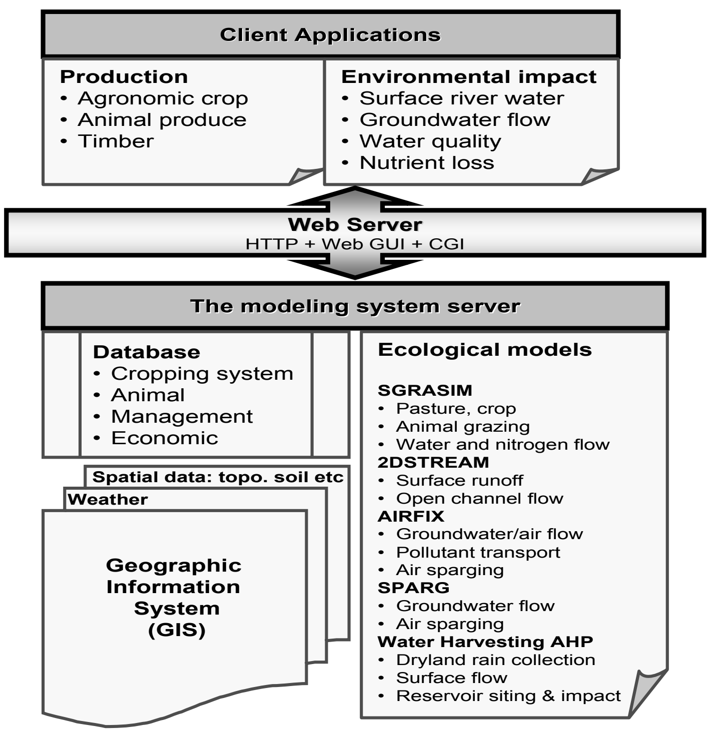

FIGURE 2 The web-based paradigm for an open and adaptive ecological modeling system.

The ultimate capability of the integrated ecological modeling system is described as follows: Users can select their local area using the online GIS digitizer. Local hydrologic, production, and environmental data are then uploaded to the server, customized options are formed as model

inputs and models are executed, and finally, results are presented for user analysis. Ongoing efforts are put forth to strengthen model robustness and to streamline this process.
As alluded to above in the discussion of DSSs, the scaling issue is intrinsically related to the level of detail that a modeling system uses to describe certain processes. In this regard, the next phase would be focusing on how to graft the well developed, fully distributed modeling framework to the current web environment. Since almost all ecological models have hydrological cycles as the central link among geographic areas, such discussion will be within the context of adapting the distributed hydrologic modeling to the web. Vieux et al. (2004) provided an up-to-date overview of the physically based distributed hydrologic modeling. They defined the fully distributed models as grid-cell based, or finite element based hydrologic models, such as 2DSTREAM. Based on their description of the approach they used to convert a basin-scale lumped model into a distributed sub-basin lumped model, a bottom-up approach that uses a finite element model to represent each sub-basin, and then, at higher orders of integration, uses a single cell to represent each sub-basin in the transfer and routing functions, is seen as a way to "buildup a watershed-scale process model from small-scale elements such as hillslopes or grids" (Vieux et al., 2004). Such a scheme coincides with the conceptual model for kinematic wave analogy used by the 2DSTREAM model in the current package.

The discretization of a watershed would allow the use of finite element based hydrologic models over large watersheds. When coupled with other ecologic modeling components over such grid-cell based systems, we can truly achieve the much sought scaling capacity to conduct simulations across multiple scales. However, such achievement in the web environment is not without difficulties. First and foremost is the computation overhead for using such a simulation scheme. It is well known that finite element based models typically take a long time to run to completion. Hence, on a large watershed, the waiting time of such a simulation could be too long to allow a client to stay connected to the server. Second, a flexible watershed delineation application is also needed to create the first sub-watershed boundaries as basis for further discretization. Engel et al. (2003) has achieved online watershed delineation using software associated with the MapServer, a free web application that can publish maps in various formats. However, their algorithm only allows delineation of one sub-watershed at a time, based on the user provided initial outlet point. This limitation must be resolved in the future in a well-organized Web modeling environment.

To facilitate user application, an online interactive modeling assistant service is under construction as a continuation of the online workshop described above. The end goal of the service is a web-based tool kit that can provide real time guidance to model users in basic training, data preparation, application monitoring/debugging, and modeling results analysis. The service can be invaluable in both higher education and consulting in agro-eco-production systems and environmental engineering.

CONCLUSIONS

The critical challenge for the agricultural industry in the next century will continue to be sustainable food production. As sustainability includes economic, environmental, and social implications, it must also involve more efficient and conscientious use of resources while improving productivity. To meet the ever-increasing demands for food and, simultaneously, prevention of environmental degradation, our role, as educators and agricultural engineers, is to

focus on the integrated conservation and protection of natural resources, including water, land, and air, and to promote research and support of biodiversity.
Computer models have long been used for knowledge integration for research on complex ecosystems. In the past, their use has been mostly confined to academia due to the difficulties in model input preparation, model execution, and result interpretation. The proposed web-based modeling system aims to provide state-of-the-art, science-based agro-ecosystem and environmental computer models to facilitate real decision making processes in production systems and natural resources management.

The web-based paradigm (Figures 1 and 2) is considered as a new generation of application development and deployment. It allows fast model deployment to a wide range of audience/platforms and centralized application development/updates without incurring additional operational or investment costs from the users. It also allows remote training and live assistance in custom model implementation. The model repository included in the current modeling package (Figure 2) is under centralized development, management, and extension to form an open, flexible, and extensible decision support system. It can be quickly reconfigured to fit an individual user's needs or a particular application.

Future development of comprehensive and yet flexible modeling systems for decision support hinges on the following:

- Digital data storage and management using Web-GIS enabled database management systems;
- Logical management and organization of web-based modeling systems composed of an ensemble of independent models, each of which functions at a specific spatial and temporal scale, with the end goal of dynamic creation of user oriented applications using appropriate models and data combination;
- Web-GIS mediated scaling of modeling systems to achieve a proper level of detailed simulation for specific applications;
- Post modeling recommendations based on combined quantitative modeling results and other social and economic factors;
- Continued model development at the process level.[2]

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Regional Initiative for Dryland Management in Tunisia

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WATERSHED MANAGEMENT AND VEGETATIVE COVER

Background

The forests of Tunisia represent a national heritage for every citizen of the country. In many cases the forests have been lost, harming the forest's natural resources, including wildlife, under story vegetation, soils and rainfall that once infiltrated and fed the water table through the hydrological cycle. Forest conservation and development is therefore linked to the broader quality of life and the ability to extract an economic return from the land for thousands of communities. As the country loses the very ecosystems that sustain rural life, there is a slow change taking place which puts the responsibility of forestry and land management into the hands of the communities (the forestry population is estimated at 900.000 persons).

In Tunisia, there are about 10.600.000 hectares (ha) of arid and semi-arid lands affected by desertification. This represents about 65 % of the total country surface area. In the south, almost all lands are being desertified. The desertification process is induced by the retrogression of vegetation cover which is in turn is caused by an over use of natural rangelands and an irrational utilization of agricultural lands. Furthermore, the marginal physiographic conditions, unfavorable hydrological and climatological patterns, as well as socio-economic factors affecting these lands also contribute towards their degradation and ultimately their loss. This is especially true for those lands receiving less than 200 mm annual rainfall which are jeopardized by increasing erosion which leads to lower soil fertility.

Since 1990, the government of Tunisia has undertaken an ambitious program in reforestation and combating desertification which consists of:

- Reforestation of 280.000 ha.
- Establishment of 40.000 ha of forestry belts, wind brakes, road plantations, and biological sand dune fixation.
- Planting 580.000 ha of fodder shrubs.
- Management of 1 million ha of rangeland (private and collective land).
- Construction of 4.000 km of artificial dunes.
- Heightening of 8.000 km of artificial dunes.

The results to date are not particularly positive. It will be necessary to engage the rural communities in holistic pilot projects to demonstrate the value of joint action. Ten pilot projects have been under taken since 1995 in the north, west and central part of the country with the collaboration of the World Bank. Menzel El Habib is the only project in the south undertaken since 1997 to control natural resources degradation and lands the pilot effort in Gabes governorate in south east Tunisia. This area covers approximately 120.000 ha forest of desertified plateau and coastal plain. The average annual rainfall is estimated at 80 - 100 mm.

The population is estimated about 13.000 and is mostly involved in livestock production of some 50.000 heads of sheep and goat.

In the late 1980's, government protection programs were intensified in this area to address the movement of sand dunes and the need to provide alternatives for pastoral communities. In spite of this effort, better techniques and strengthened community involvement are necessary to make programs successful.

Main objectives of the project are the following:

- Infrastructure and agricultural land protection against sand erosion.
- Rangeland development and livestock protection
- Soil and water conservation
- Improvement of rural population sources of revenues and combating rural exodus.

Main Accomplishments:

- Seed collection and inventory of indigenous and exotic adapted species in the region.
- Nursery work :
    - Nursery bud preparation.
    - Techniques of seeding production.
    - Local and exotic species grown and offered to farmers and organizations
    - Plantation in Menzel Habib (Henchir Snoussi)
- Indigenous species (14)
    - Exotic species (2) were planted for multiple uses and for combating desertification with community participatory approach.
- Rangeland management: target species were planted for rangeland improvement with the collaboration of the forestry department of Gabes.

Continuing activities:

Create an inventory of indigenous and cultivated species and collect genetic materials

- Procure a drier and treatment unit for vegetative material.
- Improve strategies for conservation of target species.
- Elaborate and publish a guide for rational rangeland use.
- Train farmers in rangeland management.
- Install plant nurseries on local farms.
- Regional exchanges

Treated Wastewater and Biosolids reuse

Project Description

Tunisian arid regions cover more than 75% of the country's area. In these regions, the average annual precipitation ranges between 100 and 350 mm/year, with 90% of this area receiving less than 200 mm/year. With the awareness of limited water resources in the arid Tunisian zone, the Ministry of Agriculture has undertaken great efforts to mobilize available run-off by watershed management. However, the limited quantities of runoff and its high sediment and salt concentration and the high evaporation rates make it difficult to manage this water resource at a large scale. Therefore, fossil ground water is still the most significant water resource supply for all economic activities requiring water. Tunisian water planners are continually searching for additional sources of water that can be used economically and effectively to promote further development.

In order to alleviate the problem of fresh water scarcity, the government has adapted a policy calling for the reuse of treated wastewater. Tunisia has extensive experience in the area of wastewater reuse in irrigation of agronomic crops and green areas. Treated wastewater has been reused to irrigate the Soukra agricultural area (600 ha: citrus and olive trees orchards) since the early 1960s. Currently, secondary level wastewater effluent is used to irrigate about 6.000 ha of orchards, forage crops, cotton, cereals and golf courses. The total area with reclaimed wastewater is projected to be 22.000 ha during the next decade. Considerable research has been undertaken to study various aspects of agricultural reuse, showing that treated wastewater irrigation produced higher yields than groundwater irrigation. Studies of contamination of crops and groundwater, when treated wastewater is used, revealed little significant impact on soils, crops or groundwater. Both opportunities and problems exist in using treated wastewater and biosolids. Problems are not only due to the quality of water and biosolids or standards adapted but also due to climate, soil types, choice of crops, agricultural and land use practices and farmers and public attitudes.

The objectives of our project are:

- To utilize treated wastewater and biosolids under controlled conditions which ensure minimum health risks to human and environment.
- To identify economic crop varieties that present the optimum mix of income and public safety.
- To study public acceptance attitudes of wastewater and biosolids reuse for agricultural purposes in arid areas of Tunisia.
- To study socioeconomic impacts of the reuse.

Main Accomplishments

- Achievement of a complementary treatment station using infiltration percolation:
    - Realization of the civil engineering works and installation of three pumping stations with 10l/s capacity/station.
    - Realization of the civil genius works of the infiltration percolation station and the installation of a pivot.
    - Construction of a tank for the treated waste water with a capacity of 100 m^3.
    - Realization of electric equipment.
    - The cost of the pilot is about 158147, 120DT.

- Monitoring of treated wastewater quality from Gabes' treatment plant.
- Monitoring of complementary treated wastewater quality from the pilot unit of complementary treatment by infiltration percolation in Gabes' treatment plant. See tables.
- Adoption of the standard of the biosolids reuse by legislative instance in Tunisia.

- Participation of members from initiative in the regional technical workshop related to TWW and Biosolids in Granada.

TUNISIAN ACTION PLAN (JULY 2003-JUNE 2005)

Component I: Principal objective work is the Watershed management

Initiative site for phase II

Menzel Habib, located in the Gabes Governorate of southeast Tunisia, was selected as a site where a holistic and integrated approach could be implemented through pilot projects. The area of the pilot zone covers approximately 100.000 ha in the form of mountain foothills that give way to plateau and costal plain (Menzel el Habib), and has a population of 12.000.

Project objectives

- Establish a regional plan for forestry development in the arid zones, which takes into account research, extension and dispersal/collection of necessary information to plan, manage and reforest the pilot zone.
- Regenerate degraded lands by introducing well-adapted forest species while linking the forest activity to a simultaneous provision of forage resources as a means of compensation for "lost" grazing.
- Protect infrastructure developments in the pilot zone from sand dune formation (roads, villages, agricultural perimeters).
- Conserve water and soil through targeted actions on specific sites that stop soil erosion and maximize water recharge by the use of bands, dams, dikes, ridges, pits and other forms of water harvesting
- Contribute to a community action plan, which adopts conservation or rehabilitation of critical areas of forest and provides a system of management that permits the use of these areas to be flexible and exploitable but also renewable as a source of woods and a feed resource during times of drought.

Activities

In Menzel Habib, the main activity is the incorporation of indigenous knowledge and local germplasm to meet soil conservation and land stabilization. The socio-economic purposes could come from exchange of materials knowledge, experience and genetic resources in the area of plant adaptation, selection, propagation and delivery to rural communities. (See table)

Component II: Principal objective work is the TWW and Biosolids Management

Both opportunities and problems exist in using treated wastewater and biosolids. Problems are not only due to quality of water and biosolids or standards adapted but also due to climate, soil types, choice of crops, agricultural and land use practices and farmers and public attitudes.

Project objectives

- To utilize treated wastewater and biosolids under controlled conditions which ensure minimum health risks to human and environment.
- To identify economic crop varieties that present the optimum mix of income and public safety
- To study public acceptance attitudes of wastewater and biosolids reuse for agricultural purposes in arid area of Tunisia.
- To study socioeconomic impacts of the reuse.

APPENDIXES

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APPENDIX A

AGENDA

Strengthening Science-Based Decision Making in Developing Countries:
Agricultural Water Management
Tunis, Tunisia
June 7-9, 2005

Tuesday, June 7

SESSION 1: Overview and Principles

0900 Opening Ceremony

Professor Mohamed Limam, Chief of Cabinet, Ministry of Science, Technology, and Capacity
John Boright, Executive Director, International Affairs, The U.S. National Academy of Sciences
Workshop Co-Chair, Sihem Benabdallah, Professor, Labo. Geochemistry Physics and Chemistry of Water-INRST
Workshop Co-Chair, Henry Vaux, Jr., Professor University of California, Berkeley
Moneef Zou'bi, Director General, Islamic World Academy of Sciences

0940 Keynote Address: "The Water Resources and Water Management Regimes in the North of Tunisia"

Sihem Benabdallah, Professor, Labo. Geochemistry Physics and Chemistry of Water-INRST

1010 Questions and Discussion

1040 Keynote Address: "Agriculture in Tunisia: An Overview of Current Conditions and Future Prospects"

Mme. Raquia Boutiti, Director, Irrigation and Water Use Authority

1110 Questions and Discussion

1140 Break

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1155 "Scientific Principles of Agricultural Water Management."
Dr. John Letey, Professor Emeritus, University of California, Riverside

1225 Questions and Discussion

1255 End of Morning Session

1300 Lunch

1430 "The Role of Science in Agricultural Water Management"
Mr. Tom Huntzinger, Water Appropriations Program, Kansas Dept. of Agriculture

1500 Questions and Discussion

1530 "Scientific Innovations in Agricultural Water Management: Regulated Deficit Irrigation in Trees and Vines."
Dr. David Goldhamer, Kearney Agricultural Center

1600 Questions and Discussion

1630 Roundtable Discussion: Conclusions for the Day

1700 Adjourn for Day

Wednesday, June 8

**SESSION 2: What do Decision-Makers Need from Scientists?
Perspectives of Decision-Makers from the Federal to Local Levels**

0900 Panel 1: Science and Agricultural Water Management in the United States

What the grower needs: *Mr. Dan Dooley, Grower, Visalia, California*
Discussant, government perspectives: *Ms. Rita Maguire, President and CEO, ThinkAZ and former Director, Arizona Department of Water Resources*

1000 Questions and Discussion

1030 Break

1045 The Role of Science in Managing Water: A National Perspective
M. Horchani, Former Secretary of State of Water Resources, Ministry of Agriculture, Tunisia

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1115 Questions and Discussion

1145 "The state of the art in decision making and management of water risks at the national level"
Professor Fouad Ben Abdelaziz, Tunisian Institute of Management, and University of Sharjah, United Arab Emirates

"Decision Support Systems for Agricultural Water Management"
Dr. Rabi Mohtar, Professor, Purdue University

1230 Questions and Discussion

1300 Lunch

SESSION 3: Providing Scientific Advice

1430 Panel: "What are the Elements of Good Scientific Advice"
Dr. Henry Vaux, Jr. Professor, University of California, Berkeley
Ms. Rita Maguire, President and CEO, ThinkAZ and former Director, Arizona Department of Water Resources

1530 Questions and Discussion

SESSION 4: Linking Science to Action

Session Chair: *Professor Fouad Ben Abdelaziz, Tunisian Institute of Management, and University of Sharjah, United Arab Emirates*

1600 Panel: Scientific Institutions that Provide Science Advice for Agricultural Water Management

The U.S. National Academy of Sciences
Dr. John Boright, The National Academies

Tunisian International Center for Environmental Technologies
Dr. Amel Jrad, TICET

1700 Questions and Discussion

1730 Adjourn for the day

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GPCE
LABORATOIRE DE GEOCHIMIE ET DE PHYSICO-CHIMIE DES EAUX

Thursday, June 9

SESSION 4: Linking Science to Action (continued)

0900 Linking Science to Action

James Dobrowolski, Associate Professor, Washington State University
Moneef Zou'bi, Director General, Islamic World Academy of Sciences

1000 Questions and Discussion

1030 Perspectives from Other Countries

Iran
Algeria
Senegal

1115 Break

1130 Perspectives from Other Countries (continued)

Jordan
Palestine
Egypt
Turkey

1300 Lunch

SESSION 5: Conclusions and Next Steps

1430 Group Discussion

What are the most important scientific needs?

How can communication between scientists, managers and decision makers be facilitated?

1600 Roundtable Discussion: What are the next steps?

1700 Closing Ceremony

1730 Reception

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APPENDIX B
List of Participants

Sihem Benabdallah
Symposium Co-Chair
Professor
Laboratory of Geochemistry, Physics, and Chemistry of Water,
Institut National de Recherche Scientifique et Technique (INRST), Tunisia

Henry Vaux, Jr.
Symposium Co-Chair
University of California, Berkeley
United States

Fouad Ben Abdelaziz
Professor
Institut Superieur de Gestion
Tunisia

Ibrahim Akram
Department Head
Ministry of Agriculture
Palestine

Abdelrahim Al-Asad
Director
Palestinian Engineers Association
Palestine

Raquia Al Atiri
Director
Irrigation and Water Use Authority
Tunisia

John Boright
Deputy Director, Policy and Global Affairs
The National Academies
United States

Rachid Boukhchem
Institut National de la RechercheAgronomique d'Algerie
Algeria

Abdelkrim Charef
Director
Institut National de Recherche Scientifique et Technique
Tunisia

James Dobrowolski
Associate Professor
Washington State University
United States

Dan Dooley
Grower and Partner
Dooley & Herr, LLP
United States

Mohammad El-Mourid
Regional Director
ICARDA
Tunisia

Moustafa Gaweesh
Director
National Water Research Center
Egypt

Dhahbi Ghanmi
Direction Generale de Genie Rural et de l'Exploitation des Eaux
Tunisia

David A. Goldhamer
Water Management Specialist
Kearney Agricultural Center, University of California, Davis

Ameur Horchani
Former Secretary of State for Water Resources
Ministry of Agriculture
Tunisia

Laura Holliday
Senior Program Associate
The National Academies
United States

Thomas L. Huntzinger
Program Manager
Kansas Department of Agriculture
United States

Lounas Iftene
Director of Agricultural Hydrology
Agence Nationale des Resources Hydrauliques
Algeria

Amel Jrad
International Center for
Agricultural Research in the Dry Areas
Tunisia

John Letey
Professor Emeritus
University of California, Riverside
United States

Rita P. Maguire
President and CEO
ThinkAZ
United States

Rabi Mohtar
Professor
Purdue University
United States

Sayed-Farhad Mousavi
Professor
Isfahan University of Technology
Iran

Mohammed Ouessar
Institut des Regions Arides
Tunisia

Oumar Sock
Professor
University Cheikh Anta Diop and Founding
Member, The Academy of Science and
Technology of Senegal

Abdel Rahman Sultan
Friends of the Earth (Middle East)
Jordan

Derek Vollmer
Program Assistant
The National Academies
United States

M. Fatih Yildiz
Agricultural Engineer-Contract Manager
EU Central Finance and Contracts Unit,
Turkey

Moneef R. Zou'bi
Director General
Islamic Academy of Sciences
Jordan